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The Requirements, Benefits, and Barriers of IoT Solutions to Support Well-Being in Elementary Schools

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ABSTRACT In most parts of the world, minors' access to education is guaranteed, resulting in most of their time being spent in the school building. Similarly, school staff spend a relatively long time in the same building. This unique setting requires both groups to stay inside the school walls throughout the working days, which might negatively affect their well-being. Studies show that low indoor air quality might negatively affect well-being. Moreover, school staff and students mention other problems, such as worrisome declining students' attendance, motivation, social relations, safety, stress, and pressure, among others. Technological solutions, such as IoT-based systems, might be one way to tackle the well-being issue at schools. However, most of the existing solutions focus on the quality of the indoor environment, disregarding the needs and pains of school inhabitants. In the current article, we present an investigation of how IoT-based solutions could extend beyond solely environment-measuring tools and fulfill the needs of school inhabitants. Through an interview study with eleven IoT experts guided by user (school inhabitants) requirements identified in the previous research, we assess functional and non-functional system requirements that such systems should build on. These are discussed against the five-layer IoT architecture model. Moreover, the study identifies barriers and benefits of IoT-based solutions, which are discussed in the context of existing scientific and legal frameworks. The exploratory findings presented in the paper could be used as a guide for decision-makers at schools to ensure that the students' and staff's well-being is maintained, as well as by IoT suppliers to produce holistic or compatible solutions that could be easily integrated into the unique contexts of school.

INDEX TERMS IoT, IoT architecture, IoT in Schools, Privacy, Security, User requirements, Well-being

I. INTRODUCTION

Internet of Things (IoT) is a powerful and complex system of sensor-based devices that originated in 1999 when Kevin Ashton introduced the concept at MIT in the context of the network of things connected with Radio-Frequency-Identification Technology (RFID) [1]. Today, the "uniquely identifiable objects/things and their virtual representations in an internet-like structure" [2] become immense, and their presence is unavoidable. The applicability of IoT-based solutions is broad, ranging from smart homes, helping to regulate the indoor environment (e.g., changes in temperature, lightning), offering real-time automation, smart TVs, and more, to manufacturing, smart grids, intelligent transportation systems, and smart cities [1], [3]. IoT sensors can be embedded in many everyday objects, including medical equipment, home appliances, and wearables. Such an omnipresence of IoT devices and their progress in communication and computing capabilities may influence how people interact with the environment [4].

The role of IoT in day-to-day life becomes apparent, considering the predictions for the future. The number of connected devices is expected to reach 42 billion in 2027 [5]. This growth is unsurprisingly reasonable due to the immense advances in communication technologies, e.g., 5G networks and beyond, the advances in Artificial Intelligence (AI) and Machine Learning (ML) technologies, and IoT becoming

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more cost-effective.

Already, IoT-based services are utilized in different sectors such as health, education, environment, urban design, transportation, business, and revenue growth. For example, AirQ, proposed by Choudhary et al. [6], is a platform designed to monitor real-time air quality for a specific location. The platform is designed to be a cost-effective solution that can be used to build more extensive air quality monitoring networks. Another example is the framework proposed by Tabuenca et al. [7] along with an IoT system designed to monitor plants in learning spaces, aiming to educate young people and teachers and create environmental awareness towards ecological learning spaces, greenery, and plants.

Despite the growth of IoT and its extensive applicability to various sectors, its use in schools is still limited. Yet, IoT-based solutions carry the potential to improve the well-being of schools' inhabitants, not only by ensuring the good indoor quality of the building but also by utilizing IoT to make learning, teaching, and other school-related activities a better and more effective experience. Still, the research on the applicability of IoT in schools is scarce and often limited topic-wise—concerning only interactive learning, or context-wise—focusing predominantly on higher-education institutions (e.g., colleges or universities) [8]–[10].

Hence, in the present research, we consider this research gap and focus on the applicability of IoT in school settings, considering schools for children from seventh to ninth grade. Utilizing previous users' requirements collected from school students and staff (e.g., teachers and healthcare personnel) through qualitative inquiry, the present research aims to gain insights into understanding why IoT-based solutions are rarely utilized in the school setting. Therefore, the goal is to answer the following research questions.

RQ1. How can schools' staff and students' well-being requirements be met with IoT-based systems?
RQ2. What are the main barriers to using IoT-based systems at schools?
RQ3. What benefits could IoT-based systems bring to schools?

We utilized the qualitative method — expert interviews — to answer the above research questions. The experts from different IoT backgrounds were gathered from academia and industry. Thematic analysis was applied to analyze the interviews' transcripts. As a result of such a systematic data analysis, IoT-based system requirements were derived, as well as barriers and benefits that relate to such systems in the context of the school environment.

Considering our exploratory findings, we recognize the two-fold contributions that our research brings. First, our results can be used to inform IoT practitioners (designers, architects) about building IoT-based solutions that could be applied in the school environment. Moreover, our findings can assist decision-makers, for instance, school management, in making choices related to which IoT components should be included in the system they are considering installing. Second, our research, albeit exploratory, contributes to the field by outlining what future research on the design and development of IoT-based solutions for schools should focus on.

The remaining part of the paper is structured as follows. First, in the Background section, we present relevant literature providing an overview of IoT architecture, as well as past research that motivated our research questions and methods. Next, in the Method section, we explain the study design, protocol, and approach used to analyze the data. Following, we present the results in two subsections. The first one is dedicated to the results regarding the user requirements (functional and non-functional), and the second one is to the barriers and benefits of IoT-based systems at schools. The next section, Discussion, focuses on discussing the findings in the context of IoT architecture as well as in the context of their practical applicability. The article is finished with brief conclusions.

II. BACKGROUND

Although our research neither investigates nor proposes a technical solution, a basic understanding of how IoT technology is structured, considering the IoT architecture, is required to understand the research findings better. Therefore, in this section, we first briefly describe the structure of IoT. Next, we present related work that motivated our research, including subsections on well-being, privacy, and security and how they are associated with IoT.

A. IOT ARCHITECTURE

The most straightforward IoT architecture could be explained as comprising three layers: application, network, and perception [11]. However, modern approaches suggest additional layers [12]. For instance, Guth et al. [13] defined the more complex architecture, containing Application, IoT Integration Middleware, Gateway, and Device components. In their model, the Device component includes drivers, and drivers connect with sensors and actuators. A different IoT architecture was presented by Karale [1], which we consider more relevant to the present research. Karale [1] proposed the five-layered architecture, regarded as the basic and the most widely used model, consisting of Perception, Network, Middleware, Application, and Business layers. Below, we describe the model depicted in Figure 1. We apply this model to discuss our study results, making them more relevant to the research on IoT-based solutions.

1) Perception Layer is the layer of the sensors and devices; it collects data from the surrounding environment, e.g., sensors, smart watches, gateways, and RFID tags.
2) Network Layer is the layer of data transmission; it connects devices to each other and to the processing services such as cloud servers, e.g., Bluetooth, signal, WiFi, and Internet.
3) Middleware Layer is a software layer that links services and enables linking information and databases, e.g. storage services and cloud services.

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4) Application Layer is the layer of service delivery; it provides the necessary services that form IoT applications to the users, e.g. smartCities, smartHealth, smartHomes.
5) Business Layer is the layer of business models; it manages the systems and builds data-driven models, e.g. monitors, pay-per-usage.

B. WELL-BEING

To better understand why IoT-based solutions could be beneficial in the educational context, it is crucial to explain the concept of well-being and its relationship with IoT technologies. The concept of well-being is a subject of discussion among researchers from various fields [14]. One proposed definition of well-being defines it as "a state of persons which designates that they are happy or flourishing and that their life is going well for them," placing it at the top in the hierarchy of human values [15, p.2]. The World Health Organization (WHO) provides a more generic definition of well-being, describing it as a positive state experienced by individuals and societies [16]. Here, well-being is not perceived as a subjective construct but amplifies people's meaningful and purposeful contributions to the world. Within the WHO's description, it is clear that societal well-being is essential as it strengthens resilience, raises opportunities for action, and prepares to overcome challenges. Thus, the present research that considers the well-being of the young population, which, in most countries around the globe, spends the majority of its time in educational institutions, conforms to the WHO's descriptions of well-being promotion.

