Using privacy-friendly crowd counting sensors to create a smart environment for education

Paul Boersen

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Abstract

Privacy is very important in the 21st century. One way of offering this is via anonymity. Currently, most crowd counting sensors use video footage, which can't offer this. This research aims to create a privacy friendly non-image based crowd counting sensor and use it to create a smart environment for studying. This is done by researching available non-image based crowd counting methods and findings of students' study space preferences. Then, an ethnographic interview of users of the study space is performed, after which brainstorming is done to create smart environment ideas. Afterwards, the product is realised using functional and nonfunctional requirements, and evaluated using experiments and interviews. Plans for improvements and further work are made. It was found that offering insight into the usage of a study space might be useful to users, by showing them how much room is left and inviting them to visit. This can be done via a website, where data is best displayed using graphs that show expected usage of rooms throughout the week. Also, a screen that visualises how busy a room is might connect different parts of the building to make rooms more interconnected and invite people to socialise. Furthermore, using crowd tracking might enable users to see what facilities are available. Crowd counting data for this purpose can best be measured using a passive infrared sensor located in the doorway combined with another sensor which makes estimations based on current measurements only. Finally, passive infrared sensors do not work as well on people wearing headwear.

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Contents

List of Figures

List of Tables

1 Introduction

Crowd counting solutions are often used for HVAC (heating, ventilation, and air conditioning) energy reduction [3], public transportation [4], and reducing possibility of infection [5]. Many types of crowd counting technologies have been created [6], which track crowd numbers with many different types of data, like sound levels, temperature, or air quality. Besides crowd size, this data collected can pose other valuable insights on what is happening in the room as well. By using this data in an opportunistic way, the data may be used for other purposes, like creating a smart environment. An example of a smart study space was made by Jou [7] where students were observed using sensors to identify how they learn and what goes wrong, to help them overcome problems in the future.

The context for the design and implementation of these interventions will be the Interaction Lab in the University of twente [8]. The Interaction Lab provides technology and space for students and researchers to work on their university projects. Sometimes, events are hosted there to educate students about technology and show to students what the Interaction Lab offers. The Interaction lab consists of two main rooms, the lab space on the ground floor and the tower room on the first floor where there is space for studying and using technology. There are also meeting rooms and project rooms around these spaces. Although the lab is available for all students, it is mostly used by Creative technology Bachelor students and Interaction technology master students. For identifying moments of congestion, and finding data on space use throughout the week, it is asked to create a prototype for a crowd counting tool. This is where the prototype will be tested.

Besides making a tool that counts people, a smart environment will also be made that enhances the experience of users. A smart environment is an application of ubiquitous computing, first introduced by Mark Weisser [9]. This is a system that has interconnected sensors and computers that make the experience of users better, without users actively noticing. In this research, the crowd counting sensor will also be used to create a smart environment that makes the experience of users better. The prototype will be installed in the tower room, which is primarily a study space, so most likely, options for creating a smart environment to enhance study experience will be made.

In the information revolution, information security is a foundational ethical issue [4]. Often, sensors are directly connected to the internet, where they can be accessed by malevolent users if they are not protected well enough. When these sensors collect private information, this poses potential privacy violations. Collecting data that is privacy-friendly, like data that is not personally identifiable, averts this problem.

Traditionally, Image-based crowd counting is a very powerful tool for sensing data on the number of people [6]. However, the data recorded contains much privacy intrusive information, as the data is not only personally identifiable but captures almost everything that happens. Also, cameras are costly to install and require heavy image processing. As a response to this, research is being performed on non-image based solutions that offer opportunities for crowd counting that works with more privacy-friendly data and cheaper, simpler sensors [6]. The cost of installing cameras and the data processing might be unsuitable for this project. Also, because of the data security opportunities offered and relevance of non-image crowd counting research, this project only focuses on non-image sensing technologies.

Non-image sensing technologies are subdivided into two categories: device-based and device-free [6]. Device-based technologies require users to carry technology to be counted. This technology could range from phones and laptops to RFID tags. Device-free technologies don't require users to carry devices to be counted; they are counted by the way their presence influences the environment.

The goal of this research is to create and evaluate an information secure prototype for a smart environment that uses non-image crowd counting to track the amount of people in the interaction lab for the purpose of analytics and improves their experience. To guide this research, the following research questions are identified:

How to create and evaluate an information secure prototype for a smart environment that uses non-image crowd counting to track the amount of people in the interaction lab for the purpose of analytics, and improves their experience?

1. What opportunities can be drawn from research to do this?
   (a) What are the evaluation criteria for state-of-the-art crowd counting sensors to track the amount of people for the purpose of analytics in the Interaction Lab?
   (b) How well do state-of-the-art crowd counting sensors fit the criteria?
   (c) What are opportunities from literature for improving study environments for students?
2. What is a promising project idea and its functional requirements?
   (a) What are the opportunities for improving the experience of users of the interaction lab?
   (b) What is a good project idea?
   (c) What are the design requirements of this project idea?
3. How to realise the specified project idea and functional requirements?
   (a) What technology best fits the design requirements?
   (b) How to build a prototype for this realisation?
4. How to evaluate the built prototype?
   (a) Does the system fulfill the functional requirements?
   (b) Does the system enhance the experience of users?
   (c) Are there any ethical concerns?

In chapter 2, background research is done to answer research question a. In chapter 4, Ideation is done to answer question b i and ii. In chapter 5, question b iii is answered by making design requirements. In chapter 6, question c is answered, and in chapter 7, question d is answered through evaluation.

2 Background Research

The background research featured in this chapter was featured in a literature review performed for the course Academic Writing. In the first part, the text has been made much more detailed and explanatory. The second part has been completely rewritten. The third part has slight changes based on feedback. The fourth part was made much more detailed and explanatory.

2.1 Evaluation criteria of crowd counting sensors

2.1. Evaluation criteria of crowd counting sensors To answer the subquestion to the first research question, "What are the evaluation criteria for state-of-the-art crowd counting sensors to track the amount of people for the purpose of analytics in the Interaction Lab?", six evaluation criteria are defined. These criteria are based on what is important in existing research, and used to evaluate what sensors are useful for the scope of this project. Afterwards these criteria are applied to identified sensors to see which sensors can be used for this project.

The first criterion is cost: The monetary and time cost of developing, installing and maintaining sensors can vary wildly. Some sensors need extensive machine learning specific to where they are installed, making them very costly due to the need for advanced statistics to develop them and machine learning experts to install them. An example of this is RSSI (Received Signal Strength Indicator) sensors that use WiFi signal strength: These sensors use data that can only be interpreted by advanced statistical models and is very much affected by the shape of the room [10]. Interestingly, RSSI sensors opportunistically use WiFi devices that are often already in place, so the components are very cheap to install. Other sensors use expensive components, which also make them costly to install. For example, LiDAR (Light Detection And Ranging) sensors use laser sensing, a technology which is quite expensive [11]. Some sensors use very simple algorithms and cheap components, like PIR (Passive InfraRed) sensors making them have a low cost [1]. For this project, it is important that the monetary cost of the sensors is reasonably low to be able to fund the research. Because the Interaction Lab only has two rooms that need to be assessed, the installation costs are relatively unimportant.

