# A Human Sensing Framework for Smart Buildings Facilities

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This dissertation is submitted for the degree of
*Doctor of Philosophy*

February 2025

# Abstract

Faults and incidents can occur in building facilities and detecting and reporting them is considered a challenge. Building managers need to have real-time condition updates about the facility or potential incidents (e.g., loose door handles, sensors not working affecting lights and temperature) that might lead to safety and security losses if they are not detected and fixed. As buildings become smarter, technological solutions can help, but can equally be the source of faults and incidents. Human participation is still needed to help have adequate awareness of the situation in the building environment, but building occupants may not always spontaneously report faults as quickly and reliably as needed.

Crowdsourcing is the practice of obtaining information by recruiting people's knowledge. Previous studies have shown that crowdsourced contributions, which are created by non-expert observations and interpretations, are fairly similar to the experts' outputs, especially for nonsensitive data, and therefore be an alternative to hiring experts or dedicated inspectors. Crowdsourcing, however, requires suitable motivational mechanisms and an appropriate design, and its applicability as a viable solution to detect and report faults in smart buildings has not been studied. To study that, I used a form of crowdsourcing known as human sensing which includes individuals contributing their observations within their local area like their neighbourhoods, workplaces, and often visited places.

This thesis provides three contributions to the application of crowdsourcing for smart buildings. First, perceptions and motivations that drive occupants to engage with smart building crowdsourcing, are informed by conducting semi-structured interviews. Second, human sensing feasibility is obtained by running a real-world experiment. Third, a framework describing a set of guidelines covering the main dimensions known in the crowdsourcing process: platform, requesters, workers, incentives, task, and environmental preparation. It was done by synthesising the results and observations discovered from the two previous studies and related research. These contributions enabled me to conclude that crowdsourcing can be a good option for reporting faults in smart buildings if a set of guidelines are followed to deploy the initiative successfully.

I would like to dedicate this thesis to my home country. . . . . . .

# Declaration

I hereby declare that except where specific reference is made to the work of others, the contents of this dissertation are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other university. This dissertation is my own work and contains nothing which is the outcome of work done in collaboration with others, except as specified in the text and Acknowledgements. This dissertation includes fewer than 50,000 words including appendices, bibliography, footnotes, tables and equations and has 26 figures.

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February 2025

# Acknowledgements

First and foremost, I would like to thank God for providing me with the opportunity to complete my research for my PhD studies. Without his blessings, this would not have been possible.

My sincere praises and acknowledgement are to my supervisors: Dr Charles Morisset, Dr Nick Taylor and Dr Maryam Mehrnezhad for their extraordinary supervision for giving me the opportunity and support to complete this research and for all their valuable comments, suggestions and many more insights that inspired this work. I would also like to thank all of those I have had the pleasure to work with during this research and all participants who contributed to this study. Also, I want to take this opportunity to express my greatest debt to my family. Finally, I would like to thank myself, for fighting the silent battles I could not talk about.

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# Chapter 1

# Introduction

## 1.1 Introduction

Faults and incidents can occur in smart building facilities, and detecting and reporting them is considered a challenge [1, 2]. Their effect can be in the form of energy waste, decreased performance, and safety issues. Faults and malfunctions of energy equipment in smart buildings can excess from 15-30% of energy [3]. Research shows that facility faults can cause about 25-45% of energy waste from HVAC energy consumption [4]. Failure may also cause a decrease in the performance of the system and its functionality [5]. Other types of incidents can be caused by cyber-attacks that can compromise the building facilities as well, by exploiting the connection between the cyber, physical, and social components in smart buildings. With this combination, not only the data is at risk, but the amount of information about the building structure can lead to other forms of attacks and physical control of the facilities [6]. For example, the German steel mill prevented the furnace from shutting down and damaging other systems like the alarm and safety systems. The collective effect may have caused the loss of control of the plant operators and caused other physical damage [7]. In the same way, a Ukrainian power grid suffered from an electricity outage that affected about 200,000 customers in 2015 due to malware on multiple devices [8]. Therefore, it is important to detect incidents and faults and recognise their sources, severity, and impact in a timely and cost-efficient manner.

Building managers need to have real-time condition updates about the facility or potential incidents (e.g., water dripping, loose door handles, trip hazards, sensors not working affecting lights and temperature) that might lead to safety and security losses if they are not detected and fixed. This falls under the umbrella of situational awareness (SA) which was defined by Endsley et al.in 1988, as "The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and a projection of their status in the near future" [9]. The definition outlines the three levels of SA [10]: *(1) Perception*, which means actively observing and collecting information about the environment or situation. This stage includes machines (sensors and cameras), human awareness (reports), and human-machine collaboration [11]. *(2) Comprehension*, refers to the understanding of the meaning and implication of the information gathered. *(3) Projection*, refers to the ability to use the perceived information to plan future events such as planning for best and worst scenarios. Therefore, being able to perceive the surroundings and detect potential faults and incidents helps in better SA which can decrease the impact and damage from occurring incidents.

As buildings become smarter, technological solutions can help, but can equally be the source of faults and incidents or not provide enough data. IoT intelligence is commonly used to capture the condition of the smart environment by the automated collection of data [12, 13]. There is a rising dependence on technologies such as passive infrared (PIR) sensors [14] and magnetic reed switches [15] to sense door movements. Still, those sensors are limited to only delivering binary information associated with noise, hence are not suitable for precise reading. Noise represents the irrelevant variation in the sensor readings that do not represent the true state of the phenomenon being measured where the output changes over time due to temperature or humidity [16]. Other fault detection and diagnostics technologies depend on AI methods like machine learning algorithms which require high computational load as well as dependency on the quality of collected data [5]. Other methods like modelling have their challenges in scalability, portability, cost, and simplicity of building the models [17]. CCTV cameras are useful to some extent; however, they can be considered intrusive [18]. Although they are accurate in detecting human movement [19], facilities defects may not be detected by current systems. Also, they cannot provide alerts for potential incidents or defects before they happen. For example, a loose door handle condition could worsen by falling off and causing the door to get stuck or locked with people inside the room affecting their security and safety. Alrimawi et al (2016) pointed out that with the high benefit of implementing technologies and intelligent systems to improve situational awareness, comes a raising possibility of subsystems and components failures since where some have not yet stood the test of time [5]. This means that the complexity of the systems and components may have failures in the future. Therefore, human participation can provide high-value help to have adequate awareness of the situation in the building environment, but building occupants may not always spontaneously report faults as quickly and reliably as needed.

Crowdsourcing is the practice of obtaining information by recruiting the knowledge of people. The term was first coined by Howe (2006) as "the act of a company or institution taking a function once performed by employees and outsourcing it to an undefined (and generally large) network of people in the form of an open call" [20]. Numerous studies have previously shown that crowdsourced contributions created by non-expert observations and interpretations are fairly similar to the experts' outputs. For instance, a study conducted by Warby et al. (2014) demonstrated their practical benefit that can be added together with the experts' efforts [21]. Other work compared the report interpretation of a semi-skilled cohort and the crowd and described the similarities between them, suggesting the indication to use it as an alternative to the estimates of experts [22, 23]. Researchers found the same usability issues reported on content and quality by non-expert guided groups, providing minimal cost and time to employ experts [24]. Additionally, study findings pointed out the learning potential of the crowd suggesting the possibility of using their assessments in situations where they were provided basic training or guidelines [25]. Therefore, the preceding research shows that crowdsourcing is useful in several situations and can be used with non-sensitive data that is difficult to handle automatically [26], yet simple and does not require expertise by a human. From that, this research will start on the premise that crowdsourcing can also help with situations of occupied or lack of employed expert inspectors.

The 'Human as a Sensor' concept is an application of crowdsourcing and the term was first used by Lewis by examining the role of humans as "perceptual sensors" [27]. that provides an attractive solution by utilising individuals' knowledge and observations to benefit situational awareness via monitoring, event/incident detection, reporting potential issues or emergency response [28–32]. In this paradigm, the building occupants voluntarily select and respond to a few location-specific tasks requested by the system to provide their updates without a required high level of expertise. Wang et al. (2017) stated that the human sensing approach is one of the crowdsourcing applications [26]. Studies demonstrate that effective crowdsourcing can lessen administrative expenses, enhance service effectiveness, and improve the relationship between the government/organisation and the public [33–39].

## 1.2 Research Problem

Internal crowdsourcing performed within organisations is often used as a way to collect ideas or solutions from people within these organisations and did not include utilising human sensing to check facility status in smart buildings. Previous studies investigated how occupants engage and include their evaluations and negotiating perspectives to building management around their comfort and preferences during interaction with the building. For example, the authors in [40] examine how environmental data can facilitate interactions between building managers and occupants and propose ways to influence more inclusive and bottom-up building management. Another study explored the dimensions of comfort around shared places, using a device created to conduct thermal comfort surveys of the occupants and imaging the outcomes to them, they highlight the significant role of occupant discussion and agency in decreasing tensions [41]. The study is set to focus on the comfort and opinions of the occupants instead of being active members in reporting incidents and observations of the smart building facilities. Prior to this PhD thesis, it was unknown how smart building occupants perceive reporting incidents and observations when actively prompted by the building management to check the working condition of a facility, and whether it is feasible in terms of time, quality, and efficiency.

To understand this, I describe the human perception of reporting incidents and faults in the smart building and explore the motivations that encourage them to participate in the reporting process of facility conditions and facility-related incidents. Secondly, I show the feasibility of the suggested human-sensing reporting system inside the smart building. Thirdly, I provide a framework for future implementations of the internal crowdsourced human sensing facility reports to contribute to improving situational awareness.

The selected case study was a smart building named the Urban Sciences Building (USB) at Newcastle University in the UK. The selection of smart buildings as a case study lies in several elements. Previous work has shown that the presence of technology in smart commercial buildings affects their occupants. For example, occupants may have some privacy concerns due to not being fully aware of the type of data that is being captured [42, 43]. Additionally, Harper et al. (2020) mentioned people's concerns about not having enough control over their collected data [44]. This may lead to occupants changing their behaviour when they learn about the existence of monitoring and tracking devices such as surveillance cameras.

## 1.3 Research Questions

To address the research problem, this thesis explores the following research questions:
**Question 1**
**What are the perceptions and motivations that smart building occupants have towards reporting incidents and observations in smart buildings?**
It provides answers about user perceptions towards incident reporting, and whether the presence of technology affects their reporting decision. It also identifies the motivations of the occupant's reporting decision of faults and incidents, and whether these motivations change when being asked by the system to perform the checking task. Chapter 3 discusses this question.
**Question 2**

**How feasible is using human sensing to improve situational awareness by reporting facility conditions in a smart building?**

It provides answers about the feasibility of running the human sensing reporting system and receiving accurate and sufficient replies promptly. Participants are requested to perform checks on the facilities of the smart building including the distributed IoT devices. Chapter 4 discusses this question.

**Question 3**

**How can we design an internal crowdsourcing framework for human sensing facility conditions in the context of smart buildings?**

The answer to this question is provided by synthesising the results to provide a framework with a set of steps and guidelines to perform when creating a human sensing reporting system that requests individuals to perform facility checks in smart buildings. Chapter 5 discusses this question.

## 1.4 Contributions

The most significant contribution of this thesis is the proposal of a human sensing framework that provides a set of guidelines to implement an internal crowdsourcing practice within a smart building. It aims to include the people in the process of reporting their observations on facility conditions by responding to a received check task. The contributions of this research can be summarised as follows:

- To answer the first research question, an investigation is conducted using semi-structured interviews with 17 occupants of a smart building regarding their perceptions and motivations towards reporting facility conditions in the smart building they work in. The study also presents a comparison between the motivations of reporting detected facility faults or incidents and being a participant responding to a task asking to check a facility in the building. Altruism and enjoyment elements were found to be the leading motivations for the smart building occupants. This study uses a qualitative thematic analysis of data from open-ended question interviews by counting the emergence of different themes mentioned by participants. The extracted themes were found to match some crowdsourcing dimensions (problem, platform, crowd, environment). It was found that people expect smart buildings to be "smart" and able to regulate themselves in terms of tracking and surveillance to support their reports.

- To answer the second question, a mock system was designed to test the feasibility of running the human sensing reporting system. An experiment was conducted for 4 weeks with 21 participants inside the USB building. The experiment aims to check the quality of replies, the number of replies, and their completion time as metrics of success. The chapter presents quantitative and qualitative results that explain the benefit of including several features such as having supporting data and rating task difficulty. Finally, participants were interviewed to provide their feedback on their experience in reporting their observations on the facility conditions when receiving a check request task from the reporting system. The results showed that the system is feasible with enough accurate responses received in an acceptable time. Precisely, to improve the quality of the received responses, a clear description of the task and the facility location is recommended.

- To answer the third question, I went through a process of synthesising the previous results of Chapters 3 and 4 along with the available literature to draw out actionable insights to feed forward into creating a framework for designing internal crowdsourcing reporting systems for human sensing smart building facilities for any organisation with different demographics, characteristics, culture, and needs. The framework consists of a set of steps that can be followed as general guidelines for the implementation of the system. It covers the key dimensions of the crowdsourcing process: platform, requesters, workers, incentives, and tasks. It also highlights the importance of environmental preparation in smart buildings in particular.

## 1.5 Publications

**Conference Paper:** N. A. Abah, N. Taylor, C. Morisset and M. Mehrnezhad, "U-Sense: Feasibility Study of “Human as a Sensor” in Incident Reporting Systems in a Smart Campus," 2023 IEEE European Symposium on Security and Privacy Workshops (EuroS&PW), Delft, Netherlands, 2023, pp. 641-652, doi: 10.1109/EuroSPW59978.2023.00075. A version of this paper is presented in Chapter 4.

## 1.6 Thesis Structure

- **Chapter 2 Background, related work, and methodology:** The chapter provides background information about smart environments, crowdsourcing and human sensing. Followed by a list of related work in human-building interaction, and incident reporting. Finally, it describes the research methods used in this thesis.

- **Chapter 3 User perceptions, practice, and motivations:** This chapter answers the first research question and presents the first contribution. It explores the user perceptions towards incident reporting, environmental and technology impact, and motivations.
- **Chapter 4 Feasibility study of human sensing facility conditions in smart buildings:** This chapter answers the second research question and presents the second contribution. It tests the human sensing concept by assessing several aspects.
- **Chapter 5 Human sensing framework for smart buildings facilities:** This chapter answers the third research question and presents the third contribution. It presents a framework that outlines general guidelines for the management to implement the system. It then discusses different challenges associated with the framework.
- **Chapter 6 Conclusion:** This chapter summarises the contributions and results of this research, the limitations, and finally the future work of the research.

# Chapter 2

# Background, Related Work and Methodology

**Overview** This chapter provides background information on the concepts, methods, and technologies related to the research carried out in this thesis. Section 2.1 provides a general overview and background information on the definition of smart buildings, crowdsourcing, and human sensing, as well as a description of the case study. Section 2.2 provides an overview of related work on smart building-occupants interaction, incident reporting, and the utilisation of the human sensing method. Section 2.3 summarises the data collection methods followed to complete this research. Lastly, Section 2.4 concludes the chapter.

## 2.1 Background Information

This section provides background information on smart buildings, crowdsourcing and its two types internal and external crowdsourcing, terminology, and motivations. In addition, details about the case study, Urban Science Building, are presented in this section. Finally, this section describes human sensing, one of the crowdsourcing applications that will be followed in this thesis.

### 2.1.1 Smart Buildings

Smart buildings are expected to be intelligent and sustainable due to the use of a range of technologies to attain occupant comfort and energy consumption [45]. Automation is a desired goal in smart buildings and is achieved by the installation of various interconnected devices and sensors in the building [46]. The level of knowledge and awareness of the environment is associated with smart buildings; McGlinn et al. (2010) define smart buildings as "a subset of intelligent environments that are capable of maintaining and using knowledge about the environment and its occupants to enhance their overall experience in that environment" [47]. Similarly, Kiliccote et al. (2011) mentioned awareness of smart buildings along with the response to real-time mandates to meet requirements such as responsiveness, adaptability, and flexibility [48].

The main characteristics of smart buildings are the presence of sensors, systems, automation, and data analysis that provide effectiveness, and sustainability, and improve the living experience of their occupants. This “smartness” is not specific to a certain field; in fact, it expanded to cover various activities such as healthcare, vendors, airports, universities, headquarters and offices, or manufacturing [49–56]. All these buildings have their own occupants’ demographics based on the purpose of the building. For example, a smart campus can contain a diverse group of staff and students.

**Building management systems (BMS)** are cyber-physical systems that are commonly used in smart buildings to monitor and control the performance of the building and its devices [57]. Generally, BMS is a set of sensors and IoT devices, software systems, and microprocessor-based controllers to manage the smart building areas and zones. BMS range in their complexity and consists of ventilation, lights, and temperature adjustment. Building management systems serve the smart building by performing tasks such as: sensing environmental changes and occupant presence, scheduling and adjustment of temperature and lighting, controlling access in and out of the building its zones, etc. As BMS supports the integration of various objects with dissimilar natures, they are considered highly complex. This indicates that they are susceptible to errors and faults that are unexpected. Also, because they are used in critical buildings, this indicates the importance of fault detection in a timely and precise manner to perceive the energy and safety of the building occupants and devices [58].

### 2.1.2 Case Study - Urban Science Building

The research study was conducted in the Urban Sciences Building (USB) at Newcastle University, Newcastle upon Tyne, UK. A smart university building was built in 2017, comprising around 134,500 sq ft. Its residents are diverse, including academic and professional support staff, research staff and undergraduate and postgraduate students. The building has around 1,200 students, 55 academic staff and 120 postdoctoral researchers as well as other visitors from academia, business and government. Large parts of the USB are also accessible to the public. Furthermore, building occupants typically receive a short overview of the building features throughout general induction sessions. No signs or informational brochures show the existence and functionality of sensors that serve building purposes. Moreover, staff and students do not receive induction sessions about the sensors within the building. Nevertheless, more detailed information is available online for those who want to learn more about the subject (http://newcastlehelix.com/about/urban-sciences-building).

It consists of six floors designed for teaching, laboratory research, events and testing real-time smart technologies for urban sustainability. Its spaces include individual and open-plan offices, computer labs, seminar rooms, and lecture theatres [59]. The building is considered to be “smart” due to its data gathering system used by facilities supervisors to support problem analysis and to regulate energy consumption, joined with a BMS (Building Management System) that adjusts comfort settings, such as the temperature and lighting. It is a suitable environment for research in several fields like HCI and HBI. Several experiments and workshops were conducted to study the building users and how they perceive and interact with the building. For example, Mitchell et al. (2020) explored how HCI and HBI practitioners can design interactions that adopt activity and contribution to facilities management processes [59]. Margariti et al. (2023) focused on the human experience pointing out grey zones and concerns regarding data collection [60].

Designed as a Building as-a-Lab, the USB differs from other smart buildings by offering an operational test bed for recognising the relationship between buildings and their interior and exterior surroundings. The Building-as-a-Lab concept enables controlled experiments, by including around 20 plant rooms with differing configurations, and 3 building units with their own circuits and supplies. The USB includes more than 4,000 sensors and 15,000 data networks, all integrated in the open places of the building. This makes it one of the most highly monitored buildings in the world, where the huge count of sensors allows a nonstop collection and analysis of large amounts of data (over 1 million data points on average per day). In addition, it also provides basic environmental data for the workspace such as CO2 levels, temperature, humidity, brightness, and occupancy. These sensors gather digital or analogue data associated with temperature, noise, and attendance [61].

### 2.1.3 Crowdsourcing

Increasing citizen connectivity and digitalisation of government and business information systems have opened new ways of sourcing knowledge from residents through the internet-based approach, for example, mobile apps [38, 62]. The term "crowdsourcing" was coined by Howe in 2006 and defined it as defined as: "the act of taking a job traditionally performed by a designated agent (usually an employee) and outsourcing it to an undefined, generally large group of people in an open call” [20]. Other terms were also used describing similar ideas such as peer production, user-generated content, and smart mobs [63–65]. Estellés-Arolas et. al in [66] provided a definition which stated that it is an online participation activity by a group of people varying in knowledge and number who volunteer to complete a task sent by a requester that can be a person, private or governmental organisation. Tasks can be in different complexity levels that require contributions of diverse types of forms such as work, knowledge, money, or experience. The crowdsourcer then will benefit and utilise what the crowd provided and reward them with a benefit for accomplishing a task like monetary, social recognition, self-esteem or skill improvement.

Blohm et al. (2018) have distinguished four types of crowdsourcing based on the diversity and aggregation of the contributions: micro-tasking, information pooling, broadcast search, and open collaboration [67].

- *Microtasking* is where people perform microtasks that result in benefiting a larger project. It is better suited to the need for scalability and time-saving of vastly repetitive tasks like categorizing data or labelling images. Amazon Mechanical Turk is a case of micro-tasking.
- *Information pooling* is useful for cumulative distributed contributions such as votes, opinions, assessments, and forecasts. Examples of this approach are platforms gathering location-based information like GoogleMaps.
- *Broadcast search* accumulates contributions to receive alternative perceptions and solutions to a problem from individuals outside the organization. It fits the most in projects that require problem-solving, technical and analytical challenges, and scientific or inventive tasks. One example is Applause for software testing. Also, Netflix Prize

asked contributors to propose algorithms for customer preference prediction that are more accurate than the existing Netflix algorithm.

- *Open collaboration* platforms call participants to team up to cooperatively solve a complex task where the result requires the combination of different knowledge and the skills of several individuals. OpenIDEO platform of the agency IDEO has requested people to openly team up to provide shared solutions to universal problems like maternal health or urbanization.

Crowdsourcing platforms can include several traits. For example, the Netflix Prize has the attributes of both broadcast search and open collaboration [67].

### 2.1.4 Internal and External Crowdsourcing

A main advantage of crowdsourcing relies on the size and diversity of the contributors, which allows requesters to attract more and various knowledge and skills. Therefore, two types of crowdsourcing have emerged based on the size of the crowd. External crowdsourcing aims to reach a wide range of external people as a source of ideas and contributions. On the other hand, internal crowdsourcing focuses on a large and diverse population of participants inside an organisation leveraging the skills and experience differences of employees distributed across several locations, job roles, and positions within the organisational hierarchy [68]. Many organisations across the industry domain have their attention towards internal crowdsourcing. The majority of prior work on internal crowdsourcing emphasises on exploring design and implementation decisions companies need to make if they plan to use these platforms internally [69].

Several organisations started moving from external crowdsourcing to internal crowdsourcing to mitigate the risks and limitations attached to the former like issues with the leakage of sensitive information of the organisation and the intellectual rights dispute [12]. Internal crowdsourcing, on the other hand, provides the same advantage of having a large and diverse crowd (employees from different levels and business departments) but at the same time keeping the process focused and internal [70, 71]. Despite the extensive research in crowdsourcing motivation, no all-purpose model has been decided on regarding what motivates workers there. For example, there are opposing views on the usefulness of financial incentives [72, 73]. Some work recommends financial rewards as they work best [26, 74], while others propose that non-financial rewards are more effective [72, 73, 75]. Therefore, this contradiction points to the fact that each internal crowdsourcing enterprise situation is unique and thus does not fall under a simple generalisation [76]. This observation informs

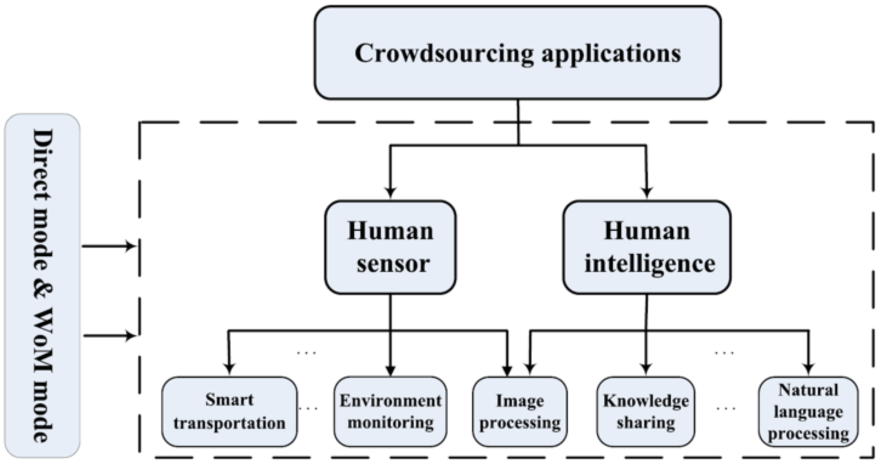



Fig. 2.1 Human sensing as an application of crowdsourcing and used for environmental monitoring [26]

the first research question of this thesis regarding understanding human sensor perception and motivations in the context of smart buildings.

### 2.1.5 Human Sensing

Human sensing or sometimes called the 'Human as a Sensor', is a form of crowdsourcing to collect data using mobile sensors and human observations. It is similar to spatial crowdsourcing, but with the discrepancy that individuals would focus on contributing within their local area like their neighbourhoods, workplaces and often visited places [77, 78]. User intervention in crowdsensing platforms can be either implicit or explicit. The implicit way depends on the sensors in the mobile devices to collect data where they have specific apps that run in the background and the only contribution a person makes is open the app [79], or it can be by using web 2.0 services (e.g., social networks) where they unintentionally contribute valuable data [80]. The explicit sensing does not essentially include sensors in the conventional technical sense, as people can contribute by sending their observations themselves, with slight or no support from technology. As this requires labour-intensive involvement, it often includes providing incentives for them [79, 81]. This method is the one I am investigating in this thesis where participants will contribute willingly their environment observations to the requester. This may fall into a self-selection bias where participants choose themselves into a group causing a biased sample [82].

Human sensing has been utilised in a wide variety of contexts to collect data on a larger scale than would be achievable through other approaches. It is mainly suitable for settings in which task requesters wish to comprehend the experiences of people in a certain place or environment or to extract feedback from them [83]. Crowdsourcing and human sensing have several applications, such as environmental monitoring [84–86], event/incident detection and response [28–32], traffic forecasting [87, 88], healthcare monitoring [89, 90] and location services [91, 92]. Figure 2.1 illustrates the several applications of crowdsourcing. Human intelligence is where the system can benefit from the human by several methods like natural language processing, knowledge sharing, or image processing. The other application is human sensing where humans can move around to provide observations. For instance, smart transformation and environmental monitoring. The figure shows that human sensing is a part of crowdsourcing applications as Wang et. al presented in their taxonomy [26].

### 2.1.6 Motivations

One of the main reasons of success in any internal crowdsourcing initiative in an organisation is subject to the motivating system selected to encourage their employees to participate in distributed tasks [93, 94]. Therefore, organizations that apply crowdsourcing should convince their staff to engage with their tasks and contribute to the intended solutions by assigning the task to be resolved through a suitable platform [95]. Accordingly, the organisation and the internal crowd involve in an exchange process— the participants put effort into performing the tasks and submitting answers and expect to obtain rewards for their efforts [95]. There are several definitions of motivation, yet the definitions fundamentally focus on the reasons that influence a person to perform a task [93]. Parashar defined motivation as the underlying reason influencing a person to act in a certain way [96]. A motivated individual is derived to perform certain actions, while an unmotivated person does not obtain the energy to participate or be involved [97]. Motivation mechanisms commonly have two goals: stimulate workers to actively join and input accurate data, and encourage requesters to deliver honest comments about the quality of the received answers. Based on their activities, it may reward/penalize workers and requesters with financial, ethical, entertainment, and priority [26].

Ryan and Deci divided the motivation into two different groups: intrinsic and extrinsic motivations that impact a person's purpose to contribute and affect their engaging behaviour to different levels [97]. The variance is that intrinsic motivation is determined by internal stimulus, and individuals do not expect personal benefit from doing any actions whereas extrinsic drives include a gain of personal benefit [98]. However, motives may differ significantly based on the user type, the situational context, and the system itself. This is one of the reasons that such studies are important before implementing a crowdsourcing initiative in an organisation.

Katmada et al. (2016) have identified 7 motives: learning/personal achievement, altruism, enjoyment,social motives, self-marketing, implicit work,and direct compensation [99]. The first four can be considered as intrinsic motives that align with the Maslow hierarchy of needs [66]. Motivations can also be triggered by applying some incentive mechanisms in the platform designs. Katmada et al. also presented four basic incentive mechanisms that motivate people to participate:

- Reputational systems: The engagement level and quality can be improved by adding a rating feature among participants.
- Social mechanisms: Social image is highly appreciated among participants in online communities, who want to be seen as “good” overall. Some incentives are like adding them to a special mailing list, delivered feedback, praise features, and event invitations [100].
- Gamification: is the use of game-design elements in a non-game context [101], such as earning points, badges and levels, and leaderboards.
- Financial rewards: cause extrinsic motives like vouchers and token rewards. For example, the app Waze - used for traffic monitoring and accident reporting by users’ phones- utilises the gamification mechanism by providing avatars for the users, collecting points and badges.

### 2.1.7 Crowdsourcing Terminology

It is important to clarify some of the terminology being used in the context of crowdsourcing applications. These terms are used, as well as the ones specified for this research project inside a university smart building:

- **Human as a sensor**: Is the process of utilising human observations by having them as participants in providing updates on facility conditions and incidents in the buildings. Lewis (2009) started using this term by examining the role of humans as "perceptual sensors" [27].
- **Task, check task, check request**: Is any task that is sent by the system to the building occupant to check a facility’s condition.
- **Requester, administrator**: Is the person who sets up the task and its requirement and sends it to the building occupant through the system.
- **Responder, occupant, participant, worker, crowd**: Is the person who receives the task through the system and decides to delay, cancel, or respond. When deciding to

respond, they go to the facility location to check its condition and then respond to the system.

- **Received data, responses, answers, replies**: data submitted from the responder to the task request.

## 2.2 Related Work

This section presents the related work that has been conducted to improve situational awareness in several contexts like smart buildings, cyber security, and human sensing. It lists some of the contributions that were offered as steps towards better situational awareness like technical solutions and software, frameworks, qualitative research, etc. This section also lists some of the studies conducted in smart buildings on human-building interaction and occupancy detection. Finally, the section presents a description of the current state of incident reporting systems user studies and sharing the knowledge in several contexts in environment observation and crisis management.

### 2.2.1 Human-Building Interaction (HBI)

When it comes to the "smart agenda" for any environment, research has focused on improving efficiency, sustainability and reducing costs. HBI emphasizes human values, requests, and preferences to understand occupants' interactions with such environments. Different building type has their own purposes, needing a number of contextual requirements demanding the expansion of attentive research where the outcomes may have differences and similarities with other contexts [59, 102].

Describing HBI in *Space is the Machine* [103], Bill Hillier said that: "Built environments are a construction of physical elements that create and protect a space. Each of these two aspects, the physical and the spatial, carry a social value: the former by the shaping and decoration of elements (with functional or cultural significance), and the latter by providing spatial patterning of activities and relationships. Designing Human–Building Interaction, in that perspective, consists of providing interactive opportunities for the people to shape the physical, spatial, and social impacts of their built environment." Thus, HBI focuses on the multi-functional concepts of the building, comprising three interconnected features: physical-material, spatial-configurational, and social-cultural [102].