1) Well-being in IoT research

Within IoT-related research, well-being is often considered, frequently in the context of health (both physical and mental). However, the research on IoT and well-being (or health) in school settings is scarce, particularly concerning primary and secondary schools.

Health-related research. Research with the general population has been conducted about psychological well-being and IoT acceptance [14]. Here, researchers identified that hedonic motivations positively affect the use of IoT and well-being in the context of smart home services. In sum, they established that hedonic motivations to utilize IoT depend on individuals' feelings of pleasure and enjoyment and that hedonic motivation is directly related to well-being. Another example of research on IoT and well-being could be work by Gyrard and Sheth [17], focusing on recommender systems that use sensor information. Following a thorough literature review, the authors proposed a semantic-based recommender system for happiness that uses not only sensor data but integrates knowledge repositories and, as a result, feeds smart data back to the user. Others, like Navarro-Alaman et al. [18], proposed an emotion-prediction system, which could be used to identify IoT systems that aim to improve well-being.

Most IoT and well-being research focuses on health-related issues of specific populations, particularly the elderly and people requiring assisted living. For instance, Khan et al. [19] demonstrated that a lot of IoT research concentrates on the elderly, identifying 173 papers, of which 69 looked into physical well-being (e.g., fall detection, stroke detection, real-time monitoring) and 104 papers focused on the psychological and social well-being. Moreover, the authors identified five technologies applied in the development of IoT-based solutions for elderly well-being: Safety technologies, Intelligent networks, Cloud computing, Big data, and Fog computing. Similarly, Tunc et al. [20] provided an overview of IoT smart healthcare, defining technologies used in such systems. They identified applications and services where smart healthcare could be used, such as health monitoring through electrocardiograms, blood pressure, sensing glucose levels, oxygen, and body temperature. However, the review recognized multiple challenges to using smart healthcare, such as large data volumes, immense power consumption, security and privacy issues, and problems related to interoperability and scalability.

Workplace-related research. Still, health-related sectors are not the only ones where IoT technologies could be utilized. One other applicability is in the workplace. Bavaresco et al. [21] examined previous work on occupational well-being and proposed a taxonomy of IoT in occupational well-being, defining different modes of communication, devices, techniques (data fusion and classification methods), industries, sensing, and health (psychological—cognitive states, mental fatigue, mood disorders, stress; and physical—accident prevention, ergonomics, fire or gas, injuries). Somewhat related to occupational health, studies looked at indoor workplace quality and how IoT could be used to monitor and improve it. Saini et al. [22] showed that most of the systems measuring indoor air quality (IAQ) focus on the measurement of specific parameters, predominantly temperature, humidity, CO2, CO, PM, and VOC. Therefore, the sensors used belong to four types: thermal comfort sensors, multi-gas sensors, single gas sensors, and dust [22]. What has also been indicated in the review is the fact that IAQ monitoring systems exist and can certainly help prevent indoor quality levels from decreasing below the desired thresholds. However, the use of such systems effectively and efficiently is still a concern.

C. IOT, SCHOOLS AND WELL-BEING

Considering the indoor quality environment in schools, there is a relatively large body of research that focuses on the topic, and in general, the recommendation is to, in such environments, focus on CO2, CO, O3, HCHO, VOCs, fungi, and bacteria [22]. The effects that the low-quality air in the school has on pupils were also emphasized in the research. For instance, a literature review by Fisk confirmed the association between air quality and both health and students' performance [23]. Lower CO2 and increased ventilation rates were found to improve performance. Similarly, considering health, the reviewed studies indicated that there might be an association between ventilation rates and health (e.g., nasal

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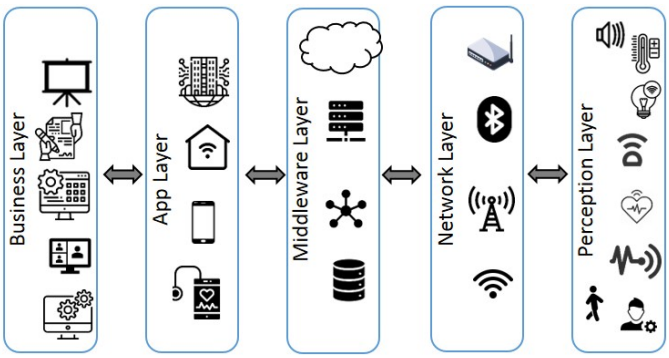

FIGURE 1: **IoT Architecture: Five-Layers Model (based on Karale [1]).**

inflammation), but the results are not conclusive. However, the decrease in the students' absences was visible among students who frequented schools with higher ventilation rates and lower CO2 concentrations.

In a more recent, comprehensive literature review of research from the last 50 years on IAQ in schools, Sadrizadeh et al. [24] present similar findings, outlining action points for practice and research. Their work extends to the negative effects of VOC pollutants on health issues in children and adults (e.g., increased carcinogenic risk levels, irritation, allergies, and respiratory health issues, among others). Moreover, particulate matter (PM) is a major source of indoor air pollution. It may be produced by chalk dust, new furniture, cleaning, particle resuspension due to pupil movement, combustion, and outdoor sources. It might have negative effects on health (e.g., asthma and other respiratory system problems and an increased risk of lung cancer). Similar effects on health, including wheezing, asthma, headaches, sore throat, and other respiratory symptoms, are caused by fungi and bacteria exposure [24], which can be found in schools.

The applicability of IoT beyond the assessment and management of indoor air quality in the context of schools was also previously researched but on a smaller scale. One topic of interest was how to teach students about IoT to enhance their understanding of such technologies. For instance, Hu et al. [25] investigated the implementation of IoT courses/development in the curricula. Other researchers build the pupil's knowledge of IoT solutions. For instance, Ghiazzi et al. [26] studied knowledge gains while the pupils were using an interactive game for cultural heritage education. Putjorn [27] builds on pupils' curiosity and merges IoT solutions with chatbots to give answers to the younger pupils' questions, regardless of in- or out-of-school hours. The pupils ask questions using their mobile phones, and the solutions immediately prompt an adequate answer.

Another topic concerned how IoT could help teachers to perform their work better. For instance, Basjaruddin et al. [28] looked into IoT-based solutions measuring pupils' weights and heights, substituting paper and pen solutions for the same purpose. One described benefit of such a system, besides efficiency, is the ease of transferring data from one system to another. Lyutikova et al. [29] describe an IoT platform for elementary schools, including functionality such as monitoring environmental conditions but also identifying pupils and educational staff and improving fire safety.

D. PRIVACY AND SECURITY

When discussing IoT, in particular considering its applicability in schools, it is crucial to elaborate on its privacy and security. Previous research identified several security challenges and attacks due to the imperfect and weak security of the interconnected devices (e.g., smart medical devices) and platforms at the different layers of the IoT solution. Karale [1] categorized security threats as Physical security attacks on devices, Network attacks like eavesdropping, Encryption attacks like side-channel attacks, and Software attacks like viruses and social engineering. Nevertheless, the privacy issues are beyond the aforementioned security threats as they are byproducts of security problems. The multitude of applications of IoT solutions, along with the nature of their architecture and new methods of data collection, raise privacy concerns, which are significant issues for the adoption of IoT systems. On the one hand, inexpensive commercial off-the-shelf (COTS) sensors make it easier for humans and "things" to be connected anywhere and anytime to various networks. On the other hand, cloud-based services support the processing, storage, and sharing of vast amounts of collected data, i.e., it is considered an essential infrastructure in IoT solutions.