The second criterion is invasiveness: Some sensors don't need any invasive technology, whereas others do. Invasiveness denotes how much extra technology users need to carry before they can be counted. Device-free methods don't need the users to carry technology, but device-based methods do [6]. Many device-based methods use mobile phones, because of how many people use them. Some device-based methods require users to carry wearable devices, like RFID tags [12]. For this Project, it is important to be able to count people that don't use the Interaction Lab very often, so providing users with wearable devices is not an option. Therefore, the invasiveness needs to be kept relatively low.

The third criterion is scalability: It is desirable for sensors to work for multiple group and room sizes. Being able to perform in many contexts makes a sensor scaleable. Many sensors become less accurate when measuring more people. With RSSI sensors, for example, the data becomes harder to interpret when there are more people in a room [10]. Also, in RSSI sensors might not work in a bigger room. On the contrary, D2D (Device-to-Device) sensors only work when there is a large crowd. For this project, scalability is reasonably important. The sensors should at least be able to accurately count 0 to 20 people and work in the rooms the size of the Interaction Lab

The fourth criterion is latency: For many use cases of crowd counting it is desired to recognize changes in crowd size immediately. Latency denotes how long it takes for a system to note changes in people count. Most sensors have no noteworthy latency, like PIR sensors that are installed in doorways [1]. Hybrid sensors use a combination of air contents like CO2 and temperature data, which is influenced by the presence of humans [13]. Changes in the air content and temperature take some time to happen when humans enter or leave a room, so these sensors have quite some latency. In this project, latency is not very important for finding moments of congestion, but it might be important for making a smart environment.

The fifth criterion is accuracy: This represents the error margin with which a sensor counts the amount of people. Almost all research on sensors reports the accuracy of the sensors: There is a review entirely focusing on different methods to increase accuracy of the amount of people in sensors [14]. For this project, to find meaningful data on the moments of congestion, the sensor's accuracy is relatively important.

The sixth criterion is reliability: A sensor is reliable when it can't be fooled by malicious users. This criterion is rarely covered by research. Some sensors are really easy to fool, like PIR sensors in doorways, which don't notice the difference between one person walking through, or two people walking through closely [1]. A hybrid sensor was developed for situations where reliability is very important, like inside a bank vault [13]. For this project, reliability is unimportant for finding data on crowd count, because it is unexpected that users will be malevolent. However, for a smart environment, reliability might be important.

The seventh criterion is privacy: A sensor offers more privacy when less personal information is sensed about the people being counted. For many non-image based crowd counting approaches privacy is not a problem, because the data that is sensed is not PI (Personally Identifiable) data. This means that even with the raw data sensed, nothing can be done to find out who was sensed. For some approaches individuals may still be identifiable, like with LiDAR sensors, which can provide very accurate information about the shape of what is being sensed [11]. Because research done on non-image crowd counting is often in response to the invasiveness of image based crowd counting, almost all non-image based approaches report on privacy. For this project, privacy is very important.

2.2 State of the art crowd counting sensors

In a survey of Kouyoumdjieva et al. non-image based crowd counting sensors are classified into 17 types [6]. To answer the research question "How well do state-of-the-art crowd counting sensors fit the criteria?" all types of sensors are evaluated on all criteria where data could be found about it, and a selection of the most promising sensors is made. To evaluate the sensors the most well-performing sensors in literature are identified and given a score "- -", "-", "+" or "++" for each criteria, based on how well-suited the sensor fits the requirements of this project. When two different sensors of one type perform better than each other in different criteria, the best performing sensor is considered for each criterion. When no data could be found, the score "no data" is given. Also, a short description of each sensor is given. The evaluation can be found in table 1.

PIR (Passive InfraRed) sensors perform great at almost every criterion. These sensors use many infrared sensors that form a grid that recognizes the temperature of the surface they are facing. When a human enters the room as shown in figure 1, the sensor recognizes the shape of where there are warmer temperatures of users entering and leaving, as shown in figure 2. These sensors have especially low cost due to cheap components and simple counting algorithms [15]. Because PIR sensors are device-free and don't record PI information, no invasiveness or privacy concerns are present. Because the Interaction lab has standard doorways, the PIR sensors can be installed there easily to provide for good scalability, and there is no latency because every change in the amount of people in a room is immediately noticed. Besides this, PIR sensors have proven to have great accuracy, reaching up to 100% accuracy under the right conditions [1]. A potential drawback is that PIR sensors can be fooled easily and intuitively. For example, when malevolent users leave the room clumped tightly together, the sensor will only recognize one user leaving the room. The users can then enter the room again separately to artificially increase the amount of people in the room. Because users are not expected to do this, the sensor still performs reasonably well on reliability. However, if the smart environment provides reason for users to deceive the system, this is of concern. Because of these reasons, if there are no concerns about reliability, and the smart environment requires only data on crowd count, the PIR sensor is an obvious choice.

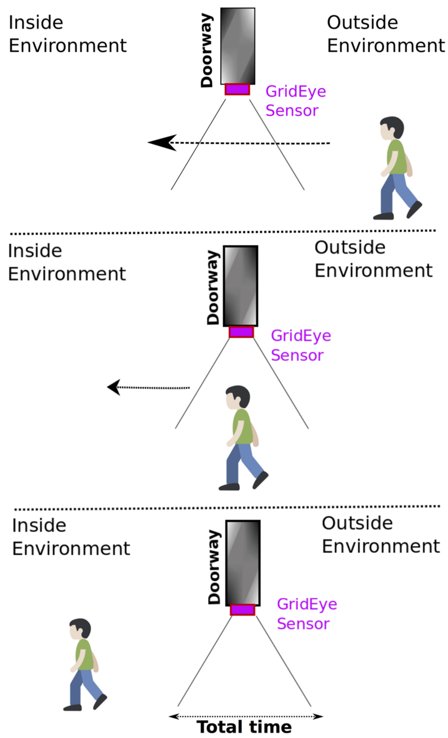


Figure 1: human entering room [1].

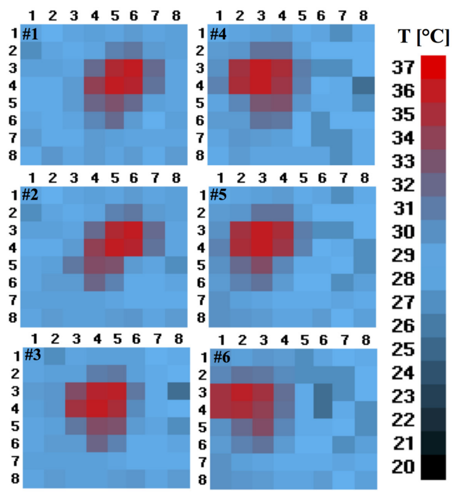


Figure 2: sensor recognizes human temperature [1].