Research conducted by Verma et al. (2017) who analysed the use of building space based on sensor data [104]. Finnigan et al. (2017) also used sensor data (proposing a wireless sensor toolkit) in the auditing routine of building managers to assess building performance and monitoring standards compliance [105]. Other studies involved occupant complaints as an approach for facility supervisors to evaluate their satisfaction with the indoor environment [59]. Clear et al. (2018) set their attention on occupant contribution in building assessment and administration [40, 41]. They examine how environmental data can facilitate interactions between building managers and occupants, and propose ways to influence more inclusive and bottom-up building management [40]. Other studies explored the dimensions of comfort around shared places, using a device created to conduct thermal comfort surveys of the occupants and imaging the outcomes to them, they highlight the significant role of occupant discussion and agency in decreasing tensions [41]. The observation that occupants are involved in the incessant making [106] and appropriation [107] of place informed the research questions mentioned in section (1.3) on how can occupants engage with management in terms of maintenance and facility conditions.

### 2.2.2 Occupant detection

When it comes to smart buildings, occupant and vacancy detection has been a research focus in the last decade for its benefit in different applications such as situational awareness and energy consumption. One of its challenges is how to receive a high-accuracy estimation without using camera data and image processing methods [108] due to privacy concerns. Therefore, leveraging sensor data for enclosed residence detection is a present trend in the ambient sensing research field [108]. Below, is a list of the used methods for occupancy count and detection:

- **Simulation-based Indoor Human Occupancy Detection** Creating simulation models for estimating occupant count inside enclosed areas is a known method that can be used for several reasons including situational awareness and studying residents' behaviour for the objective of energy consumption. Research papers like [109–111] present this type of solution.
- **Radio-based Indoor Human Occupancy Detection** Radio-based Indoor Human Occupancy Detection refers to using devices such as WiFi, Bluetooth, electromagnetic waves and gamma rays. A research paper proposed a model that only uses WIFI power for human detection [112].
- **Indoor Human Occupancy Detection with Homogeneous Sensors** This type of research depends on only one sensor type to count and detect occupants. Multiple research used some algorithms in this direction like [113, 114]. One of the most

utilised sensor types is the passive infrared (PIR) sensor to detect people's movement [113, 115]

- **Indoor Human Occupancy Detection with Heterogeneous Sensors** This type of research depends on several sensor types to count and detect occupants. A project from the University of Southern California has a collection of sensors (light, sound, motion, CO2, temperature, and humidity sensors) to produce a model to expect people's presence. Moreover, a study result attained an accuracy of over 80% with 45 participants using mobile crowd sensing where they managed to leverage a set of smartphone sensors (microphone, Bluetooth and WiFi) [116].

- **CO2-based Indoor Human Occupancy Detection** The benefit of this method is that CO2 sensors do not raise the operational cost because they are already installed and integrated into the building management systems (BMS). Some papers used machine learning algorithms with sensors deployed in and out of the room [117]. Another work utilised the carbon dioxide sensor in their solution (CD-HOC) to help estimate the number of occupants inside a room [108].

### 2.2.3 Incident Reporting and Response Systems

Incident response is the process of detecting alarming events that could affect resources (digital or physical) and then taking the proper planned steps to assess and fix the situation as necessary [118]. Governments and organisations set guidelines, policies and rules to prevent incidents from happening [118]. One of the important aspects of handling incidents is how early they are detected. There are different ways of detecting alarming events, such as having monitoring systems, human reports, and combined methods. Incident reporting is considered the first step in this chain. In this context, there is a difference between an 'incident' and an 'accident' [119]. An *accident* is defined as an unexpected action ending with serious injury, illness, or property damage [119]. An *incident* is an occurrence that does not result in harmful damage yet has the potential to cause harm. In the context of a workplace, incidents are more likely to happen [119]. According to the Australian risk management consultancy IPM, accidents cover only 2 % of the incidents in the workplace [119].

#### User studies on incident reporting systems

Several studies have focused on analysing the existing reporting systems. For instance, Bach et al. (2011) focused on the user side of the reporting tools and analysed 23 incident reporting systems [120]. They studied urban contexts to understand users' insights into incident reporting applications and aspects affecting the user experience [121]. They found that UX dimensions that can be utilised to trigger and motivate users to report incidents in urban places. Likewise, Winckler et al. (2016) explored the user experience of a reporting system app [122]. They reported certain requirements such as presenting reportable items in the app menu to avoid non-specific forms, identification for avoiding fake reports and features for uploading evidence such as pictures and videos. Grant et al.(2015) conducted a study to assess the usability of an incident reporting tool by recruiting users to conduct tasks using the prototype tool and then filling Ravden and Johnson's Human-Computer Interaction (HCI) checklist [123].

**Human sensing in reporting information security incidents and attacks**

In several cyber security scenarios, people can outperform technical security procedures in noticing threats. This is mainly in the deception-based attacks (e.g., spear-phishing) rather than exploitation of a precise technical fault [124]. Heartfeild et al. (2017) had a series of experiments on human sensors in the field of cyber security semantic attacks in social media. Their focus was specifically on the attacks that involved human deception of the individuals more than the technical flaws. They started with assessing the human sensor's ability to detect cyber-attacks by asking a large sample of users with different profiles to answer a questionnaire asking if the provided scenarios are attacks [125]. They have demonstrated that it is possible to predict to a certain level people's capability as sensors of such attacks. Then they followed this with another study where they designed a human-as-a-security-sensor framework and a real-world implementation in the form of a prototype named (Cogni-Sense) that is designed to help and reassure users to actively spot and report semantic social engineering attacks [126]. Related to that, Rahman et al (2017) introduced a method for evaluating reports in regards to their cyber-trustworthiness based on characteristics of the mobile devices [127].

Related to that, Vielberth et. al., claimed that the security awareness campaigns for employees did not achieve the full potential of the raised awareness in terms of leveraging the type of contextual information about incidents reported by the human factor. Therefore, they propose an approach to enable people to systematically report found anomalies or incidents in a structured manner. They also considered the collected data analysis part by the integration of the Security Information and Event Management system (SIEM) [128].

### 2.2.4 Incident reporting and sharing knowledge in smart spaces

The combination of processes, software, and devices in smart buildings empowers interactions between cyber and physical elements within. This connection means that in some cases, an event triggered by a cyber element can affect physical ones, and vice-versa. For example, in a smart building, an increase in the temperature of a room can activate a start cooling command to the air conditioning system. Based on that, previous work focused on dealing with incidents in smart buildings. Alrimawi et al, (2020) work set the focus on incident reporting and **sharing the knowledge of incidents** in smart spaces. They contributed with two meta-models to show incident patterns and the smart spaces. They also developed an automated method to share incident knowledge across diverse organizations [6, 129]. Another solution to improve incident reporting and monitoring in smart spaces is the study conducted by Scheuermann et al. (2015) [130]. They developed a Cyber-Physical Human System, that provides simultaneous incident monitoring and management via peoples' wearables shared with smartphones and Bluetooth tracking technology.

The work presented by Eckhart et al. (2019) is one of the papers that contributed to the area of situational awareness enhancement, the authors utilised the concept of **digital twins** to improve cyber situational awareness [131]. They used the virtual copies of systems that work as equivalents to their physical counterparts and offered a thorough examination of their performance avoiding the risk of affecting operational technology services. Their contribution is to create a cyber situational awareness framework built on digital twins that delivers a deep, complete, and up-to-date assessment of the cyber condition of smart buildings. They delivered a prototype presenting simultaneous visualization elements such as the program variables of devices.

Moreover, other papers were concerned with the improvement of the monitoring software to benefit physical security and work on the development and integration of the Security Information and Event Management system (SIEM). Frattini et al (2019) tried to merge the well-known IBM SIEM (QRadar) with another physical protection system. This integration aims to assist physical security employees in finding unseen threats, and the cyber-security team to be aware of the potential threats related to the physical system [132].

On the other hand, some studies cover the **risk assessment** guidance in smart infrastructure such as IoT [133], smart grid [134], and smart homes [135]. Mace et al, (2020) handled the lack of standardised risk assessment methodology for smart buildings. In their paper, the authors state about a risk assessment conducted in 2018 on a real-life high-tech smart building, holding more than 1300 people. Specifically, they highlight the challenges faced, such as the absence of risk ownership and change monitoring, and they also provide some recommendations for evaluation and supervision of risk [61].

### 2.2.5 Human sensing in crises management and environmental observations

In times of crises, people have generally been considered as individuals to be rescued rather than active contributors [136]. As stated by Fraustino et al. "oftentimes, individuals experiencing the event first-hand are on the scene of the disaster and can provide updates more quickly than traditional news sources and disaster response organization". Preceding research papers have found that socio-mobile applications in emergency circumstances can be valuable to enable the collection of information, as well as keeping the sense of belonging and human connection between society members [137]. Nevertheless, extracting information from social media posts involves some peculiarities like noise, briefness, and conversational types (e.g., hashtags, shortened URLs, wrong grammar, absence of context) [138].

Web 2.0 technologies accompanied by the digitalisation of the information systems of governments and businesses have opened ways for the interaction between authorities and residents via an Internet-based approach, e.g., a mobile app designed for people to share their knowledge [38, 62]. Some authorities and organisational entities have utilised the concept of crowdsourcing and human sensing to gain access to collective insights, skills, and ideas from the virtual crowd [139]. Human sensing is used in smart cities to utilise individuals' observations for the authorities to broaden their situational awareness among several fields such as event/incident detection and monitoring and emergency response to natural catastrophes [28–32]. Bennett used this concept to reduce crimes inside neighbourhoods [140]. He et al. (2013) used the tweet semantics to predict traffic [141]. Alkhatib et al. (2018) applied text mining techniques to Twitter feeds in Arabic to extract reports from the public to help manage incidents and events in smart cities [142].

Some reporting systems do not focus exclusively on incidents, but instead on people's observations. Therefore, incidents are not happening to trigger the user to engage and report. For example, citizens can be observers monitor the environment and report potential incidents. Hence it is considered an efficient method for administration for monitoring ecological data with less resources and costs [143, 144]. In citizen science, Preece mentioned various approaches used for gathering and monitoring data [145]. Such approaches include mobile apps, drones, webcams and gamification. Salfinger et al. (2013) surveyed situational awareness systems for improving ecological monitoring responsibilities [146]. Stavrakantonakis et al. (2012) offered an assessment framework for social media monitoring software, concentrating on ideas, user interfaces, and technology [147]. An example of an app that uses human reports and observations is *FixMyStreet* in the United Kingdom for reporting unlit streetlamps in the street.

## 2.3 Research Methods

This section describes the approaches and studies that I used to answer the research questions asked in Chapter 1. Two comprehensive studies were conducted to understand the perception of the building occupant in reporting to a crowdsourcing system and the readiness of the prototype to be applied in a smart building (smart campus in particular). These two studies discussed in Chapters 3 and 4 helped design a framework that sets guidelines to plan and implement a human sensing system for smart building facilities in Chapter 5.

As mentioned in Chapter 1, to formulate the research problem and explore how a smart building environment can affect occupants' participation in human sensing reporting systems, a qualitative research method was followed to gather data through interviews to understand in-depth occupants' perceptions of incident reporting in smart buildings and the motivations behind it to extract the requirements and components of the proposed solution. The interview approach allows researchers to gain comprehensive data directly from the interviewees, capturing their feelings, drives, and interpretations through their terms and expressions. This stage of the study delivers details of smart building users' perceptions of reporting incidents, the effect of technology on their reporting decisions, and the motivations to participate in human sensing reports of the smart building facilities. Next, based on the analysis of the results of the study conducted above and mapping them to the main dimensions of crowdsourcing systems, the main points and guidelines of the proposed solution are initiated.

Moving to the empirical approach, the next step was to explore the feasibility of leveraging human sensor observations to improve situational awareness in a smart building. To test the feasibility, a mock human sensing system was designed to run for a month in the Urban Science Building at Newcastle University. The system was sending tasks to participants to check facilities' conditions for occurring or potential defects. Quantitative data was collected throughout the experiment such as task completion rate and number of replies. This data was used for the success criteria of the proposed system. After completing the trial, I extracted qualitative data by interviewing the participants to collect their feedback about their experience as contributors to the human sensing system in the building. Both Quantitative and qualitative results provided several key implications that were used as an extended base to design the proposed human sensing framework of smart buildings. The strategies mentioned above are outlined and defined in more detail below:

### 2.3.1 Qualitative Analysis

Data analysis can be performed by three methods: qualitative, quantitative, and a blend of both known as mixed-methods [148]. The qualitative analysis approach relies on interpretivism way which includes probing the social reality by using their understanding and subjective interpretation of the studied phenomenon [149, 150]. Aspers defined qualitative research as "an iterative process in which improved understanding for the scientific community is achieved by making new significant distinctions resulting from getting closer to the phenomenon studied" [151].

Qualitative research uses a multi-method style, emphasising interpretation and a naturalistic investigation of the topic. This style involves learning about the phenomena in real settings, to grasp and interpret the importance attributed to them by the people involved [152]. Qualitative research covers the utilisation and assembling of various experimental resources, such as case studies, interviews, observations, historical records, interactive data, visual texts, personal experiences, introspection, and life stories. These resources help to show both regular and challenging moments as well as the importance attributed to them in people's lives [153]. Moreover, there has been considerable advance in the use of quantitative methods in the last five decades [152].

Qualitative research often produces conceptual frameworks that are applied through a variety of methods for data collection and analysis. It does not follow a set of pre-defined questions or structured steps, allowing for the appearance of unexpected discoveries [154]. Main data collection practices often used in qualitative research cover narratives, case studies, ethnographies, and grounded theories [155]. This method was used in chapter 3 when interviewing the participants.

### 2.3.2 Quantitative Analysis

Creswell briefly defined quantitative research as a research method to describe a phenomenon by collecting numerical data and analysing them via mathematical procedures, particularly statistics [156]. Quantitative research comprises the numerical illustration and manipulation of observations to clarify and explain the phenomena they present. This approach is widely used in natural and social sciences and fields such as physics, biology, psychology, and sociology. Also, Cohen described quantitative research, as social research that applies experiential methods and makes experiential declarations [157]. According to Cohen, an empirical declaration is considered as a descriptive declaration that refers to what is found in the "real world" instead of articulating prescriptive decisions about what should be [157]. Quantitative research usually describes empirical reports in numerical terms. Another characteristic of quantitative research is the application of empirical assessments, which comprise evaluating the level to which a certain program or policy successfully matches or fails to match a certain standard or norm through empirical observation [157].

The quantitative method differs from qualitative research with its strict objectivity, which is regularly connected to the positivist model [158, 159]. Quantitative research intends to extract knowledge by hypothesis testing to find variable correlations. Therefore, the analysis emphasises numeric and measurable data to evaluate these relationships and correlations [152]. The analysed data is put through different statistical methods, which go together with the evaluation steps that contain performing reliability and validity tests. Common methods of data collection in quantitative research cover experiments, cross-sectional studies, and longitudinal strategies [160]. Moreover, quantitative experiments tend to have more validity due to the possibility of introducing control conditions [161, 162]. This method was used in chapter 4 during the real-world experiment by collecting some numeric data such as the number of replies.

### 2.3.3 Mixed-method

Mixed-method research includes features of both quantitative and qualitative methods, joining aspects from both. This form of method does not adhere firmly to either the interpretive or positivist research models. In a way, the method takes a pragmatic style, where the selection of research methods depends on the context. The investigator has the liberty to apply the technique that is most appropriate for a certain situation to study the research problem efficiently [156]. The motivation for mixing research approaches must be sufficiently justified [154]. There are several reasons behind choosing to follow the mixed method approach, one is the need to complement conclusions, get a profound understanding of the phenomenon under study, or present a transformative outline to the investigation [163].

Mixed-method research techniques can differ based on how two opposing methodologies are joined. The integration can be partial, meaning it happens within the same phases. On the contrary, it can be full integration, meaning the integration of the approaches happens at different phases [164, 165]. Moreover, qualitative and quantitative research approaches can be used simultaneously, meaning they can be applied at a single stage, or consecutively, applied at different stages [154]. This was represented in chapter 4 when analysing the experiment numeric data collected during the experiment and qualitative data by interviewing the participants.

### 2.3.4 Thematic Analysis

Thematic analysis (TA) is a commonly used approach for analysing data and creating insights in psychology and other disciplines [166]. In this approach, themes and content analyses are recognised [167] for qualitative [168] and quantitative data [169]. Regarding qualitative data, a lot of information is mostly collected through different ways like interviews, observations, and document analysis. The reason behind that is that qualitative data comes in the form of texts or visual data which requires interpretation. This is contrary to the form of quantitative data, where numeric forms can be measured and analysed via statistical procedures without difficulty.

Thematic analysis is often used for data interpretation, deductive and inductive analysis in two different phases of the data and coding and classification. Interpretation is significant in the process of qualitative data analysis as it results in making sense of the given material, detecting emerging themes, and patterns, how they are connected, and concluding meaningful perceptions from the data. The thematic analysis includes a step of coding, classifying, and organizing the data to reveal any meanings and themes [157, 170]. Usually, the first step is to conduct a descriptive level of coding by classifying and labelling different parts or pieces of data based on their subject or properties. This initial coding supports organizing the content and providing a primary structure for analysis. This comprises making links between codes, discovering the underlying meanings, and producing a conceptual knowledge of the data. After that, in the later steps of the analysis, researchers may revisit the codes and their groups to improve or review, combine similar codes, or produce new codes or groups to find emerging themes. This iterative process of coding and analysis benefits in finding hidden perceptions about the data [171].

Additionally, the flexibility of thematic analysis provides an opportunity to perform inductive and deductive approaches [172]. The inductive method begins with particular content then transfers to wider generalisations and ends with theories. On the contrary, the deductive technique intends to test present theories. To study the matched observational data in regards to the created perception that occurred from participants' views or feedback during the study, a thorough analysis can be performed with a focus on the viewpoints of people [160].

Dealing with data during preparation and analysis can be performed in different ways. Researchers can select manual or automated methods like using NVIVO software. NVIVO and similar tools are advantageous for the analysis process of qualitative data as they facilitate the collection and classifying of the context into themes or concepts. It improves the accuracy of the process by creating an organised framework for analysis and validating conclusions that may exceed the researcher's subjective opinion of the data. Furthermore, tools support the analysis at a more detailed level, allowing deeper investigation of the data [173].

### 2.3.5 Data Collection Method

This section discusses the data collection methods conducted in this research to identify occupants' perceptions and motivations towards human sensing in smart building facilities, to test the feasibility of the proposed solution, and then finally synthesise the results to the internal human sensing framework for smart buildings.

#### Interviews

Researchers broadly use interviews as principal approaches for collecting qualitative data. One reason for that is that they help as resources to probe into the perspectives, practises, views and motivations of the interviewees [174]. Interviews have their drawbacks such as being time-consuming and resource-intensive for the researcher. There is also a cultural and language barrier that might arise during the interviews. Another drawback that the researcher should be aware of is the social desirability bias. People may be affected by the interviewer's presence and questions and feel pressured to answer with socially acceptable responses instead of expressing their actual opinions and thoughts. [174]

#### Semi structure Interview

The importance of performing qualitative research is in offering a holistic view of the phenomenon under analysis using principally subjective qualitative data, where the findings are determined based on observational and other quantitative data [175, 176]. One example of qualitative research methods is the interviews, which serve as a valuable source for scholars to directly collect data. From the interview questions, the participant answers the question and provides information, that is analysed and studied to build an understanding of the subject study [177]. Interviews are conducted via conversation between two parties, the interviewer and the interviewee. However, the interviewee can be one person or a group. Both forms provide a purposeful interaction that is designed to reach precise goals [178].

There are three types of interviews, structured, unstructured, and semi-structured. The main difference between the three is to what extent the interview is structured and questions are prepared. In this research, I performed the structured and semi-structured interviews. The semi-structured interview comes in between the two other interview types. This means that the researcher needs to prepare a set of predefined questions or topics to direct the dialogue, yet there is still space to explore new concepts and probe deeper into some places based on the participant's replies. Unlike structured interviews where there is the least amount of flexibility in exploring other topics in the conversation. Semi-structured interviews are as they are a precise style in the wider spectrum of interview styles. They offer a balance between the firm construct of an entirely structured interview and the open-ended style of an unstructured interview. This method allows for both homogenous data collection and the chance for participants to deliver more nuanced and related information about emotional state, views, and perceptions on specific matters [179, 180].

## 2.4 Conclusion

This chapter presents a comprehensive background to the main subjects relevant to the research performed in this thesis. Its goals are to offer thorough background information and review related work about studies on smart buildings and human sensing incident reporting solutions and identify the research gaps that the research questions are answering. The chapter showed that crowdsourcing is a well-employed technique that has been applied in several applications and contexts. The chapter presented a research gap regarding participants' motivations. Despite the extensive research in crowdsourcing motivation, no all-purpose model has been decided regarding what motivates workers there. For example, there are opposing views on the usefulness of financial incentives. Some work recommends financial rewards as they work best, while others propose that non-financial rewards are more effective. Therefore, this contradiction points to the fact that each internal crowdsourcing enterprise situation is unique and thus does not fall under a simple generalisation. This observation informs the first research question of this thesis to investigate the human sensor perception and motivations towards contributing to human sensing in the context of smart buildings.

In the context of smart buildings, the chapter presented that current research is directed to improving situational awareness by providing technical solutions and integration discarding the human assistant. Although technical solutions are a crucial part, the importance of human contribution to be included in the loop is vital as well. It also showed that human observation and contextual knowledge tend to be used in occupant preferences and satisfaction like the adjustments of shared places by studying their complaints. The interactions between building managers and occupants can influence a more inclusive and bottom-up building management process. These observations regarding occupants being involved in the making and appropriation of places inspire the research question on the feasibility of occupants engaging with management via human sensing regarding maintenance and facility conditions. From the related work listed before, there is a lack of studies on applying human sensing for the use of reporting facility conditions that may lead to safety incidents in smart buildings.

# Chapter 3

# User Perception, Practice, and Motivations

**Overview**

The first step in employing the human sensor concept in any organisation is understanding the human factor involved. Since every environment has its own characteristics and dynamics, its occupants may have differences as well in terms of their demographics and motives. Based on that, I decided to understand the occupants' perceptions and motivations to input the findings into the smart buildings' human-sensing framework design. To build this understanding, I employed an in-depth qualitative research method. In this chapter, I present some work in which I used semi-structured interviews to ask occupants of different ages and job positions about their perception of incident reporting and their motives behind reporting incidents. I found a set of themes related to reporting factors and the surrounding environment. I discovered that people expect Smart buildings to be "smart" and able to regulate themselves in terms of tracking and surveillance to support their reports. My main observation was the shift between the motives driving people to participate in typical reporting systems and acting as a human sensor to perform check tasks received by the system. The change was represented in the rise of enjoyment and financial incentive as main drivers when participating as human sensors. On the other hand, altruism was the only high drive when people report incidents without being asked to do it. Finally, at the end of the chapter, I tried to map the themes to the crowdsourcing dimensions.

## 3.1 Introduction

Chapter 2, section 2.1.6 demonstrated that one of the main reasons of success in any internal crowdsourcing initiative in an organisation is subject to the motivating system selected to encourage their employees to participate in distributed tasks [93, 94]. Despite the extensive research in crowdsourcing motivation, no all-purpose model has been decided on regarding what motivates workers there. For example, there are opposing views on the usefulness of financial incentives [72, 73]. Some work recommends financial rewards as they work best [26, 74], while others propose that non-financial rewards are more effective [72, 73, 75]. Therefore, this contradiction points to the fact that each internal crowdsourcing enterprise situation is unique and thus does not fall under a simple generalisation [76]. Workers' drive and commitment level in internal crowdsourcing differs from that in external crowdsourcing. This is because the employees do not choose to self-select to contribute to distributed tasks to the same degree as the external crowds [181]. This means that employees may participate in a strategic act (e.g., promotion) [76]. From a managerial perspective, finding proper motivation structures is significant for the success of crowdsourcing projects. Therefore, organisations must consider the nature of the work environment, the complexity of the task, and the diverse intrinsic and extrinsic stimuli when designing incentives [95].

This chapter is dedicated to answering the first question of this thesis: **What are the perceptions and motivations that smart building occupants have towards reporting incidents and observations in smart buildings?** To answer this question, three points were addressed in this study on the smart building. (1) the perception of reporting faults and incidents and factors influencing the reporting decision. (2) The impact of the technology on the smart building occupants' reporting decisions. (3) Smart building occupants' motivations to participate in the human sensing process to check the condition of the facilities.

To answer these questions, I adopt a qualitative research approach [182] to conduct semi-structured interviews with 17 participants. The study was conducted with the occupants of the Urban Sciences Building (USB) to ensure that the questions were relevant to the context. The study found several themes affecting the reporting decisions of smart building occupants. Precisely, when looking at smart buildings, people expect them to be "smart" and able to regulate themselves in terms of tracking and surveillance to support their reports. The main observation was the shift between the motives driving people to participate in typical reporting systems and acting as a human sensor to perform check tasks received by the system. Finally, the extracted themes were found to be aligned with the known crowdsourcing dimensions: Problem/task, platform, crowd, motivations, and environment.

## 3.2 Related Work

Numerous preceding studies have investigated motivations (Chapter 2, section 2.1.6) and what influences people to participate in crowdsourcing groups [183–186]. Wang et. al. categorised incentives generally into three types [26]: Possibly, the most prominent motivational mechanism in the current crowdsourcing market is the monetary rewards [26]. The second type is entertainment-based incentives. The system may offer a form of fun in the distributed task (e.g., design a game around the requested problem) [26]. The third way of incentivising people is social recognition. Some people may join and solve a crowdsourced activity to gain reputation or public credit [187].

Görzen argued that a meaningful task can be considered as an indirect motivator where it stimulates a positive attitude among responders [188]. For example, Pee et al. (2918) showed that members who are driven to develop competence put their attention on high-commitment activities, while others who are moved by the "love of the community" concentrate on requests that involve communication between workers [184]. Correspondingly, administrators ought to find ways to reward intrinsically driven workers to develop skills and learn from experience. Learning and competence motives are incentivised by expert feedback [189]. Therefore, including feedback incentives can be useful to adopt learning and competence growth. It is found that constructive feedback and helping others increase a sense of identity in society and can affect participation and retention [190]. These intrinsic drives demonstrate that crowdsourcing is not exclusively a monetary relationship and exchange method [191]. On the other hand, some research considers the financial rewards as an essential extrinsic incentive, positively influences the number and quality of the response [74]. Likewise, studies on crowd motivation on TaskRabbit and GigWalk displayed that monetary reward and the ability to set task lists were key motivators for users [192].

Even though the preceding work recommends the use of intrinsic and extrinsic incentives especially in crowdsourcing competitions [193], crowdsourcing organisations need to consider the nature and complexity of the task when preparing rewards. Because a complex task involves more time and effort, monetary compensations are mostly important [67, 193–195]. Similarly, another research paper showed that only 10% of the crowd responders complete 80 % of tasks for reasons related to the task complexity and its corresponding rewards [196]. Another study has shown that closeness and task location with the socio-economic level of the task zone impact users' inclination to help [197]. They found that the socioeconomic status of a task area is linked with the willingness of crowd workers to perform a task. Lower socioeconomic status leads to fewer people willing to respond. In addition, they showed how far the task is, impacts both the willingness of a participant to conduct a task and the monetary incentive at which the participant is willing to conduct it [197]. From a

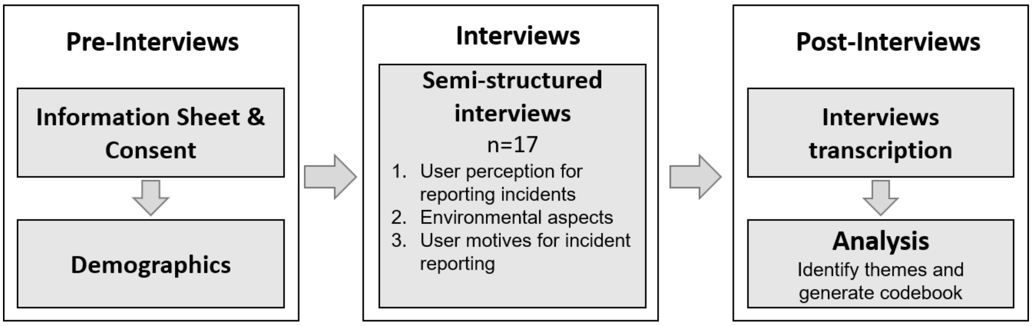



Fig. 3.1 Study Design

managerial perspective, providing proper motivation structures is significant for the success of crowdsourcing projects. organisations must consider the nature and complexity of the task, and the diverse intrinsic and extrinsic stimuli when designing incentives. [95].

## 3.3 Method

This section contains the interview design, data analysis, participant recruitment, and research ethics. The user studies were conducted via semi-structured interviews. Figure 3.1 summarizes the study design.

### 3.3.1 Interview Design

A semi-structured interview template was designed to find answers to the research questions Additionally, the study was stationed in the university building (USB) assuring that the questions are relevant to the context (section 2.1.2). For more details, refer to Appendix A to view the interview questions. The interview had three parts and was expanded in the questions based on the user responses to this set of questions accordingly. Below, are the three main **topics** covered in the semi-structured interviews:

#### User perception

The first part was aimed at setting up the scene. It included questions about incident reporting and experiences that relate to the interview topic. The talk in this part included probing questions to understand perception, blockers, and concerns affecting reporting decision. This was beneficial to extracting related themes that can be linked to the crowdsourcing dimensions such as the problem definition of what to report and the complications faced by the reporting platforms. Also, this part sets the focus on the importance of understanding the occupant (crowd) demographics and their differences.

**Environmental aspects**

The next set of questions discussed different aspects of the environment with the participants. For example, the difference between reporting observations in work environments where they have specific job roles and responsibilities to any other public area. This led to probing the online(cyber) incidents people may encounter in their online work accounts. Finally, I ask about the effect of the technology embedded in the smart campus on dealing with incidents and reporting them.

**Motives driving user engagement**

In this part, participants were asked about what motivates them to report any observed facility fault or issue in the smart building they work/study in. Then they were introduced to the crowdsourcing concept and the human sensing application role in contributing their observations as an answer to the requested task. This part of the interview aims to see what would change if the occupants were considered as *"crowd"*, and requested to check facilities instead of waiting for incidents to happen. As previous research shows [94], motivations are key factors in crowdsourcing success, and studying demographic characteristics adds to that. Therefore, the next step was to explore the incentives that the building occupants wanted for future implementations.

Table 3.1 Participants' demographic data

| **Gender** | | **Age** | | **Occupation** | | **Employment** | | **Nationality** | |
|---|---|---|---|---|---|---|---|---|---|
| Female | 9 | 20-30 | 6 | PhD students | 5 | Staff | 8 | UK | 7 |
| Male | 8 | 30-40 | 7 | Masters student | 1 | Student | 9 | EU | 4 |
| 40-50 3 | | 40-50 | 3 | Bachelor students | 3 | | | Other | 6 |
| | | 50+ | 1 | Lecturer | 3 | | | | |
| | | | | Research Assistant | 3 | | | | |
| | | | | Professional support | 2 | | | | |

## 3.3.2 Participants

All interviews were conducted in English via online video calls. The interviews lasted around 45-60 minutes. Two pilot interviews with colleagues were conducted to assess the clarity of the questions and the flow and time of the interviews. The participants were given space to elaborate, express their ideas, opinions, and feelings, and interact with the conversation.

Some participants shared stories about a previous smart university in which they used to work. Their responses were accepted.