Various studies have been discussing the privacy, security, and trust challenges in IoT applications from different perspectives, such as privacy issues in smart building [30], users' awareness, expectations and preferences (e.g. allowing users to control and/or customize data collection, sharing and usage limited to the stated purposes) [31], [32], and concerns in smart homes for owners and bystanders [33]. IoT privacy issues are broad and can include behavioral profiling, identification, linkage, personalization (social-based and location-based), and tracking [1]. For example, smart cities increase the possibility of deducing users' location and identity in transportation and inferring their lifestyle from intelligent surveillance in the smart cities context. Another

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example is the smart home ecosystem devices, such as Ok Google [34] or Alexa [35]. The solutions provide the needed tasks and assistance to the users and are turned on by a voice command. This indicates that the devices detect and listen to the environment all of the time, which elevates concerns for the residents' privacy. Moreover, as personal information is collected and becomes available for remote access. Hence, smart homes expose users to a wide range of privacy threats. In smart Building applications, data about the buildings and inhabitants is collected to provide information that helps improve the quality of services, comfort, safety, energy consumption, social interactions, and more. Pappachan et al. [36] studied the importance of capturing privacy policy in such systems and proposed a framework to describe privacy preference and assist in managing users' privacy in the space.

One way to tackle IoT privacy issues is through policies and legislation. For instance, legal frameworks, such as the General Data Protection Regulation (GDPR) [37], provide definitions of personal data and common privacy principles and goals, such as lawfulness, fairness and transparency, purpose limitation, data minimization, accuracy, storage limitation, integrity and confidentiality, and accountability. Although the regulation's applicability is geographically limited (i.e., applies only to services that process information from users located in the European Union (EU) area), many services located beyond the EU have to comply to ensure privacy protection. Thus, IoT manufacturers and service providers shall implement measures to embrace the GDPR's principles to address the challenges in the connected systems.

III. METHOD

This section contains information on how the study was designed, including a description of motivational factors that affected the choice of the method, previous studies whose results were used as a basis of the present research, and, lastly, the interview process demonstrating how the present research was conducted.

A. CHOICE OF THE METHOD

To answer the research questions, we designed an expert interview-based study. The expert interview is a qualitative method that focuses on the knowledge of the interviewee—their expertise in a given field [38]. The expert interviews were selected as a method of inquiry for a few reasons. Mainly due to the nature of the research questions: we wanted to know what types of IoT-based solutions could be used to improve school staff and students' health and well-being. Considering that the general public often lacks an understanding of what IoT is and how IoT-based systems should be built, we need experts who understand these issues. Moreover, the study design was grounded in the users' needs and requirements that had been identified in the earlier studies conducted as a part of the same project. In short, the project is a case of a newly built school located in Sweden [1]. The project's overall aim was to identify solutions on how to improve the well-being of students with the help of IoT by providing a testbed for IoT companies.

The reliability and validity are often described as unsuitable for qualitative research [39], and unlike quantitative research, no quantifiable metrics could be used. In the present research, we ensured the reliability of the study by choosing the method that best fits to answer the exploratory research questions — expert interviews — as described above. Moreover, reliability in qualitative research can be perceived as dependent on consistency [39]. We ensure consistency by following best practices regarding the data collection (as described in Section III-C) and analysis (thematic analysis, as described in Section III-D, applying the methods systematically, with scientific rigor. As recommended in [39], we also considered the trustworthiness of the present study by ensuring that the data comes from verifiable experts and maintaining within-expertise variance.

B. PREVIOUS STUDIES

In the first phase of the project, interviews and focus groups with the school staff (teachers and health care personnel) were conducted. Participants were asked about their day-to-day activities, problems that they encountered, opinions about students' health, and more. Next, the study with students was conducted. In an online survey, through open-ended questions, students had an opportunity to describe what a good school should look like and what are their imagined best school characteristics. Moreover, they could also express their opinions about the new school building. Based on the findings from the studies conducted in the first phase of the project, a set of user requirements was identified. In particular, the requirements are concerned with the struggles that school staff and students have regarding their day-to-day activities. We applied the identified user requirements as a fundament for expert interviews, as described below. The previous and current phases of the project are depicted in Figure 2.

C. INTERVIEWS PROCESS

Eleven experts were interviewed in English. To participate in the interviews, the experts first received information for participants explaining the study details and how their data would be processed, which they needed to acknowledge by signing the consent form. The experts worked in academia and industry. All interviewees had IT backgrounds and various roles at their current employment. There were experts from the field of privacy and security, IoT engineers, and those currently working in managerial or sales positions in IoT companies. The experts were located in different countries, including Sweden (six participants), Norway, Germany,

[1]The school hosts students of 7th-9th grade. Interested readers can find more information about the Swedish school system on https://www.norden.org/en/info-norden/compulsory-schools-sweden

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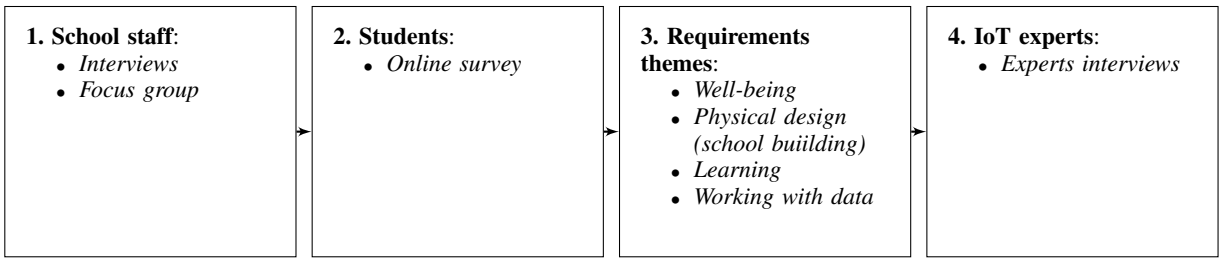

FIGURE 2: The whole project phases. The present paper considers phase 4, which builds on the findings of the previous phases.

the USA, the UK, and Spain. Hence, all interviews were conducted online. With the permission of all experts, the interviews were recorded and then transcribed. Each interview was approximately an hour long, with one exception (30 minutes).

The interviews were semistructured to enable a conversation between the interviewer and experts [40]. Using predetermined questions that structured interviews enforce or having an unstructured conversation would not achieve the same result.

1) Detailed description of interview

One researcher conducted all interviews to ensure consistency within the interview process. One interviewer is recommended for one-to-one interviews to avoid overwhelming the interviewee. Moreover, having a second interviewer working independently, without training, could lead to differences in follow-up questions that semi-structured interviews allow for.

The following steps have been undertaken during each of the interviews.

1) Interview briefing. Consent and information for participants were sent over email to all interviewees, and signed documents were sent back to the researcher in the lead prior to the interview. Only participants who signed the documents could participate in the study. Before the interview commenced, they were reminded of the information in the consent form, and their willingness to be recorded was reviewed.
2) Participants were asked to tell about themselves, their role in the company, and their self-assessed expertise in IoT.
3) Each participant was presented with a short verbal description of the IoT in Schools project (as described in Section III-B), including information about the school building. The verbal description was supported with an image presenting a table with the qualitative findings from previous studies, which was shown to participants (see Figure 3). The interviewer briefly described the user requirements identified in the past research, one by one.
4) Participants were asked interview questions. The following interview guide was used.
   - Can all or any of the presented user requirements be fulfilled with IoT-based solutions? (Participants were asked to consider existing solutions but also describe possible "dream-like future scenarios" if they thought of such solutions.)
   - Are there any barriers to applying IoT-based solutions in school settings? If there are some barriers, is it possible to overcome them, and how?
5) Interview closure includes asking participants whether there is anything they would like to add, discussing how the results will be analyzed and published, and explaining participants' contributions.

D. DATA ANALYSIS

All interviews were recorded and transcribed. The leading researcher was responsible for transcription. The thematic analysis was applied to the data to answer the research questions. Two researchers were engaged in the thematic analysis, following the subsequent steps as recommended in best practices for the thematic analysis [41]. The data analysis procedure can be described as follows:

- *Familiarization.* First, researchers familiarized themselves with the dataset by reading the transcripts.
- *Code generation.* Next, researchers independently coded the data, keeping in mind the research questions of the study as well as the questions asked during the interviews.
- *Themes creation.* In this phase, researchers created themes. They first discussed the codes to ensure that any differences in coding were removed and resolved. The results of the discussion were used to generate themes.
- *Themes revision and definition.* In the last step of the analysis, the two researchers finalized the proposed themes, taking into consideration how elaborating the themes are and the potential overlaps between them.