Type	**Description**	**Cost**	**Invasiveness**	**Scalability**	**Latency**	**Accuracy**	**Reliability**	**Privacy**	**Source**
RSSI	Measures the power level a WLAN Access point receives from another. This gets worse when there are more people	-	++	-	++	+	No Data	++	[10]
CSI	Channel State Information is like RSSI, which considers information on different paths between access points to have more information about its surroundings	-	++	++	++	++	No Data	++	[16]
UWB	Works with low frequency, like a radar. Sends pulses and measures distance based on delay of when they return	- -	++	+	++	+	No Data	++	[17]
PIR	Motion sensors at entrances count when a user enters or leaves to infer occupancy	++	++	++	++	++	+	++	[15]
LED	Occupancy is inferred from the reflection of light on the floor. When a person is on the floor, this reflection is less.	- -	++	- -	++	+	+	++	[18]
Acoustic	A sound is sent out and signal decay is measured; this is higher when there's more people.	+	++	++	++	+	No Data	+	[2]
CO2	CO2 level is measured	+	++	+	+	+	No Data	++	[19]

Hybrid	A multitude of environmental parameters such as CO, CO2, temperature, humidity are combined to create more accurate sensors	-	++	-	+	+	+	++	[13][20]
LiDAR	LiDAR allows for making images with distance information. Based on technology that tracks the location of individuals, Kouyoumdjieva et al. theorize a low resolution LiDAR solution that counts only the occupied parts, not the shape of what is sensed, and are therefore non-image based	- -	++	No Data	++	++	+	-	[11]
Tones broadcast	Mobile phones use an application to communicate with each other and track each other using their microphones and speakers	+	- -	-	+	+	No Data	++	[2]
Speech recognition	Mobile phones use an application to count users based on recognizing different speech patterns	+	- -	-	+	+	No Data	-	[21]
RFID	RFID readers count users that carry RFID tags	+	- -	+	++	+	No Data	-	[12][22]

WSN	Many sensory nodes carried by users configure a Wireless Sensor Network that communicates using radio signals	+	- -	++	++	++	No Data	-	[23]
Wi-Fi	The WiFi connection requests from devices like mobile phones is counted	++	++	++	++	+	+	+	[24]
Bluetooth	Bluetooth scanners scan the area for devices with Bluetooth on, to infer crowd size	++	++	++	++	+	+	+	[25]
Cellular	Cell phone connection information is collected at cell towers to count the amount of cellphones in an area	- -	++	- -	++	++	+	+	[26]
D2D	Mobile phones communicate with each other using Bluetooth or WiFi to create sensory networks	++	- -	- -	++	+	+	+	[26]

Table 1: Comparison of Various Crowd Counting Technologies

Acoustic sensors also offer a great fit for this project. These sensors use ultrasonic audio signals called 'chirps' and listen for the sound strength when they return, as seen in figure 3. When a human interferes with the sound trajectory, the sound is not returned as loud resulting in signal decay. When more people are in the room, there is more signal decay. The sound needs to be filtered and multiple statistical analysis need to be done on the input, resulting in a reasonable cost for development [2]. Acoustic sensors have no invasiveness or latency concerns. Even though the accuracy of acoustic sensors goes down in larger rooms [2], the rooms in the Interaction Lab are not big enough to cause this effect to happen. The Accuracy of acoustic sensors is reasonable, with a room of up to 30 persons having an average error of 1.6% [2]. However, there are ways to lower the accuracy of acoustic sensors by interfering with the sound trajectory, for example by opening doors or windows [2]. This allows for malevolent use to happen to acoustic sensors, giving it only a reasonable reliability. Finally, because recorded sound is personally identifiable and is a personal matter, it is important to make sure that unintentionally recorded sounds are protected and filtered out. Acoustic sensors may offer opportunities for smart environments that interact with noise levels, as well.

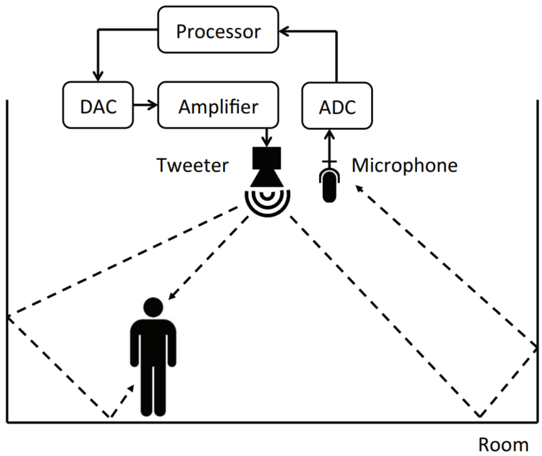


Figure 3: working of Acoustic sensors [2]

Hybrid sensors are often developed to opportunistically use multiple sensing options provided by existing infrastructure in buildings. They perform statistical analysis on many different environmental data influenced by the presence of humans, like CO2, LPG, NO2 and SO2, temperature and humidity [20]. Even though in the case of opportunistic sensing there are no material costs, because of the training required and statistical analysis performed, the cost is quite high. Though research up to this point has not provided evidence for effectiveness of hybrid sensors in rooms as big as the Interaction Lab, research on CO2 sensors has [19]. Because hybrid sensors often use CO2 as one of their parameters, it is reasonable to assume hybrid sensors are able to perform in scalability like this as well. Hybrid sensors have some latency in recognizing changes in crowd size, but unless low latency is required by the smart environment, this should not be a problem. Hybrid sensors show the potential for great accuracy, in some cases reaching an accuracy of up to 95% [20]. However, this accuracy was only proven in a small room with limited participants, so it may be lower for the Interaction Lab. Research on hybrid sensors is the only research to explicitly consider reliability, being researched because of their use of environmental data that can't always be altered by malevolent users easily, even when hidden away from users [13]. However, in the Interaction Lab, users may still influence environmental data by opening windows or activating HVAC devices. Also, hybrid sensors have no privacy concerns. FInally, environmental data might be useful for creating a smart environment, because data like humidity, air quality and temperature might be important.

Wi-Fi sensing is a very cheap and opportunistic way of sensing. By counting the amount of connection requests to access points that are already in place, it is a very simple algorithm that does not need any installations, resulting in a great cost. Because it is expected most users of the Interaction Lab have a smartphone with Wi-Fi on, there is no need for invasive technology. Wi-Fi can offer crowd counting for the amount of people in the Interaction Lab at a reasonable accuracy. There are some problems involving rooms however, as devices might connect to an access point in a different room or floor, resulting in false information at times [24]. This can perhaps be fixed by placing an access point only for sensing in each room. Also, there are opportunities for increasing the accuracy of Wi-Fi sensing by having more advanced algorithms, but these have not been developed yet [24]. A malevolent user would easily be able to deceive the system by turning off their Wi-Fi adapter. Finally, it is important to make sure no personally identifiable data like MAC-addresses is collected to protect the privacy of users.

In this project, the sensor cannot be too expensive, or require too much training, so any sensor in table 1 with a - or - - in cost is not used. Because privacy is so important to this research, also only sensors with a + or higher in this category are considered. In the leftover sensors, the 5 sensors that score highest on all the other categories are considered eligible for this research. These are PIR, Acoustic, CO2, Wi-Fi and Bluetooth.