The recruiting procedure was to contact the USB occupants via email or in person asking if they were interested in the study and offered a compensation of £20 worth Amazon voucher. I followed the convenience sampling method to select the participants. It is a sampling approach where participants are chosen based on their approachability and availability to the researcher [198]. This method has its drawbacks in terms of limited representativeness. Because the sample is a close and small group of people who are available instead of a random large population. This can lead to an increased risk of bias where researchers unconsciously choose participants who appear most interested in participating. Such biases may affect the reliability and validity of the research results [198].

During the interviews, I asked the participants if they had any incident that happened at the building and reported it. Overall, 10 participants reported an incident in the building. 5 of them reported an issue with the automatic doors being locked and preventing access, 2 reported a trip hazard. 3 reported a cyber-incident that may affect the building,1 witnessed an incident of a stuck elevator but did not report it (others did before them). From their answers, I was able to extract some of the challenges and blockers that impacted the reporting process for them. Regarding the participants' experiences in human sensing, none had an experience in reporting facility conditions. However, some have their tries in some other crowdsourcing apps like the NHS Volunteer Responders.

The focus was to recruit a diverse set of participants and a balanced number of males and females, student and staff participants. Those who accepted to contribute had to complete an online questionnaire for collecting demographic data (age, gender, employment, role, and nationality). Most of the participants had a technological background as occupants of the USB. The USB is where the School of Computing is located, and all lectures, offices, and labs are conducted in this building. Leading to the majority of the participants being educated about technology. Therefore, they might have some knowledge and understanding of the research idea and smart buildings.

Table 3.1 presents the demographic data of the participants. It shows that there were 9 females and 8 males in the study. 6 of them were between the ages of 20-30, 7 participants were aged between (30-40), 3 of them were between (40-50), and one participant was 50+. In terms of occupation, 6 participants were postgraduates (5 PhD, 1 MSc), 3 undergraduate students, 3 lecturers, 3 research assistants, and 2 professional support. Professional support means any administrative office job such as a receptionist. In total 8 of the participants were hired staff and 9 were students. There were 7 participants from the UK, 4 from the EU, and 6 from other countries. Finally, 4 participants had administrative/managerial roles:

one was a department head, and the other participant was in charge of a research group and other administrative tasks. The other 2 were receptionists responsible for several student and department jobs.

### 3.3.3 Data Collection and Analysis

Interviews were recorded by a voice recorder (Zoom recorded meetings), and transcribed into a password-protected file (using Nvivo 12). Each interview was manually coded and analysed using thematic analysis [199, 200]. This method is used to identify, analyse, and detect patterns within data to recognise themes embedded throughout qualitative data. The saturation [201] was detected around the 13th and 17th participants. It means that when reaching these interviews, no new themes appeared and I stopped recruiting.

### 3.3.4 Ethics

The research project was approved by the Ethics Board at Newcastle University in the UK. Before each interview, every participant was provided with an information sheet about the purpose of the research and signed a consent form explaining that the interviews would be anonymised and that the data would be confidential (Appendix A). Participants were informed that they could withdraw during the research without the need to provide reasons. No participant was withdrawn.

## 3.4 Analysis

This section presents an example of the analysis process performed on the interviews. I conducted a content analysis on the transcripts that aims to systematically convert a large transcript into a highly organised and brief summary of key findings [202]. The analysis approach was inspired by method done by Erlingsson and Brysiewicz (2017) "A hands-on guide to doing content analysis". In content analysis, it is common to begin with transcribing the interview texts [202]. I used Nvivo to produce the transcripts only and managed to perform the analysis manually (no codes were extracted). It is worth mentioning that the analysis was conducted several times. The first time was done in a period around 3-4 months. Then it was re-done after being submitted to two peer-review venues and receiving the feedback, adding 2 extra months of revision.

Below, I present an excerpt from an interview and the process of extracting condensed meaning units, and then extracting codes from the condensed meaning units. After that, the codes are collected under categories. Finally, the categories are grouped into main themes.

| | |
|---|---|
| Interviewer: | What about the Internet? Have you ever faced a cyber incident at work with any different at any level? |
| Participant: | Yes. So we get lots of spam emails all the time. Right. So a lot of the times I forward them to IT and I tell them that I think it's a spam. Please be aware. So that's how I take action in an incident like that. There was one time that there was this spam e-mail, and I engaged with it for fun. It was really fun. So this person pretended that they were the school manager and wanted me to buy them some Amazon voucher or something. And I just played around because I knew that this was probably someone sitting in a different country. And I just told them that I don't have access. They said they were in a meeting and they couldn't do it now, but they really immediately needed it. And I really recognized the language and I said, OK, I'm in a meeting now as well, so I can't get it to what I can do it in the evening or at night. Is that OK? And they said, yes , yes, that would be helpful. So it was going on for a few days and I had really a lot of fun. But then I also reported it. I said that this is a scam, but I've been having a lot of fun with it. It's just funny to engage with the scam emails. And plus because I work in cyber security and privacy, for me, it's an observation as well to see how the scammers' behaviour changes from time to time. |
| Interviewer: | And how do you feel about incidents? |
| Participant: | Oh. I'm not sure. But I feel like cyber security incidents are a part of cyber life now, so we can't avoid them, we just need to find a way to deal with them properly. That's why I keep emphasizing on the effect of training, training the staff to be able to protect them, training children. Because I have a child, I keep thinking about children online, training children to be able to protect themselves online. |

Fig. 3.2 Excerpt from interview text exploring participant's experience in a work incident

*1- Familiarising oneself with the data and understanding the interviews:* The first step was to read and re-read the interviews to gain a general understanding of what the interviewees were talking about. Fig 3.2 shows an excerpt from an interview transcript and I explain the process in each step.

*2- Dividing up the text into meaning units and condensing meaning units:* After reading the interview several times. The following step is to divide up the text into meaning units. This is done by breaking the text into short sentences where each sentence has a meaning without any changes to the original text. The formulated meaning units are then condensed further while keeping the original meaning intact. Condensation is a shortened form of the same sentence that still carries the main message of the meaning unit. Fig 3.3 presents the process of locating meaning units and shortening them into condensed meaning units. For example, the sentance "That's why I keep emphasizing on the effect of training, training the staff to be able to protect them" can be shortened to "emphasizing on training staff to protect them".

| Meaning Units | Condensed Meaning Units |
|---|---|
| Yes. So we get lots of spam emails all the time. Right. | (get lots of spam emails) |
| So a lot of the times I forward them to IT and I tell them that I think it's a spam. Please be aware. | (lot of times, forward them to IT) |
| So that's how I take action in an incident like that. | (how to take action in incidents like that) |
| There was one time that there was this spam e-mail, and I engaged with it for fun. It was really fun. | (one time, engages with scam email. Was fun) |
| So this person pretended that they were the school manager and wanted me to buy them some Amazon voucher or something. | (person pretend to be school manager, wanted me to buy them Amazon vouchers) |
| And I just played around because I knew that this was probably someone sitting in a different country. | (I played around, knew they were someone in a different country) |
| And I just told them that I don't have access. They said they were in a meeting and they couldn't do it now, but they really immediately needed it. | (told them I don't have access, they said they were in a meeting but they immediately needed it) |
| And I really recognized the language and I said, OK, | (I recognised the language, said OK) |
| I'm in a meeting now as well, so I can't get it too. what I can do it in the evening or at night. Is that OK? And they said, yes , yes, that would be helpful. | (Im in a meeting now, I cant get it. I can do it in the evening or night) |
| So it was going on for a few days and I had really a lot of fun. | (was going for few days, had lots of fun) |
| But then I also reported it. I said that this is a scam, but I've been having a lot of fun with it. | (Then I reported it, said it's a scam, I have fun) |
| It's just funny to engage with the scam emails. | (Funny to engage with scam emails) |
| And plus because I work in cyber security and privacy. | (I work in cyber security and privacy) |
| For me, it's an observation as well to see how the scammers' behaviour changes from time to time. | (It's an observation, to see how scammers' behaviour changes) |
| Oh. I'm not sure. | (not sure) |
| But I feel like we just need to find a way to deal with them properly. | (find a way to deal with them) |
| That's why I keep emphasizing on the effect of training, training the staff to be able to protect them, | (emphasizing on training staff to protect them) |
| Training children. Because I have a child, I keep thinking about children online, | (thinking about children online) |
| Training children to be able to protect themselves online. | (training children to protect themselves online) |

Fig. 3.3 Text divided into meaning units and condensed meaning units (examples of coding)

*3- Formulating codes:* Codes that are descriptive labels for the condensed meaning units. They briefly describe the condensed meaning unit and are used to simplify the recognised relations between meaning units. Fig 3.4 presents the formulation of codes about each condensed meaning unit. An example of that is turning the text "It's an observation, to see how scammers' behaviour changes" into a code (Observing behaviour)

*4- Developing categories and themes:* The next step is to sort codes into categories. This is performed by comparing codes and reviewing them to find which codes appear to fit together and deal with the same issue, thus creating a category. After that, categories can join together to create themes. A theme expresses underlying meaning, i.e., latent content, and is created by grouping two or more categories. As Fig 3.5 shows, the code "Cyber security expert" can be in the same category as the code "Recognising the language". They both fit into the category "Experience and familiarity". Additionally, the analysis can continue further into grouping categories into a theme i.e., Experience and familiarity which corresponds to the theme Reporter.

| Condensed Meaning Units | Codes |
|---|---|
| (get lots of spam emails) | Lots of spam |
| (lot of times, forward them to IT) | Forward them |
| (how to take action in incidents like that) | Taking action |
| (one time, engaged with scam email. Was fun) | Fun of engaging with spam |
| (person pretend to be school manager, wanted me to buy them Amazon vouchers) | The scam incident |
| (I played around, knew they were someone in a different country) | Playing around while knowing |
| (told them I don't have access, they said they were in a meeting but they immediately needed it) | The scam incident |
| (I recognised the language, said OK) | Recognising the language |
| (Im in a meeting now, I cant get it. I can do it in the evening or night) | The scam incident |
| (was going for few days, had lots of fun) | Had fun |
| (Then I reported it, said it's a scam, I have fun) | Reported spam |
| (Funny to engage with scam emails) | Fun of engaging with spam |
| (I work in cyber security and privacy) | Cyber security expert |
| (It's an observation, to see how scammers' behaviour changes) | Observing behaviour |
| (find a way to deal with them) | Way of dealing |
| (emphasizing on training staff to protect them) | Training need |
| (thinking about children online) | Motherhood and children |
| (training children to protect themselves online) | Children training |

Fig. 3.4 examples of coding of condensed meaning units

### 3.4.1 Extracted themes from analysis:

This process was performed on all of the interviews and I was able to extract codes, categories, themes and sub-themes related to the topic. It is worth mentioning that the founded themes were grouped as sub-themes within wider themes. For example, the sub-themes of reporting platform, reporter, and incident type were grouped together to formulate a more general theme called: factors affecting reporting decisions.

- **Theme 1: factors affecting reporting decisions** and its sub-themes: reporting platform, reporter, and incident type. Fig 3.6 demonstrates the extracted themes and their occurrences.
- **Theme 2: Environmental impacts** and its sub-themes: smart buildings and technology, work and public places, and online and offline incidents. Fig 3.7 demonstrates the extracted themes and their occurrences.

| Codes | Category | Theme |
|---|---|---|
| - Lots of spam | The incident | The incident |
| - Forward them | Availability and accessibility of the platform | Reporting platform |
| - Taking action | Availability and accessibility of the platform | Reporting platform |
| - Fun of engaging with spam | Enjoyment motivation | Motivation of reporting incident |
| - The scam incident | The incident | The incident |
| - Playing around while knowing | Experience and familiarity | Reporter |
| - The scam incident | The incident | The incident |
| - Recognising the language | Experience and familiarity | Reporter |
| - The scam incident | The incident | The incident |
| - Had fun | Enjoyment motivation | Motivation of reporting incident |
| - Reported spam | Availability and accessibility of the platform | Reporting platform |
| - Fun of engaging with spam | Enjoyment motivation | Motivation of reporting incident |
| - Cyber security expert | Experience and familiarity | Reporter |
| - Observing behaviour | Learning motivation | Motivation of reporting incident |
| - Way of dealing | Awareness and training | Reporting platform |
| - Training need | Awareness and training | Reporting platform |
| - Motherhood and children | Responsibility (out of scope) | Reporter- Out of scope |
| - Children training | Training (out of scope) | Reporter- Out of scope |

Fig. 3.5 organisation of codes into categories and themes

- **Theme 3: Motivations** and its sub-themes: Motivations for reporting occurring incidents, and motivations to respond to a check task. Fig 3.8 demonstrates the extracted themes and their occurrences.

## 3.5 Results

This section presents the main emerging themes extracted from the interviews. A high-level presentation of the main themes is provided in Table 3.2. Throughout the results, participants' answers were quoted and each participant was assigned a code from P1 to P17. In addition, the number of occurrences of each theme is presented to provide an idea of the density and distribution of the themes within their respective sections.

| Theme1: Factors Affecting Reporting Decision | Occurences |
|---|---|
| **Sub-theme: reporting platform** | |
| **Category: Availability and accessibility** | 10 |
| *"two days, long time, long procedures, nightmare"* | |
| *"respond, acknowledged, with bit of knowledge"* | |
| **Category:Awareness and trainging** | 8 |
| *"train staff ,induction, was trained, tell me you need to this, not sure, don't know"* | |
| **Sub-theme: reporter** | |
| **Category: Personality** | 5 |
| *"my personality, I provide feedback"* | |
| *"tell my friends, talking about it to my friends, others to agree"* | |
| **Category:Experience and familiarity** | 14 |
| *"expert, I reognise, relaxed, I stay long time, familiar surroundings"* | |
| *"embarresed"* | |
| *"responsible, require, instructor"* | |
| **Category: Privacy and anonymity** | 8 |
| *"loophole, identify yourself, keep track "* | |
| *" want my I.D, read the whole GDPR"* | |
| **Category: Different cultural backgrounds** | 2 |
| *"diferent culture, people assume"* | |
| **Sub-theme: incident type** | |
| **Category: Severity of incident** | 5 |
| *"severe, important, damage, big"* | |
| **Category: Impact level** | 13 |
| *" affect me, personally, your day "* | |
| *"risks to others, happen to someone else, extra job for them, everyone involved"* | |
| *"wasting energy or costing money, recycling"* | |

Fig. 3.6 Sample codes, categories, and sub-themes for the theme of factors affecting the reporting decisions

| Theme2: Environmental Impacts | Occurences |
|---|---|
| **Sub-theme: smart building and technolgy** | |
| **Category: Expectations** | 12 |
| *"regulate itself, integrate with sensors, team, maintenance"* | |
| *"Signs, QR code"* | |
| **Category: Positives** | 17 |
| *"back up and support claim, evidence, proof"* | |
| *"safe, secure, prefer, deterrent"* | |
| *"assess the situation, make life easier"* | |
| **Category: Downsides** | 10 |
| *"trapped, cause incidents on their own, I could not enter"* | |
| *"Know it is me, more conscious, privacy concerns, fingerprint checking in"* | |
| **Sub-theme: work vs public incidents** | |
| **Category: Policies and guidelines** | 5 |
| *"guidance and boundaries, less people"* | |
| **Category: Relations/ reporting others** | 6 |
| *" war zone, tensions, assign blame"* | |
| **Sub-theme: online Vs offline incidents** | |
| **Category: Proof availability** | 2 |
| *"screenshot, your word against theirs"* | |
| **Category: Susceptible** | 2 |
| *"more likely to happen, susceptible, take other measures"* | |
| **Category: Word of mouth** | 3 |
| *"I reported to my colleagues, I sent a what's up message"* | |

Fig. 3.7 Sample codes, categories, and sub-themes for the theme of environmental Impacts

| Theme3: Motivations | | | | | |
|---|---|---|---|---|---|
| **Sub-theme: motivation for reporting occurring incidents** | | | | | |
| **Category: Altruism** | **18** | **Category:Awareness/Accessibility** | **9** | **Category:Recognition** | **4** |
| *"responsibility, duty"* | | *"ease of access, easy system"* | | *"acknowledgement,thanking messages"* | |
| *"community,help others,environment"* | | *"awareness of importance, explain importance, signs"* | | **Category:External Rewards** | **2** |
| *"feedback, usefull, fixed"* | | | | *"credit,vouchers"* | |
| | | *"explore, improve skills, observing behaviour"* | | **Category: Enjoyment** | **1** |
| | | | | *"had fun, freetime, enjoy"* | |
| **Sub-theme: motivations for responding to check tasks** | | | | | |
| **Category: Altruism** | **11** | **Category: Awareness of importance** | 3 | **Category: Recognition** | **2** |
| *"helping your colleagues"* | | *"tell me how it helps"* | | *"Getting acknowledged, thanked"* | |
| *"I care enough about the building"* | | **Category: Gamification and Enjoyment** | 7 | **Category: External rewards** | **6** |
| | | *"I'm getting more points than that person!"* | | *"printer credits, customised mug"* | |

Fig. 3.8 Sample codes, categories, and sub-themes for the theme of motivations

### 3.5.1 Factors Affecting Reporting Decision

Figure 3.9 summarises the reporting factors theme and the related sub-themes. It includes reporting platform, reporter, and incident type.

#### Reporting platform

One of the main reasons that people choose to report incidents happening in their building is the process **availability and accessibility**. Occupants see that reporting should not be complicated and require more effort and time to do so. For example, finding a suitable reporting form, email, personnel, etc. P1 expressed her experience in reporting an online stalking incident at her workplace *"It took me two days! all my time to find the right person and to find the right procedure to report it"*. This also raises the aspect of having a simple and structured interface. P9 mentioned *"It's nice to have one official form, that is automatically structured form"*. These points raise a sign of the importance of having a user-friendly platform that users find non-complex, with a clear structure allowing them to add additional information that may be helpful. This also can improve the accuracy of the received reports. Moreover, **awareness of the reporting platform and procedures** themwas found as well. Having orientation sessions and training were raised in the interviews: *"In the induction for the building, they were saying: .. you should report these odd situations and explaining the security measures and the badges"*. Additionally, older participants (over 60) have stressed the importance of receiving training on electronic reporting systems if they are required to use them like an app on their phones. Participants also mentioned the need for communication and feedback with those who are responsible for dealing with the issue. P17 exclaimed: *"It would be a great insight for me to know that it's been fixed, and what I reported has been acknowledged"*. It shows that occupants prefer receiving feedback as a motivation to engage

Table 3.2 Summary of recurring themes

| **Theme 1: Reporting factors** | **Theme 2: Environmental Impacts** |
|---|---|
| Reporting platform | Smart building technology |
| Reporter | Online and offline incidents |
| Incident type | Work and public places |
| **Theme 3: Motivations** | |
| Motivations of reporting occurring incidents | |
| Motivations of responding to a check task | |

in such tasks and assist if there is more information that needs to be clarified from the other side. Figure 3.6 demonstrates the extracted themes and their occurrences.

**Reporter**

The analysis extracted the *reporter* aspect impacting the reporting decision (presented in Figure 3.6). Some individuals expressed that their **personal preferences** or attributes plays a role in their reporting decision *"It's because of my personality, I provide feedback to systems and people even when I'm not asked"* P1. Another reason was described as being less vocal and preferring to only talk to friends instead of reporting directly. As P11 and P4 expressed respectively: *"I would tell my friends, as everybody knew about it", "I wait for others to agree"*. Extraversion and talkativeness were found to have a role in employee voice behaviour, with extraverts more willing to speak up irrespective of job attitudes [203]. With the goal of creating a safer workplace, organizations not only need to reduce interpersonal mistreatment and shape more positive attitudes towards reporting but also take into account individual differences in traits and effectiveness of voice behaviour in doing so [203, 204]. The **experience and familiarity** theme was found especially when it comes to situations that are frequent, common, or require technical skills to be resolved. It can prominently influence the reporting decision and response among individuals. Employees with more job experience and familiarity with the place demonstrate higher levels of perceived safety skills, such as better hazard identification [205]. This was presented when a receptionist who worked in the building for a long time recalled several reports she made in the building, saying that she knew what would happen if it was left unfixed. Another participant also mentioned that they already know how to deal with some issues as they already have the experience, and it happened a couple of times when they did not feel the need to ask for help. Additionally, those who come to work more frequently and are more involved and familiar with their work environment (staff and PhD students vs undergrad students) tend to report more due to the high possibility of being affected. "It's more likely to affect me, I stay a long time here" P10 (PhD student). The familiarity of the place and its surroundings drives them to take action as well *"You're in a work environment, you're in familiar surroundings, familiar people around you"* P16 (professional staff). P9 mentioned the difference between his reporting attitude between his new and old job: *"I was there a very long time I knew who to contact, everybody knew me. I was very relaxed about speaking my mind."* Furthermore, some negative feelings such as shame are associated with reporting incidents which could be due to the lack of user knowledge or skills. For instance, P8 expressed their embarrassment on an online data breach saying: *"I was embarrassed, I would say, because I should have known better"*. This aligns with the literature that fears of punitive action and concerns about loss of prestige can discourage reporting [206]. Organisations should promote a supportive culture that encourages reporting and offers guarantee to individuals by implementing a no-blame system to lessen concerns about punishment if someone caused an incident at work involved in incidents [207, 208]. This leads to the question of privacy and how it can be managed in the internal crowdsourcing system. P8 had some doubts about perceiving her identity *"and there is a chance of maybe other people knowing about it besides who I report it to"*

Participants who have some authority and managing responsibilities tend to report potential risks and minor incidents more than others. Reasoning that for the responsibility they have: *"I feel more responsible, I am responsible for more than seven hundred students"* P17. Four participants answered the questionnaire that they have managerial or administrative roles giving them more authority and responsibilities in the building: one was a department head, and the other participant was in charge of a research group and other administrative tasks. The other 2 were receptionists who are responsible for several student and department jobs. Another noticeable point was that more than half of the demographics are from outside the EU, this highlighted the impact of the cultural backgrounds when it comes to selecting a reporting method. P3 shared his experience and confusion when reporting issues at his workplace *"most people assume that you already know"*. Overall, these sub-themes show the benefit of understanding the internal crowd in terms of their characteristics and demographics. For example, having some experienced long-term occupants with specific responsibilities can help improve the report quality in some complicated tasks.

**Privacy** is a challenge in reporting. The level of required information about the reporter may lead to a decision not to be reported. P2 mentioned her refusal to report a bug to a certain organisation when asking about her information *"When I realized that they want my I.D. and they want my address and that kind of information, I just said, no"*. On the other hand. P7 faced difficulties in knowing the minimum requirements of information to report someone,

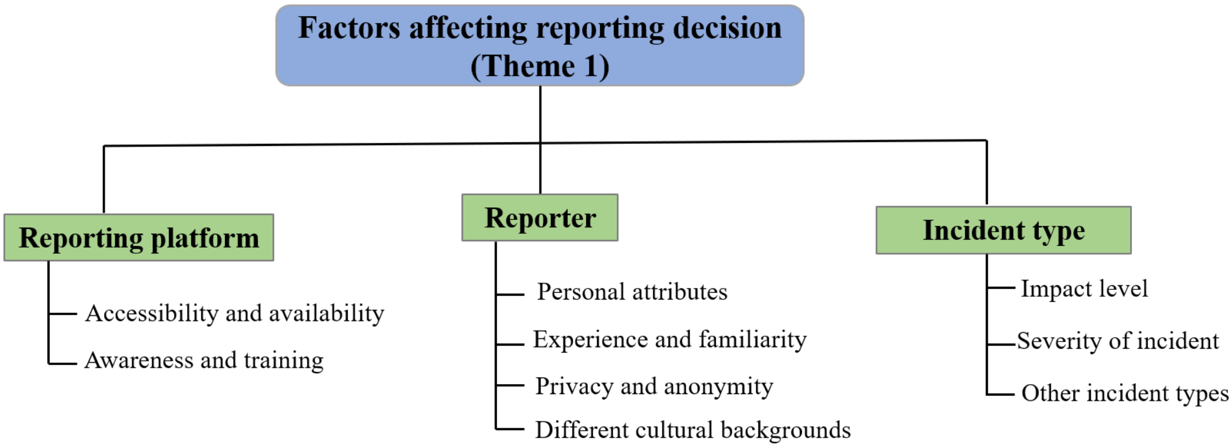



Fig. 3.9 Factors affecting reporting decision (theme1)

causing hesitation in invading that person's privacy by adding unnecessary information to the report. *"I think guidance about what information is necessary. I think this is one of the big issues I had with the report on 'AUTHORITY NAME' was GDPR and guidance about what you need to know. The minimum that you need to know because they were so vague with what they needed to know. I had this ethical GDPR dilemma about how much do I give you because you might not take this forward."*

**Incident Type**

The analysis revealed that the **severity** of the incident plays a significant role in the decision to report as safety was their main concern. Similarly, other concerns like cost and energy waste were related to the **impact level** of the incident affecting user response and reporting. For instance, participants mentioned that they would report incidents that may impact their daily life *"if it affected me personally"* P14. Also, people may report if the impact extends to other people or the organisation. Quoted by participants P8 and P4 respectively. *"It means risks to others as well. It's not just a personal risk", "Wasting energy, and that costs money. And at the end of the year, it's not just a couple of pounds, it's a bit more then".* This indicates that occupants are motivated to engage with the system if they feel it can make an impact on them, the organisation community, and the building environment. Therefore, since the impact affects occupants' reporting decisions, it can leverage the process of task allocation where occupants are asked to check the facilities close to them. Figure 3.6 demonstrates the extracted themes and their occurrences.

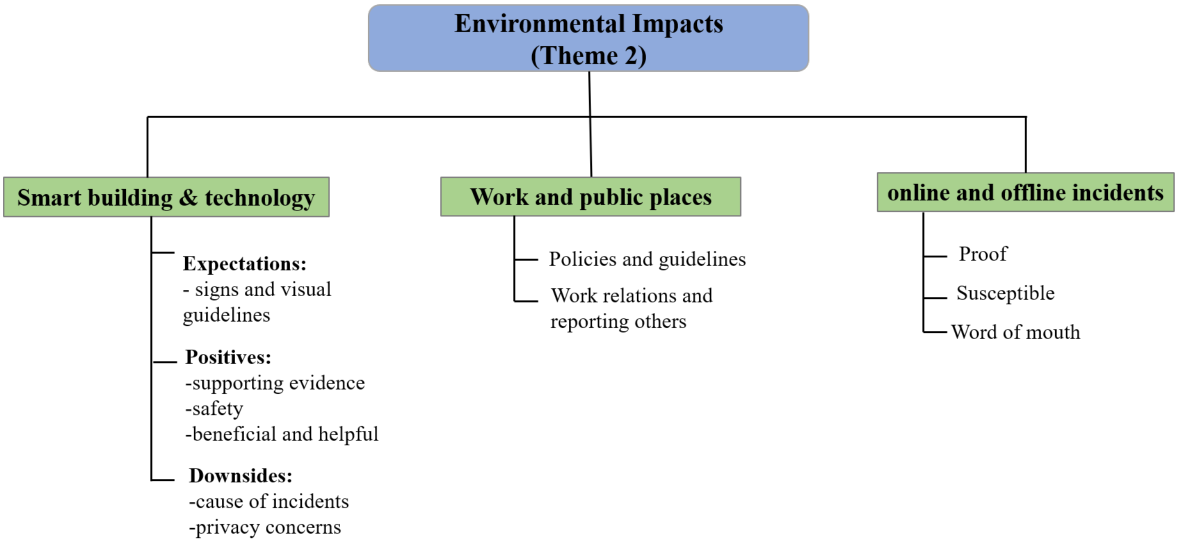



Fig. 3.10 Environmental Impacts (theme2)

### 3.5.2 Environmental Impacts

Figure 3.10 summarises the environmental impacts theme and the related sub-themes. It includes smart buildings, work, and public places, online and offline incidents. The following presents the emerging themes in the three environments and their occurrences.

#### Smart Buildings

This part explored the level of impact of technology on the reporting process especially in smart buildings. The first task for me was to explore the **occupants' expectations** of what should and should not be in the smart buildings. Figure 3.7 demonstrates the extracted themes and their occurrences. As mentioned before, since it is a newly built building some interviewees see the importance of including occupants' observations and reports regarding the building facilities and smart equipment. As pointed out by P10 "*It's like a test sort of building, people should be involved* ". Several participants agreed on the necessity of having a maintenance team responsible for these systems (sensors, CCTV cameras, monitoring, and tracking systems) "*There should be a team looking for maintenance and just keeping an eye on these devices"* P8. Also, it was noticed that participants have raised some insights that smart building should have a higher ability to control and regulate itself than a traditional one *"what's the point of a smart building if it cannot manage itself and regulate itself "* P1.

Participants were specifically asked about how embedding their workplace with modern technologies may affect their response and reporting decisions. Both positive and negative themes found in the participants' responses regarding smart buildings. On one hand, CCTV cameras and smart cards were considered as **proof and evidence** of claims, as P12 expressed: *"they would be more likely to report something if they know that there's evidence"*. The additional sense of feeling more **secure and safe** was raised specifically among female participants *"would help to have a safer workplace"* P1, *"I feel safer with cameras around"* P6. Monitoring systems also were perceived **beneficial to situational awareness** by helping responders assess the incident *"It says there are people in the room by the sensor"* P8. For example, P9 mentioned the use of having a monitoring system during an incident of an elevator that was stuck for several hours with a person with a heart condition: *"When the camera was there, the operator can assess the situation, provide help"*.

On the other hand, such technologies in smart buildings were also considered as potential **causes of incidents**. For example, some doors are set on timers to lock for reasons such as safety and security. This may cause people to get locked in if they do not know about these rules. P10 commented on that *"Set to a timer, after a certain time and I know two people are out there and the doors lock on them"*, P17 had the same problem when the fire alarm went off in the building *"One time I got locked, locked up in our university. When the alarm goes off, the doors shut"* P17. Building on that, P2 focused on the importance of having manual alternatives in such situations: *"We should consider all the situations, all the scenarios that could happen"*. These themes support the main argument of this thesis as it aims to improve situational awareness by not depending on smart building technologies alone.

Another angle is that people may respond differently towards an incident knowing that they are recorded by cameras raises some **privacy concern**s and they may become more **conscious** about their actions in general, e.g., P9 said: *"Not because you are doing anything bad, just because you're more conscious of what you're doing"*. Another interesting point that participants raised was to have **signs and visual guidance** to lead those who want to report. P6 who was talking about a printer problem in the campus *"Having a QR code leading to a report webpage for printers"*. P9 mentioned a time when he benefited from a sign to report a problem that happened on the campus. Environmental adjustments such as signs and directions can help improve reporting issues in the building as well.

#### Work place Vs public place

As illustrated in Figure 3.7, the analysis results with two aspects related to the work and public places. Overall, people consider workplaces more **organised with policies** compared to public places *"in a workplace, when there's guidance and boundaries and policies"* P7. This can be presented in the availability of a first point of contact like having a reception desk, mentors, or colleagues with more experience. Participants mentioned repeatedly that having clarity and direct contact encourages them to report. *"I just report it because I'm* *familiar with the building, with the receptionist. I know what floors: One, two, three. I could easily just go in and be like this happened, and just walk away"* P16. This points to a requirement from the crowd side, which is that confusion and vagueness are blockers for reporting incidents. Additionally, **work relationships** play a role in reporting. If an incident is caused by a friend or a colleague, people tend to show more hesitation or delay in reporting e.g., *"End up in living in a war zone"* P1, P15, *"I don't want to create tensions between people"* P8, *"don't assign blame"*, the blame game was not mentioned in relation to work relationship category where the work environment can affect the behaviour of people.