IV. RESULTS

A. MEETING USER REQUIREMENTS

During the data analysis, a clear division into functional and non-functional requirements surfaced among participants' responses, which has been used to group the results of thematic analysis into two high-level themes. Table 1 presents the categorization of themes, codes, and subcodes of the identified requirements. Note that although requirement specification should clarify what a system should do instead of how it should do it, in this paper, we take a broad approach to requirements and include descriptions of how the systems

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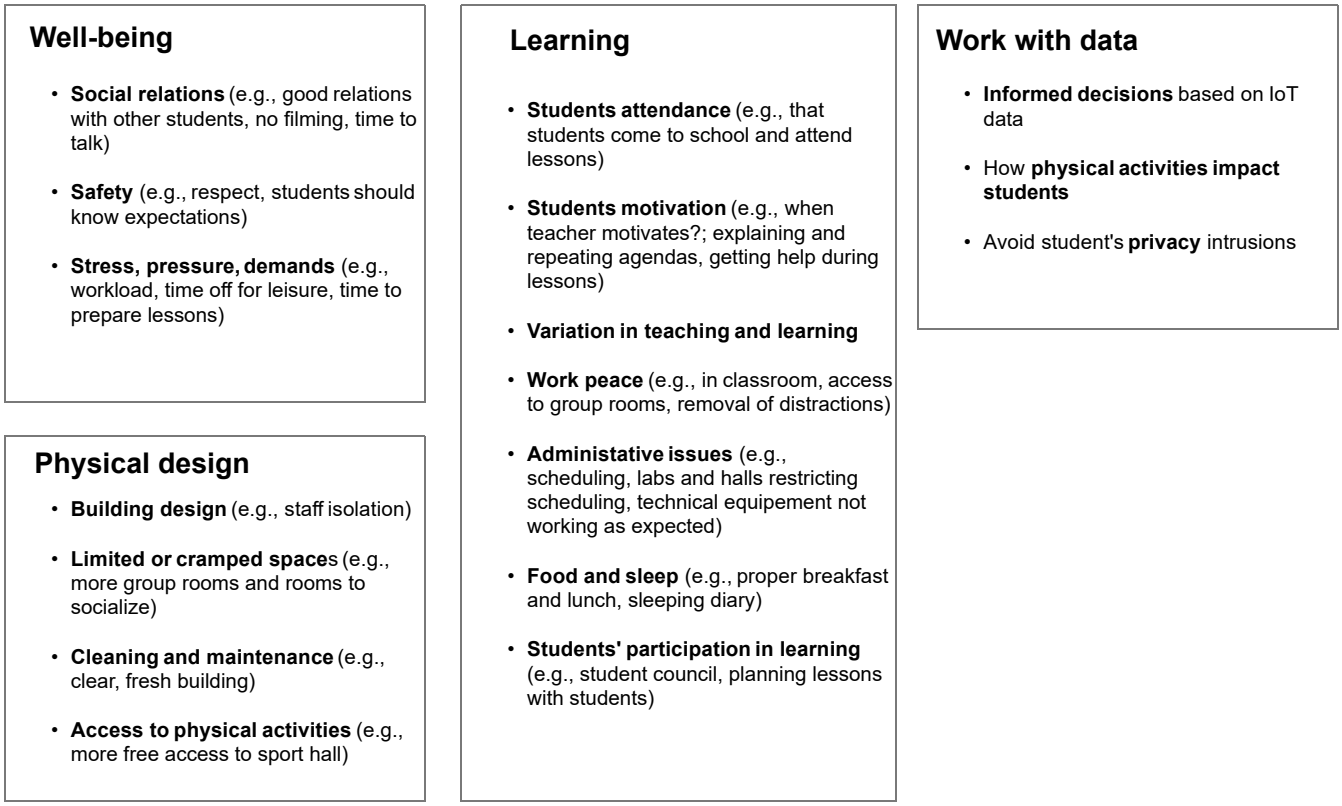

FIGURE 3: **User requirements chart used during the interviews.**

TABLE 1: **Functional and non-functional requirements. N stands for the code and subcode occurrences. Subcodes are in *italics*.**

Functional requirements	N	Non-functional requirements	N
Tracking		Sensor types	
People	15	*Wearables & body*	17
Assetts	5	*Furniture*	7
Rooms	4	*Sound & voice*	4
		Environmental	15
Notifications	5	Edge IoT	3
Personalization	4	UI/Dashboards	11
Integrating other technologies	28		

might look like. Therefore, we use the functional and non-functional thematic categorization in a loose sense to enable a better understanding of how to match the users' needs with solutions that systems, including IoT-based systems, might provide.

We also present two themes that consider applying IoT-based systems in schools, discussing the barriers and benefits that such systems might bring.

1) Functional requirements

Functional system requirements can be defined as requirements that specify functions that a given system must perform, should do, and what product has to do [42]. Additionally, functional requirements might describe how the system should behave and specify what should be system inputs and outputs and the relationship between them [42].

Gamification. Experts discussed gamification but frequently not in the context of standalone IoT-based solutions. For instance, the suggestions of gamifying the experiences related to food, "so that they eat properly and so on, is that if you built like a gamification around this so that they challenge each other to have lunch, and you can gain points and build some kind of competition around the healthier things." Similarly, organizing students' challenges was suggested considering the use of phones, e.g., which lasted the longest without using the phone at night.

Considering the IoT sensors, there were suggestions to use game-like quizzes, which, on their own, are not directly related to IoT but the experts implied that the answers to such quizzes could be correlated with data from environmental sensors to assess how, e.g., CO2 influences students participation. Similarly, the applicability of noise sensors could be gamified; "to gamify the sound level in a room. So in a certain school, what classes have the best noise levels? So you can make that into small like competition."

Notifications. Notifications, in various forms, were discussed in the interviews. In the context of a food cafeteria, sensors could be used to ensure that the temperature is appropriate

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for different forms of storing food, e.g., freezer or cooler. Alarms could be sent to the kitchen staff in instances when the desired temperature changes. Another idea was to send students notifications based on tracking their food intake; "the students do not care about themselves when they eat and when they don't eat. You know I don't know what will help more than having alarm system. In their phone like tells them all: You have not eaten of not had your breakfast. "

Others discussed how tracking students' movement and geofencing, e.g., when they are leaving school premises, could trigger an alarm. Similarly, the indoor quality changes identified by sensor measurements could be used to automatically raise alarms and react, e.g., to open a window in a room.

One of the experts also discussed social relationships. Particularly how tracking could help to identify whether students are isolated; at times, patterns about individuals that imply that others never surround a student could indicate that the student has social-related issues, e.g., difficulties in making friends, perhaps is a victim of bullying, or similar. Such information could be sent to the school staff so they could intervene.

Personalization. Personalization was mentioned in the context of systems connecting various sensors and regulating the environment based on the information from different individuals. For instance, experts described how a future system could look like if physiological information about individuals was automatically transmitted to the indoor climate management grid to adjust it to the inhabitant's needs. "[...] this system can understand that, okay, there is a person in this room, and his body temperature is this. But he also has this kind of temperature in the area around it. So then we could have, you know, the sensors that we wear, these smartwatches, the AirPods and the sensors in the building surround us."

Tracking. Considering tracking, respondents talked about it in three different ways. First, they mentioned tracking of rooms/physical spaces, for instance, to enable easier scheduling and access to rooms. Some mentioned tracking assets, either their location or tracking their status, e.g., "on things that are not working as expected, put a connected [...] IoT button and press this button if that doesn't work and then it, it's automatically sort of reported as broken or so." Lastly, quite a few experts discussed issues of tracking people, such as using RFID tracking or other tracking beacons, cameras, and tagging students to enable geofencing, managing flows of people in physical spaces, and checking attendance. Others talked about tracking individuals, including physiological measurements via, e.g., smartwatches, to assess students' sleep habits, stress levels, food intake, and movements.