2.3 Opportunities for smart environments in study spaces

This subchapter answers the subquestion "What are opportunities from literature for improving study environments for students?". Because the target audience is students that come there to study, a review on study spaces on campus is performed. The crowd counting sensors that could interact with the identified desires or problems are listed.

Even though there are many different spaces for learning, almost all research on study spaces on campus focuses on academic libraries. Harrop & Turpin [27] find people choose a wide variety of study locations based on their own needs and preferences, whether this is in the library or not. Even within the library, there is not one type of preferred space [28]. This shows that investigating study locations besides the library is very important.

The importance in researching different study locations is reflected in the different desires in ambiences. Students report that working in a library alongside others gives a sense of common purpose [27] or makes it easier to focus [28]. In a quantitative study performed in a library, noise level and crowdedness were identified to be the second and third most important factors in choosing where to study [29]. From this study, it is not clear what the preferred noise level or crowdedness is. Students generally prefer libraries to be quiet [30], but some students like an ambience with more sound, buzz and activity [27]. According to [27], who also quotes Hunley and Challer, to redesignate the type of ambience in a study area, physical reconfiguration is needed. To create a smart environment, all crowd counting sensors can provide data on crowdedness, and acoustic sensors can provide data on sound levels.

There are many sensing opportunities related to study environments. Having good/natural lighting is important to many students [30][27], And having a view of the outside and fresh air is preferred [27]. When it gets colder, students also appear to find temperature more important [31][28]. Women find temperature significantly more important than men [29]. Students prefer to have plants around and have the library look like a homely environment [32]. Students say they focus better in the library because there are no distractions [28]. Hybrid sensors and LED sensors work with temperature, air quality or light levels, offering opportunities for smart environments that react to these factors.

Students find the availability of study rooms very important. Study rooms are very popular for providing privacy [33][27]. Students appreciate having the space to work in groups [32][34]. It is common for students to work alongside friends [29], going to places their friends will likely go [27]. Near the exam period, group studying increased [28][33]. When working with groups, study rooms are popular because it provides students a place to talk, where they don't have to listen to others around them also talking [33]. For project work with unfamiliar students, group spaces are a nice location, because it is seen as neutral ground [27]. Students like to take their time while studying. 55% of students stay over 3 hours in the library [29], and desire for the library to be open very late [27]. Students preferred locations that had consistent availability [27]. Also, booking project rooms is very popular, but last minute availability is also important [27]. Providing data on the occupancy of study rooms is therefore very useful to students, which can be done with crowd counting.

There is a lot of data on the furnishing desires of students. Many students reported wanting outlets to plug in their electronic devices[19][32][34]. This is reflected by a study that shows that students with laptops use areas less if there are no outlets [33]. After a renovation, it was found that new outlets were the most popular feature [35]. In another study a renovation was performed, adding more outlets, and even though the outlet demand went down, it was still one of the main demands [34]. Also, students seem to find it very important to have big tables [27][30]. Students also asked for printers [30][27], good desktops [32][30][27] and large screens for project work [35][27]. Comfort of furnishing is also very important [29]. Whereas some students prefer active chairs [27], others prefer comfortable chairs [27][32]. For privacy reasons, some students specifically choose seats in the corner of the room [27], and some students would like to have moveable partitions [32]. Students that want privacy use cubicles when there are no study rooms available [33]. It would be a possibility to create a crowd counting option that records what furnishing options are in use, to create a smart environment that can help students know where there are resources available.

Adding to furnishing, there seems to be conflicting data about comfortable chairs. In one study, it was found that although many students expressed the desire for comfortable chairs, the comfortable chairs offered were rarely used [30]. This might suggest that students don't always know what they want. Another study also found that their comfortable chairs were rarely used, but realised those did not have access to outlets and tables [31]. This might suggest that wrong conclusions may be drawn when one makes an oversight.

Another study found that after they improved their comfortable chairs, the users found the space met their comfort needs [34]. This suggests in turn that students do know what they want. It can be concluded that while it can't be assumed that end users always know what they want, researchers may also make an oversight in making these assumptions.

2.4 Conclusion of background research

To answer the subquestion "How well do state-of-the-art crowd counting sensors fit the criteria?" it is sufficient to look at the scores given to the sensors in the evaluation.

The sensor that scores best on most criteria is the PIR sensor. This sensor fulfils all the needs for creating a working crowd counting intervention. It also offers opportunities for a smart environment: Having the right level of crowdedness in a room is very important to students. If the smart environment requires reliability, this is not something the PIR sensor can offer very well, however: The sensor can be fooled by malicious users. Because reliability is not often considered in research, there is not much data on what sensor would be more reliable. Also, most of the sensors that scored well and have been explained in detail can be deceived quite easily. One way of increasing reliability would be to combine different sensors, to make it harder to deceive all of them.

To combine different sensors for more reliability, it would be nice to use sensors that perform well in the cost category, to make it possible for this research. Wi-Fi sensors could be a great option for this. It seems affordable for this research to create both a PIR sensor and a Wi-Fi sensor for more reliability, if that is required by the smart environment.

To answer the subquestion "What are opportunities from literature for improving study environments for students?", three opportunities that might be enhanced with sensors were identified:

The first identified opportunity is noise level. For students, having the right noise level for studying is important. A smart environment that interacts with this can be created using an acoustic sensor. An acoustic sensor alone could also fulfil the requirements of finding moments of congestion. This limits the possibilities of smart environments in other ways, however. As they are more costly to create, it might not be possible to combine this sensor with another to get better reliability, should that be required. Also, if the smart environment requires high accuracy, this might also not be possible to provide.

Also, literature points out temperature and air quality may be important to users of the interaction lab. An opportunity for sensing this can be done by creating a hybrid sensor. There are also drawbacks to this, however: creating a hybrid sensor costs a lot of time, which might not be possible in this research. Also, there is no direct evidence hybrid sensors work in a room the size of the Interaction Lab. This might still be possible, because CO2 sensors, which are a component of many hybrid sensors, have proven to work in rooms of this size. Also, hybrid sensors limit the possibility of creating smart environments that require high accuracy or low latency, because these are not great strengths of hybrid sensors. It seems outside the scope of this project to combine hybrid sensors with another sensor for more reliability, so this also can't be provided, should this be required.

Finally, the availability of devices and specific furnishing is also important to students. Therefore, a solution that measures what devices and furnishing are used offers a possibility for smart environments. The studied crowd counting devices do not offer a sensor for this, however. If this were to be implemented extra research would need to be done on location sensing or activity identification [36]. Location sensing could track where users are, and from this data identify what devices or furnishing is used. Activity identification could be used to identify what users are doing, and from this data learn what devices or furnishing is used. Then, the data provided by these sensors could be used to learn about moments of congestion as well. This seems complicated to implement, as location sensing or activity identification are not the most straightforward ways of solving the research questions. However, if from ideation is learned that information about what devices and furnishing is used is very important, then this is an option.