#### Online and offline incidents

This part sheds light on the incident mode (e.g., online vs offline). The answers pointed to the differences people experience in both modes. The interview contained some exploration points regarding personal and work-related online accounts as well (presented in Figure 3.7). Indeed, it was found that incident mode informs people's decisions. Some think that they are more **susceptible** to online incidents *"you are susceptible to other kinds of problems in the virtual world other than the physical"* P15.

Answers have pointed to an advantage of reporting an online issue is the ability to **provide proof** easily by taking a screenshot where this is not completely available in offline incidents, *"take a screenshot"* P15,*"It's hard to just be your word against theirs without eyewitness or CCTV"* P14. I found that work-related online incidents can be communicated to other colleagues in terms of spreading news quickly to warn others since it is perceived as a **smaller community** with work-related accounts *"I reported to my colleagues because I don't want them to send information"* P2. Therefore, this indicates that people may prefer spreading requests to others that can be utilised. Crowdsourcing adopts multiple techniques to distribute a task, one of the methods is word of mouth (WOM) in which participants, use their mobile social encounters and online social networks to ask other suitable persons to work on the task [209].

### 3.5.3 User Motivations for Reporting Facility Conditions in Smart Buildings

This section presents the findings on the user drives for reporting facility faults and issues and then compares them with the crowdsourced approach where occupants engage in human sensing tasks to check and report the facility condition.

### Motivations of reporting facility conditions

In the second half of the interview, the participants were asked about their main drives for reporting facility incidents or observations in their smart campus.

**Altruism** was the leading motivation. Themes such as being responsible, having a sense of community, and perceiving a better environment were found in this analysis. Noticeably, these terms were more expressed by older participants (age 30+) and those who are more involved in the building (i.e. have offices and spend longer time e.g., staff and PhD students vs. undergraduates). Additionally, the participants stated a significant incentive that drives them to report a facility problem that aligns with other studies is receiving feedback about fixing the problem. This gives them a positive feeling of making a difference and that their voice is heard [26, 190]. An emphasis on the human touch is expressed in different ways between the reporter and the responsible personnel instead of receiving an automatic reply.

**Awareness and learning motivations** were the second to drive occupants to report issues such as building facility problems. *"Awareness is an incentive itself"* P15, by providing information on how and why reporting is imperative in the work environment. Reminders, posters, and orientation sessions were mentioned as an effective approach to raising occupants' awareness of their surroundings. In the context of smart buildings, as many equipment and IoT devices are connected, reporting an issue can be a reason for solving the other. For example, a broken window lock can allow the air inside the room, this impacts the sensor and how it reads the room temperature, therefore, not adjusting the temperature to the desired level or closing the heater/cooling system. As Participant P4 mentioned, this was an important level of understanding of the building. Another aspect that encourages people to report a problem is the availability of signs and reminders that facilitate the reporting process where there is the least required time and effort.

**Recognition, external rewards, and enjoyment** were mentioned as well, though they were not popular. Some participants prefer being acknowledged when reporting or receiving some compensation as a reward. However, some expressed their concerns about their time commitment and how over-reporting might create misuse opportunities such as "*taking a revenge from a colleague or teacher by reporting a fake incident*" P1. Having fun was raised in the context of online work situations. For instance, some spam emails were reported after engaging with them for fun and exploration.

### Motivations to engage in human sensing crowdsourced facility checks

At this stage of the interview, I explained the concept of crowdsourcing definition and human sensing and mentioned some examples of mobile apps such as FixMyCity. Followed by

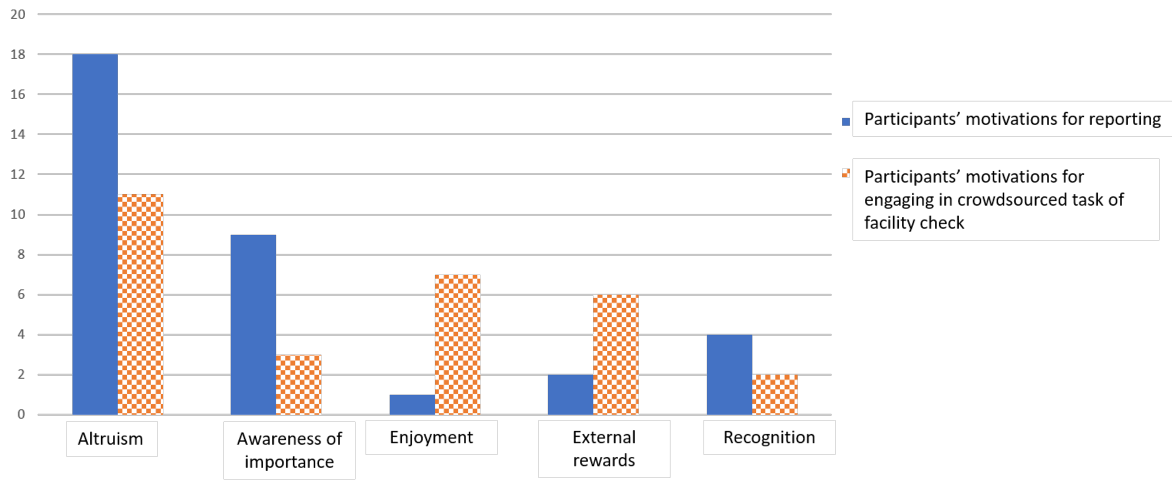



Fig. 3.11 Incentives compared between typical reporting and human sensing reporting in smart building

describing the proposed crowdsourcing reporting system and its functionalities inside their smart campus: (1) The system will send a task request for occupants to check a certain facility in the building. (2) The task should be done by observation only with no need to fix it. (3) Occupants have a choice to accept or decline the request.

This part presents the preferred incentives for participants to engage in the human sensing request tasks compared to just reporting facility faults ( 3.5.3). After analysing the answers and calculating the results, Figure 3.11 illustrates a clear shift in occupants' motives to contribute to completing requests in the human sensing system compared to the typical way of incident reporting. As it shows, there is a decrease in the altruism and learning motives and an increase in enjoyment and external rewards motives.

**Altruism motive**: Although it decreased in count, some participants did not change their opinion and it was present in their answers repeatedly. For instance, P7 said: *"I suppose it's nice to know that you're helping your colleagues because I think it's like it's part of the compassion, isn't it? It's like I care enough about was in a building that I do this."* It is worth mentioning that altruism was the first self-reported reason in both reporting approaches might be a providing of a socially accepted answer which can be a social desirability bias [210].

**Enjoyment motives** have raised significantly especially from the participants describing their selves as competitive; more repeated in the younger participants. For example, earning stars/points and being first in a ranking list/leaderboard were terms that was used among such participants. P6 stated that the idea of competing by itself is worth participating *"If I'm getting more points than that person next to me, I'm doing it, you know what I mean? It gives me more of an incentive than like a voucher."* However, the majority preferred receiving a simple reward for the winner eventually. The reason for this raise is probably impacted by the participants' demographics being university students.

**External rewards** were found to be attached to the competition factor, where winners receive a form of rewards or vouchers (e.g. coffee discounts and Amazon vouchers). Some rewards in the form of credits were valued. Such as 5 pounds printing credit. This amount can be encouraging and adds fun to the process. Simple rewards like pins and badges, mugs or hoodies were mentioned by younger participants too *"adding to the fun"* P6.

Participants valued the reminders and posters and orientation as forms of **awareness and learning** motives. However, it was not mentioned as much as it was for solely reporting an issue. This may be because participants depend on the requests specifying what is requested from them. Regarding the **recognition and acknowledgments** incentives, it was not found to be common. This finding does not align with other research that investigated the motivations of employees in internal crowdsourcing initiatives where recognition is considered an important drive. The reason for that is probably the university context and its demographics. For example, an employee may consider his/her engagement as a strategic act (e.g., for promotion [76]) whereas the occupants and their relations are different in a university. For example, 9 of the participants are students (BSc,MSc,PhD) who will eventually graduate and leave the campus. Therefore, they do not have the objective of building a reputation with the upper management.

## 3.6 Discussion

This section will discuss the following points:

### 3.6.1 Reporting themes

**Reporting platform:** The findings align with the literature on the impact of availability and accessibility, awareness and training regarding reporting systems can significantly impact reporting rates. Research demonstrates that electronic systems that are easily accessible, safe, and easy to use increase reporting [211]. Availability and perceived security of the system also promotes reporting [211]. Nevertheless, the reporting can be hindered by poor workplace safety culture and lack of feedback on reported events [211, 212]. Management support, as well as timely feedback, promotes the reporting process [213, 214]. Regarding people's awareness of incident reporting systems, the findings align with its noticeable effect on reporting rates in several settings. Braithwaite et al. (2010) reported that training on system use and positive evaluations of such training is associated with increased reporting

[211]. Moreover, including clear procedures on how and what to report is a key motivational factor for staff engagement [214].

**Reporter:** The interview analysis and results raised a similar aspect regarding the impact on a person's traits when deciding to report an incident. In particular, Extraversion and talkativeness were found to have a role in employee voice behaviour, with extraverts more willing to speak up irrespective of job attitudes [203]. With the goal of creating a safer workplace, organizations not only need to reduce interpersonal mistreatment and shape more positive attitudes towards reporting but also take into account individual differences in traits and effectiveness of voice behaviour in doing so [203, 204]. Another sub-theme extracted from the interviews was that privacy and anonymity can be a reporting blocker. It aligns with the literature that privacy and anonymity play crucial roles in encouraging incident reporting in the workplace. It was found that anonymity is important especially for critical incidents, as people may fear punitive action which prevents them from reporting [215].

**Incident type:** Some conditions and environments in the workplace may have a negative impact on employee productivity, health, and morale. Conditions such as unsuitable furniture, poor ventilation, excessive noise, and poor lighting have all been shown to impact workplace productivity and health [216]. Therefore, front-line staff views on operational failures (such as equipment/supplies and facility problems) can help uncover safety risks that are overlooked in national priorities [217]. This was raised by the professional support participants in the interviews, emphasising the importance of reporting facility issues that may have a high impact on others, as well as the other participants mentioning their reporting decision depending highly on the severity and impact of the issue.

**Smart buildings and technology** Studies show that occupants value having CCTV cameras deployed in the smart building for reasons such as occupancy detection and localisation, which can provide valuable information on energy management and building performance [218]. The findings are consistent with the literature on the effect of CCTV on crime prevention in commercial buildings whilst safety was one of their primary concerns [219]. CCTV technology in smart buildings can be integrated with other technologies to enhance overall safety and comfort in the smart domains. One example is their integration with fire safety systems to detect smoke and help lead individuals to safe exits. Furthermore, in the case of critical situations, if CCTV cameras are integrated with the public addressing systems, they can assist the communication in such a way that the overall safety of building occupants is achieved [220]. This was raised in the participants' answers as well.

**Work and public places:** The results show how workplace relations have an influence on the reporting decision. While some showed reluctance in doing it, some presented a choice of talking to either a supervisor or a colleague about it. This relates to some studies that indicated that perceptions of supervisory or organisational support have a positive relationship with high-involvement responses such as formal reporting, whereas perceptions of collegiality may give rise to low-involvement responses such as talking to colleagues about incidents [221]. Regarding the existence of clear policies sub-theme found in the analysis of the interviews, it relates to the recommendation of Hertzog et al. (2008) that having policies in place alone is not enough; the organisational culture supports the environment that encourages reporting [222]. Reporting blockers can include fear of blame, lack of support, and uncertain reporting procedures [223].

### 3.6.2 Motivations

The study outcomes display the shift of motivations from a typical reporting process to an interactive human sensing facility check. There is a high presence of intrinsic motivations like altruism, a sense of community, and perceiving a better environment in both ways. This aligns with studies that support the use of intrinsic incentives [26, 190]. It is worth mentioning that altruism was the first self-reported reason in both reporting approaches might be a providing of a socially accepted answer which can be a social desirability bias [210]. From a psychological perspective, intrinsic motivation relates to self-determination theory, which asserts that humans have inherent psychological needs for autonomy, competence, and relatedness. [224]. Within the context of crowdsourcing, intrinsic motivation can arise from a desire to help serve a greater Good. A lot of people are driven by altruism, the desire to contribute to a cause or benefit society [225]. People are looking for a connection much deeper than that of the reiterative nature of business concepts to be shared and borrowed by those who are seeking to self-actualise their ideas. Moreover, feedback may create a sense of community and motivate people to work together [226]. It encourages belongingness and social support, which are key factors in human motivation [226].

However, this slightly changes if the system involves the occupants interactively responding to facility-check tasks. People also prefer another intrinsic motive in the form of enjoyment and fun properties. A detected rise of extrinsic motivation in the form of rewards was found. This aligns with the other research supporting that workers do need extrinsic motivations to keep participating [26, 192]. The study findings show that occupants are inclined to compete in finishing the tasks. This links to the need of competence, as people want to learn new things and grow their skills. A study conducted by Hidi and Renninger (2000) found that feeling challenged and experiencing a state of flow is intrinsic motivation for individuals [227]. Contests are also quite effective in encouraging people to strive for their best and come up with quality work [228]. This uses principles in social psychology of competition and the need to achieve [228]. Thus, integrating game elements like points, badges and leaderboards into crowdsourcing actually makes the experience more engaging, fun to participate in, and motivates people to do work. Gamification also makes use of inner drives like challenge, curiosity, and being "in the zone".

The findings indicate that external rewards are increasing, whether through rewards or monetary gain. Positive reinforcement is a valid technique that may be used, as a means to encourage further participation. For example, Eisenberger and Cameron (1996) conducted a study that suggests that extrinsic rewards can potentially undermine intrinsic motivation when: the rewards are controlling/perceived as contingent with the participation stopping if the rewards are stopped [229]. Another motive which did not show a high intreset among the particpants is the recignition. However, for the particpants that prefer it, it taps into the human need for esteem and self-actualization within Maslow's hierarchy of needs. Fehr and Falk (2002) demonstrated that social recognition can be a stronger motivator than monetary rewards in some circumstances [230]. Finally, the motives provided in the results and outcomes of the chapter are answers from participants theoretically in an interview. At the time of the study, the answers still need practical proof that the selected motives indeed drive occupants to participate and engage in the interactive reporting system. Nevertheless, this will be solved in the next chapter with a real-life experiment for a month to answer the motives questions again.

### 3.6.3 Limitations

Conducting a qualitative study may include some limitations of the work in terms of the generalisation of the results to be transferred to another environment with different settings [231–233]. The study was conducted with the USB occupants only, it did not cover a wide range of cultural backgrounds of people in different smart buildings. However, the interview protocol stages were documented making it possible to repeat the study again by other researchers in different contexts. In addition, like other qualitative methods, the quality of the work depends on the researcher's skills and hence might present a personal bias. However, I learned how to lead and conduct all 17 interviews by reading and practising before conducting the interviews, using open-ended and non-leading questions to exclude any influence on the participants' replies during the interview.

## 3.7 Conclusion

This chapter is dedicated to understanding the smart building user's perception of incident reporting. To answer this question, three points were covered: Firstly, incident reporting influencing factors, which were found to be the problem type, the way people will deliver their report, and reporter's aspects like their job position and personal preferences or attributes. Secondly, the impact of the technology on the smart building occupants' perception. Occupants expect the buildings to be smart by utilising sensors' data to regulate themselves regarding tracking and surveillance to support their reports. Additionally, occupants are not fully aware of the fault condition or how it affects the building. Thirdly, the study found a shift between the motives driving people to participate in typical reporting systems and acting as a human sensor to perform check tasks received by the system. Finally, at the end of the chapter, the discussion section presented a mapping of the themes to the crowdsourcing dimensions.

# Chapter 4

# Feasibility Study Of Human Sensing Facility Conditions in Smart Buildings

**Overview**

The previous chapter focused on understanding the perception and motivations of people toward incident reporting systems. This chapter explores the feasibility of applying human sensing to provide facility condition updates via an internal crowdsourcing mock-up system to improve situational awareness in a smart campus. Specifically, the chapter focuses on testing the response quality and time required to complete the requested task. To test that, a real-world experiment was conducted for one month by sending tasks to participants to check the conditions of the facilities for potential incidents. 21 occupants of a smart campus participated in this study. To reduce the number of ignored tasks, participants were asked to fill in their day and time preferences to receive their check tasks. After completing the experiment, I interviewed the participants to collect their feedback about their experience as contributors to the system. The results showed that the system is feasible and has benefits for the building facilities and the community. Precisely, I found that the quality of the received responses requires a clear description of the task and the facility location (especially IoT devices such as sensors) since this may confuse the participant if not provided clearly. Additionally, the analysis found that contributing to such systems raised occupants' awareness of their environment and they became more observant of the resources and their functionality. Accordingly, this study has an important input influencing several key implications for the human sensing framework including task-related aspects, human sensor availability preferences, and participation motives that is discussed in detail in Chapter 5.

A version of this chapter was published with the title: "U-Sense: Feasibility Study of "Human as a Sensor" in Incident Reporting Systems in a Smart Campus," in the European Symposium on Security and Privacy Workshops (EuroSPW), Delft, Netherlands.

## 4.1 Introduction

Crowdsourcing has several applications in environmental monitoring [84–86] and incident detection and response [28, 29]. Human sensing is also used to utilise individuals' observations for the authorities to broaden their situational awareness among several fields such as event or incident detection, monitoring, and emergency response to natural catastrophes [28–32]. However, crowdsourcing has a common challenge among its practices regarding the quality of the responses sent by the crowd. It can be challenging for different reasons; one of them is that the crowd is not necessarily experienced or motivated [234].

The previous chapter contributed to the knowledge by providing the perceptions and motivations of smart building occupants towards participating in crowdsourcing initiatives for their building facilities. However, the outcomes were based on theoretical scenarios and that does not necessarily apply in practice [235]. Numerous research studies that investigated crowd motivations are conducted theoretically or by agent-based models. This approach misses to capture the real-world behaviour of the crowd in internal and external crowdsourcing [235]. In this particular case, the semi-structured interviews conducted in Chapter 3 provided hypothetical answers without actually living the experience. For this reason, this chapter fills the gap of extracting real-world data to empirically test the feasibility of human sensing facility conditions in smart buildings.

The chapter is dedicated to answering the second research question of this thesis: **How feasible to use human sensing to improve situational awareness by reporting facility conditions in a smart building?** To answer this question, I focus on three aspects: (1) Whether the motivations are the same as the ones found in the previous chapter after participating in human sensing in a real-world setting. This means that altruism, enjoyment, and external rewards are the main motivations driving smart building occupants to participate in human sensing facility checks. (2) The second aspect to address is the quality (accuracy) of the user responses for the human sensing tasks that are received by the requester (e.g., facility manager or maintenance staff). (3) The third aspect to consider is the time duration to receive a useful reply from the participants. Therefore, addressing these three aspects together can answer the main research question of this chapter regarding the feasibility of the human sensing system in the smart building.

In this chapter, I present a feasibility study of the internal human sensing concept by using a mock-up system named "U-Sense". I conducted a month-long experiment with 21 occupants of the Urban Sciences Building (USB) as participants in a real-world setting. Participants received a check request task every day based on their selected time and day preferences to provide their observations and updates on the specific facility conditions. Qualitative and quantitative data were collected and analysed to investigate the feasibility of the proposed concept. I analysed the response quality, task completion time, and number of responses per task as basic success factors. Finally, I followed that with interviews to ask the participants about their feedback.

The results show that participants who experimented with the mock-up system in a real-world setting within their regular working days reported the same motivations as those who answered to the hypothetical scenarios provided in Chapter 3. Having altruism as the main drive, followed by the enjoyment factor in the form of competitions and also receiving external rewards. The trial also discovered some points about the accuracy of the data. Although most of the responses were accurate, some were not. The reason behind that is the lack of details and guidance for the participants. This was useful input to add important insights and implications for the human sensing framework designed in Chapter 5. Finally, the last aspect was to consider the time duration of the results. As the study did not ask for quick replies from the participants and conditioned it in one work day, most tasks received replies in less than one hour, the quickest taking only two minutes. This was expected due to the available data on user preference and availability which provided an indicator of the time and number of received replies. Overall, the findings show that the system is feasible to be implemented in smart buildings.

## 4.2 Related Work

Kandappu et al. (2016) conducted their research in testing the feasibility of crowdsourcing systems [235]. They developed a crowdsourcing system named TaSker and empirically tested it in a real-world setting. Their research was focused on understanding the worker responses to the two approaches of task allocation and selection. In the push approach, the requesting engine suggests tasks that are based on a specific worker's predicted movement route. This usually comes with a more limited list of choices. The pull-based approach is where the user selects a task from a list of available tasks from the system based on their choice; usually, the selection is based on the closeness of the task location. The analysis also included the '*super agents*' who complete many of the tasks compared to other users. They found that the crowd seemed to favour simple tasks that easy to complete (e.g., choosing one from a pre-defined set of answers) over more complex tasks. Also, workers tend to prefer the push-based approach instead of outperforming the pull-based approach.

Moreover, Kandappu et al. (2018) followed with another research to understand the preferences and the concerns that people have towards using their mobile devices to participate in location-specific tasks via conducting a survey to extract the citizens' opinions [13]. Then they followed that with an empirical study to test task allocation, user location and routes, privacy, and variable pricing. They found that the success of urban measure smart city implementation is subject to behavioural preferences and user concerns. They proposed a civic resource monitoring system that leverages the citizens while integrating features such as task recommendations based on a person's mobility patterns.

Another study was conducted by Hara et al. (2012) to test the feasibility of using individuals as crowd workers to assess sidewalk problems [236]. To achieve that, they built a database of 100 Google Street View images. They aimed to observe the changes in task correctness and completion time that occur when users are provided with different interactive labelling interfaces (Point, Rectangle, and Outline) to use when solving the task. In another research [236], authors focused on the design and the user experience of incident reporting systems to understand what factors influence the user experience of the reporting systems. The authors conducted an experiment in which people reported incidents they noticed in a designed path for them. They found that user experience dimensions such as emotions, social relatedness, and values can be successfully utilised as triggers to encourage individuals to report incidents in urban places. They also reported that people tend to talk about incidents rather than report them [236]. The study relied on people reporting incidents without receiving a request to check for them.

The quality of the responses is one of the most common challenges in crowdsourcing initiatives [237]. It can be challenging for different reasons; one of them is that the crowd is not necessarily experienced or motivated [234]. For this reason, multiple research projects focused on controlling and ensuring the quality of responses to crowd-sourced tasks. Daniel et al. (2018) proposed a comprehensive survey of the crowd-sourcing quality control literature in [238]. Other work has focused on specific contexts like the one conducted by Othman [237], where the author investigated the issues of response quality and completion time. He presented a quality control method depending on the user's self-verification with a specific focus on two types of data: eye tracking and speech data (impaired speech).

## 4.3 Methodology

The study includes designing an incident reporting form (U-Sense) to use the concept of 'Human as a Sensor', testing it in a real-world setting with the occupants (n=21) of a smart university building (Urban Sciences Building in Newcastle University) and interviewing the participants for more feedback. Figure 4.1 illustrates the steps of the study starting from the design phase to the analysis.

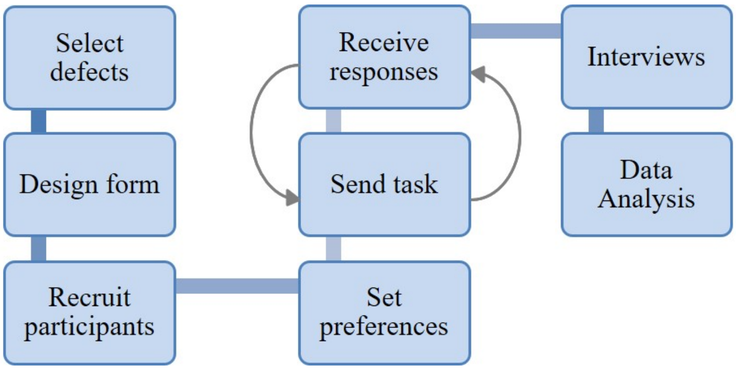



Fig. 4.1 Experiments' steps and flow.

### 4.3.1 Form Design

Prior to the experiment, a mock-up system was set to test the feasibility of the proposed idea which is to send several 'check requests' to the participating occupants, to check the condition of the facility in the building. The participants receive an electronic form with a task they need to perform, then they send their observations back as a response to this task. A Microsoft Office form was designed, where each form represents a 'check request' dedicated to one task. Figure 4.2 shows a sample task containing one required question and four optional ones. The questions are structured as follows:

1. The main question asks the participant to check the condition of a certain facility. The answers are always multiple choices of: yes, no, not sure, or I can't check it. It also contained a photo of the facility for clarification.

2. A question that allows users to upload media, such as photos or videos, as supporting evidence for their answers.

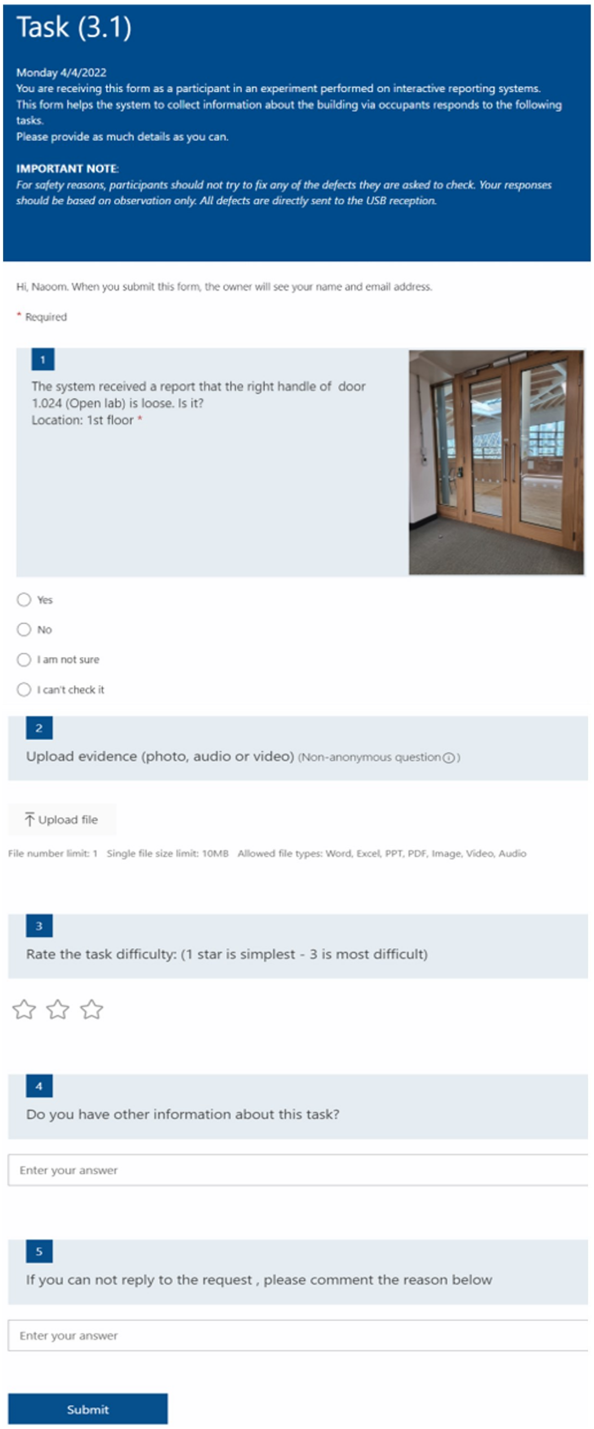
3. A text box to add comments related to the task.

4. A 3-star rating question for the user to rate the difficulty of the task.

5. An extra comment box for participants to add any information regarding the experiment or their availability (e.g. being busy or not in the building).

### 4.3.2 Participants

The experiment was conducted in the Urban Sciences Building (USB) at Newcastle University, Newcastle upon Tyne, UK (Chapter 2, section 2.1.2. **Table1** 4.1 describes the demographic data of the 21 recruited participants as occupants in the smart building where



# Task (3.1)

Monday 4/4/2022
You are receiving this form as a participant in an experiment performed on interactive reporting systems.
This form helps the system to collect information about the building via occupants responds to the following tasks.
Please provide as much details as you can.

**IMPORTANT NOTE:**
*For safety reasons, participants should not try to fix any of the defects they are asked to check. Your responses should be based on observation only. All defects are directly sent to the USB reception.*

Hi, Naoom. When you submit this form, the owner will see your name and email address.

* Required

1
The system received a report that the right handle of door 1.024 (Open lab) is loose. Is it?
Location: 1st floor *

- Yes
- No
- I am not sure
- I can't check it

2
Upload evidence (photo, audio or video) (Non-anonymous question)

Upload file

File number limit: 1 Single file size limit: 10MB Allowed file types: Word, Excel, PPT, PDF, Image, Video, Audio

3
Rate the task difficulty: (1 star is simplest - 3 is most difficult)

4
Do you have other information about this task?

Enter your answer

5
If you can not reply to the request , please comment the reason below

Enter your answer

Submit

Fig. 4.2 Experiment Task Sample

the trial system was running. The participants were 8 male, 12 female, and 1 non-binary. 6 of them were under the age of 20, while 8 of them were between 20-30 years old. there were 4 participants aged between 30-40 and 2 participants were between 40-50 years old, and 1 participant was above the age of 50. The majority (around 14) were from the UK, while 2 were from the European Union and 4 were from different parts of the world. Regarding their locations, 2 participants had their offices on the 1st floor while the 2nd floor had 4 participant offices. The majority stayed and studied on the 3rd floor (10 people), 1 person on the 4th floor and 2 people located on the 6th floor. When asked about anonymity preference, 14 of the participants did not care about their identity reveal whereas 7 of them preferred anonymity. In terms of their role in the building, 5 of them had the position of professional support with administrative roles while 7 other people were PhD students and 9 were undergraduate students that do not have administrative responsibilities.

A recruiting email was sent to all occupants to invite them to this study. Those who accepted signed a consent form and received an information sheet describing the experiment and requirements (provided in Appendix B) and filled out a pre-screening questionnaire for demographic data collection as well as some questions about their preferences, including available days and times, and preferred platform for contact like using email or Microsoft Teams (Provided in Appendix B). Each participant had a minimum of two weeks to participate in the testing of the mock-up system. Each participant was compensated with £20 for their participation and £10 for the final feedback interview.

Table 4.1 Participants' demographic data

| **Gender** | | **Age** | | **Nationality** | | **Available in** | |
|---|---|---|---|---|---|---|---|
| Male | 8 | Under 20 years | 6 | Outside of the UK/EU | 5 | 1st floor | 2 |
| Female | 12 | 20-30 years | 8 | EU | 2 | 2nd floor | 4 |
| Non binary | 1 | 30-40 years | 4 | UK | 14 | 3rd floor | 10 |
| | | 40-50 years | 2 | | | 4th floor | 2 |
| | | 50+ | 1 | | | 5th floor | 1 |
| | | | | | | 6th floor | 2 |
| **Anonymity** | | **Role** | | **Administrative roles** | | | |
| Yes | 7 | Professional support | 5 | Yes | 5 | | |
| No | 14 | PhD student | 7 | No | 16 | | |
| | | Undergraduate | 9 | | | | |

### 4.3.3 Experiment Design

The experiment was conducted in the wild for one month in the Urban Science Building, a smart campus in the UK. The participants received a link to a task called a "check request", asking them to check a facility condition in the building (e.g., light is not working, or motion sensors not detecting motion). Participants had a full day to respond to these requests and the choice of whether to respond to the request or ignore it for any reason. Before the experiment, an orientation session was set explaining the mock-up system to the participants. The orientation session included:

1. Display of the task form and the required/optional questions included.
2. The duration of participation in the experiment (2-4 weeks).
3. The time and method to receive their tasks.
4. Time to respond to each task (full work day).
5. How to contact the researcher when having any questions about the task/experiment.
6. For safety reasons, the participants were advised not to try to fix any of the defects they were asked to check and only respond based on their observations.
7. All defects were sent directly to the building maintenance team to be fixed by responsible personnel.
8. The feedback interview at the end of the experiment.