Integrating other technologies. All of the interviewees mentioned other technologies that need to be integrated with IoT-based solutions. Some mentioned larger systems that could provide students or teachers with real-time information. For instance, the information about meals or occupancy should be delivered to students' mobile phones, requiring integration between sensors and mobile applications or websites. "if we could have this is a very simple system. Why don't you have the possibility to choose between two different meals for the next week? I mean, there is always these vegetarian alternative or vegan alternative, and there are some people that are cannot eat pork and so on."

Considering integration with other technologies, participants frequently discussed aggregation of information from sensors that might be useful only when algorithmically manipulated. To perform calculations on data from users, there would have to be some form of artificial intelligence in place, such as simple statistical analysis or more advanced machine learning models. "The sensor is combined with machine learning, so then they're very, you know, technically advanced and then you train the sensors to detect different kind of things. So in the coffee scenario, you would train it on a model for machine learning to train it. So depending on what you would like to detect, I'm not really sure what that implies in school, but that might be interesting. Machine learning overall combined with what IoT gives you." Correlations between different data points were mentioned as one way to gain better insights about indoor quality, "perhaps we should test if there is a correlation between the sound level because that could be triggered by how many people is there in a room. And then look at the air quality metrics as well and see if it sort of correlates to each other."

An interesting point made by one of the experts was to aggregate information external to the school to identify the potential impact that different factors might have on learning, particularly student engagement; "simple things such as seasonality could be interesting here. Perhaps in the summer, there is more attendance, maybe in the winter there's less [...] I think things like that and you could even plot it against events. I mean, as far as I know, students and young students as these probably play some games as well; maybe that could even impact it." Similarly, if physiological data could be collected from students, some suggested using it to recognize emotional states and learn more about students' active participation in classes and student-teacher interactions. Respondents also talked about pattern recognition in data, particularly data from the cafeteria, which could be used to ensure a better layout of tables or chairs that could be altered according to the changes in data points.

2) Non-functional requirements

There are several ways to view non-functional requirements, where one focuses on describing everything besides the functional requirements [42]

Sensor types. Considering non-functional requirements, participants talked about the different sensor types that might be used in the school setting. One category of sensors included environmental sensors commonly used to assess indoor quality. For instance, sensors measuring temperature, air quality (CO2 levels, TVOC), presence detectors, light and noise levels, and newly developed scent detectors. The environmental sensors were discussed mostly in the context

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of school indoor quality management, how the information gathered by such sensors could support decision makers in improving the indoor environment for students and staff's well-being and energy management.

The sensors' location was one of the topics discussed by the experts. They often mentioned integrating sensors with furniture, which could enhance learning engagement or enable better assessment of the number of people present in a given space (e.g., when sensors are integrated into chairs). Considering engagement in classroom activities, some also mentioned how sound and voice-recognizing sensors could be used to improve students learning and also give teachers a chance to better understand their teaching methods in relation to students' reactions.

Lastly, wearable and body area sensors were mentioned, particularly concerning sleep measurement or physical activities. However, despite the ease of access to such sensors (e.g., smartwatches, fitness bands), the applicability of such sensors has been scrutinized due to privacy concerns (e.g., sensitive information, surveillance), as discussed later.

Edge IoT. A few experts mentioned the concept of edge computing, which might be suitable for the school setting since the information about vulnerable populations, such as minors, is sensitive. Therefore, edge computing—when the data is processed on the device instead of being transferred, e.g., to the cloud—could help overcome some of the privacy issues frequently reoccurring among the interviewees' responses. For instance, edge computing could be used in security cameras, "So usually the security cameras in the past used to send all the time the data to a cloud and then someone out far away from that security camera was watching like tons of cameras, and I don't know, watching something, especially on one of the multiple cameras that they had in front of them. [...]. And now, with edge computing, this part is changing just a little bit because what can happen is that the device itself can have some artificial intelligence models or some machine learning models."

User Interface/Dashboard. When discussing issues related to data aggregations, the experts frequently mentioned how such information should be presented, indicating the need for a system that efficiently conveys aggregated information to users. For instance, experts mentioned that providing end-users with an interface that allows them to complain may make people happier. Different interfaces presenting the sensors' readings and allowing people to provide feedback could affect their satisfaction with the indoor climate and overall well-being, e.g., "if you can see, for instance, which temperature it is or you can see, I mean, what this is like here, then perhaps a really simple complaining disappears. Having an easy way of letting people making their voices heard."

Among the experts, there was also a voice that UI is sometimes unnecessary, particularly in the context of maintenance and cleaning. "I think the system should know directly if something is not working. I mean, many times, the best UI is no UI, because if you don't need it, if it's good in a way, that's the best thing, I think."

TABLE 2: **Barriers and benefits. N stands for the code occurrence. Subcodes in *italics*.**

Barriers	N	Benefits	N
Security	8	Learning/teaching	
		Student performance	4
		Problem detection	3
		Student involvement	6
		Teacher performance	3
Privacy	27	Safety	4
Data utilization	8	Waste management	4
IoT limitations	6	Improved decision-making	5
Cost	9	Automation	
		Resources & time	4
		Task optimization	3

B. BARRIERS AND BENEFITS

The respondents described several barriers for the customers to implement IoT solutions, which in our analysis we refer to as a theme. We have divided the barriers into codes cost, security, privacy, data utilization, and limitations of IoT. Similarly, the experts reflected on the different benefits that IoT-based solutions could bring, which we present as another theme. The benefits could be summarized in five codes: automation, learning/teaching, safety, waste management, and improved decision-making. Table 2 presents these two themes, including codes and subcodes that contribute to theme creation.

1) Barriers

Cosf of sensors, systems, cost/benefit analyses. Several respondents declared that one of the most significant barriers to the widespread adoption of IoT is the difficulty in finding a willingness to use IoT devices among potential users. Many people still need to be convinced about the usage of IoT devices and are hesitant to embrace the technology. Finding compelling use cases for IoT devices, particularly those requiring specialized sensors, can be challenging. For example, it may be challenging to identify a specific use case for a humidity sensor or a light sensor, making it hard for users to see the value in investing in these types of devices. One respondent even declared that arguing for the value of IoT solutions in a school environment is problematic because counter-arguments constantly compare the costs and risks of new technology with the more familiar costs of hiring more teachers, saying, "I mean, if you would say there are two ways we can increase the productivity in this school. We can either you know, get ten more teachers or we can just work with a better working environment so that all the students will perform better, have the chance to perform better". To overcome these barriers, it is essential to provide clear and compelling use cases for each type of sensor, highlighting the benefits they can provide regarding energy, efficiency, safety, and convenience.

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Another emphasized cost-related barrier is conducting a cost-benefit analysis related to measurements. The cost part of analyses is often easy to measure and includes hardware, system, and human resources. Other cost elements include other technical equipment, employee education, and costs related to implementation, support, and maintenance. The benefits may be harder to measure as they can be quantitative and qualitative. One such example involves how to measure improved communication, peace of mind, safety, and health. If an organization focuses only on measurable benefits, then the understanding of potential benefits is limited. Concerning the cost-benefit analyses, some respondents emphasized that each individual IoT solution gives rise to one use case. Understanding the net benefits of several implementations, each with its own use-case in, e.g., one organization quickly becomes overly complex. One respondent declared it as "then the problem is that if you're going to want to do both air quality and fire security and the queue length to the cafeteria and noise levels, and then then you will end up with a number of different vertical solutions."

Security. Security is emphasized as a barrier by the interviewees, frequently in the context of a lack of security. Any IoT solution could easily be hacked even if there are passwords for using it, and sensitive data could be spread or used unexpectedly. One worst-case related to hacking is that data is updated uncontrollably, resulting in wrong decisions based on obsolete or inconsistent data. The time spent restoring the data could easily be used for other purposes. Another security issue involves sensor communication since it is essential to place all sensors according to careful planning and precisely so they would work continuously.

In addition, the environment should be resilient and have the ability to deal with cyber-attacks, unexpected damages, e.g., one of the sensors breaks, or any other fault.