3 Methods and Techniques

For this project, the design process for creative technology by Mader and Eggink [37] is applied to this project. This design method combines cyclical approaches with a divergence and convergence design method to provide structured design steps.

This means that the first step, Ideation, has a goal to find an elaborate project idea and define requirements of this idea for the specification phase. To do this, early ideas are identified based on information found in background research. Then, the needs and wishes of stakeholders of the Interaction Lab are evaluated through exploratory, semi-structured interviews. During these interviews, the ideas are discussed as well. Then, a brainstorm is performed where 50 ideas are generated to fulfil the needs and wishes of stakeholders based on the interview results. These ideas are then intuitively ranked on how well they would fulfil the needs and wishes of stakeholders, and how ethical they are. The most promising ideas are discussed with stakeholders, to find an elaborate project idea. Requirements of this idea are then generated based on what user needs and wishes it fulfils, and the requirements of the client.

In the second step, specification, the idea is further refined by setting up function requirements. To do this, first an initial list of function requirements is created. Then simple prototypes are created through methods like tinkering, pen and paper prototypes or wizard of Oz techniques to do a preliminary evaluation of function requirements that might not be possible. Finally, the function requirements are evaluated with the findings of these prototypes and use scenarios. This may lead to changes in the function requirement or the addition of new problem requirements. When the prototypes seem to show the function requirements are realistically possible, the project specification can be concluded.

In the third step, realisation, the prototype is put together. This is done in a linear fashion, where the realisation process of the prototype is performed in a logical, fixed order. First, a logical order is created through consideration of what the most important parts are to make sure the prototype can be evaluated throughout the building process. Also, parts that are likely to need more consideration when building, as they might be less likely to work, are built first. When a building decision appears to not work, the building process can be backtracked to go in a different direction.

The final step is evaluation. In this step, user testing and functional testing is performed, to see whether the prototype fits the requirements and answer the evaluation research questions. This can be done by showing prototypes to users, doing interviews and surveys, and by pilot testing. In this step, recommendations for future work are generated.

4 Ideation

In this chapter, an elaborate project idea is determined and the problem requirements of this idea are defined. First, early ideas that came up during background research are identified. Then, the setup of an exploratory, semi-structured interview to find the needs and wishes of users of the Interaction Lab is explained. During this interview, questions are asked about what users do in the Interaction Lab, why they do it, and what they would want to change. During these interviews, the ideas are discussed as well. The results of the interview are then given and discussed. Then, a brainstorm is explained, and the results are given and evaluated through intuitive ranking.

4.1 Early ideas

During background research, some two ideas came up. These ideas are based on the opportunities for creating smart environments that were found in background research. When the ideas came up, they were written down, so they could be discussed in the interviews to see whether users like them and figure out how accepting users are towards smart environments.

The first idea is to help users decide whether they want to work in the Interaction Lab. Because it was found that students decide where to work based on topics such as crowdedness, noise level, temperature and air quality, the idea is to provide them with this data through a web application. This web application can be accessed by the user before deciding to go to the interaction lab, and this will show them one or multiple of these data points. This helps the user get insight on whether they want to go there to work there.

The second idea is to make sure the noise level is not too high. Because of the opportunities found with acoustic sensing, it seemed possible to make a smart environment that influences people to be quiet when they speak too loud. This will be done in either an obvious or not obvious way, depending on what is needed to have this happen.

4.2 Ethnographic interviews

In order to answer the subquestion “What are the opportunities for improving the experience of users of the interaction lab?”, an exploratory ethnographic interview is performed. In this interview, employees and students are asked about the topics brought forward by the background research. Also, since the interview is exploratory, it is expected that topics come up that have not been considered in background research, and some of these topics should be asked about in later interviews as well. For these reasons, a semi-structured interview is performed.

4.2.1 Demographics

In order to determine potential differences between groups of stakeholders, questions about demographics are asked. When a group has significantly different desires from another group, knowing about these differences allows for better inclusion by catering to the needs of groups that may otherwise be in the minority.

Asking questions about demographics poses a moral dilemma. During the course Reflection, it was asked to think about moral dilemmas that show up during the graduation project, and the following dilemma was identified: Having more precise questions about demographics, like study year and age, will allow for better inclusion of users by identifying and adapting to the different needs for each group. However, having these precise questions makes the information personally identifiable, which makes it impossible to preserve the privacy of the interview participants against the supervisor of the research. The supervisor is also the organiser of the interaction lab and a lecturer of some possible participants. This puts the participants in a subordinate position against the supervisor, where the supervisor may lower their grades or otherwise misuse their power if the supervisor doesn't like the answers of the stakeholders. Also, in case of a data breach, having information that is personally identifiable, will make it hard to provide the participants with information security.

The questions about demographics also offer an interview design dilemma. When participants learn their identity may be revealed to the supervisor, they might answer things that they normally would not answer. This is because they may not feel free to show all their needs and wishes if they fear this might conflict with the desires of the supervisor. This would lead to the withholding of information or even false information being provided, which can greatly hinder the process and accuracy of the research.

The potential for inclusion offered by asking personally identifiable information is not very big: Because not a large number of participants will be interviewed, it is unlikely that significant differences between groups will be noticed. Also, it would be very problematic if participants did not feel free to show all their needs and desires. For these reasons, it was decided that personally identifiable questions about demographics would be asked.

Four questions about demographics are asked: Whether the participant is a student or employee, what study they do, whether they use the interaction lab regularly, and what gender they identify with. All of these questions seem to have large enough groups that it would be hard to personally identify anyone from this data. Participants are asked whether they are students or employers, because students and employees play a very different role in the university and in the Interaction Lab. Because it is expected that students that do different studies which are either bachelor or master studies have different needs and wishes, questions about this are asked. It is also expected that a participant that does not use the Interaction Lab regularly has very different desires and needs for studying in the Interaction Lab than one that does, so questions are asked about this. Finally the participants gender is identified because in the background research, significantly more women than men find temperature to be important.

4.2.2 Questions

For the interviews, questions about six uses of the Tower Room were prepared: Studying alone, studying in groups, group project work, spending breaks, meeting with friends/hanging out and performing user testing/interviews for projects. Because not much was known about the participants yet, it was decided to have the interview be semi-structured. This allows for focus on certain uses when they seem important for the research. Not all questions are covered by every interview: For every use, questions were only covered if the participant communicated something that makes their answer on the question seem important for the research. The question list can be found in Appendix A.

All participants are asked about how they use the interaction lab, and how they think others use it, to find out what uses of the interaction are already being done and can be emphasised for a better experience. Secondly, for each way a participant might use the interaction lab, participants are asked about what is important to them and why they do or don't do it in the interaction lab, to see what aspects can be emphasised upon for a better experience or to add extra functionality to the interaction lab. Then, participants are asked the early ideas, to reflect on how these might or might not be useful and learn how accepting users are towards smart environments. Then, participants are asked whether they would change anything about the interaction lab. To learn about their general wishes and desires. Finally participants are asked whether they have anything to add about the interview or the project, to see whether they can provide new opportunities.