As the experiment was conducted in the Urban Sciences Building (USB) at Newcastle University, I checked the reporting procedure that exist in the building and being used at the time. The building has three reporting channels, the first one is for building defects and issues which is included in the scope of this research, the second is related to security and is being reported to the security department of the university. The third channel is dedicated for IT and cyber incidents. In terms of the channels, there are some contact numbers on the walls for reaching out after work hours. In general, the reception and school offices are the first point of contact when it comes to facility incidents.

### 4.3.4 Incident Selection

To make the experiment realistic, a specific procedure for selecting incidents was followed.

- The first step was to analyse a defect log file provided by the building reception and maintenance of all the reported incidents and defects in the years 2017-2020. I analysed the 1161 logs to calculate the most occurring and reported incidents. Details of collected incidents keywords are available in Appendix B. This approach was used in previous research (such as [121, 239]) when examining the user experience and usability of their proposed incident reporting system.
- A second method of choosing incidents was using live incidents reported to the researcher by the building reception, who are the first point of contact used to receive reports. Live incidents refer to any incident or defect that is currently happening in the building and was not handled or fixed yet.

The tasks used in this experiment met the following criteria:

1. Tasks should be based on most reported incidents and defects in the building or recent occurring incidents.
2. Priority is for live incidents (received directly from the reception defect log)
3. Tasks should be safe and secure for both occupants and facilities.
4. Some tasks are related to specific characteristics of USB as an example of a smart building.
5. Some restrictions were applied for privacy reasons, for example, all incidents were issues in public places excluding personal offices or any other access-restricted areas.

Table 4.2 shows the facilities included in the trial ( Door handle(2), wet floor (1), window (2), computer cable (1), screen display (2), lifts (1), lights/motion sensors (2), temperature (2), smart card readers (2), intermittent noise (2), table (1), sink (1), dripping water fountain (1)). The full tasks used are shown in Figure 4.3. In this thesis, I decided to make the task questions specific and not general as some other systems do. For example, some systems (mostly external crowdsourcing systems, see 2.1.4) tend to ask a general question such as (If you see something, report it!). However, I am studying the feasibility of it inside smart buildings and focusing on other aspects that will be mentioned in detail in section 4.3.6. Generally, organisations can select the format that suits their needs. Another aspect to consider is the differences when depending on human sensing to respond to a certain task compared to typical incident reporting where people reporting current incidents without requests. Although they are both important and useful, some individuals create false reports or creating issues in order to receive prizes. This is important part to consider when setting incentives.

| Week1 | Task | Type |
|---|---|---|
| 2. 1 | The system received a report that the window in lab 4.022 - left corner- is not closing well? | Window |
| 2. 2 | An intermittent banging heard above room 3.032 and 3.033 coming from the heating pipes in the ceiling. Do you hear the banging noise? | Noise |
| 2. 3 | The system received a report that water is spilled on the floor of lab (4.022). Please check the floor between 2nd and 3rd lines of computers from the left near the window. Is the floor wet in that place? | Wet floor |
| 2. 4 | The system received a report that the smart card reader (Chubb) is flashing and not granting access in room 2.037. Can you access with your smart card? | Smart card |
| 2. 5 | The system received a complaint that room 2.022 is very cold (reading is 17 degrees) - Is the room cold? | Temperature |
| **Week2** | **Task** | **Type** |
| 3. 1 | The system received a report that the right handle of door 1.024 (Open lab) is loose. Is it? | Door handle |
| 3. 2 | Can you check if the timetable screen for room (USB.3.018) is displaying today's timetable? | Screen Display |
| 3. 3 | The system received a report that lift 145 is slightly higher than the floor when it stops on the 3rd floor. Is it? | Lift |
| 3. 4 | The system received a report that light sensors are not working. They never come on on their own, on request either, or dim over time. Is that true? | Light/motion sensors |
| 3. 5 | The system received a report that a cable tube hanging from the ceiling - Do you see a cable hanging? | Computer cable |
| **Week3** | **Task** | **Type** |
| 4. 1 | The system received a report that the left handle of door 1.024 (from the inside) is a bit loose . - Is it loose? | Door handle |
| 4. 2 | The system received a complaint that room 2.022 is very cold (reading is 17 degrees) - Does it show 17 degrees? | Temperature |
| 4. 3 | The system received a report that the motion senor is not detecting hand movement in the sink of the disabled toilet. - Is it working? | Sink/Motion sensor |
| 4. 4 | The system received a report that the sink in the student refreshment area is constantly dripping. - Is it still dripping ? | Water fountain |
| 4. 5 | Is the timetable screen for room (USB.3.018) displaying today's timetable (Friday 13th)? | Screen Display |
| **Week4** | **Task** | **Type** |
| 5. 1 | Does your smart card grant you access to room 3.018? | Smart card |
| 5. 2 | The system received a report that there is an intermittent banging heard above room 3.032 coming from the heating pipes in the ceiling.- Do you hear the banging noise? | Noise |
| 5. 3 | The system received a report that the window in lab 4.022 is not closing - closer broken. - Can the window be closed ? | Window |
| 5. 4 | The system received a report that light sensors are not working. They never come on on their own, on request either, or dim over time. | Motion sensors/lights |
| 5. 5 | Is the small round table of the meeting space (3.029) wobbly? | Table |

Fig. 4.3 Check requests sent throughout the experiment

Table 4.2 Facilities included in the mock-up system trial

| Facility Type | Number of requests |
|---|---|
| Door handle | 2 |
| Wet floor | 1 |
| Window | 2 |
| Computer cable | 1 |
| Screen display | 2 |
| Lifts | 1 |
| Lights/motion sensors | 2 |
| Temperature | 2 |
| Smartcard readers | 2 |
| Intermittent noise | 2 |
| Table | 1 |
| Sink | 1 |
| Dripping water fountain | 1 |

### 4.3.5 Data Collection and Analysis

The trial ended by gathering both quantitative and qualitative data (see section 2.3). Quantitative results related to the responses such as correctness, duration, number of replies, comments, and difficulty ranking of the task. The qualitative results were obtained by two approaches. The first approach was inspired by the Experience Sampling Method (ESM). In ESM studies, participants are instructed to report some information about their actions, emotions, or other elements related to the study during the day. These self-reports are delivered by responding to some short questions when receiving a notification (i.e., the task request from the reporting system) [240]. The optional questions added to the task form described above were used for this reason. Although the questions were optional in the task, they helped me understand the underlying issues with each task and any other situation. The second approach was post-trial interviews (see section 2.3.5) that lasted around 30 minutes asking users about their experience in acting as a human sensor while recording these interviews for analysis. The interview answers are described in five parts: experience, feelings, motives, and tasks.

### 4.3.6 Feasibility Assessment

It is known that one of the main challenges that task requesters face when sending their tasks through any crowdsourcing platform is the quality of the answers [237], especially because they are coming from responders who are not necessarily skilled or experts in the matter. Therefore, one of the introduced solutions to control this problem is response redundancy. Requesters tend to ask for more than one response for a task as a quality control method to compare answers. This works well with a structured response format (e.g., multiple-choice questions) where requesters can conduct statistical means to accumulate multiple responses [234, 241]. It also indicates the task's complexity level where participants decide to complete the requested task [234, 241]. Another challenge is to receive responses in a reasonable time. This means that the task completion time is acceptable to the requester and is not considered late or useless to get the best use of the reporting system [242]. Based on the arguments above, I decided to measure the three aspects of the human sensor engagement in the system as a criterion for measuring feasibility of U-Sense:

1. Quality of task replies.
2. Number of replies per task
3. Task completion time to receive a useful reply

### 4.3.7 Ethics

This study has received ethical approval from the Ethics Committee of Newcastle University, UK. Participants consented to participate in this study and could withdraw at any time. Interviews were recorded and saved anonymously on a password-protected file.

## 4.4 Results

This section presents the engagement level of the participants working with the trial system, as well as their feedback through interviews and self-reporting forms. The feasibility of (U-Sense) is reported by measuring three aspects of human sensor engagement in the system: the accuracy of the results, duration, and number of replies. In addition, user comments, other supporting data, and their reported difficulty in responding to the assigned tasks.

### 4.4.1 Quality of Replies

Across the one-month experiment, a total of 143 responses were received through the system. It is crucial to evaluate the quality of the information received. This is an important characteristic to decide the trustworthiness of the human sensor concept when utilised in an incident reporting system. To evaluate the response quality, I performed a check on the facility condition before and after the request was sent for each request. Accordingly, I talked to the participants about any inaccurate answers during the feedback interview to understand the reasons behind them.

Among 143 responses, there were only 8 inaccurate responses, split across 4 tasks (shown in Table 4.3). Each of these answers has been revisited to see whether the participants were confident about their responses or not. When looking at the replies, it was noticed that 6 responses were based on a lack of understanding of the task and may have been more successful if there had been a more detailed description (as suggested by participants in the feedback interviews). For example, a request to check the temperature in a room was not clear to some of the participants who did not notice the placement of the thermostat in the room. In another case, participants were asked to check a broken lock on a window, the participants thought that if it closed that meant it was fine, despite the handle not locking. When asking the participants, we noticed that three of the inaccurate responses to the tasks could have been avoided by providing more details. Only two responses out of 143 were inaccurate due to misreading or misinterpretation from the participant side (i.e., tasks 2 and 4 in Table 4.3).

Two tasks received a *"not sure"* answer about an intermittent noise and a wobbly table. Although participants did not select a yes or no answer, they provided a clear explanation of the facility condition in the comment section and the evidence section. The first task was expected since the noise was intermittent and not clear all the time. The wobbly table received an explanation that it was wobbly to some extent, but it was not a problem to report. We can see here the ability of the human sensors to understand and provide insights into subjective situations.

Table 4.3 Inaccurate responses during the study

| Task | Response | Reason | Inaccurate Responses |
|---|---|---|---|
| Temperature | Thermometer placement | Description | 2 |
| Motion sensor/ sink | Checked lights instead | | 1 |
| Window | Closes but not lock | Description | 3 |
| Window | Checked wrong window | | 1 |
| Smart card / door | Wrong door | Description | 1 |

### 4.4.2 Number of Replies

During the month of the experiment, 20 task requests were sent and all of them received replies. Figure 4.4 shows that around 70% of the tasks received responses from more than half of the participants, regardless of the place or type of task. One interpretation for that

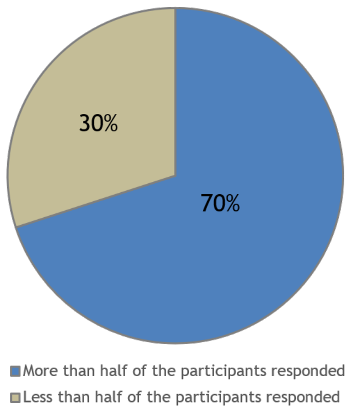



Fig. 4.4 Tasks received replies from participants

is that the workers are participants in the study, therefore completion rates are expected to be high. Furthermore, it is worth mentioning that the number of replies was predicted in some way due to the day preferences provided by the occupants before participating. This provided a general idea of what to expect for the task. For example, task number 4.2 which was the second day in the third week. I -the requester- already know that this day had the highest number of available responders, hence expecting many replies. In contrast, the last task in the experiment had the least available responders (as it was close to exams week). The requester expected that the task would not receive as much as replies compared to other tasks. Additionally, the number of replies and completed tasks may be affected by the nature of the task itself. For example, a simple task may have a higher number of replies compared to a more complex task that may seem more complicated and require more time and effort. This means that the level of complexity and the solving effort during the design of the task should be considered [243, 244]. Afuah and Tucci suggest that highly complex tasks can be challenging to describe, leading to a higher misinterpretation rate [194].

### 4.4.3 Task Completion Time

In this trial, the participants were told that they had a full workday to respond to the check requests. To test the duration of each response, the procedure was to calculate the duration between the task sending time for each participant and the time of receiving the response. Any declined responses were excluded. I performed these calculations on the first accurate responses received by the system, as this would be the point at which the system administrators received useful data.

As illustrated in Figure 4.5, most tasks received responses in less than an hour, the quickest taking only two minutes. The average of receiving a useful reply throughout the

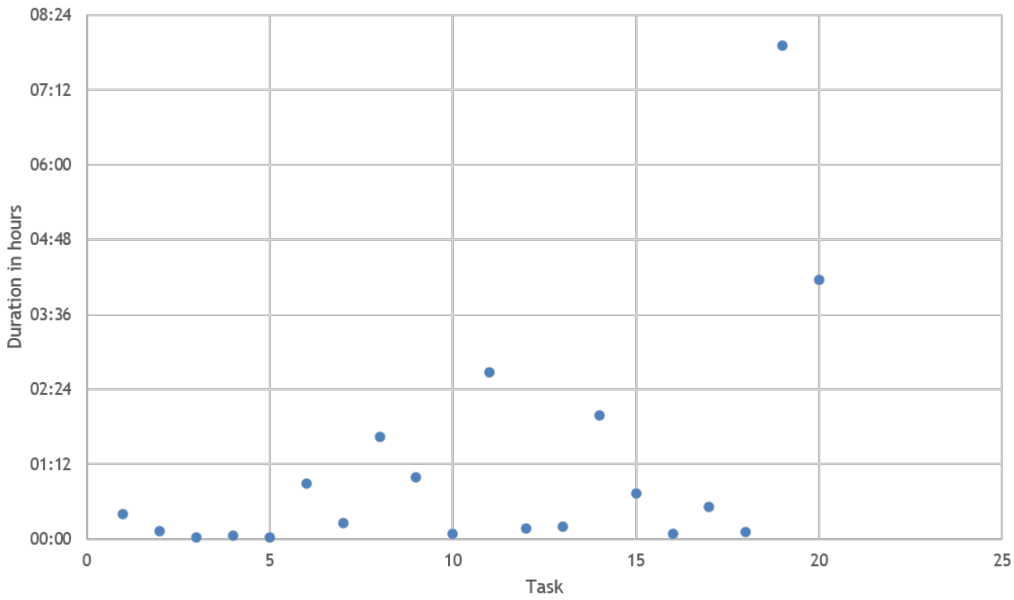



Fig. 4.5 Time to receive one response for each task request

experiment was found to be around an hour and 9 minutes. However, there were some exceptions, with two tasks taking longer than expected and reaching 4 and 8 hours. This was expected given that these tasks took place on Thursday and Friday, which were the days when the fewest participants were available based on the pre-experiment data about their preferences and availability. For example, there were only 4 participants on Friday (2 replied they were not in the USB, and the other 2 responded). This shows the importance of understanding the availability of human sensors to predict if replies will be rapid. In addition, it is important to note that the job role and culture of the work building may have a significant effect on the human sensor collaboration and availability. For instance, the case study was a university building comprising professional staff with offices, teaching staff with lectures, and students with lectures and exams. The timing of the experiment may have influenced the duration and number of responses in which students were preparing for their exams and did not attend every day.

### 4.4.4 Further Responses

Apart from assessing the incident, The form had questions asking the participants to report further comments, provide more information (e.g., a photo), and rate the difficulty level that they experienced with each assigned task.

**User Comments**

Each task had two optional text boxes available for occupants to add any comments regarding the task or their ability to do it. During the month trial, around 117 responses included additional information.

41 comments contained explanatory content. These descriptions could be as simple as reiterating their main answer to the response (e.g., stating that a window is closing well or that it could not close). The other 13 comments included clarifying difficulties such as sensor placement, finding room location, access restrictions, and room availability/occupation. Furthermore, 17 notes included participants providing their points of view. Expressions of subjective opinions as noticed, such as describing the level of the defect (e.g. *"slightly wobbly", "slight noise won't consider it banging", "might drip intermittently", "long time to wait for drips", "placement of sensor might affect the defect report", "temperature shows 20 but it feels cold"*). Other useful answers included raising further information (e.g., *"another door handle is loose as well", "noise related to another separate room", "lights turned on by the control panel but not by sensor", "I am sure it is working"*). Also, there were around 33 notes of occupants cancelling the task because they were not inside the building for different reasons such as working from home, illness, travel, or simply being busy and forgetting to reply. **Based on that, the comments section can be used as an additional method to assess the quality of the responses along with redundant replies.**

**Task Difficulty Rating**

The participants had an option to rank the difficulty of the tasks received. As presented in Figure 4.6, most votes stated that the tasks were simple. Around eight tasks were ranked as moderate by one or two participants, and around six tasks received a complex rating describing some challenges while checking the place. To understand the causes of difficulty, I investigated the participants' difficulty ratings by asking them about this during the interviews. Answers associated with the temperature, intermittent noise, and motion sensors were the most rated as difficult. This might be affected by the number of participants available on the days that I distributed these tasks. However, the analysis was able to find common aspects of some tasks that make them more difficult than others as stated in participants' comments:

1. Lack of familiarity with facilities and devices

   (*"I wasn't sure where the temperature meter was", "I don't know what is meant by 'does it show 17 degrees' Does what show 17 degrees?"*).

2. Difficulty reaching the location

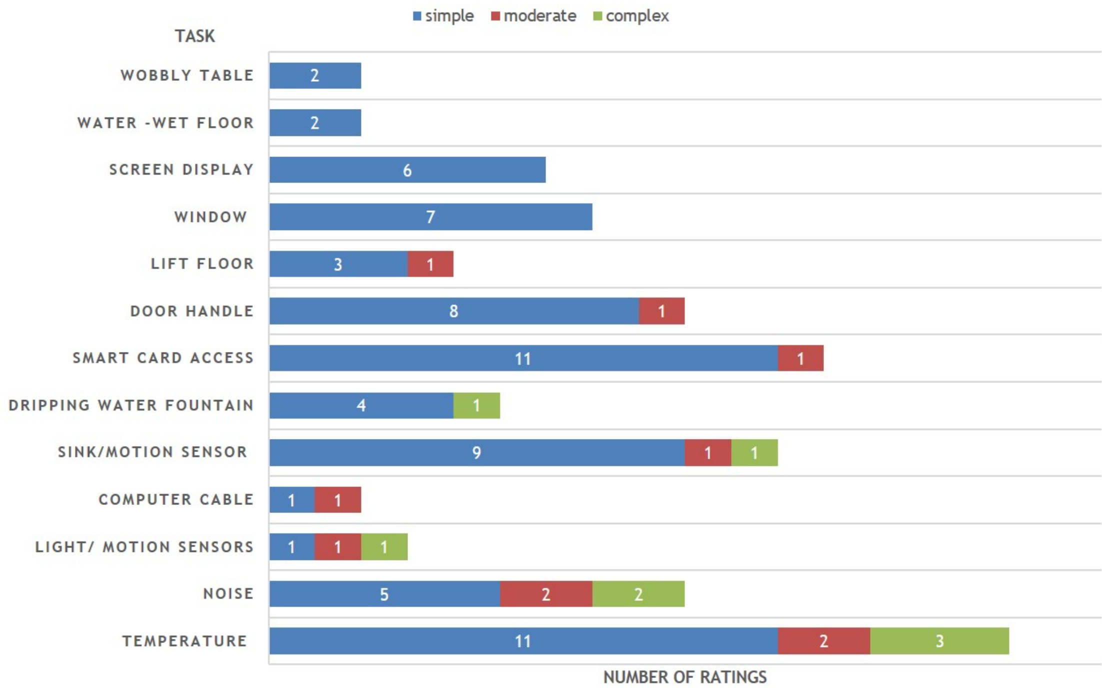



Fig. 4.6 Task difficulty rating

(*"It was hard to find the door as the room takes up half of the first floor and there are many entrances"*).

3. Subjective possibilities of answers (*"Thermostat shows 20.8 but the room does feel cold", "Definite temperature drop when I went into 2.022 compared to other rooms on the floor"*).

4. Access control over the facility

   (*"doors won't unlock for me", "The room is occupied"*).

5. Time spent to perform the task

   (*"I kept waiting for the right lift to arrive to be able to check it", "took me a while to find the correct desk"*).

6. Intermittent defects that cannot be easily detected

   (*"stayed in 3.032 for 5 minutes, heard nothing", "it might be dripping slightly intermittently, but I was by it for like a minute and didn't notice any dripping"*).

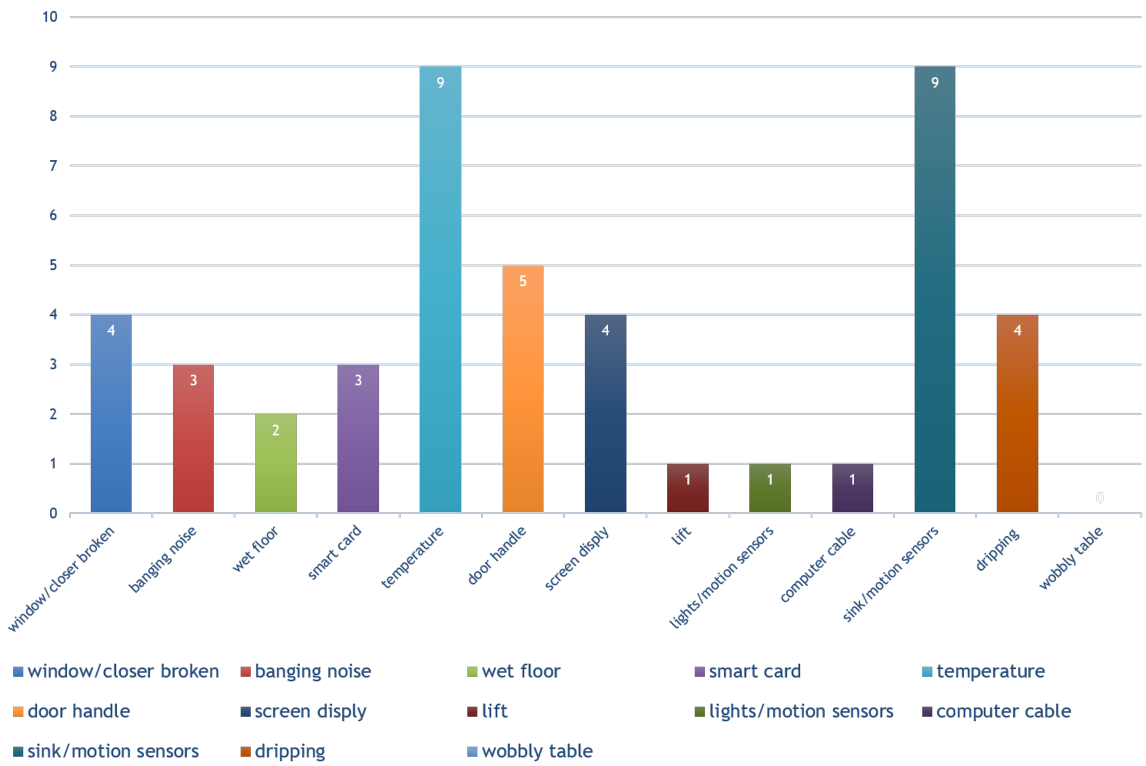



Fig. 4.7 Received supporting files corresponding to each task type

### Providing Supporting Data

Participants had the option of providing supportive information that benefits their reports. They could upload any media file, whether it is photo, audio, or video. During the experiment, the system received a total of 46 supportive files, which were both photos and videos. Overall, of the 20 tasks, 14 tasks (in 14 days) received evidence supporting their responses while 6 others did not. It can be observed that the number of available participants in a day influences the quantity of received evidence: for example, weeks 3 and 4 had more available participants than weeks 1 and 2, hence receiving more supporting data in those weeks. Figure 4.7 illustrates the percentage of received supporting files for each task type.

Another observation was that the highest number of supportive files submitted to the system was associated with the tasks with the highest complexity rank. By observing these photos, the temperature check task was supported with proof of a thermostat photo (to remove any subjective opinion on the temperature). The second task was associated with motion detection sensors. Although the participants' comments contained some explanations of the situation, they also tried to support their claims with the video recordings. Figure 4.8 shows


Fig. 4.8 Received supporting files corresponding to each task type.

a screenshot of a person moving their hand to test the motion detection of the sensors, the other photo is sent by a participant to show the temperature in the thermostat.

Another point to mention is the type of supportive media files. Many tasks received photos taken by users. In some tasks, such as the ones requiring human interaction to check the condition, participants decided to support their answers with recordings of their attempts. This was evident in tasks including checking a loose door handle, testing motion sensors on a sink, a dripping water fountain, and smart card access to a room. **The analysis recommends that this type of supportive data can improve the quality of responses, as descriptive recordings of the situation can clarify the condition of the facility**. In some cases, it might be beneficial to make supportive media compulsory.

### 4.4.5 Feedback Interviews

I conducted structured post-study interviews with the participants for around 30 minutes each to talk about their experience in human sensing actions. This included asking about their experience, task types and task design (full questions are available in Appendix B). The interview answers helped provide results for this chapter regarding the human sensor experience, motives, and tasks specifically in a smart building and the rest of the results are used as input for Chapter 5 to design the suggested human sensing framework for facility checks in smart buildings.

**Human Sensing Experience**

When asking participants about their experience during the study, simplicity was found as one of the most common themes.

14 participants described the **simplicity** of the proposed reporting system as one of its main positive features. They mentioned the ease of task requests, the way of receiving the tasks, and that it did not require a long time. 12 answers emphasised on the points of no urgency or stress *“Because it is based on preferences, I feel free to decline"* P17.

The **flexibility** of the requests also appeared to be a positive factor, as highlighted by 12 interviewees who said that there was no urgency or pressure to do the task in a certain time. The option to opt out and set their own preferences to receive requests was highly appreciated by participants. Another theme emerging from the interviews was **obligation**. Participants described feelings such as *“I liked being included to help maintain the new building"* P19, while another answer explained *“when I received the tasks, it felt like a manager’s order"*P4.

Five occupants of the building enjoyed the **excitement** in the human sensing work where they see it as a chance to break the routine. Some expressions were found among the answers like *“It was fun walking around, like a treasure hunt!"*P4 . **Concerns** from participants included duplicate responses *“what about people performing duplicate tasks?"* P7. Also, Finding and accessing a room or facility was a concern, especially for those unfamiliar with the building. Few explained their concerns by mentioning: *"What if I am not granted access to the place?"*P10. This suggests that similar systems might add an alert or disable the task when it is already fulfilled correctly and no further help is needed. Regarding restricted access, some solutions can be implemented such as cluster occupant groups based on their access rights, or providing the volunteers with a special pass.

A significant positive theme was raised among the answers where interviewees reported increasing levels of **awareness** and familiarity with the building and its facilities. Fifteen participants pointed to improvements in their knowledge: *“I became more observant"*P12, “I explored new places in the building and noticed new features like thermometers” P17, *“I paid attention to issues I’ve never noticed before, I guess I’m used to issues being there!" P16, “I knew my way around”* P13. However, five of the participants did not report any difference, as their job role already required that they deal with facility defect reports.

#### Participants Feelings

The second question explored how it feels to act as a human sensor when receiving check requests. A sense of feeling **helpful and belonging** was raised by 7 participants, mentioning: "*I felt important and involved by adding value to the community"*P19. Some liked the feeling of being helpful: *"It is a rewarding feeling to collaborate preserving better environment"* P1. At the same time, participating as a human sensor brought a sense of obligation and responsibility *"I had this sense of obligation because I signed up for it, so I had to"* P20, *"it is similar to my job"* P6.

While performing human sensing tasks for the first time, participants reported feelings of **vigilance and prudence** by doing things that they are not used to doing. In the beginning, some participants described feelings of discomfort *"I felt strange when checking things"* P5, *"I felt weird doing something, not my responsibility"* P11. However, participants felt more neutral once the requests became anticipated *"well, it was expected"* P14, *"it was fine, I did not feel pushed"* P15. Some mentioned that they felt interrupted sometimes: *"I did not mind, however sometimes it feels inconvenient and interrupting, especially when I am busy"* P2.

#### Motivations to participate in a Human Sensing Reporting System

This part explored the intrinsic or extrinsic [245] motivations for participating in the internal crowdsourcing human sensing mock-up system (U-sense). Starting with a general question, participants were asked if they would continue working with the new system. 12 of them agreed they would continue using it with no external incentives. 4 agreed with some conditions such as assigning tasks to places close to their offices. The remaining 4 required external incentives.

Regarding incentives and motivations, occupants were asked again about the drives after trying the system in real-time. Overall, the findings are aligned with the results mentioned in (Chapter3, Figure 3.11). Figure 4.9 shows the types of motives that were apparent in the answers. Altruism and intrinsic motives presented in the concepts of "helping the community, having a better environment" were found to be the highest with 10 participants. Followed by the desire to add a factor of enjoyment and competition, around 5 occupants suggested having a point system such as scores or ranking lists with winner announcements. Related to that, participants recommended that if winners were to be given rewards or compensation, it should be a simple amount like vouchers or university credits for long-term users. Finally, some participants preferred to be recognised and counted as members of a specified group at work.

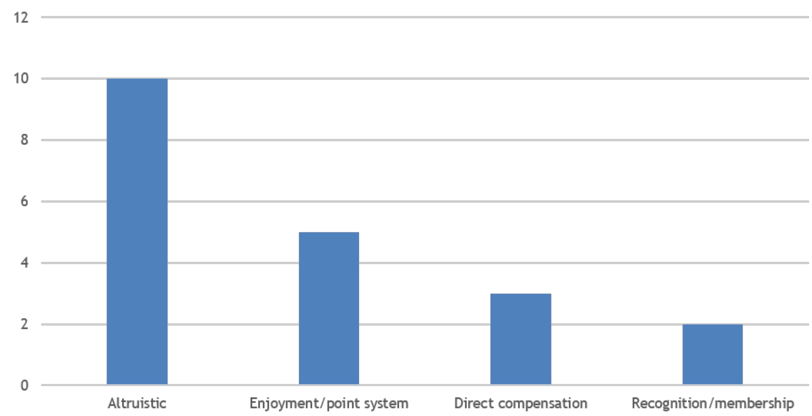



Fig. 4.9 Preferred incentives after the trial

### Tasks Related to Smart Buildings

One of the key objectives of this chapter is to see how occupants deal with tasks that are associated with the smartness of the building (i.e., smart campus). Therefore, it was inevitable to include check requests for the smart features associated with it that require interaction and observation. As shown in Table 4.3, some check requests asked the users to check if sensors for lights, temperature, or sinks were operating correctly, or if smart cards and smart card readers were providing proper access.

Occupants were asked if they found any differences in checking tasks related to smart buildings or traditional ones. Around 12 responders raised some differences in some aspects. One aspect of this was **complexity** of performing checks *"technology is always harder to check, interaction is not like observing"*P10, *"Tasks were simple and basic but it's about not knowing how it meant to work"*P17. This was also linked to them seeing it as an **interconnected system** where the defect of something might affect the other. Participants explained that to check/report a smart feature problem, there are several related variables to consider affecting the quality of the response such as the way of interaction, sensor placement, and a person's level of knowledge and familiarity with the building.