Privacy. Privacy risk is often highlighted in the interviews as a barrier — the discussion related to privacy in general and the General Data Protection Regulation (GDPR) specifically. For example, students might not feel comfortable being measured while entering a classroom or dining hall. Measuring such situations can be viewed as surveillance, even if the intention is to understand crowded situations. In the long run, the data can be used to understand student policies, such as timetable and grading, and their intended and unintended schedules solely based on data showing geographical location. Another perspective related explicitly to IoT solutions in school is that children must go to school, and the school environment should be a safe place without surveillance.

One often discussed part of privacy is the question of who owns the data generated by IoT solutions. One respondent claimed that cheap cloud solutions could create unintended effects, such as the owners of the cloud solutions claiming the ownership of data and using the data for other purposes. One respondent declared an easy view on data ownership by various stakeholders as "I think that's a mean we need to understand that data should be pushed in these kind of cases, at least to, first of all, a server within the EU and also to have a great security integrity between the sensor and where, whatever data is published." Another possibility is whether the students can claim the data from those situations on a group level or individually. Data storage is also viewed as a barrier to privacy, time, and what to archive. The requirements for archiving are not easy to foresee, and an easy solution is not to add any archiving requirements. The second part of the discussion concerned GDPR. National suppliers know how to deal with the privacy requirements of a country, but it might be more challenging to deal with global IoT solutions. Handling GDPR properly according to the national requirements of different countries can become problematic.

Data utilization, skills, competencies. There was a discussion among the interviewees on using sensor data. It started with what we are able to and allowed to measure, and that question often compared quantitative measurements against experiences. Another barrier discussed by the interviewees was understanding what data/information is of interest. Output from the IoT solutions, the data, and its content must be translated into useful information, requiring a solid understanding of its meaning. The current isolated IoT solutions require a broad understanding of the data and how to transform it into usable information for the end users. Often, end-users, such as staff or students, have problems verbalizing their perspective on what information is usable, relating to a few occasions where they enacted usable information. One respondent declared that end-users could relate to "a happy or sad face to show if it is good or bad air in the facility. We don't need all those levels and all those numbers and everything we need if there's good or bad." Sometimes, the answer to lacking data skills and competencies is obvious, and the stakeholders are aware of their choices or interest in the data/information. Their perspective, however, could be focused on the problem of interpreting data to create information and the problem of knowing what data is needed to create a positive change for the individuals. In those cases, a visualization can determine whether the interpretation is correct. The existing solutions must be more comprehensive regarding what they measure and how they measure according to the stakeholders' expressed requirements. One result could be that standard information is used, which does not create value.

Additionally, the end-users often need one app for each IoT solution, and as a result, end up having numerous apps, which does not create the required synthesized information environment. Therefore, the organization's IT architecture is of the highest interest in all aspects of the IoT-solutions.

Another barrier related to the purchase of IoT is that the IoT-based solutions are often purchased by co-workers with technical knowledge, omitting the requirements of end-users in their organization, who might have little to no technical knowledge. The solutions need to add the intended value, marking them as useless and wasted money from the end-users perspectives.

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Proprietary IoT solutions add specific barriers, such as knowledge, use of terminology, and specific data. An organization needs access to knowledge related to the specific IoT solution, detailing it into knowledge on hardware, software, and the output and content of the data. One respondent added hardware semantics as a barrier, declaring that IoT businesses invent new terms monthly. The new inventions and terminology need to be understood and investigated within the current practice in the organization. Maintenance is also impacted if the current IoT solution needs to be updated regularly.

IoT limitations. Limitations discussed by the experts involved the lack of customization of IoT solutions, ongoing changes in terminology and usage based on required updates, communication between a purchaser (with a high degree of technical knowledge) and end-users (who may have much less technical knowledge), and use of the outputs from IoT solutions. IoT solutions are often purchased as as-is solutions, limiting specific requirements from the organization. There are possibilities for organizations to construct their own IoT solutions, but it requires specific knowledge and can be expensive. One respondent declared the problem of personalizing the suppliers' IoT hardware to the organization's requirements. This respondent pointed out that only some requirements could be implemented in the software, and suppliers limit what can be changed from the standard solution.

2) Benefits

Automation. One of the benefits described by the experts was the reduced effort and workload from teachers. The experts mentioned that automation of day-to-day tasks, such as switching on and off the lights, opening or closing windows, or automated attendance reports, could reduce teachers' workload. "I guess that that could be done quite easily with an automated attendance report saying that, you know, either you have like a machine learning thing that recognizes each person that is seen in the classroom, that would be one way." Similarly, automation could optimize cleaning, affecting the workload of cleaning staff, e.g., "I mean optimize cleaning is something of course, and knowing where people are and which rooms have been used instead of just cleaning according to a certain schedule of cleaning according to usage instead. " Moreover, automation could aid in saving resources and time. For instance, automated light, keeping the right temperature in freezers, could help save energy, while keeping track of rooms in use could be used to better manage the resources dedicated to cleaning.

Learning/Teaching. The interviewees also mentioned the learning and teaching benefits of IoT-based solutions. As mentioned above, integrating IoT in the classroom could enable students to provide real-time feedback to the teacher, potentially enhancing both learning and teaching performance. For instance, students could press buttons embedded in the classroom desks to ask the teacher to review some topics slower or faster. Moreover, IoT itself could be used to engage students in the learning process, "we encourage the student or involve them in the analysis of the sensor reading process. So, for example, let's say yes, to the idea of correlation I like this is one of the things that I did some research about is how to use the correlation between different measurements from different sensors for getting meaningful results." Similarly, learning programming and problem-solving skills could be taught to students with the support of IoT sensors implemented in the school environment. Also, the performance of teachers and students could be measured.

Safety. Safety could be another benefit of using IoT-based solutions. The experts discussed safety from two different angles. First is the incident response and identification of risks. For instance, sensors detecting falls or buttons that people could press when in distress could be embedded as a part of the larger security and safety systems. "IoT projects of people who want this type of product like with a GPS and just a button, and then you just link this button to your family or friends or your parents partners or whatever, and then they receive this message."

The second angle from which safety was discussed is the context of the indoor environment. That is, environmental IoT sensors could help detect harmful or toxic substances early. "We have had one customer, a public housing company, that has been asking us whether or not we can detect if there are typically young people in the basements, in the cellar corridors, smoking, which we could actually do with this kind of sensor. But in a school setting, it might, you know, add use cases both for security or safety reasons to detect different gases."

Waste management. Some experts discussed improved waste management, particularly in school cafeterias, considering students' dietary requirements. IoT sensors could help assess how much food students eat each day. Such information could be forwarded to the kitchen to ensure that the right amounts of food are being prepared and that only the most popular foods are prepared. The interviewees also mentioned that IoT could help with recycling since it might be problematic for some kitchen staff. For instance, cameras could detect which food items should be recycled and where. The obvious applicability of IoT-based solutions was recognized as cleaning and maintenance, e.g., cameras or sensors that detect dust particles and toxic substances in the air. Some experts also suggested the AI-based systems that cleaning companies could use;" I think IoT could play a vital role in like measuring air quality and it could also most likely just measure [...] how often the facilities are cleaned and maybe if you have some AI interpretation of what the cleaner looks like or [...] on the cleaner, you could tag something that would, you know, be recognized by an AI solution."

Improved decision-making. The overall benefit of the IoT-based solution in schools was the potential for improved decision-making in various contexts, e.g., resource management or teaching (as mentioned above). For instance, some experts talked about how information from such solutions could be used by building managers to reduce costs of

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energy; "You don't want to have people scattered across a big building if it's not necessarily so, because it takes quite a lot of energy to have everything and lamps and so is energy."

V. DISCUSSION

In summary, our results indicate that the implementation of a holistic system integrating IoT with other technologies tailored to the school context is one way to fulfil user requirements (RQ1). However, the design, development, and implementation of such a system can be difficult because of the barriers revealed in our research.