4.2.3 Results

6 participants were interviewed. Of these people, 5 were students, and one was an employee. Of the students, 4 studied Interaction technology, and one studied Creative technology. All participants regularly used the Interaction Lab. 3 participants identified as men, and 3 participants identified as women.

Three participants used the Interaction Lab daily to study in a group. They were all working on their master thesis and worked together in the tower room. One participant regularly worked alone in the Interaction Lab, to have access to high-tech hardware and software required for their work. They also enjoyed being able to work in a group. One participant used the meeting room in the tower room for user testing, to have a space where they could leave their testing setup between tests. A final participant organised workshops in the Interaction Lab. One participant also sometimes borrows technology offered by the Interaction Lab. One participant explained that some users of the Interaction Lab also offer technical support for hardware provided by the Interaction Lab. Some participants pointed out that sometimes, people held a project meeting in the tower room, and user tests happen in the main room of the interaction Lab

The participants that studied in a group explained that they did this to find motivation for working on their thesis by making it a regular habit to work, and motivate each other. They also report it helps them focus to not be at home. Also, they appreciate the high quality devices and furniture the tower room offers. This group also takes brakes together, by taking a walk outside. Most reported trying to be there every day, and some showed desire to be able to motivate themselves to be there more often. Not all participants of the study group knew each other before making it a habit to study there: Some met in the Interaction Lab.

> "Studying together has as advantage that it is very fun and sociable, but as disadvantage that it is very fun and sociable" -Participant from study group

The participants of the study group pointed out that sometimes, when working together, they started a conversation. Two participants found this a problem, whereas a third did not. The two participants that found this a problem usually solve it by putting on noise-cancelling headphones while the conversation continues. When the participants of the study group were asked about the idea of pointing out when people are too loud, they generally reacted positively. They pointed out that they would want the intervention to be implicit rather than explicit. Also, participants pointed out that sometimes they learned the Interaction Lab was used for a workshop or lecture when they already arrived there. They solved this problem by noting down every week in their calendars when the events are, based on the calendar at the door of the Tower Room. The Tower Room is often not crowded, participants said there was a maximum of 10 people present, and that this was often less.

> “Others might say they will be there, but whether they are really there is not always the case. This morning there was noone at all” -Participant from study group

On the contrary, participants in the study group pointed out they were sometimes disappointed to arrive in the Tower Room and not find anyone else in the study group there. When asked about the idea that informs people how many people are in the room via a web application, a dilemma arose. On the one hand, participants pointed out that it would be nice to prevent disappointment from arriving in the Interaction Lab without anyone there, but on the other hand, participants pointed out it would be demotivating to go if no one was there. One participant pointed out the intervention would be useful if it ever got more busy in the tower room regularly. When members of the study group were asked whether they would want to change anything about the Interaction Lab, they pointed out that they wanted to have more people in the tower room regularly. They also pointed out that the tower room could be made more inviting: The tower room is hidden away in a corner of the building, disconnected from the main Interaction Lab room and has a door without a window. Finally, one participant pointed out they would like to have free coffee.

The participant that regularly held user testing, did so in a meeting room in the tower room. They did this here because they could leave their test setup in this room between tests, and that it was nice to always have the same room to test in. This helped with preparing for user tests as well. They pointed out that it is nice to have a room that will make the user feel comfortable. They pointed out that the meeting room in the tower room has bad sound isolation. This poses a problem when it is busy in the tower room. They reacted positively when asked about the idea of pointing out when people are too loud. This would make it so the participants of user tests are more at ease and there is no noise over audio recordings. When asked about the idea that informs people how many people are in the room via a web application, they said it would be nice to have a prediction for every day how busy it will be at times.

The participant that goes to the Interaction Lab for hardware, works in the main Interaction Lab room. They do this here, because for their work they need hardware which is only offered in certain places at university. They also feel like it is a nice space to work, and to not be at home. Also, they enjoy being able to work in parallel to other students in the Interaction Lab. Sometimes, the hardware is already in use when the participant arrives, but they reserve the hardware, so they get to use it then. Sometimes they run into problems when there are events at the Interaction Lab. Rarely there is too much noise in the Interaction Lab. When asked about the idea that points out that people are too loud, they felt it would be nice, but perhaps better reserved for an area where silence is more important, like a library. When asked about whether they would change anything about the Interaction Lab, they would want more meeting rooms. They also would want more light and a view of the outside in the main Interaction Lab, but this is impossible because then some VR tracking hardware would not work.

The participant that organises workshops in the events and workshop team to promote the Interaction Lab, so students know they can use the Interaction lab and what the Interaction Lab offers. Events are also there for teaching students about technology. Many students don't know what the Interaction Lab offers. At an event, it is important to give people a good impression, show them what the interaction lab is like, and to teach people something. Most events take place in the tower room, but sometimes events also happen downstairs, like the opening day. When asked about whether it would be useful to have a system that counts the exact number of participants, this is not necessary for events, because the events team already notes down how many people were there on average. It would however be useful for deciding how many workers at the Interaction Lab should be present to help all visitors. If the Interaction Lab gets more busy, this might also be useful for organising events when it is not busy.

One of the participants also sometimes borrows materials in the Interaction Lab. They did this, because it is free. Sometimes they want to use hardware, at which point it turns out it is already reserved. They fix this by reserving the hardware in advance.

Finally, all participants showed their excitement about the research, and asked questions about it.

4.2.4 Interview conclusion

The interviews were analysed using an latent inductive thematic analysis: Common themes were identified based on the interviews, and assumptions were made about the subtext that users might have had during interviews. To do this, the results were transcribed and themes were identified by critically comparing users with regards to demographics and how they answered the same questions.

After analysing the interview results, it was found that users that use the space for studying generally adhere to the findings of the insights of the literature review: They liked studying together, cared about furnishings and physical environment, and some preferred it to be more and some less crowded. 3 opportunities for problems that might be solved by a smart environment using the identified sensors were found.

Firstly, it was pointed out that it would be nice to have more people present. Students that came to the place to study together pointed out it was not nice to arrive when there was no one present. This is reflected by the Background Research, where it was found that some students have clear preferences for how busy they want their workspace to be. Another participant organises events mainly to allow people to get to know more about the Interaction lab. Participants had mixed reactions about a proposed application that allows people to know how many people are in the interaction lab before going there: Having no one there would make it unmotivating to come, but people would be more motivated to come if they knew in advance there was someone. It was pointed out that the tower room is quite uninviting: the room is hard to find, in a corner of the building and the door has no window. Not knowing how many people are there, makes it uninviting as well.

Secondly, a majority of participants go to the interaction lab to study together. In the background research it was pointed out that sound level is important in deciding where to study. Sometimes participants pointed out that people struck up a conversation. This problem is not a reason to leave: Participants that were most bothered by this wear noise-cancelling headphones to keep working. These participants would however be happy with an intervention that makes it so people watch how loud they are.

Finally, the Interaction Lab is also used for performing user testing. Participants enjoyed having the same room for every experiment, knowing what to expect as a researcher and having the ability to leave their hardware in the room between experiments. For user experiments, it is important to have a nice room, without too much noise during audio recordings. There may be opportunities involving sound or crowdedness sensors to facilitate this environment.