Similarly, the background and **level of experience** theme was raised as an important factor affecting the quality of the report. Factors including the amount of time spent in the building and the role such as being a maintenance staff or field researcher of smart buildings may affect the level of observation and quality of reports where others were unaware of sensors in the building. *"It depends on user experience; others might need more time... it is not complex or technical for me"*P8. Occupants who had no experience mentioned that it was new and interesting to explore these aspects of the building. Some professional support staff who have experience in receiving these types of reports mentioned that the building's smart features can be **temperamental** *"goes on and off occasionally"* P6.

Other interviewees noticed that some tasks could have two answers in terms of a facility working either **automatically or manually**. This was raised in requests to check lights where they could be switched on manually yet not automatically when entering the room. This can also be attributed to the movement and sensor placement in the room. On the other hand, 8 participants did not find it different due to the simple observation requests they were required to do, mentioning that they did not require any technical understanding.

## 4.5 Discussion

### 4.5.1 Design implications of human sensing framework

The experiment interviews resulted in some design implications for designing the human sensing framework which is presented in Chapter 5. Smart building occupants showed interest in the task type that impacted their decision to perform the checks. Attributes like safety, impact, or damage that might affect the building. Others highlighted their preference for simple and tangible tasks with minimum effort. Related to that, the close location of the facility and if they are regular users of it. This was related to their **preferences** of being available in the building and being able to fit the tasks into their schedule and plan their day. This indicates a solution of classifying users into **zones** based on their preferred places and times. Also, giving them the option to update their preferences whenever needed. Regarding the task difficulty **rating**, it was viewed by the users as useful or managers especially at the first stage of the process to be able to classify tasks and set incentives based on their difficulty. This also can help divide tasks into groups for maintenance that require more work and another group can be for building occupants.

**Consistency** of the task descriptions and clarity is a required aspect in listing the tasks. Having a clear and specific request of what is expected from the workers is a good way of receiving high-quality and useful replies. Workers prefer having specific guidance that is not open to interpretation. Moreover, providing **directions** to the facility may have an impact on the response decision, especially for those who are less familiar with the building. Presenting a **photo** of the facility may assist the participants as a visual reference of the facility and it speeds up the process.

In terms of the **wording** of the task and providing some context about the task, some participants prefer direct questions that are more friendly and informal and save time, while others consider having more information about the tasks to provide a story and make them feel responsible and part of the system. Additionally, some preferred having their **name** mentioned in each task request where it gets their attention of being specifically selected. On the other hand, it may cause pressure on participants. Some details were preferred in the **notification** part as well. For example, providing the floor number of the task can help occupants instantly decide whether they can do it or not.

Other design implications such as adding more attributes for the task such as time stamps and reporting date, and the importance and **urgency** of the task by setting a specific timeframe, adding delay and **reminder** options for those who cannot perform the task instantly, saving a list of unsolved **pending** tasks. Moreover, adding **statistical** data to track user engagement and points if associated with incentives. Finally, there were some notes from **dyslexic** users who pointed out the importance of simplifying the text and fonts. This aspect is open for future work and usability studies.

Most of the participants preferred not knowing the identity of the personnel behind the request to avoid biased replies. However, a few participants preferred knowing the requester's name to keep human contact and have the feeling to help others. **Participant anonymity**: The experiment questionnaire shows that most of the participants did not mind showing their identity in responses because the presented information is not considered personal (name and work email), especially in a work environment. Another reason is being responsible and accountable for their response, therefore available when asked any further questions about the task and facility. Besides, participants see it as a constructive contribution where their image and reputation are presented positively. This relates to the recognition incentive. Finally, users prefer their identity to be shown to system administrators especially when incentives are provided (competition points, lists and external rewards). On the other hand, the rest favoured anonymous replies to provide more genuine responses and have the freedom to decline.

### 4.5.2 Trustworthiness and credibility

To assess the success of the idea, it must meet three criteria to prove its feasibility: The responses need to be correct, on time, and sufficient. The experiment also evaluates this by two other methods of data collection, one is where the participants provide supportive data, and additional comments on the task. The other method was the post-experiment interviews. Having more than one way of data collection increases the confidence of the findings. In qualitative research, collecting different types of data and running different approaches in research is called triangulation [246, 247]. Triangulation supports the credibility of the study where the weaknesses in some data/method can be compensated by the other provided data/method [246, 247].

### 4.5.3 Motives and sample size

The study conducted in Chapter 3 showed the main desired motives to participate in the system based on the interview answers. This was seen as theoretical findings and required experimental proof. Therefore, during the experiment design phase, it was planned to have two groups of participants where one group will not have any external incentive, and participants of this sample will respond to the task based on the idea of improving the university system and the building environment (presenting altruism motive). The other group should have tasks assigned in points where participants' answers are rated every time they respond to a task (presenting the enjoyment motive). However, when the recruitment email was sent, accepting participants were considered not enough to execute the first plan. The reason behind this might be that the experiment started after the COVID-19 pandemic when the university -especially the USB- started depending on working from home. This may have affected the number of occupants available at that time. This led to running the experiment and focusing on the length of the experiment, then asking them about the incentive mechanism that would have maintained their participation for a longer time if the system had been deployed in the building.

### 4.5.4 Mock-up system design

Although the experiment could have been executed with a running system built specifically for this reason, using a web form provided a simple available, and easy-to-access method. The study aims to test the feasibility in terms of response quality, completion time, and number of replies, and the web form seems to answer the question. Another reason for choosing not to design a specific tool or mobile app at this stage is that not all occupants have smartphones and will not be able to participate in the tasks (specifically some participants from the professional support teams made it clear when asked about their preferred approach of receiving requests). Lastly, both interviews in Chapter 3 and 4 had questions exploring what are the most recommended characteristics that should be in the designed tool in the future. This is discussed in Chapter 5 of designing the framework using the users' feedback as a data source.

## 4.6 Conclusion

The chapter explored the feasibility of leveraging the knowledge and observations of the smart building occupants in reporting facility condition updates to a requester to improve situational awareness. A real-world experiment was conducted for one month by sending tasks to participants to check facility conditions for potential incidents. 21 occupants of the Urban Sciences Building (USB) participated in this study. The concept proved effective in gathering reports on the state of facilities in the building, suggesting the possibility of more permanent use in a wide range of places. The findings showed positive data in terms of the number of responses, the quality of provided information, and the time duration of receiving responses. Responses' quality results indicate the importance of stating tasks consistently and clearly, describing the location and the placement of the facility and how to reach it (especially smart devices such as sensors). Moreover, the study outcomes were aligned with the ones described in Chapter 3. It raised interest in altruistic motives in terms of being in a community and having a newly constructed building also elevated the participants' interest in maintaining their campus in the best condition. Another desired incentive was the fun factor, where participants expressed their enjoyment of the "treasure hunt" and of moving around. Being in a work/study place, people may like to get out of their offices and walk around nearby places. Additionally, the analysis found that contributing to such systems raised occupants' awareness of their environment and they became more observant of the resources and their functionality. Finally, the month-long experiment helped extracting a set of design implications and future recommendations for the system based on the participants' experience. The next chapter presents a solution in the form of a human sensing framework designed for smart buildings.

# Chapter 5

# Human Sensing Framework for Smart Buildings Facilities

**Overview**

This chapter presents the final contribution of this PhD research: a conceptual framework to implement an internal crowdsourcing initiative for human-sensing facility conditions in smart buildings. To create this framework, I synthesised the results extracted from the two previously conducted studies in addition to the previous literature. The framework discusses the main steps that organization management (building facility managers specifically) should implement to take advantage of the use of human sensing of smart building facilities. It covers the main dimensions known in the crowdsourcing process: platform, requesters, workers, incentives, and tasks. It also adds another element that is particular for smart buildings, like environmental preparation. Each dimension contains some elements and their attributes that the management should consider. Finally, the chapter lists some of the challenges to reflect throughout the process of implementing the human sensing system and discusses the trade-offs associated with the delivered framework and its limitations.

## 5.1 Introduction

Chapter 3 and 4 demonstrated that smart building occupants are willing to engage in the human sensing of facility checks in theory and practice when provided with the right incentives. In addition, previous studies investigated several crowdsourcing aspects such as motivations and incentives of the workers [189, 193], task design and allocation [235, 248, 249], communications and feedback methods [250–252]. Some researchers explored the crowdsourcing initiatives in smart environments on technical or investigating specific aspects (e.g., crowd behaviour) [13, 235, 253]. These studies focus on precise design aspects and techniques without developing comprehensive guidelines and standard framework to understand and manage crowdsourcing initiatives [95, 254, 255]. Frameworks offer a roadmap for researchers, decision-makers, or administrators assisting them in navigating complex data and its analysis. This structured path is essential for preserving a clear and logical progression in the process. It aids in organising the study, ensuring that every phase is methodically planned and implemented. Frameworks significantly speed up the process and enable more efficient progress [256].

Smart buildings have their unique structure of service automation, occupants may find it challenging to complete some tasks. To the best of my knowledge, no found work contributes a guided framework dedicated to smart building environments that uses human sensing to obtain updates about the condition of its facilities. This chapter is dedicated to designing a general framework for smart buildings that considers the tasks related to its facility equipment and IOT devices and their functionality. This chapter is dedicated to answering the research question:

***RQ: Can we design an internal crowdsourcing framework for human sensing facility conditions in the context of smart buildings?***

This chapter is structured as follow: The second section is about the related work, the third describes the methodology of designing the framework. The fourth section presents the human sensing of the smart building facilities framework, followed by the addressed challenges in section five. The sixth section discusses the contribution and its underlying trade-offs and limitations. Finally, a conclusion section that summarizes the chapter.

## 5.2 Related Work

Some papers conducted systematic literature reviews and eventually presented frameworks like the work by Zuchowski et al in 2016 [76]. Others focused on specific contexts where the authors created a theoretical framework for designing innovation contests for the crowd

[95]. Such frameworks were used in other research papers such as [257–261]. For instance, Phuttharak et al. (2018) presented a survey of the research conducted on mobile crowdsourcing, pointing out some implementation concerns, designs, and main reflections for their development [259]. They relied on the recommendations of Wang et al. (2017), in their work on the dimension and architecture of mobile crowdsourcing systems, on the importance of addressing the challenges such as quality control, task administration, motivations, security, and privacy [26]. Campos et al. (2023), studied the influence of internal crowdsourcing on the growth of an innovation culture [257]. They relied on the differential aspects between corporate internal and external crowdsourcing mentioned by Zuchowski in [76].

To the best of my knowledge, no found work contributes a guided framework dedicated to smart building environments as they have their unique structure of service automation, occupants may find it challenging to complete some tasks.

## 5.3 Methodology

Consider the case of an organisation in a smart building that aims to improve situational awareness and smart building monitoring by implementing the human as a sensor solution to receive facility updates and incident reports in their smart buildings. This chapter provides a framework with execution guidelines for management to be used as a blueprint to follow and use the suggested dimensions, design parameters, and their attributes as a checklist to select from (e.g., incentives, distribution modes, duration, etc.). The guidelines also provide some example attributes for the manager to choose from. It also raises the question of possible trade-offs that the managers need to take in some situations. The framework then lists some of the challenges that may face the implementing process and options on how to deal with them. However, this study did not examine the management perspective on receiving facility updates via human sensing. It focused on the workers' side and their perception and practice of reporting and responding to requests from requesters. Different levels of stakeholders (e.g., upper management, reception, maintenance) were not included in this study.

The guidelines were set to be clear, coherent, and consistent to keep the framework clear and easy to follow. The terms and concept are similar to those used in the related literature [26, 76, 95, 235], and each crowdsourcing term and dimension is defined for the reader. The framework aligns with other crowdsourcing frameworks in the general structure, including dimensions such as the crowdsourced problem, platform, stakeholders (requesters, and crowd), and incentives. The key difference is that this framework specifies the smart building context and sets the light on the tasks related to its technology and devices. It considers the environmental setup regarding the occupants' navigation and guidance in identifying the facility under investigation.

This chapter is built as a result of two sources: Findings in Chapter 3 and 4 and previous work and investigation in crowdsourcing literature. Regarding the information extraction of the existing literature, this work did not follow the precise protocol of a systematic literature review [262]. The research process started with a keyword-based search to extract papers that were self-identified as being concerned with crowdsourcing. This included work on internal crowdsourcing, mobile crowdsourcing, innovation-based crowdsourcing, and human sensing. The framework design was inspired by the work in: [26, 76, 95].

## 5.4 Human Sensing Framework for Smart Buildings

This section presents the designed framework for implementing an internal crowdsourcing system for human sensing to report facility conditions in smart buildings. The framework is presented in three levels:

- Figure 5.1 presents a high-level overview of the main steps that need to be covered before implementing the crowdsourced reporting system. The bottom of it lists the challenges that need to be addressed throughout the process. Figure 5.2 illustrates the interactions between the main dimensions of the framework.
- Each dimension is discussed separately in the following sections and summarised in the tables in Figure. 5.4 and 5.5
- A representation of the design implementation by presenting some sample interfaces (See Appendix C).

### 5.4.1 Crowd sourced problem and scope

**Problem type:**

One of the main reasons for deciding to apply crowdsourcing in the organisation is to get a solution for a problem. The scope of this framework is human sensing within a smart building. It is dedicated to the specific problem of getting updates on facility conditions in smart buildings. So, deciding the type of problems and tasks that will be asked is a major aspect in which identifying a problem type from the beginning influences other dimensions of the task design [95].

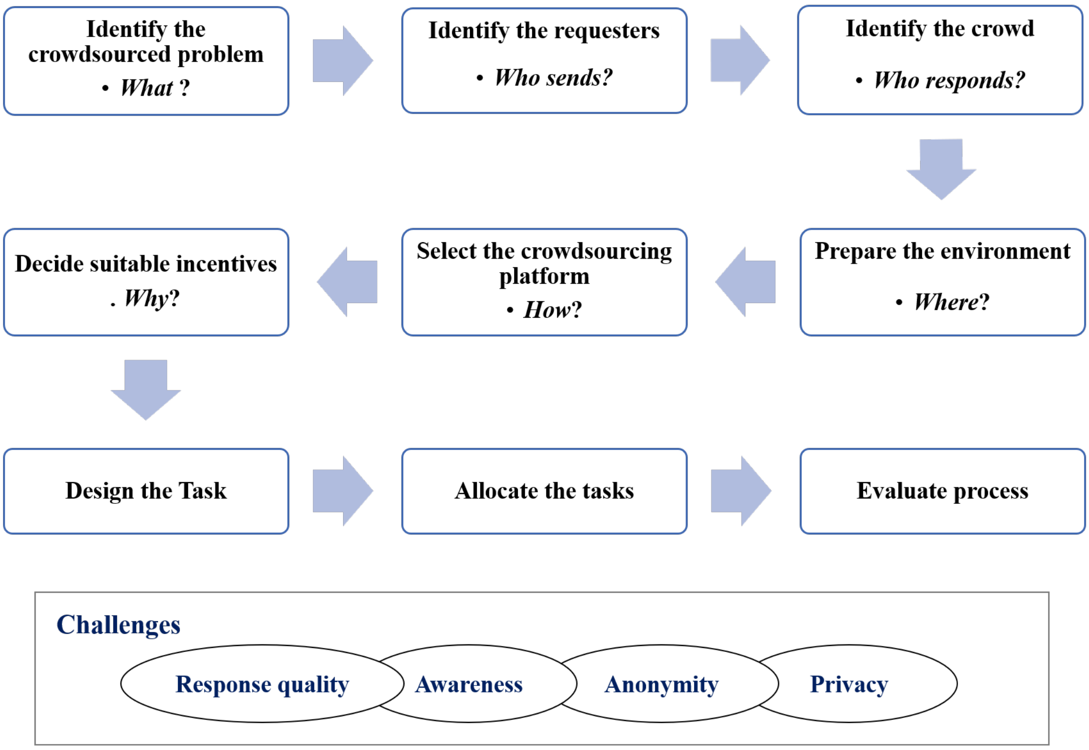



Fig. 5.1 Framework for human sensing facility condition in smart buildings

**Level of interaction and engagement:**

Setting the level of engagement with the facilities for the occupants to perform the task is under the scope of the problem. Unlike other crowd-sourced tasks, human-sensed tasks are not performed only on their devices, they require reaching a specific location to check a facility. As observed in the conducted experiment mentioned in Chapter 4, section 4.4.4, the checking process occasionally needs a level of interaction with some facilities to complete the task (i.e., moving hands to check the motion sensor for the sink faucet). Some tasks may require fixing a facility and some may not for safety reasons. So, addressing that helps understand what is expected of the workers. Another requirement is to specify the open and available facilities for occupants' checks. This may exclude some critical equipment for complexity, safety, or being in access-controlled places. This step of planning and defining the problem has its time cost from the managers' side. However, if prepared properly, it can lead to a successful internal crowdsourcing initiative.

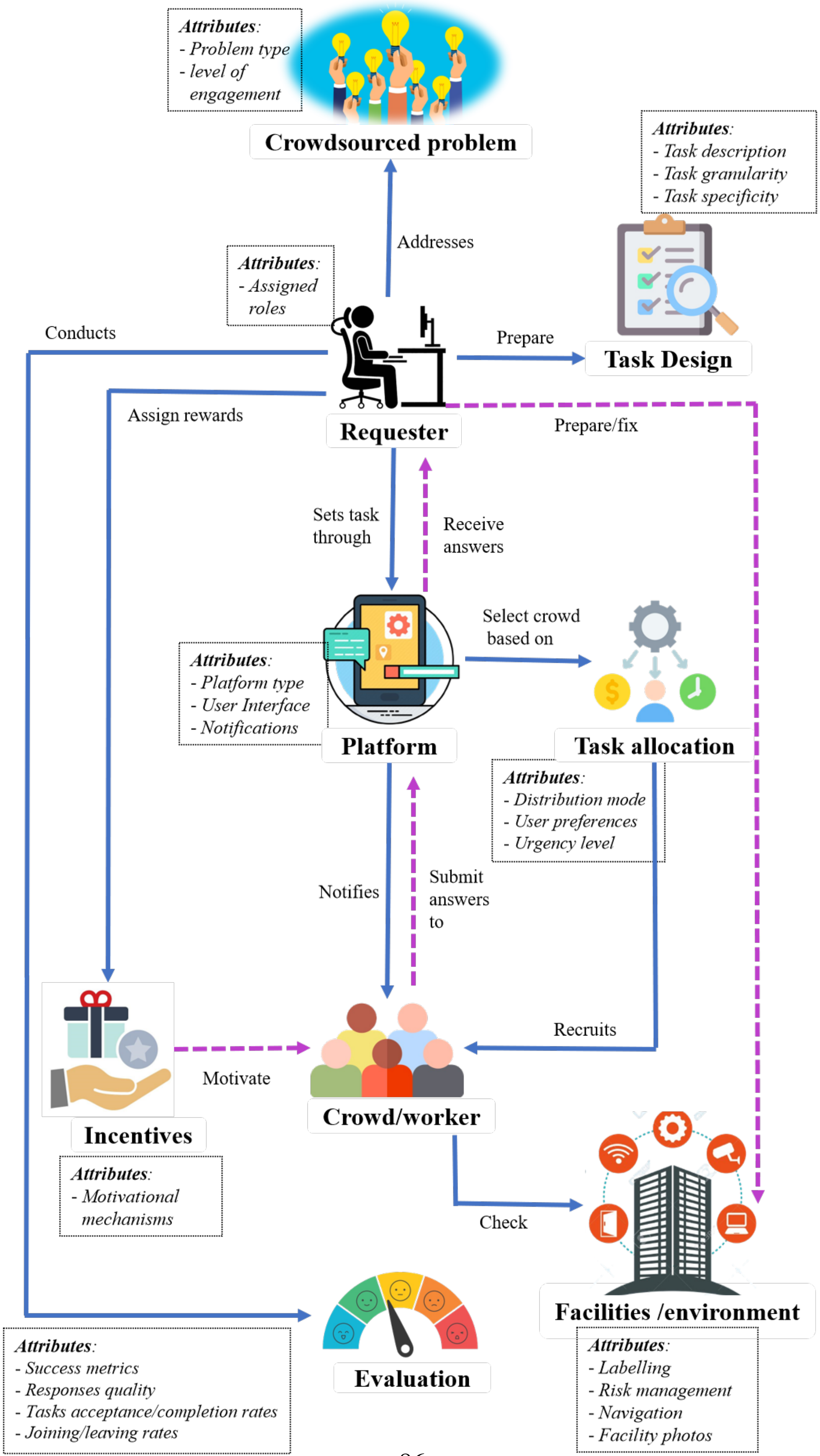





Fig. 5.2 Main interactions between human sensing framework dimensions in smart buildings

### 5.4.2 Requesters

**Assign roles:**

When it comes to organisations, requesters of the internal crowdsourcing are mainly from the management, and are responsible for arranging and handling the crowdsourcing process [263]. Upper and lower management can have different roles. For instance, the building facility manager is responsible for the preparation phase of implementing the human sensing solution and assigning roles. In contrast, the officers and lower management can be concerned about the detailed parts of the process like sending the tasks and setting the incentives. Additionally, if there are any task-related responsibilities such as clarifying to the workers by answering their inquiries and comparing the number of redundant answers to ensure response quality, they need clarification. Employee training can be conducted in this step as well. Additionally, building managers may consider integration with the regular reporting process that is used in the building. For example, some organisations assign the reporting process to the receptionists since they are the first point of contact when something is not right regarding the facility's status. Likewise, the role of dealing with or fixing the equipment needs to be assigned. Based on that, managers need to assess and assign the responsibilities to fit best within the organisation's workflow.

### 5.4.3 Crowd/Workers

Internal crowdsourcing differs from external crowdsourcing in the scale of the crowd. In the former, the crowd is employees in the organisation with job contracts and reporting relationships. Some studies indicated that requesters and responders share some similarities in their aims regarding the organisation [181].

**Internal crowd perception and practice:**

As the two previous studies show, people have high expectations of what smart buildings can do in terms of detecting issues (Section 3.5.2). Another finding was that the occupants are not fully aware of the devices installed in the building that typically play a role in their comfort, such as temperature sensors (Section 4.5.1). This was clear during the experiment where some participants were confused about some device's locations. Therefore, conducting similar studies and surveys to assess the level of knowledge of the workers and their perceptions, expectations, concerns, culture and motivations can help provide some training and orientation sessions to raise awareness of building resources before running the system (More in section 5.5). Moreover, Denyer et al. (2011) raised the importance of the cultural settings of the organisations that administrators need to consider to use a guide on how to implement the crowdsourcing system [264]. Contrary to external crowdsourcing, enterprise members can have a long-term affiliation between them and the enterprise. And, as expressed by Prpic et al. (2015), it can be a positive ground for continuing collaboration [265].

**Internal crowd demographics:**

Understanding the participants' demographics and social attributes helps assign suitable workers. For example, some tasks may be more complex than others, so the requester can select a group of workers with specific job positions and experience to complete the tasks. Plentiful studies examined several aspects of the worker's skills and abilities. Some focused on their demographic profile such as participants' place or education level to identify their skill sets [237]. The results of the system trial (Section 4.4.4 have shown that some demographics complete the task differently than others). As the university building includes different types of occupants (students, academic staff, and professional support) who spend varied amounts of time in the building, different levels of access, and use of facilities. To utilise this difference, occupants can be classified based on means that benefit the organisation [266]. For example, it can be helpful to set a group based on the closeness and level of use of a facility (i.e., a defect of a water fountain on the 4th floor can be sent to the occupants of the fourth floor). Correspondingly, a group can be created based on the job title (i.e., the receptionist group could receive a different task than the students who mostly attend one classroom/lab every time). There are different ways to set these groups, one is by calculating the occupants' data in the subscription process with the assigned preferences of suitable times and places (as followed in section 4.5.1). However, human sensing tasks are typically not complex and require high skills. In a university context, not all occupants stay for a long time in the university (they graduate and leave). So, the skills or personalities clustering may not be the best choice here. Another important aspect to explore is the motivations of the workers. Although there are lots of studies on crowd motivation incentives, the demographic of the occupants in the organisation may suggest otherwise (more in section 5.4.8). Understanding the crowd is an important step before implementing the system. However, it requires time and resources to conduct the research to understand the participants.

### 5.4.4 Environment/infrastructure

As human sensing is in a smart building, occupants may not be fully aware of all available facilities and their locations. Therefore, working on preparing the environment may help in having fast and accurate responses.

**Equipment labelling guidance:**

In the preparation phase, an important factor that can eliminate occupant confusion and decrease the error rate is the equipment label. One of the reasons that led to answer inaccuracy during the mock system test (Chapter 4 section 4.4.4), is the nonexistence of the labelling guidance, and participants were confused between multiple similar equipment (e.g., checking the wrong windows or the wrong sensor). This raises a question of the importance of having a labelling system in the building. Today, most newly built buildings (especially smart ones) have their labelling system included in their building specification plan. Accordingly, management can select to create a new labelling system or use and improve the existing one (i.e., the labelling system used in the building management system (BMS)).

**Environment risk management:**

Labelling is required for safety reasons as well for both occupants and those who will fix the problem. This leads to the next question regarding environmental risk management. Management needs to study and deal with the uncertainties of crowdsourcing implementation. Although many former studies have focused on presenting the benefits of crowdsourcing, it is similarly significant for organisations to consider the possible risks related to crowdsourcing initiatives [95]. Management needs to identify what tasks to send, equipment to be checked and fixed, and zones opened for access. For example, server rooms can be excluded from the requests because they are restricted, critical, and should be under specialised employee checks. These three points are vital to agree on before implementing the system for the safety of participants, good condition of the facilities, and to maintain the security and privacy of the other building occupants in different places of the building. This was applied in the trial where occupants were informed that they should not try and fix any faults in the orientation session and the information sheet of the participation (sections 4.3.3, 4.3.4).

**Building navigation guidance:**

The ability to reach the requested place can be challenging for occupants. Although some may expect that occupants should know their way inside the building, this is not always the case. As observed in the trial in Chapter 4 section 4.4.4, some participants were not able to find the place or spent more time navigating the building. This made the task seem more complex than it was because of the absence of a guidance system within the building. This is for the management to decide whether they can use an existing system such as the one used in some buildings: zones that are colour-coded, rooms have a numbering system, and each floor has a map. The alternative way is to create a human-sensing customised navigation guide, such as installing signs, providing a QR code, and installing several iBeacons into the building as an indoor positioning system, which can assist in determining the place automatically for the responder as used in [267].

**Facility photos database:**

As it was found in the post-trial interviews in Chapter 4 section 4.5.1, including a facility photo in the requested task page can act as a visual reference for the participants. To apply this, managers may need to have a prepared set of photos of the facilities that are available for human observation. It does not have to be the exact item, yet the device photo can be useful. This may be required in smart buildings in particular, where occupants are not aware of some of the IoT devices or controls in the building. (e.g., thermometer controller). All these methods can help simplify the process of human sensing which in turn can improve the engagement level and response quality. Finally, there is a trade-off regarding the preparation of the building infrastructure/environment where it has its implementation cost to gain high-quality responses and engagement.

### 5.4.5 Platform

**Platform Type:**

The platform refers to the interface through which an organisation sends the task to be answered by workers. In the crowdsourcing preparation phase, the organisation needs to decide what type of platform will be used. In external crowdsourcing where the public can be workers, some social network platforms can be utilised for that [76]. The other type of platforms are the purpose-specific platforms that are designed explicitly for that reason. This type is typically preferred by enterprises for several reasons. One, it enables repeatable and clearly defined tasks that have similar fixed features [268]. In addition, it can be well integrated into the current system and the business processes of the organisations to minimise the blockers of members' participation like using single-sign-on (SSO) [269]. The work in [270], was about an intranet forum used for collective propositions and ideas. Other organisations can use other tools for crowdsourcing initiatives such as Yammer (an internal micro-blogging tool). Several well-known enterprises (including Dell, Google, and LEGO) have positively established their own crowdsourcing platforms [95], however, it is central to consider the implementation and management costs of such systems [271, 272].

**User interface:**

User interface refers to the interface which the participants access and read and respond to the task request. It can be a Web UI, an API, or any other kind of UI [26]. Although there is no one best UI, the experiment results showed the importance of using mobile phones to access the task interface. This helps the participants with mobility and moving around the building to perform the tasks and take pictures if needed. In contrast, others prefer a web-based interface to receive task notifications on their office PCs. To ensure increased participation, having both interfaces can be helpful.

The visual component is the main entry point for the responders to interact and respond to a task. Previous work found a positive correlation between the task design and the quality of crowd replies. [273, 274] reported that a user-friendly interface with clear instructions improves the quality of people's replies. They also reported their findings in having the same task presented in different interface designs, where one was clear and simple with a structured layout and the other was complex with a patterned background and unstructured layout. They found that the overall outcomes were more accurate for those who engaged with the simple GUI. [275] focused on understanding the reasons behind low engagement and refusal of tasks. It reported several reasons one of them being the poorly designed task interfaces, vague task directions and technical issues.

**Tasks notification messages:**

The first step to connect with the occupant is by receiving a notification message asking them to check a certain facility. When a request is sent, a notification message will appear on their devices. The type of notification depends on what platform is being used. The message text can be customised and contain the name or username of the participant or a generic message. An example of a generic notification text can be:*"Hi there! There is a check request waiting for your reply on floor 3!"*. Additionally, providing more information about the task such as the floor it is on can speed up the decision of accepting or rejecting the task. The other option is to include the participant name in the text: "*Hi @ParticipantName! There is a check request waiting for your reply on floor 3!*". These suggestions were proposed by the participants during the post-trial interviews in Chapter 4 section 4.5.1. An example of a task notification message is illustrated in Figure 5.3.

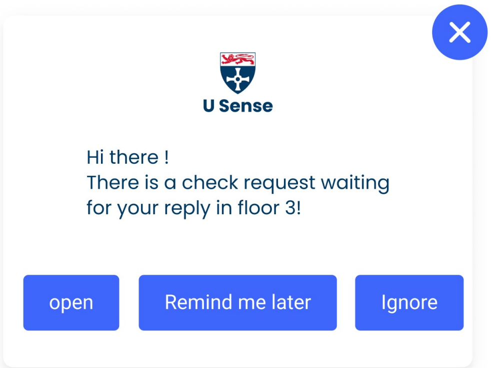



Fig. 5.3 Example of a notification message

### 5.4.6 Task Design

A central dimension of the crowdsourcing is the task. The way that a task is designed helps clarify the task goal, the selected suitable workers, and the incentives policies [26]. Three important elements were found to be affected in my research and supported by the previous literature [273]. A sample of a task design is presented in Figure 5.6.

#### Task Description:

Task description means how the task content and questions are formulated [194]. Well-articulated task is one of the most essential steps in crowdsourcing. As some research found, a clear problem statement improves the responder's understanding of the task requirement and therefore the response quality [243, 273, 276–279]. In contrast, poorly delineated tasks can raise the likelihood of being misinterpreted [194, 280–282]. The following part lists some characteristics that are preferably considered when designing a task.