Overall, our results indicate that the IoT-based solutions could help meet the well-being requirements in school settings. Integration of solutions similar to the IoT systems proposed in past research in the context of health [17], [19] and schools (e.g., increasing knowledge of IoT among students [26] were mentioned by the interviewed experts. However, unlike in cases of IoT solutions for older generations or other adult populations, applying holistic systems integrating environmental, physiological, and psychological measurements of school inhabitants, although beneficial, could be challenging due to some of the barriers discussed by the experts, mainly around privacy and security, but also costs and lack of competence. Below, we discuss the present research findings in more detail.

A. FULFILLING USER REQUIREMENTS

Our results demonstrate how IoT-based systems could be utilized to meet the users' requirements identified in the previous study (*RQ1*). In short, the experts provided ideas about either full-functioning systems (mainly considering functional requirements, e.g., systems to use in the cafeteria and engage students in better dietary behaviors) or solutions to individual problems (mainly in non-functional requirements, e.g., identification of sensor types or edge IoT).

To better present the results and explain how they relate to the present research objectives — how to improve the well-being of school inhabitants with the support of IoT-based solutions — we propose a mapping of our findings into the five-layer model of IoT architecture. We map functional and non-functional IoT requirements as they contribute to defining IoT-based solutions suitable for the school environment. Next, we map the barriers that might affect the design and development of such solutions to enable discussion on potential ways to overcome them. We do not map the benefits, as they are the outcome of the IoT solutions, given that the barriers can be accounted for or overcome. Table 3 illustrates the five-layer model and the mapped resulting themes. We discuss some examples of the mapping below.

Perception layer. Our results indicate that in the context of IoT in schools, non-functional requirements identified to satisfy users' needs relate to sensor types. A wide range of sensor types should be used to build IoT-based solutions for schools, ranging from sensors measuring indoor air quality to body-area-network sensors. However, using some of the sensors might bring privacy and security risks, even when sensors do not process data directly linked to individuals, since some information could be derived about individuals through data aggregation and linkage.

Moreover, one must remember that the IoT on its own is insufficient to satisfy user requirements. Other system components must be added to enable the generation of the information needed to satisfy user requirements, e.g., wearable devices such as smartwatches or the integration of sensors with everyday objects, like chairs or tables.

Network layer. Within this layer, both functional and non-functional requirements arise to fulfill users' needs. In particular, tracking might be needed to ensure that the whereabouts of students are known or to ensure that their physical or mental well-being is accounted for. However, once again, tracking might introduce risks to privacy. One possible way around it is through non-functional requirements—edge IoT—which may decrease privacy risks as long as appropriate levels of security are in place.

Middlewere layer. Considering the software linking information and databases, our results suggest consideration of functional requirements, in particular aspects of integrating IoT with other technologies and using aggregated data that sensors might collect. Such an approach could help fulfill requirements related to maintaining students' better dietary habits or their engagement in learning activities. Still, large datasets collected from students may create a barrier for the middleware layer of IoT architecture — increasing risks to privacy. One way to overcome this barrier could be, again, through the utilization of edge computing, which improves privacy protection.

Application layer. At the application layer, functional and non-functional requirements surfaced, together with potential barriers. Considering functional requirements, the IoT-based solutions should become parts of a larger system built on sensor-based data. Such systems should be personalized and use design elements aiming to affect behavior, such as notifications or gamification. Therefore, there is a need for well-designed interactive UIs that enable useful and usable visualizations.

However, to build such solutions, an appropriate level of security is needed, considering that some of the sensor data might be sensitive in nature. Moreover, not all information about individuals can be quantified with the measurements from sensors. For instance, measurements of stress or emotional states based only on the sensor data might be insufficient and inaccurate. They must be accompanied by other data inputs (e.g., perceptions of learning activities or other self-reported measures).

Business layer. The business layer incorporates functional and non-functional requirements similar to the application layer. What is different at the business layer is the increased number of barriers. These include cost, privacy, and data utilization/skills and competencies. This means that embedding IoT-based solutions in the school environment might be costly since it may require not only purchasing one holistic system but also investing in multiple systems that are not

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TABLE 3: **The experts' interview results mapped to IoT architecture.**

Layer	Layer description	Results	
Perception	Sensors and devices that collect data	*Non-functional*	Sensor type
		Barriers	Security
			Privacy
			IoT limitations
Network	Data transmissions, connecting devices, sending data to servers	*Functional*	Tracking
		Non-functional	Edge IoT
		Barriers	Security
			Privacy
Middleware	Software linking information and database	*Functional*	Integrations/data aggregation
		Non-functional	Edge IoT
		Barriers	Privacy
Application	Delivering information to the user	*Functional*	Gamification
			Notifications
			Personalization
			Integrations/data aggregation
		Non-functional	UI/dashboard
		Barriers	Security
			IoT limitations
Business	Business models; manages systems and builds data-driven models	*Functional*	Gamification
			Personalization
			Integrations/data aggregation
		Non-functional	UI/dashboard
		Barriers	Cost
			Privacy
			Data utilization/skills, competencies

necessarily compatible. Thus, this creates another barrier — who is responsible for the management and interpretation of information supplied by such systems? The expertise would have to be built among the school staff, or external companies would have to be hired to help. Lastly, having multiple systems, collecting, processing, and producing new data related to individuals would require appropriate privacy protection measures, which might be more difficult than in cases of IoT-based solutions for the general population since the majority of the school inhabitants are underage — the "vulnerable" subset of the population who might not be able to provide consent to data collection and processing.

1) Overcoming barriers

The present research asked about the barriers to using IoT-based solutions at schools (*RQ2*). Some of the experts who were interviewed talked about IoT's cost, data utilization, and limitations as examples of barriers. However, the barriers that experts mentioned more frequently relate to privacy and security issues. Hence, below, we discuss how such barriers could be overcome.

Rizou et al. [43] proposed the GDPR-based framework that could help overcome minors' privacy issues in the smart home environment. Although the framework is suggested for contexts different than the educational setting, its generic principles could be applied to schools. The framework consists of four main components. The first one is anonymization — the data controller must ensure that personal data is anonymized. If this first requirement is satisfied, then there is no need to apply further measurements. However, some research implies that complete data anonymization is difficult to achieve [44], [45]. Hence, this first requirement might be challenging to fulfill. If that is the case, the remaining three privacy-protective measures should be implemented: privacy by design (PbD), data protection impact assessment (DPIA), and parental control, minority and parental consent.

Privacy by design, in short, implies that privacy should be embedded in the system design and development process from the start. It should be rooted in the seven principles of PbD [46]: (1) Privacy should be proactive and preventive; (2) Privacy as the default setting; (3) Privacy embedded into the design; (4) Positive-sum (no trade-offs); (5) End-to-end security (full lifecycle protection); (6) Visibility and transparency; (7) Respect for user privacy. Moreover, PbD is also reflected in Article 25 of GDPR [47]. Developers are obliged to implement solutions following the PbD principles. Nevertheless, developers generally need support when it comes to privacy engineering and design, especially in the context of IoT, as it might be more challenging to implement PbD than in mobile applications and web-based services. Kuhtreiber et al. [48] surveyed the frameworks and tools that are available for IoT application developers. In the study, the existing solutions were classified into privacy guidelines, frameworks, and data flow tools based on nature. Some tools are helpful in assisting developers with engineering privacy. The data flow tools are useful for tracking sensitive data during the system's design and covering all IoT layers. However, the study showed that the existing solutions are still insufficient. Automated tool support is highly recommended to increase the adoption of privacy guidelines and frameworks for IoT, which are currently only envisioned.

Similarly, Data Protection Impact Assessment (DPIA) — another element of the recommended framework — is rooted in the GDPR, Article 35, stating that "Where a type of

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processing, in particular, using new technologies, and taking into account the nature, scope, context, and purposes of the processing, is likely to result in a high risk to the rights and freedoms of natural persons, the controller shall, prior to the processing, carry out an assessment of the impact of the envisaged processing operations on the protection of personal data." [47]. The Rizou et al.'s [43] framework lists factors of applying the DPIA in smart home environments, where the vulnerability of children is present, together with systematic processing of big data, automated decision-making, and the IoT is considered an innovative technology that carries potential risks to privacy. A similar approach could be used in the context of IoT-based solutions in schools.