4.3 Brainstorming

To start answering the subquestion "What is a good project idea?", a brainstorm is performed. First, opportunities provided by the background research and the user interviews are listed. These are used as inspiration for the next step: Fifty ideas for making a smart environment are written down. Finally, the four best ideas are picked and explained.

The first set of opportunities all have to do with having more people present. This can be done in several ways. The first way is to make the room more inviting, because the tower room can be quite uninviting given how distanced it is. Another way is to convince people to come when there is no one, because users do not like to go when there is no one else in the room.. Preventing loneliness is also important, because users do not like studying alone. Showing what happens in the tower room might make the tower room more connected to the Lab Space. Finally, making studying fun might encourage users to study more.

The second and third set of opportunities are quite small. The second set of goals is to improve possibilities for user testing. This can be done by helping people store their test setup, make the room comfortable for users, and to prevent conversations from other people in the room when a user test is going on. The third set of opportunities only has one opportunity: To prevent conversation, so users may study better, since users pointed out conversations may be distracting.

Based on these goals, 50 ideas are generated. This method of writing a large amount of ideas forces designers to come up with ideas that are not immediately obvious, and gives designers time to get in a state of mind where ideas can be generated easily. Then, all ideas are intuitively ranked on how well they would fulfil the needs and wishes of stakeholders, and how ethical they are. The ideas can be found in figure 4. The ideas that seem most effective, ethical and doable are filtered out, and sometimes combined into a single idea. This resulted in four ideas. These ideas will be further tested using interviews and low-fidelity prototypes, and may be executed on their own, or together.

The first idea tries to make the tower room more inviting. The tower room is set apart

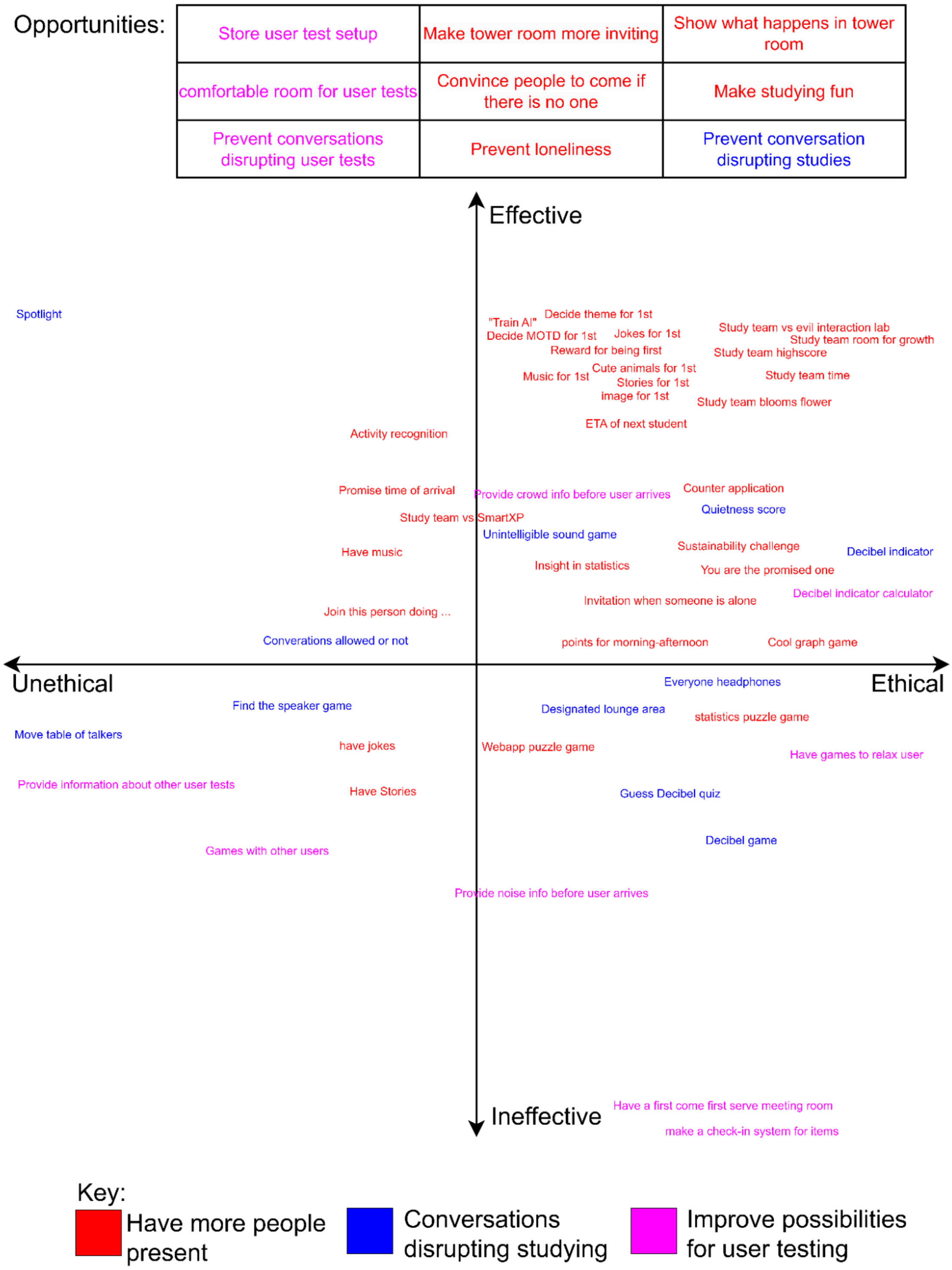


Figure 4: fifty ideas sorted on how ethical and effective they are.

from the other part of the interaction lab, and is hidden away in a narrow hallway and a windowless door. Also, users remarked it would be nice to have more people in the tower room, and it is nice to not be alone when a user arrives there. To make the tower room more inviting, an insight of what is happening there is given, to make it seem more open, and to make sure people are not disappointed to arrive there and be alone. To do this, crowd counting is used to show how many people are in the room. This information is displayed to users in a way that it is available wherever they are, so users can always access this information before deciding to go. It is also displayed in the Lab Space on the ground floor, to give a better sense of connection between the two sections. Finally, to encourage people to go even when there is no one in the tower room, an estimation of when the next person arrives is given.

A second idea encourages people to go to the tower room at the start of the workday, even when no one is there. Participants go to the tower room to motivate themselves to work by leaving home. However, it is not nice to arrive as the first person, when no one is there. To make it more fun to arrive at the start of the day, the first person that enters the tower room every day gets to experience something fun. This can be anything from writing a message that will be displayed the whole day, choosing the colours of different screens/lights or receiving a joke, piece of music or watching something mesmerising.

The third idea is to encourage people to be in the tower room more often to study together. For people studying in the tower room, it is nice to not have to work alone, and they wish more people were there, and more often. Also, they wish they were in the Interaction lab more often. To encourage people to be in the tower room more often, a cooperative game is created, where the study group earns points by being present in the tower room. In this game, the study group may try to beat a highscore every week, or face off against a virtual non-existent study group that grows harder to beat as the study group studies more. In doing this, it is hoped that study group members recruit new participants into the study group and don't feel bad when arriving and being alone. When creating this game, it is important to make sure the system is reliable, and users can't trick the system by exiting unseen and entering again.