Maintaining **question consistency** is a useful feature to simplify the process for users. As mentioned by the participants in the last experiment the consistency raised the familiarity and understanding of the requests (section 4.5.1). Clarifying what is expected from the participants can help them provide the required answers. In addition, since the tasks are mainly observation checks, the question layout can be consistent. For example, it can be a deterministic yes/no question or a multiple-choice question (Section 4.3.1). This form of question accepts one correct answer [237]. Wu and Quinn showed the impact of having concise guidelines and considering a reasonable length for task instructions on the outcome [283]. Regarding the **text style** and how the tasks are written, the trial presented two ways. The first way was by providing a preamble introducing the task: "*The system received a report that...*". The second way was to lay the task directly by saying: "*Can you check...*".

| DIMENSION | ELEMENT | ATTRIBUTE EXAMPLES: | SOURCES |
|---|---|---|---|
| WHAT IS THE CROWDSOURCED PROBLEM? | - What type of problem you would like to get solutions for?<br>- To what extent the workers will have to engage to get the answer?<br>- What facilities are available for occupants to check? | Intellectual, human sensing, design, decisions)<br>Observation, interaction, fixing | Chapter 3, section 3.4.1<br>Chapter 4, section 4.4.4<br>[178] |
| WHO ARE THE STAKEHOLDERS?<br><br>(REQUESTERS) | - Who will be sending the task requests?<br>- Who will respond to workers questions?<br>- Who will check the quality and decide the final answer?<br>- Who will act on fixing the facility? | Assign roles for one/group of requesters (e.g., receptionist, maintenance team) | [231] |
| WHO ARE THE STAKEHOLDERS?<br><br>(RESPONDERS) | - What type of occupants will be the responders in the smart building?<br>- What are their perceptions and practices towards humans sensing in smart buildings?<br><br>- What are the demographics of the responders? | All/specific groups of occupants<br><br>Perceptions & practice, awareness, motivations, concerns organisational culture and relationships<br><br>Job position, age, office location, responsibilities, preferences, dynamic topology (leave/join) | Chapter 3, section 3.4.2<br>Chapter 4, sections 4.4.4,<br>4.5.1<br><br>[177], [232], [233], [234] |
| PREPARE THE ENVIRONMENT | - What is the organisation's equipment labelling system?<br><br>- What type of building navigation guidance will be used?<br><br>- Does the organisation have a facility photo database? (BMS)<br><br>- What are the environmental risks? | Specific/existing labels (e.g., BMS).<br><br>Room numbering, colour-coded areas, maps, signs, ibeacons, QR codes, labels<br><br>Equipment and IoT devices<br><br>Equipment type, interaction level, access restrictions, participants' safety, facility condition, security & privacy of building data & occupants | Chapter 4, sections 4.3.3<br>4.3.4<br>4.4.4,<br>4.4.5,<br>4.5.1<br><br>[178],[235] |
| WHAT IS THE PLATFORM? | - What type of system will be used in the organisation? (integrated or specific)<br><br>- What type of user interface will be used?<br><br>- Notification messages | - Purpose-specific platforms/ multi-purpose platforms (social networking).<br>- Integrated/stand-alone system<br><br>Web UI, API mobile app<br><br>Generic/customised Location details | Chapter 4, section 4.5.1<br><br>[25], [76], [178], [236], [237], [239], [240],[241],[242], [243] |



Fig. 5.4 Main dimensions and their sub-elements (1)

| DIMENSIONS | ELEMENTS | ATTRIBUTE EXAMPLES: | SOURCES |
|---|---|---|---|
| TASK DESIGN | • Task description<br>What is the clear and specific question formulation to be used?<br><br>• Task granularity<br>Is the task simple or complex?<br>How long should it take to complete it?<br>Is it for a specific role with experience or skills?<br><br>• Task specificity<br>What is required for the task?<br>Is it possible to communicate with the requesters? | Question consistency (open-ended/ deterministic yes/no questions)<br><br>Users rate of task complexity<br>Task duration range,<br>Required knowledge<br><br>Required supported data: facility condition photo, available communication | Chapter 4, section 4.3.1, 4.3.4, 4.4.4, 4.4.5, 4.5.1<br><br>[25],[186] [208], [217], [218], [219], [220], [241], [191], [244], [245], [246], [247], [248], [249], [250], [251], [252], [253], [254], [255], [256], [257], [258], [259], [260], [261], [262] |
| TASK ALLOCATION | • Task distribution mode<br>How will the workers receive their tasks?<br><br>• User preferences<br><br>• Urgency and level of importance<br>What is the level of importance for each task? | Push-based/pull-based mode<br>Pending tasks<br><br>Time & location preferences<br>Number of tasks per day<br>Reminder options<br><br>Low-medium-high importance | Chapter 4, sections 4.3.2,<br>4.4.5,<br><br>[25], [178], [208], [263], [206], [264], |
| INCENTIVES | • Extrinsic and intrinsic motives<br>Provide immediate incentives (if applicable)<br>- Calculate scores of responses<br>- Announce winners in selected time | Acknowledging workers contribution<br>Track task completion rate, Providing feedback on facility status<br>Pending tasks.<br>Statistical data of contributions<br><br>Pontification and competitions<br>Ranking/winners list & prizes<br><br>Form and amount of monetary compensation<br><br>Group membership | Chapter 3, section 3.4.3<br>Chapter 4, section 4.4.5<br><br>[25], [67], [72], [73], [74], [75], [76], [96], [177], [178], [180], [181], [182], [183], [184], [186], [187], [190], [191], [192], [217], [231], [234], [251], [265], [266], [267],[268], [269], [270], [271], [272], [273], [274] |
| EVALUATION | - Address success metrics<br>- Response quality<br>- Rate task difficulty<br>- Task acceptance and completion rates<br>- System joining/leaving rates | Answers evaluation<br>Design implementation<br>High-medium-low | [239],[259] |



Fig. 5.5 Main dimensions and their elements (2)

I found that some participants prefer direct questions that are more friendly and informal and save time, while others consider having more information about the tasks to provide a story and make them feel responsible and part of the system (Section 4.3.4).

**Task granularity:**

Task granularity refers to the task's level of simplicity, which can be divided into two types: simple tasks that are short and do not require specific knowledge to be solved (e.g., tagging) [284]. Complex tasks had to be decomposed into simpler sub-tasks to be solved and required more time, effort, and cost from the responders which means that the incentives should be according to the task complexity [26]. The level of complexity and the solving effort during the design of the task is considered [243, 244]. Afuah and Tucci suggest that highly complex tasks can be challenging to describe, leading to a higher misinterpretation rate [194].

**Task duration variable:** Hossfeld et al. (2014) mentioned that the task duration should not be long and is correlated with the provided incentive to attract more committed workers [285]. In the case of human sensing applications, the tasks mainly contain extra steps of moving and navigating the buildings before being able to respond and complete the task. Unlike other crowdsourced applications where participants can complete their tasks in the same location. This adds extra time for the main task for the responder to consider when accepting a task. Therefore, the check task should be simple and contain the least number of steps.

**Required Knowledge:** Tasks relying on human sensing and observation usually do not require a high level of technical knowledge. Being in a smart building may lead to dealing with different IoT devices installed in the building, and occupants can find it challenging to respond to the task, leading to inaccurate responses or quick rejection. In this way, complex tasks that require more time and more knowledge can be delivered to those with more specialised knowledge (section 4.4.5).

**Rate task complexity:** Asking users to rate the task complexity (e.g., 3-star rating question) as designed in the experiment conducted in Chapter4 section 4.4.4 was found to be a valuable source to collect users' feedback to measure task complexity, especially for a newly deployed system. This may help improve the system by classifying tasks and distributing them among occupants and maintenance based on difficulty when having a clear measure of task complexity. Furthermore, if the system includes incentives, it can set higher points for more difficult tasks.

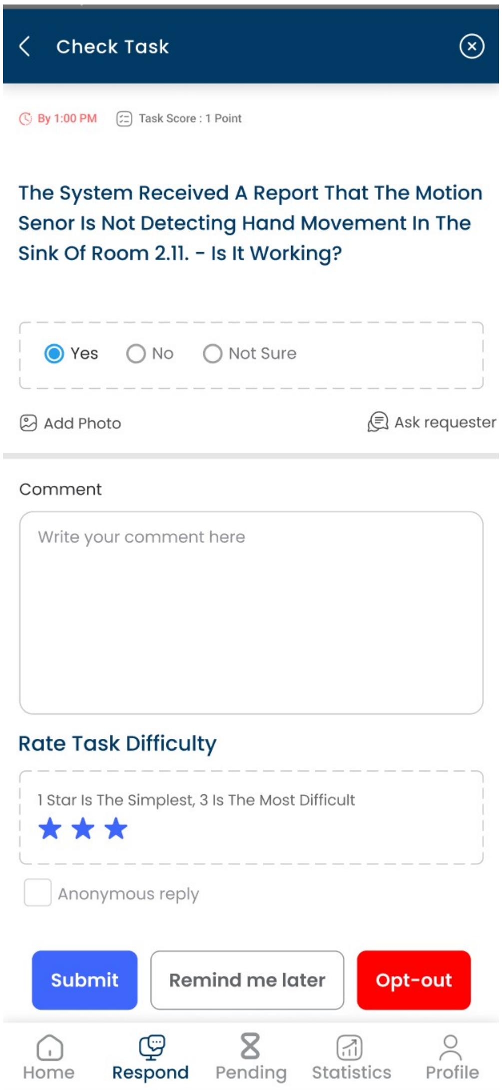



Fig. 5.6 Example of a check task interface

**Task specificity:**

Task specificity is about the scope of the requested task. A crowdsourced task can be either broad and formulated using open-ended questions, or specific tasks that have definite answers [286]. Choosing the scope of the task depends on the type of problem. Jespersen et al. (2018) state that unstructured questions can foster creativity and could lead to new information [278]. It also requires more effort from the organisation side to evaluate the received answers [287]. Specific tasks, on the other hand, tend to increase the task completion rate [278]. In both cases, the tasks should contain all the essential information to be solved [249, 282, 288]. In the context of this research, the questions were set to be specific to describe the required problem. The answers are set to be determined with specific selections (*yes, no, not sure, I cannot do it* in Figure 4.2). Results showed that participants found it to be helpful and simple, especially with the presence of an optional free-text box for adding any information that they find important to the quality of the response (Section 4.4.5).

**Facility condition photo:** In the case of users with smart devices who can take photos, requesters can ask workers to upload a photo or video of the facility as a task completion condition (if needed). This was found to be beneficial for supporting evidence to improve the response quality and to explain their answers (Chapter 4 section 4.4.4).

**Available communication:** Numerous studies confirm that communication and feedback to workers can positively impact the accuracy of the answers [189, 250–252, 289–292]. Similarly, the participants needed more clarification about some tasks in the smart building experiment. In this case, I was responsible for answering the participants' questions about the check tasks. So, adding a communication option to allow this may have significant improvement in terms of clarity and live communication. This has its requirements from the requester's side to answer the participant's questions (see Appendix C).

### 5.4.7 Task allocation

Task allocation means the distribution of the task to a particular group of people in the crowd, conditioned on different criteria such as the skills required [95]. Some aspects that may influence task allocation were studied in related work, including temporal and geographic conditions [26]. Some research took into account user movement routes for crowdsourcing applications [293]. There are some aspects to consider in this framework:

**Task distribution mode:** There are two modes for task selection. The first mode is *pull-based mode* enables users to access a list of available (pending) tasks. The user's selection decision depends on several elements their time, location, and interest. The second mode is the *push-based mode*, where the system sends a limited set of tasks based on the user's preference and predicted availability [235]. The prediction of availability can be performed either by using some tracking systems like GPS, or available sensors in the building to detect people's presence in a certain place. This can be useful, yet has some users' privacy concerns and is not necessarily required giving the building space. An alternative way is to ask the residents about their preferences in time and location similar to the way done in Chapter 4, section 4.3.2.

**User engagement preferences:** One of the important factors to keep the occupants contributing is that the system should not be perceived as intrusive or annoying to them.This was considered in the trial and participants were asked to fill out their preferences before receiving any check tasks in section 4.3.2. The importance of this is to minimise the number of occupants declining requests. Another reason is to minimise user interruption in times they would not like to perform the tasks at that time. An example of a preferences page is provided in Appendix C. The occupant can select the **days and times** of their availability based on the organisation's dynamic and culture. For instance, other designs can contain a complete schedule of the week that provides time preference selections for each day. Another design component can be the inclusion of a **suspend** property to suspend their participation and not receive any requests for a specific assigned period. This is useful as well when participants are on leave and unavailable for a long time. Additionally, allowing preferred **building zones** selection that they would like to check. However, the selection of zones should not depend only on their office location only. The reason for that is people may prefer walking or visiting other places where they have some other tasks to do. Some people may have different workplaces such as offices, laboratories, and classrooms. Another suggestion to consider is the number of tasks sent per day. Lastly, keeping this information open for editing at any time in the future can be beneficial due to the dynamic of the educational environment where staff and students have different schedules every term or less. Finally, when receiving the check request, users can have an additional option of delaying the task (with the other two options: **accept and reject**). The system can have a **reminder option** to resend the task at another suitable time. Figure 5.3 shows the options of accepting and opening the task, rejecting and ignoring, and reminding the user at another time. Figure 5.7 illustrates the option of selecting another time to get notified for the task.

The user preference and zone allocation are presented to prevent the system from obligating users or sending them lots of requests. From the participant's perspective, it provides a sense of scheduling and expectancy. From the system and requesters' perspective, this may affect getting fewer or late responses. This also could happen when limiting the number of responders by specifying specific people to specific places or zones. The number of responses may decrease and the response duration may increase as well.

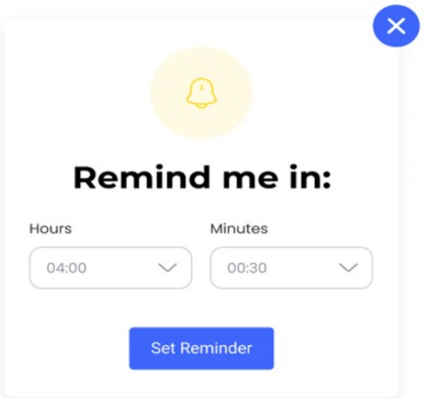



Fig. 5.7 Example of setting a task reminder

**Urgency and level of importance:** People reported in the post-trial interviews that they like to prioritise their day tasks and complete them in order. Therefore, including a feature that highlights the level of importance and urgency for the received task may assist users in arranging their tasks. For example, adding a clock icon presenting the expected time to have a reply (e.g., by 1:00 PM). It can emphasize the importance visually by colour coding the text (e.g., red, orange, and green) to represent high, medium, and low respectively. Participants raised that such information can help to commit to the system and being able to respond to the requests (Section 4.4.5) [237, 294].

### 5.4.8 Incentives

The motivation of employees to contribute to distributed tasks had more attention in research [266, 295, 296]. One reason might be data availability (e.g., survey data). Nevertheless, despite extensive research, no all-purpose model has been decided on regarding what motivates workers there. For example, there are opposing views on the usefulness of financial incentives [72, 73, 263, 297]. Therefore, this contradiction points to the fact that each internal crowdsourcing enterprise situation is unique and thus does not fall under a simple generalisation [76]. This shows the need for a more profound examination of the relationship between the various purposes of tasks in the organisations and workers' motivation. Additionally, the drive and commitment level of workers in internal crowdsourcing differs from that in external crowdsourcing. This is because the company's employees do not choose to self-select to contribute to distributed tasks to the same degree as the external crowds [181]. Participants can become discouraged if their work is not properly acknowledged [298]. Furthermore, the crowdsourcing model differs from the enterprise hierarchy structure in relying on voluntary participation. This may lead employees to participate in a strategic act (e.g. promotion). [76].

From a managerial perspective, providing proper motivation structures is significant for the success of crowdsourcing projects. Organisations must consider the nature and complexity of the task, and the diverse intrinsic and extrinsic stimuli when designing incentives. [95].

Numerous previous studies have examined the motivation part of crowdsourcing [183–186, 189, 249, 299, 300]. Motivation mechanisms commonly have two goals: stimulate workers to actively join and input accurate data, and encourage requesters to deliver honest comments about the quality of the received answers. Based on their activities, it can reward/penalise workers and requesters with financial, ethical, entertainment, and priority [26].

Even though preceding work recommends the use of intrinsic and extrinsic incentives especially in crowdsourcing competitions [193], crowdsourcing organisations need to consider some aspects related to the organisation culture or process such as annual leaves holidays and special circumstances within times with fewer available employees. Also, the nature and complexity of the task should be considered when preparing rewards. Because a complex task involves more time and effort, monetary compensation is mainly important [67, 193–195, 282]. On the other hand, this can raise the cost of providing some incentives such as monetary rewards. Other incentives may require some design efforts such as points and competitions.

So, when it comes to reporting incidents via human sensing in smart buildings motivations, my first study results showed an interest in altruistic motives, especially in being in a university community. Then it was followed by the need for enjoyment and competition such as having scores for each completed task, followed by a small prize for the winner (See section 3.5.3). In the second study, after testing the concept in real environments for a longer time, the results remained the same in this population. Altruism and enjoyment are the main drivers of the occupants of the building (See section 4.4.5). The following suggest some motivational mechanisms and design techniques that may improve engagement based on the results obtained:

#### Motivational mechanisms

**a. Altruistic motives:** Being in a community and having a newly constructed building also elevated the participants' interest in maintaining their campus in the best condition. This aligns with the results stating that helping others and receiving positive feedback increases a sense of identity in society and can affect participation and retention [190, 296].

Some suggestions were extracted from the participant's interview responses when trying the system. Therefore, organisations can consider implementing some mechanisms that fulfil this need such as: (1) Acknowledging workers' contribution by displaying a message ensuring that the report has been sent by thanking the responder: "*Thank you for being a* *valuable member of the USB!*". Appendix C displays an example of a message appearing to the user after submission. (2) Track completed tasks, by allowing participants to check back their accomplished tasks throughout the period which may influence them to engage more with the system. (3) Providing feedback on facility status to occupants when they complete the task makes them feel useful to know that their input has made a change. So, a simple feedback message could be sent for them or a notification of a task status changed as "*fixed*." However, some may not need continuous updates of their tasks and just want to have the ability to check. (4) Keep a list of pending tasks for participants who have some free time to move around the building and complete any unsolved tasks. Based on the urgency and importance of the situation. Providing access for unresolved tasks (with no responses) to allow them to perform the check. (5) Statistical data on the contributions and reports that have been received from all occupants in the building that benefit the building and its facilities. (See Appendix C for sample interfaces of pending and completed tasks)

**b. Enjoyment motives** Enjoyment and fun factors have a popular use in crowdsourcing platforms to keep users' participation. In this research, enjoyment can include participants having fun while doing the task, competing with other participants or collecting points. The fun factor was mentioned in the reflection of some participants on U-sense. Being in a work/study place, people may like to get out of their offices and walk around nearby places. This can be leveraged by providing a routine break that includes doing something useful at the same time. Some mechanisms can be (1) Pointfication and competitions by setting different points for each check task based on its location, complexity, urgency, etc. A lot of the interview answers encouraged having a points system (See Appendix C for sample motivation messages). On the other hand, point collection should consider the quality of the response to avoid random responses to accumulate more points [301]. (2) Ranking/winners list is another way to incentivise occupants. However, as it was suggested by [99], ranking lists can have a deterrent demotivating effect on new users when they see others' high points. Therefore, lists can be updated weekly/monthly to encourage new users to participate and rank top. (3) Prizes and rewards, managers can announce yearly/monthly winners via open channels like banners or emails. However, prizes can be simple organisation prizes such as coupons, credits, mugs, or badges.

**c. Monetary rewards:** Some work advice for financial rewards as they work best [26, 74, 263, 297], while others propose that non-financial rewards are more effective [72, 73, 75]. Others, however, propose that concrete incentives are as vital as they are in other forms of crowdsourcing to attain and sustain staff engagement [302] meaning that internal crowdsourcing ought to be paid for [263]. Lopez et al. (2010) demonstrated that performances and salary bonuses can be used in some organizations [295]. Meloche et al. (2009) see that a ‘crowdsourced task’ in an organization is still work; however, it should be mentioned in the job description and the workload of staff [303]. Regarding the monetary amount, Katmada et al. (2016) stated that prizes should not be very valuable to avoid free-riders who contribute for the sake of the award with no quality responses [99]. Another counter concern is that high prizes may lure people and distract them from their actual jobs Therefore, finding a suitable measuring and rewarding system that suits each environment differently can be beneficial. The compensations in the form of vouchers and credits (for example, for printing or buying a coffee) were considered as financial rewards in this research.

**d. Recognition** Finally, as the findings in both studies are aligned with [187, 189, 249, 266] that being recognised is a common motivation for some occupants to engage with the system like being a member of a known team, or getting acknowledged by managers. Therefore, visibly including administrators and other directors in the crowdsourcing events may have a positive power on the motivation of employees to participate [304]. However, managers should be careful that reward design should not be about comparing workers’ answers due to its counterproductive impact on corporate culture [263]. In the case of smart campus, the results showed a preference for compensation over recognition. This can be reasoned that the population is different. Having several younger students can increase the desire for enjoyment and prizes associated with it.

### 5.4.9 Evaluation

#### Success metrics

Success metrics are central to assessing the total performance and effectiveness of crowdsourcing processes. Organisations can have specific metrics to check the results [271, 289]. Even though not all task answers are expected to be high-quality answers, creating success measures can be useful for organizations to identify failures and encourage learning [271]. This project tests the success of the U-sense mock system by measuring three aspects: Number of responses, quality of responses, and duration of completing a task.

#### Responses quality:

As human sensing is not meant to provide creative ideas, but it requires correct observation and judgment on a facility condition. So, having a dedicated group of requesters that evaluate occupant responses on-site may not be the best option. However, there are other aspects to consider to help evaluate the participants’ input (more in section 5.5).

**Task acceptance and completion rates:**

Other ways to evaluate the success of the system is to observe the task acceptance and completion rates. This can indicate whether enough participants are accepting the tasks or not. Also, it may point out the task complexity level that made users not complete it.

**System joining and leaving rates:**

After a while, an analysis of the joining and leaving rates among the building occupants is recommended. This may be impacted by the organisation's culture (i.e., participating students who have graduated and no longer visit the building, annual leaves, holidays, etc.). This can help to understand if there is any aspect that needs to be improved or modified.

## 5.5 Human Sensing Challenges

This section describes the challenges that need to be addressed when considering human sensing of the facility's condition. Four aspects were extracted: Response quality, responder training and awareness, the anonymity of requesters and responders, and the privacy of the building occupant (participating or not). Figure 5.8 summarises the four challenges.

**Responses quality**

For the human sensing system to be beneficial, the responses of the participants should be accurate. Quality is an important measure of success in crowdsourcing [237]. Various research studies have included quality assurance as a primary mechanism for crowdsourcing platforms. To improve and maintain response quality, the crowdsourcing process can have some design implementations and answer evaluation methods to achieve that goal [76].

**For answers evaluation**, (1) Some work presented that the accuracy of contributions is grounded by the crowd's collective judgement and votes at least for a primary evaluation like [268, 297, 305]. This model can be applied here where requesters can collect several answers that support the one they received. (2) Another form of evaluation is based on a preset specific criterion [297]. However, this model cannot be implemented for human sensing tasks where the requesters can assess the answer on-site. However, requesting supportive data (e.g., defect photo) can be helpful here. (3) An alternative technique is the one developed by [237] to weigh workers' reliability. High-weighted users provide more accurate results and have a high self-rated confidence level after each submitted response. This approach improves the accuracy of opting for the true responses by 15% when compared to the "majority decision" presented in [306], where the responses with maximum votes are approved.

| Challenge | Element | Attribute examples | Sources |
|---|---|---|---|
| Anonymity | Requester's identity<br><br>Worker's anonymity | Name revealed/ system request<br><br>Visible, partially concealed, anonymous | Chapter 4, Section 4.5.1 [243], [279], [280], [281] |
| Awareness | Conduct awareness and training sessions<br>Keep consistency to raise familiarity and quality | Equipment and IoT devices' names, shape, and placement | Chapter 4, section 4.4.5 [282], [283], [284], [285], [286] |
| Response quality | Answer evaluation<br><br>Design implementation | - Compare other responders' answers<br>- Specific criterion<br>- Responders weight score and confidence level<br><br>-Consider impacting aspects (motives, user demographic profiles, task design and allocation, simple UI, etc)<br>-Include supporting data (facility photo, comments, communication) | Chapter 4, Section 4.4.4 [25], [76], [208], [236], [267], [275], [276], [277], [278] |
| Privacy | Building occupants' privacy<br><br>Participant's privacy | -Places allowed to have tasks in.<br>-Boundaries and instructions for occupied rooms<br><br>User preferences/tracking systems | Chapter 4, section 4.3.3 [25] |

Fig. 5.8 Four challenges of when implementing human sensing in smart buildings

**Regarding design implementation**, organisations need to consider the quality control methods and other impacting aspects such as motives, user demographic profiles, task design, allocation, and privacy [26, 237]. Designing tasks with a friendly and simple user interface [307], acceptable granularity, and allocating tasks to suitable participants (e.g., based on time and space preferences) are the grounds for high-quality responses. The incentives stimulate occupants to willingly contribute and focus on the tasks [26]. Additionally, assessing system testability quality can be applied to improve quality [308]. It was found in the trial conducted in Chapter 4 section 4.4.4, that there are some design features that support presenting clear and accurate data to the requesters. To mention a few, adding a section for supportive data can help occupants strengthen their answers even if not completely sure. Features like uploading facility photos or writing a comment describing the situation were effective in the experiment.

### Anonymity

Anonymity in both requesters and responders is a considerable aspect of crowdsourcing. Numerous research reported that anonymity in such platforms does not have a good impact. Prior to this work, a study reported a possibility of forming a mistrust between the two sides with anonymity leading to dehumanising their relationship [275]. In addition, Marlow et al. (2014) described that workers can become discouraged from participating [309]. Other studies mentioned that requesters could use and justify lowering the effort to work and paying workers less [310, 311].

**Requester's identity:** In internal crowdsourcing the situation may be different since the requesters are from a known group (e.g., building managers) sending relatively similar tasks to a group of participants. In the context of human sensing in smart buildings, the interview results indicate that the identity of the requester can be anonymised to avoid biased decisions and replies if the requester is someone the occupant knows, they may give a different level of attention to the task compared to a name they do not know (section 4.5.1). In such cases, the task request can be formed to be coming out from the system itself. Phrases such as: "*There is a system request to check ....*" are suitable for a request preamble.

**Responder's anonymity:** Regarding the responder's anonymity, it can be in three levels:

- *Visible*: the responder's identity can be visible showing their clear names and registered emails for the requester.
- *Partially concealed*: where the responder's identity is not visible to the requester (e.g., username) but can be tracked and found in the system (e.g., registered workers database with access restrictions). This can be useful for those who are concerned about their relationship with the requester. But at the same time, their responses can be scored if there are incentives for winners.
- *Anonymous*: Full anonymity can be applied in some systems that do not have a specific platform registration or an option to hide the identity, and present the tasks publicly. i.e., tasks are presented on an electronic billboard in the organisation and any person can respond directly without revealing their identity.

### Participants awareness

Doroudi et al. (2016) found that training workers for the tasks before starting can positively affect performance. Their study provided different types of training such as presenting instructions (e.g., 20 minutes video) before showing the task, allowing workers to validate each other's responses, or providing a set of tasks with the same nature [312].

**Raising awareness:** Smart buildings have more devices managing the services for occupants that may be faulted [313]. Occupants are not fully aware of the available devices' names, shape, or their placement in the building [313]. This may impact their human sensing process by spending more time or providing inaccurate responses (e.g., thermostat controls or motion sensors in the case of the trial). Therefore, providing some awareness sessions on what type of equipment and IoT devices are in the building and how to interact with them and read their data can be preferable.

**Familiarity of tasks:** After the system trial, participants raised such points during the feedback interviews that it got easier over time because they got used to the ways the questions are set to ask for a task (Chapter 4, section 4.4.5). They also had a general understanding of the task types and how they should handle them. This aligns with previous work that supports having similar examples to increase the accuracy and effectiveness of responses [314, 315]. Another raised point was the familiarity of the human sensing and getting involved in the check tasks. This aligns with what Shao et al. (2019) proved in their study that conducting a list of similar tasks enhances workers' efficiency [316]. Moreover, from another aspect, after the experiment, occupants raised a noticeable change in their awareness towards two things: navigating the building and the building facilities and how they work. This can have a future impact on the duration of task completion, where responders will have less confusion on how to reach a certain place.

#### Privacy of building occupants and participants

In terms of privacy, there are two levels of privacy concerns in the human sensing tasks raised during the experiment conducted in Chapter 4 (section 4.3.3). The first is **building occupants' privacy**, which did not have enough attention in previous research, especially in the crowdsourced human sensing where places are considered public. However, not all rooms inside organisations are considered public (e.g., private offices). As current tasks require participants to move around the building, organisations need to consider the privacy concerns of the other occupants. For instance, some participants cannot complete the task because the room was occupied by other people Therefore, in the planning phase, organisations need to clearly identify which places are allowed to have tasks. Another thing is that workers need to have clear instructions on what to do if the room is occupied. Another way is to provide some participants with a tag to allow them to enter the place. If boundaries are not applied, they can disturb other occupants and negatively impact the success of the proposed system.

The other level of privacy is the **privacy of the participant**: this is raised especially when the tracking systems are used to locate their places (e.g., using their mobile phones) to allocate the tasks near them or calculate the shortest route to reach the facility. Although this may be useful in terms of task allocation, it may impact the privacy of the workers, and their participation enthusiasm, hence impacting the service [26]. For this reason, one way is to apply the preferred times and zones to mitigate the risks.

## 5.6 Discussion

The framework is designed to help the building facility manager plan and implement an internal crowdsourcing system to receive updates on the condition of the facility in their smart building. I worked on the **framework's validity** using the methodology followed to collect the data. Typically, there are two ways to design the system: designing it, testing it, and then analysing the data, and evaluating it. The other way is the inductive approach where the researcher collects the data first, then analyses it, and based on the analysis results, the system is designed. The second method is the one applied in designing the framework. The two studies were conducted to collect, analyse, and investigate the data, then used to design the framework in this chapter. The framework design is logically built and supported by evidence from previous chapters and related research.

Based on the results of the trial, it can be said that the framework is applicable and can be used in similar contexts of smart buildings. It indicates that it can work inside smart buildings that share similar attributes such as size, demographics, and culture with suitable incentives. However, there is a possibility that other contexts may not have the same results. For example, buildings with different sizes or different organisational cultures.

**Managerial perspective:** As presented framework provides execution guidelines for management when considering a human-sensing crowdsourcing initiative in their smart building. They can use it as a blueprint to follow and use the suggested dimensions, design parameters, and their attributes as a checklist to select from (e.g., incentives, distribution modes, duration, etc.). However, this study did not examine a couple of aspects: First, is the management perspective on receiving facility updates via human sensing. This study has focused on the workers' side and their perception and practice of reporting and responding to requests from requesters. Different levels of stakeholders (e.g., upper management, reception, maintenance) were not included in this study. Therefore, it is open for future investigations. Second, the research did not explore the anticipated value of human sensing to a specific organisation. It states the general improvement in situational awareness of the smart environment, yet it did not thoroughly investigate the cost, or effort saved when starting the initiative.

**Implementation cost:** As the framework suggests some guidelines to implement the human sensing initiative, there is a clear implementation cost and effort required in the preparation and execution process, such as preparing the building, labelling equipment, evaluating responses, and setting suitable incentives. As advised by [95, 317], building management should take an initial step to clearly study the associated costs of resources and efforts, where it can be challenging for them to control the internal workload related to leading a crowdsourcing movement.