The last element of their framework might be the most problematic to apply in the context of school. The parental controls might be easier to apply in smaller networks of devices, where data subjects are more likely to be members of one family/group. Moreover, obtaining informed and meaningful consent from persons holding custody of the students might be challenging, as well as assessing the responsibilities of school staff in the physical absence of custodians.

2) Utilising data to create benefits

The last research question of the present research was concerned with the benefits that IoT-based solutions would bring to schools (*RQ3*). According to our respondents, embedding IoT in schools could help with task automation, reduce the workload, and improve the efficiency of school staff, for instance, teachers, maintenance, or cleaning personnel. Moreover, students and teachers could benefit from a variety of teaching and learning methods that IoT could introduce in the classrooms. Similarly, school safety could be improved with non-privacy-invasive monitoring techniques, e.g., infrared cameras or alarm systems.

Although some of the benefits are obvious, it is hard to say whether the real-life implementation of the systems that monitor school occupants would be accepted. Past research shows that, for instance, in the context of IoT used to monitor workers' mental workload, people express concerns about such technologies, i.e., instead of bringing benefits, it could further the technological dependencies or collected information could be used to affect judgments around the workers performance [49]. The ubiquitous data collection and surveillance in the context of IoT and employment was shown to bring discomfort related to being watched [50]. Still, such concerns could be overcome when privacy and security measures are in place (e.g., anonymity, description) and the benefits of applying IoT (e.g., improved mental health) triumph over the risks.

The identified benefits all relate to two ways of using business rules related to well-being in the school context, one by using IoT solutions to increase well-being and the other to give information for increasing decision-making with well-being in focus. Even though they are split into two ways, the decision-making is in focus. For the implemented business rules in the IoT solution, the decision has already been made on how to focus on well-being, and the IoT solution is an outcome of that decision. One such benefit is the safety part, where, for instance, the decision to approve air quality is implemented in the IoT solution. The other focus is to use IoT solutions to give enough and the correct information for decision-making, e.g., adding to what and how much food is prepared to minimize food waste.

Another perspective of the benefits is who contributes to the data. The sensors mainly create the data, adding facts and statistics to the business model. There is one proposed benefit where the input comes from the users: feedback on conducted teaching. The latter could be one input to the teaching, adding subjective data as input to the teacher. Even though that data could be complex to use in decision-making, it could be the foundation for discussion, adding to improving teaching.

B. PRACTICAL IMPLICATIONS

Various work groups can apply our research findings in practice. On a strategic level, school management, such as headmasters and CIOs, can draw inspiration from our work. Other roles that can benefit from practical implications are system developers and designers. In Table 4, we propose a suggestion of specific work roles that could benefit from our research findings despite their exploratory nature. Note that this is only a suggestion, and it is not an exhaustive presentation of practical contributions.

1) Business and business models barriers

The empirical material shows that management is needed in several ways. One such direction is the strategic direction of using IoT solutions to improve the school environment and enhance well-being. The described comparison between various resources, such as teachers or IoT solutions, is always challenging without referring to strategic governance pointing to specific investments [51]. The empirical evidence strongly supports the need for effective management in various areas, with strategic use of IoT solutions emerging as a critical direction to improve the school environment and enhance well-being.

Additionally, qualitative benefits take time to predict, adding to the complexity of decision-making [52]. One important area is the strategic use of IoT solutions to enhance the school environment and promote well-being. Comparing different resources, such as teachers and IoT solutions, is always a challenge without specific investments being considered through strategic governance. Strategies can guide decision-making and lay the groundwork for internal discussions. When formulating strategies, it is essential to provide business cases for specific IoT solutions. Respondents emphasize the importance of comparing different options and developing an IoT strategy based on the overall goal and aligned with governing documents. Business cases often involve cost-benefit analyses, typically based on immediate measurements and excluding qualitative benefits. Quantifying well-being in a cost-benefit analysis is complex due to its limited monetary measurements. Efforts are required to

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TABLE 4: Suggested work role-based practical contributions.

Work role	Practical implication
Politicians/Educational decision-makers at the national or regional levels	A better understanding of how school students and staff needs might be fulfilled. Such knowledge might be applied in the development of IoT strategies and policy-making.
Headmaster and CIO	Creating and implementing local IoT strategy.
CIO	Governing IoT implementation.
Chief architect/designer	Understanding and development of IoT architecture according to defined requirements.
Systems developer	Understanding and implementing end-user requirements in the school environment.
End-users	Exposure to end-user-centric IoT-based solutions. Simultaneously, providing more data that could be used to improve IoT-based solutions in schools.

include well-being in a cost-benefit analysis, such as creating scales based on questions or incorporating improvements in efficiency and students' performance as quantifiable benefits [52]. In addition to the challenge of creating such scales, qualitative benefits are hard to predict and easier to understand while being realized. The decision to implement or not, therefore, relies on implementations in use and them being transferable to the current organization.

Besides showing a way, strategies can be provided while communicating and can, before deciding, form a foundation for internal discussions. While strategies are formulated overall, it is essential to provide business cases for specific IoT solutions [53], [54]. The respondents emphasize the perspectives of weighing different options against each other instead of introducing a portfolio perspective formed by the IoT strategy. A portfolio perspective could include steps towards the goal in the current strategy, evaluated based on the governing documents. Both the portfolio perspective and the individual steps are formed by business cases, indicating which alternative to choose [54]. The business cases often include cost-benefit analyses, usually determined by momentary measurements, excluding qualitative benefits. Well-being holds few monetary measurements, affecting its inclusiveness as a benefit in a cost-benefit analysis. Therefore, including well-being in a cost-benefit analysis requires efforts, such as creating scales based on questions or addressing improvements in efficiency or students' performance as indicators and including them as benefits [53]. Besides the effort to create such a scale, there are qualitative benefits that are hard to foresee.

2) Data management

The IoT solutions create data that focuses on various aspects of well-being in school, exemplified by the empirical material. As such, the content and quality of the created data vary [55]. Data management is therefore required to overcome the barrier of understanding the data, creating usable visualizations for the end-users, understanding the users' need for data, and applying existing legislation related to data. Data management can include various perspectives, e.g., data strategies, data storage, data integrations, and master data. Governance and resources are needed at the central and local levels to maintain data management. In the school context, the limited availability of resources, such as data scientists and usability designers, can hinder the development of the most efficient IoT solutions. The use of IoT solutions generates data that focuses on different aspects of well-being in schools, as evidenced by empirical material.

VI. CONCLUSIONS

The present research aimed to assess whether IoT-based solutions fulfill the needs of users within the school contexts, considering multi-stakeholders as users (i.e., school staff and students). Moreover, the research aimed to identify the barriers to applying IoT in schools and how schools could benefit from IoT-based solutions. We identified that the different stakeholders' requirements could be fulfilled if IoT-based solutions at schools considered different functional and non-functional requirements identified by the experts. We suggested the layers of IoT architecture in which such requirements should be tackled (as presented in Table 3. Moreover, the experts interviewed in the study described a range of possibilities on how IoT-based solutions could look and be applied. Although the described solutions could bring well-being-related benefits to school inhabitants, such as improving work conditions and efficacy of teachers and health staff, enhancing the learning process, or positively affecting students' diet and other health-related matters, we identified the main barriers against implementing such solutions at schools. The significant barriers relate to security, privacy, and limitations of IoT. The issues related to the cost and utilization of information that IoT produces and the lack of skills and competencies to interpret it correctly were also identified as barriers to using IoT-based solutions at schools. Simultaneously, other benefits were identified, including automation, increase in safety, waste management, and improved decision-making. However, considering the barriers, technical and managerial mechanisms are needed to overcome them; for instance, a careful cost-benefit analysis is necessary to assess whether a given school environment (including personnel) is ready to handle such solutions and learn from the information they may produce. Moreover, the decision has to be made whether the risks associated with introducing IoT systems processing information from minors are small enough compared to the benefits.

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