**Workload and crowdsourced tasks:** The possibility of prioritising work over tasks or prioritising tasks over workload should be considered. Having the current system running in a workplace, some occupants may be busy with their jobs and might find the task notifications interrupting. This can be mitigated by providing the options of setting places and times of availability, simply cancelling, or delaying the request to be done at another selected time. On the other hand, some may use the tasks as a break between jobs. If used wisely, this will not affect the work and performance. However, if the organisation finds that responding to tasks is distracting them from their jobs, the incentives and motivational mechanisms should not be valuable in a way that people over-prioritise it over their actual jobs.

**Task decomposition and aggregation of data:** In some crowdsourcing platforms, main tasks are decomposed into crowdsourced sub-tasks to be distributed to the workers to get solved. After that, the requesters aggregate the subtask solutions to fit in the main task. However, these two steps were not addressed in the context of the human sensing framework. The reason for this is that the tasks are simple and do not require decomposition initially. On the other hand, I propose that aggregation can be used differently. For future use of similar systems, collecting long-term data and attempting to find noticeable patterns of issues.

## 5.7 Conclusion

This chapter presents the final contribution of this doctoral study: a framework for deploying an internal crowdsourcing to monitor conditions within smart building facilities using human sensing. The framework delineates essential steps that organisational leaders, particularly building facility managers, need to execute to leverage human sensing in smart buildings. The guidelines were set to be clear, coherent, and consistent to keep the framework clear and easy to follow. The terms and concepts are similar to those used in the related literature. The framework also considers the environmental setup regarding the occupants' navigation and guidance in identifying the facility under investigation. Based on my previous study results, it can be said that the framework is applicable and can be used in similar contexts of smart buildings. It indicates that it can work inside smart buildings that share similar attributes such as size, demographics, and culture with suitable incentives.

# Chapter 6

# Conclusion and Future Research

**Overview** In this chapter, I present the answers to the thesis research questions. Then I present the research limitations and future work.

## 6.1 Answers to Research Questions

The motivation for this work is that crowdsourcing can lead to better situational awareness by enhancing the element of perception of the environment. Before this PhD thesis, it was unknown if internal crowdsourcing (human sensing) could work in smart buildings and whether it is feasible regarding time, quality, and efficiency because the technology presence in smart buildings affects their occupants. For instance, having privacy concerns and being unaware of the type of data being captured may lead to occupants changing their behaviour when they learn about the existence of monitoring and tracking devices such as surveillance cameras.

This research demonstrated that it is possible to use human sensing and provided a framework that helps implement it in different smart buildings by answering three research questions outlined in Chapter 1. The following sections present the answers to these questions and point to the limitations of the work and the possibilities of future research.

### 6.1.1 User Perception, Practice, and Motivations

The first research question was: **What are the perceptions and motivations that smart building occupants have towards reporting incidents and observations in smart buildings?** To answer this question, three points were covered in Chapter 3: Firstly, incident reporting influencing factors, which were found to be the problem type, the way people will deliver their report, and reporter's aspects like their job position and personality. Secondly, the environmental impact such as the technology on the smart building occupants' perception. occupants expect the buildings to be smart by utilising sensors' data to regulate themselves regarding tracking and surveillance to support their reports. Additionally, occupants are not fully aware of the fault condition or how it affects the building. Thirdly, smart building occupants' motivations do not stay the same when they are prompted to check a facility: When occupants detect an incident, their reporting decision is motivated by intrinsic drives of altruism by helping the community and perceiving a better environment in their smart building. This was followed by the point of being informed on how and what to report in their campus. The other motives were not as high as the previous ones: direct compensation, recognition, and enjoyment. On the other hand, if users have participated in a crowdsourcing work initiative to perform facility checks and submit their responses, they would have different motivations. While keeping a good environment in the building and having a sense of community, altruism remained the first motivation for the building occupants. However, the incentive of enjoyment and having fun is raised clearly in this situation. Some occupants preferred the competition factor in ranking the responses. This was associated with the rewards that can be provided to winners. Finally, awareness of importance and recognition incentives were not as desired as the enjoyment incentive.

### 6.1.2 Feasibility Study Of Human Sensing Facility Conditions in Smart Buildings

The second research question was: **Is it feasible to use human sensing to improve situational awareness by reporting facility condition in a smart building?** Chapter 4 explored the feasibility of leveraging the knowledge and observations of the smart building occupants in reporting facility condition updates to a requester to improve situational awareness. The concept proved effective in gathering reports on the state of facilities in the building, suggesting the possibility of more permanent use in a wide range of places. The findings showed positive data in terms of the number of responses, the quality of provided information, and the time duration of receiving responses. Responses' quality results indicate the importance of stating tasks consistently and clearly, describing the location and the placement of the facility and how to reach it (especially smart devices such as sensors). Moreover, the study outcomes were aligned with the ones described in Chapter 3 regarding the motivations. It raised interest in altruistic motives in terms of being in a community and having a newly constructed building also elevated the participants' interest in maintaining their campus in the best condition. Another desired incentive was the fun factor, where participants expressed their enjoyment of the "treasure hunt" and of moving around. Being in a work/study place, people may like to get out of their offices and walk around nearby places. Additionally, the chapter found that contributing to such systems raised occupants' awareness of their environment and they became more observant of the resources and their functionality. Finally, the month-long experiment (details in Chapter 4) helped extracting a set of design implications and future recommendations for the system based on the participants' experience.

### 6.1.3 Human Sensing Framework for Smart Buildings Facilities

The third question was: **Can we design an internal crowdsourcing framework for human sensing facility conditions in the context of smart buildings?**

This chapter presents the final contribution of this doctoral study: a conceptual framework for deploying an internal crowdsourcing scheme to monitor conditions within smart building facilities using human sensing. The framework delineates essential steps that organisational leaders, particularly building facility managers, need to execute to leverage human sensing in smart buildings. The guidelines were set to be clear, coherent, and consistent to keep the framework clear and easy to follow. The terms and concepts are similar to those used in the related literature. The framework also considers the environmental setup regarding the occupants' navigation and guidance in identifying the facility under investigation. Based on my previous study results, it can be said that the framework is applicable and can be used in similar contexts of smart buildings. It indicates that it can work inside smart buildings that share similar attributes such as size, demographics, and culture with suitable incentives.

### 6.1.4 Impact of my crowdsourcing research on other disciplines

After conducting experiments on internal crowdsourcing within the USB as a smart university example, it is worth exploring the human sensing in other areas of the building. One of them is the impact on higher education. It is known that crowdsourcing provides many benefits such as better performance of students, an optimised teaching process, and increased funding opportunities. The four most commonly used are crowd wisdom, creation, funding, and voting [318]. Crowdsourcing can help students work on projects together, exchanging skills and knowledge supervised by lecturers with crowd learning [319, 320]. The concept behind this is crowd teaching which allows educators to share lecture materials [320]. Another benefit is called crowd funding where student tourism and resource procurement costs can be funded through it [319, 320]. Such approaches can enable institutions to optimize budgets and enhance learning outcomes [320]. Crowdsourcing creates opportunities to address challenges in developing countries such as reduced funding and the need to improve graduate quality

[321]. In conclusion, crowdsourcing enables higher education institutions to remain at the cutting edge of new ideas and equips students to enter the online sphere [318, 321].

Another benefit that my research can provide is the improvement of policy-making within smart buildings such as the USB. Some studies have been conducted regarding the privacy of the smart building occupants and how data collection is being perceived by them. A research conducted by Taher et al. (2022) where they suggested having a privacy committee addressing the privacy options in the building with the help of several people from different roles in the building [322]. Such a concept can be implemented by using internal crowdsourcing techniques. Generally, crowdsourcing is proving to be an effective tool in the framework of policy-making, providing democratic, epistemic, and economic benefits [323]. It promotes citizen participation, transparency, and accountability within governance processes [324]. Accordingly, there are challenges with the effective implementation of crowdsourcing itself [324]. This approach is gaining traction among governments [325], and therefore it is important to understand its nuances and implications for the various stages of the policy process.

## 6.2 Limitations

Some limitations were present in this research. This section lists the limitations in chapters 3 and 4.

- **Limitation 1:** Starting with Chapter 3, despite the sample size for a qualitative study, while the study was conducted with the USB occupants only, it did not cover a wide range of cultural backgrounds of people in different smart buildings. However, the interview protocol stages were documented making it possible to repeat the study by other researchers in different contexts. In addition, like other qualitative methods, the quality of the work depends on the researcher's skills and hence might present personal bias. However, I learned how to lead and conduct all 17 interviews by reading and practising before conducting the interviews, using open-ended and non-leading questions to exclude any influence on the participants' replies during the interview. Also, there is a possibility of interviewer bias, which impacts interviewees, leading them to feel less comfortable giving their honest opinions about some topics. Another limitation is the convenient sampling method in terms of representativeness. Because the sample is a close and small group of people who are available instead of a random large population. This can lead to an increased risk of bias where researchers unconsciously choose participants who appear most interested in participating. Such biases may affect the reliability and validity of the research results [198].

- **Limitation 2:** The system trial in Chapter 4 had some limitations as well. Regarding the investigation of what incentive will motivate the participants the most, the study did not actually provide incentives and compared the participation and engagement rates. The reason behind this is that participants were not in sufficient numbers to divide the sample into groups of different incentives. As mentioned in Chapter 4, the time of the experiment was a short period after COVID-19 recovery where number of the USB occupants were working online. This led to running the experiment with the available sample and instead, focusing on the length of the experiment to get sufficient data, and preparing multiple data sources and forms (quantitative and qualitative) to collect during the experiment such as individual interviews, participants instant notes about tasks: comments, task difficulty, and media uploads.

## 6.3 Future Research

This section lists some future research opportunities to explore to enhance and expand the work presented in this thesis. The following are the opportunities

- **Expand the study of motivations and feasibility in related contexts**. Chapter 3 explores occupants' perceptions of incident reporting and their motivations to participate in human sensing facility conditions in smart buildings. Also, Chapter 4 tested the concept feasibility in the Urban Sciences Building at Newcastle University. In future work, I would like to extend this work to explore the perceptions of smart building occupants of different universities and countries and analyse the results in comparison with this study to recognise resemblances and differences between several occupants of smart environments and to identify aspects that influence their perceptions.

- **Managerial perspective:** Chapter 5 presented a framework that provides execution guidelines for management when considering a human-sensing crowdsourcing initiative in their smart building. It did not examine the management perspective on receiving facility updates via human sensing. The study has focused on the workers' side and their perception and practice of reporting and responding to requests from requesters. Different levels of stakeholders (e.g., upper management, maintenance) were not included in this study. Therefore, it is open for future investigations. Second, the research did not explore the anticipated value of human sensing to a specific organisation. It states the general improvement in situational awareness of the smart environment, yet it did not thoroughly investigate the cost, or effort saved when starting the initiative.

- **Integration of human and machine and collecting long-term data:** For future use of similar systems, collecting long-term data and attempting to find noticeable patterns of issues can be useful. This will help to build a more resilient and trustworthy incident response system. For instance, receiving a repetitive reply about a facility defect at certain times of the year. Despite their limitations, smart buildings rely on technology and sensor data to improve situational awareness. A rising opportunity is to explore the integration between machine data and human observations in one system and improve efficiency.

- **Explore the link between crowdsourcing and EAST/MINDSPACE approach of behavioural economics** The MINDSPACE framework has nine behavioural interventions, which are: Messenger, Incentives, Norms, Defaults, Salience, Priming, Affect, Commitments and Ego, applicable for choice architecture and design [326]. This approach understands that design better be aligned with human nature and has a human-based methodology which, if nourished over time, might lead us to better decisions [326].

  Moreover, because people often do not act according to standard economic models, it is also very critical to consider the role of behavioural economics in designing incentives because information is expensive, and contracts are not always optimal in crowdsourcing [327]. In fact, rewards have been found to be a major driver of motivation among crowdsourcing workers, and the effects of cognitive psychology are unexplored enough for researchers looking to better drive engagement and performance [327]. Hence, the studies highlight the value of including behavioural insights into crowdsourcing design to maximize crowdsourcing outcomes.

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# Appendix A

# Chapter 3- Semi-Structured Interview

# Invitation Email

Dear,

My name is Naoom Abu Abah, and I am a PhD student in the smart infrastructure group supervised by Charles Morisset. We are conducting semi structure interviews as part of a research study to develop in depth understanding of user perception and practice regarding incident reporting and how to raise their engagement in the reporting process. As an occupant in the university, you are an ideal position to give us valuable first hand information from your own perspective.

The interview will last around 60 minutes, could be split into two sessions if preferred, and is informal. We are simply trying to capture your thoughts and perspectives regarding reporting incidents. At the beginning you will receive a consent to sign, your response to the questions will be kept confidential, and a voice recorder will be used to capture the session for the research study. Each interview will be assigned a number code to help ensure that personal identifiers are not revealed during the analysis and write up of findings. Also, you can withdraw from this study at any time if you decided so.

As a participant to this study you will receive a voucher worth £20, as a compensation for your time.

If you are willing to participate please suggest a day and time that suits you and I'll do my best to be available. If you have any questions please do not hesitate to ask.

Thanks,

Naoom

*March 2021*

# Incident Reporting Perception and Practice

**Naoom Abu Abah**
School of Computing

## Information for participants

Thank you for considering participating in this study which will take place in March 2021. This information sheet outlines the purpose of the study and provides a description of your involvement and rights as a participant, if you agree to take part.

**1. What is the research about?**
To develop in depth understanding of user perception and practice regarding incident reporting in different situations, and how to raise their positive engagement in the reporting process.

**2. Do I have to take part?**
It is up to you to decide whether to take part. If you do decide to take part, I will ask you to fill a consent form and send it back to me prior to the interview.

**3. What will my involvement be?**
You will be asked to take part in a semi structure interview about reporting incidents, it should take around 60 minutes.

**4. How do I withdraw from the study?**
If you wish to withdraw from the study at any point. please contact the researcher at:
N.A.A.Abu-Abah2@newcastle.ac.uk

**5. What will my information be used for?**
I will use the collected information for a PhD research.

**6. Will me taking part and my data be kept confidential? Will it be anonymised?**
The records from this study will be kept as confidential as possible. Only myself and my supervisors: Charles Morisset and Kovila Coopamootoo will have access to the files. During data collection and publishing, your data will be anonymised – your name will not be used in any reports or publications resulting from the study. All digital files, transcripts and summaries will be given codes and stored separately from any names or other direct identification of participants

**7. Who has reviewed this study?**
This study has undergone ethics review in accordance with Newcastle University Research Ethics Policy.

**8. Data Protection Privacy Notice**
The Newcastle University Research Privacy Policy can be found at:
https://www.ncl.ac.uk/research/researchgovernance/ethics/
The legal basis used to process your personal data will be Legitimate interests.

**10. What if I have a question or complaint?**
If you have any questions regarding this study please contact the researcher, Naoom Abu Abah on N.A.A.Abu-Abah2@newcastle.ac.uk , or supervisor on Charles.Morisset@newcastle.ac.uk. If you have any concerns or complaints regarding the conduct of this research, please contact the Newcastle university Research Governance via res.policy@ncl.ac.uk.

If you are happy to take part in this study, please sign the consent sheet attached.

2
# CONSENT FORM

## Incident Reporting Perception and Practice

**Naoom Abu Abah**

Please read the information below and print your name and the date below to demonstrate that you have understood taking part in this research.

1. I have read and understood the study information. I have been able to ask questions about the study and my questions have been answered to my satisfaction.
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and that I can withdraw from the study at any time up until June, without having to give a reason.
3. I understand that the information I provide will be used for research thesis and that the information will be anonymised.
4. I understand that any personal information that can identify me – such as my name, address, will be kept confidential and not shared with anyone other than myself
5. I give permission for the (anonymised) information I provide to be deposited in a data archive so that it may be used for future research.

Participant name: ________________
Date: ________________
For information please contact: Naoom Abu Abah, N.A.A.Abu-Abah2@newcastle.ac.uk

# Background Information Questionnaire

What is your role in the university? *

- ◯ Undergrad/PGT
- ◯ PhD student
- ◯ Research assistant/associate
- ◯ Academic staff
- ◯ Professional support
- ◯ Other

How old are you? *

- ◯ Under 20 years
- ◯ 20-30 years
- ◯ 30-40 years
- ◯ 40-50 years
- ◯ 50-60 years
- ◯ 60+ years
- ◯ Prefer not to say

Where are you from? *

- ◯ UK
- ◯ EU
- ◯ Outside of the UK/EU
- ◯ Prefer not to say

Gender: *

- ◯ Male
- ◯ Female
- ◯ Non-binary
- ◯ Prefer not to say

Do you have administrative/managing responsibilities? *

- ◯ Yes
- ◯ No
- ◯ Prefer not to say

# Semi-Structured Interview Questions

| | |
|---|---|
| **(A) User perception:** | |
| 1 | What do you think the term incident reporting mean? |
| 2 | What type of incidents/events you think is worth reporting? |
| 3 | Have you ever experienced an incident that you would like to share? |
| 4 | How did you respond to that? Did you consider reporting it? Why? |
| 5 | Were there any concerns or blockers that prevented you from reporting? |
| **(B) Environmental aspects**: | |
| 6 | How does the environment (work/public place) affect your reporting decision? |
| 7 | How do you think your position in general may affect your reporting decision? |
| 8 | How does the presence of technology and working/studying in a smart building) affect your reporting decision? |
| 9 | What are the differences between online (incidents occurring on the internet) and offline incidents in your perspective? |
| **(C) Motives driving user engagement**: | |
| 10 | What motivates you to report an incident or an observation in any facility of the building you work/study in? |
| 11 | What motivational incentives would you prefer to contribute to some simple investigative tasks requested by the reporting system specifically for the campus facilities? |

# Appendix B

# Chapter 4: Feasibility Study

# Invitation email

My name is Naoom Abu Abah, and I am a PhD student in the smart infrastructure group supervised by Charles Morisset. We are conducting an experiment as a part of a PhD research to test the feasibility of implementing a collaborative solution to the standard reporting system by engaging building occupants (participants) in investigative tasks to check and observe the status of facilities inside the Urban Sciences Building. The experiment will be conducted in the wild (field) and take around 2-4 weeks.

During their work day in the USB, participants will receive a “check request” message asking them to check a facility in the building (e.g. broken chair, flickering lights ). Participants have a choice whether they like to respond to the request or not.

If you agree to participate, you will be invited to an orientation session for more explanation. An information sheet and a consent form will be handled for you to sign.

As a participant to this study, you will receive a voucher worth £20, as a compensation for your time. Another £10 voucher will be provided to you when provide your feedback. If you wish to withdraw from the study, you will still have your £20 voucher.

If you have any questions please do not hesitate to ask.

Thanks,

Naoom Abu Abah

School of Computing

*March 2022*

**NEWCASTLE UNIVERSITY**

School of Computing

**Interactive Reporting System**

**Naoom Abu Abah**

**Information for participants**

Thank you for considering participating in this study which will take place in March 2022. This information sheet outlines the purpose of the study and provides a description of your involvement and rights as a participant, if you agree to take part.

**1. What is the research about?**

To test the feasibility of a adding a collaborative feature to the standard reporting system by engaging participants (building occupants) in investigative tasks to check a building facility status by observing.

**2. Do I have to take part?**

It is up to you to decide whether to take part. If you do decide to take part, I will ask you to fill a consent form and hand it back to me prior to the experiment.

**3. What will my involvement be?**

If you participate, you will be receiving a task request asking you to check a facility status in the Urban Sciences Building (e.g., room light check, door locked, etc.) You have the choice whether you like to respond to the request (yes, no, not sure, can't do it) or you can simply ignore the request for any reason. The experiment may take 2-3 weeks. Requests will be available for a day, so you have a full day to respond to the request. (All participants will be provided a demo and explanation in an orientation session). At the end of the experiment, you will meet the researcher to provide your feedback about the system. The meeting will be on Zoom and recorded for analysis purposes. All recording will be confidential and will not be accessed by others.

**IMPORTANT NOTE**:

*For safety reasons, Participants should not try to fix any of the defects they are asked to check. Your responses should be based on observation only. All defects are directly sent to the USB reception in order to be fixed by responsible personnel.*

**4. How do I withdraw from the study?**

If you wish to withdraw from the study at any point. please contact the researcher at: N.A.A.Abu-Abah2@newcastle.ac.uk

**5. What will my information be used for?**

I will use the collected information for PhD research.

**6. Will me taking part and my data be kept confidential? Will it be anonymised?**

The records from this study will be kept as confidential as possible. Only myself and my supervisors: Charles Morisset, Maryam Mehrnezhad will have access to the files. During data collection and publishing, your data will be anonymised – your name will not be used in any reports or publications resulting from the study. All digital files, records and summaries will be stored separately from any names or other direct identification of participants

**7. Who has reviewed this study?**

This study has undergone ethics review in accordance with Newcastle University Research Ethics Policy.

**8. Data Protection Privacy Notice** The Newcastle University Research Privacy Policy can be found at: https://www.ncl.ac.uk/research/researchgovernance/ethics/

The legal basis used to process your personal data will be Legitimate interests.

**10. What if I have a question or complaint?**

If you have any questions regarding this study please contact the researcher, Naoom Abu Abah on N.A.A.Abu-Abah2@newcastle.ac.uk , or supervisor on Charles.Morisset@newcastle.ac.uk. If you have any concerns or complaints regarding the conduct of this research, please contact the Newcastle university Research Governance via res.policy@ncl.ac.uk.

If you are happy to take part in this study, please sign the consent below:

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## CONSENT FORM

### Interactive Reporting System

**Naoom Abu Abah**

Please read the information below and print your name and the date below to demonstrate that you have understood taking part in this research.

1. I have read and understood the study information. I have been able to ask questions about the study and my questions have been answered to my satisfaction.
2. I consent voluntarily to be a participant in this study and understand that I can withdraw from the study at any time up until June, without having to give a reason.
3. I understand that the information I provide will be used for research thesis and that the information will be anonymised.
4. I understand that any personal information that can identify me – such as my name, address, will be kept confidential and not shared with anyone other than myself.
5. I give permission for the (anonymised) information I provide to be deposited in a data archive so that it may be used for future research.
6. I understand that I am not supposed to try and fix any of the facilities I am asked check.

Participant name: ________________

Date: ________________

For information please contact: Naoom Abu Abah, N.A.A.Abu-Abah2@newcastle.ac.uk

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# Background Information Questionnaire

What is your role in the university? *

- ◯ Undergrad/PGT
- ◯ PhD student
- ◯ Research assistant/associate
- ◯ Academic staff
- ◯ Professional support
- ◯ Other

How old are you? *

- ◯ Under 20 years
- ◯ 20-30 years
- ◯ 30-40 years
- ◯ 40-50 years
- ◯ 50-60 years
- ◯ 60+ years
- ◯ Prefer not to say

Where are you from? *

- ◯ UK
- ◯ EU
- ◯ Outside of the UK/EU
- ◯ Prefer not to say

Gender: *

- ◯ Male
- ◯ Female
- ◯ Non-binary
- ◯ Prefer not to say

Do you have administrative/managing responsibilities? *

- ◯ Yes
- ◯ No
- ◯ Prefer not to say

Are there any specific days you prefer NOT to receive check requests on? *

- ☐ Mondays
- ☐ Tuesdays
- ☐ Wednesdays
- ☐ Thursdays
- ☐ Fridays
- ☐ I don't have a day preference

On what times you prefer receiving your check requests? *

- ☐ Mornings (8:00 – 12:00)
- ☐ Afternoons (12:00 – 1:00)
- ☐ Afternoons (2:00 – 5:00)
- ☐ I don't have a time preference

Where do you usually stay when you are in the USB? (e.g. your office location) *

- ○ Ground floor
- ○ 1st floor
- ○ 2nd floor
- ○ 3rd floor
- ○ 4th floor
- ○ 5th floor
- ○ 6th floor
- ○ Other ____________

How would you prefer receiving your check requests? *

- ○ Via Microsoft Teams
- ○ Via university email

Would you like your replies – to the check requests- to be anonymous ? *

- ○ Yes
- ○ No

# Keywords of incident reports collected from the defects log of the USB building in Newcastle university

| Keywords | # reported |
|---|---|
| Doors + lock handle +maglock | 267 |
| WC + toilets + blockage + drain | 235 |
| Water +Sink + tap + puddle + leak + slip, ice | 111 |
| Furniture | 102 |
| Floor box + socket + power + electricity + cable + wire | 73 |
| Control panel + alarm + alert + screen | 58 |
| Lifts | 53 |
| Lights + bulb + sensor | 51 |
| Temperature | 22 |
| Smart cards, cameras | 17 |
| Environmental + pest + dirt + outside building | 17 |
| Filters | 32 |

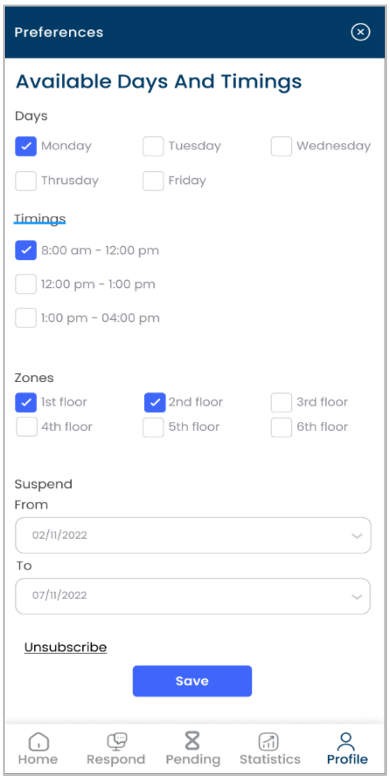
# Post-experiment feedback interview questions

| | |
|---|---|
| | **Experience** |
| 1 | How can you describe your experience in those 2 weeks? |
| 2 | What did you feel towards receiving these requests? |
| 3 | Can you describe your journey from the start, middle, and end of the experiment? |
| 4 | After participating in this mock system, would you participate in the actual system in the future? |
| 5 | Would you like any incentive type to be provided for your participation? |
| | **Tasks** |
| 6 | What was the most difficult task you received? Why? |
| 7 | What was the most time-consuming task you received? |
| 8 | What do you think about each task of these: ……. ? |
| 9 | How does the task type affect your decision to respond? |
| 10 | Were the requests clear in describing the task? If not, can you explain? |
| 11 | What about the wording? Do you prefer "The system received a report…." or "The system asks for …." or "Can you check…"? |
| 12 | How does having pictures of the facility is important for request clarity? |
| 13 | I've noticed that you included some evidence in some tasks and others not. Can you explain why? |
| 14 | Regarding the smart features of the building, what are the differences that you noticed from other tasks? (sensors, temps, smart cards) |
| | **Form** |
| 15 | Would you like to rate each task instantly in the form? |
| 16 | What do you think about the comments section in the REAL form? Required? Unnecessary? |
| 17 | Would you like to have a description of the task before opening the link? Or adding a location? |
| 18 | Is there anything you would like us to add to the form? Remove? |
| 19 | If it were designed as a system, what would you like the interface be (design)? |

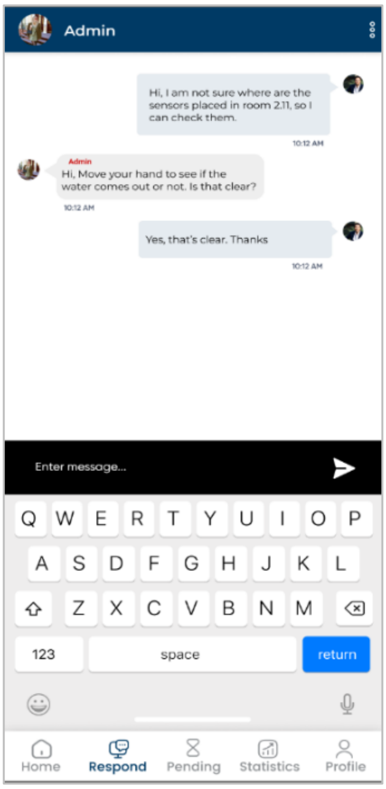
# Appendix C

# Chapter 5- Framework

**Interface design samples:**

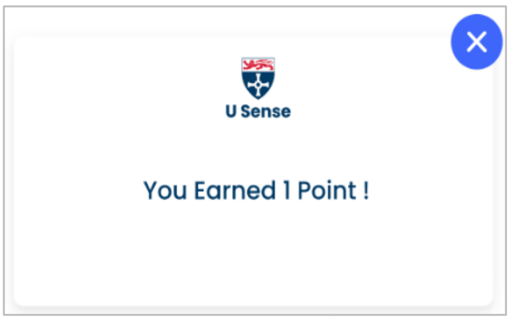



**Engagement Preferences**

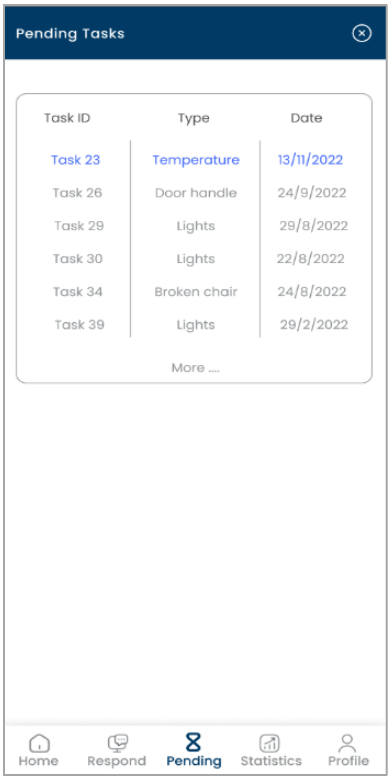



**Requester-user communication**

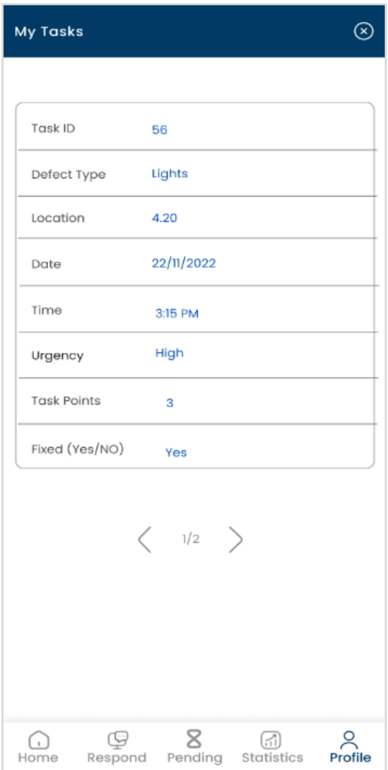

**Acknowledgement Message**

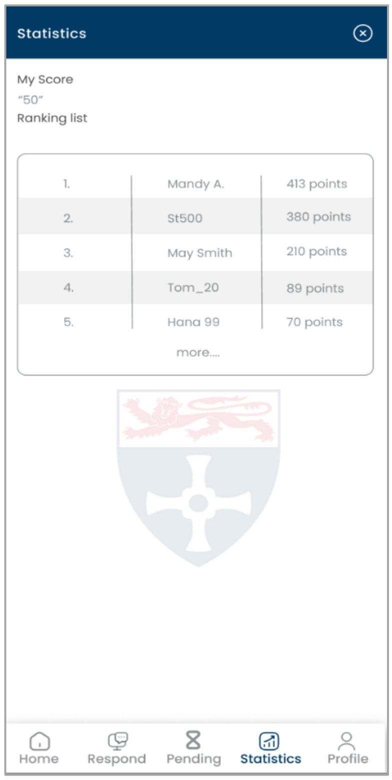

**Points and Competition Messages**




**Pending Tasks**




**User Completed Tasks**




**Statistics**