The fourth idea encourages people that study in the tower room to study for longer. Participants of the interview seemed excited about the project, and were very helpful in completing the interviews and recruiting other participants. In this idea, the users are asked to track how long they studied every day and insert it in the system, to supposedly train the AI. By asking users how long they studied every day, they may track how long they studied and try to beat their past times, or the times of their peers. When executing this idea, however, it is important to realise that it may not be ethical to deceive the users in this way.

4.4 Project idea

All in all, the first idea, the system that displays people count to users anywhere and in the lab space, is decided to be the best idea. Firstly, it seems relevant as it provides both a connection between the main room and the tower room and invites people to study there more regularly. It is also a realistic idea: It is possible to execute with the considered technology and is within the scope of the project. Finally, unlike other ideas, it is not expected there will be relevant ethical problems that may arise.

The goal of this system is as follows: To make the tower room more inviting, more connected to the main interaction lab and to encourage users to visit. To do this, the first half of the prototype will be a display in the main room Interaction Lab. This display shows how many people are in the tower room, so people in the main room have an idea as to what is going on there. This is expected to create a sense of connection between the main room and the tower room. It also is expected to make the tower room seem more open. It also makes the tower room more inviting, as people considering working there know whether they will be alone there or not.

The second half will be a system which is available for access to all potential users of the tower room. This system shows how many people are in the tower room, and makes an estimation of when the next person will arrive. It is expected this will encourage users to study in the room by eliminating their doubts as to whether they will be alone. When the room is empty, it shows an estimate of when the next person will arrive, which ensures a user that when they arrive there, they will not be alone. It is expected that when multiple users see this, they are all encouraged to go and will all not be alone.

5 Specification

In this chapter, functional and non-functional requirements are introduced, and it is explained how they are changed based on unexpected circumstances. To guide the design process and answer the subquestion "What are the design requirements of this project idea?", design requirements are created. These requirements will also be used to evaluate the system later. The design requirements are separated into functional and non-functional requirements. The Functional requirements explain the functionality of the system, and the non-functional requirements explain how the system works.

In the next tables 2 and 3, the functional and nonfunctional requirements are made and shortly explained. The requirements are based on the project idea as explained in chapter 4.

Number	**Requirement**	**Comments**	**Importance**
FR 1	The system needs to give an estimate of how many people are in the room at any time	This is important for the system to function as a crowd counter	Must-have
FR 2	The system lets users check the number of people in the Tower Room from anywhere.	Users explained that they do not like to go to the Tower Room when it is empty, this lets them check.	Must-have
FR 3	The system lets users check the expected number of people in the Tower Room from anywhere.	In case the Tower Room is empty, having the system show when someone is expected might encourage users to go, creating a self-fulfilling prophecy.	Must-have
FR 4	The system needs to display the amount of people in the Interaction Lab ground floor	This is to make the Tower Room more connected to the main Interaction Lab, and more inviting.	Must-have
FR 5	The system needs to provide privacy		Must-have
FR 6	The system needs to be able to be connected to the Interaction Lab home system	This is important for the system to function as a usable crowd counter	Must-have

Table 2: Functional Requirements for the system

Number	Requirement	Comment	Importance
NFR 1	When there are ten or fewer people, the system needs to know how many people are in the room with a maximum error of 2	This is important to the users using the website and screen, to see how much space is left. The number is chosen intuitively based on user interviews.	Should have
NFR 2	When there are ten or more people, the system needs to know how many people are in the room with a 20% error range	This is important to the organisers of the interaction lab, to see how many people were at events. The number is chosen intuitively based on meetings with the organiser.	Should have
NFR 3	The system needs to know whether the room is empty 90% of the time.	This is important, because having the system show the room is empty when it is not can encourage users not to come. The number is chosen intuitively based on user interviews.	Should have
NFR 4	The system uses colours in the theme of the interaction lab	The interaction lab has colours that do not scare away the user, and it is nice to follow the theme	Should have
NFR 5	The system has colours with enough contrast	The WCAG 2.1 guidelines should be followed	Should have
NFR 6	The system in the lab space automatically turns on when the Interaction Lab is open	This is so no one has to turn it on manually.	Should have
NFR 7	The system must not discriminate against people.	Any technology should consider this	Should have

Table 3: Non-Functional Requirements for the system

5.1 Artificial Intelligence

In the initial idea, it was planned to use AI to show website users whether the amount of people would go up, down or stay the same in the next hour. This was done to learn whether expecting someone to show up might motivate users to visit the Tower Room when otherwise they might expect to be alone. It was decided that using a multiple regression model would likely be appropriate, because it is relatively easy to create without much data. The coefficients that were considered were coefficients that are expected to have the biggest impact on the expected amount of people in the near future: The first coefficient is the current amount of people, because people are expected to stay a while if they are already there. The second coefficient is the amount of people in the last few weeks on this day, because it is expected that for each unique weekday, the number of people entering and leaving is quite similar. The third coefficient is the week number of the quartile, as background research pointed out that students tend to study more near the end of quartiles. The last coefficient is rainfall, as users are expected to stay home more often when it rains.

However, in the planning phase of this AI, it turned out a lot of training data would be needed to make an accurate artificial intelligence. This is because it was expected that the data would change over quartiles, so this would have to be at least 11 weeks of accurate measurements. Two options were considered to find whether it would still be possible to learn about how expectations of the future might affect decision making in users.

The first option is to deceive the users, by pretending the AI is more accurate than it actually is. Doing this would not stop the initial goal of adding the AI: If the users are successfully deceived, they would still be able to offer their experiences in using the AI. However, because the AI will not be accurate, all users are experienced with creating AI themselves and understand the scope of this study does not allow for advanced AI, it might not be possible to deceive them. Ofcourse, ethical concerns should also be considered when deceiving users. If users find out they are being deceived, they might feel negative emotions, like embarrassment or betrayal. As it is likely users will find out, this is not ethical.

The second option is to offer truthful information to the users, that might not be very accurate. This could be done by showing the data of last week, to help users decide whether they want to go when the Tower Room is empty. The goal of this would still be to investigate a function that might encourage users to go when the tower room is empty. Though it is not expected to be as successful as an accurate AI, it might still offer insightful information about how users experience using it. Also, it might be a good stepping point to discuss an accurate AI, and to see whether users think that would be useful.

Because the first option is not expected to be effective or ethical, it seems the second option would be the best option for a prototype. Therefore, a new nonfunctional requirement is added in table 4:

Number	**Requirement**	**Importance**
NFR 7	The system shows the expected amount of people by showing the data of last week	Must have

Table 4: Additional Non-Functional Requirement

5.2 Concessions

During the creation of the prototypes, it turned out that it was outside the scope of this project to achieve all product requirements. Therefore, no running website is made for the users to use during the testing period, as this requires too much programming. The website and screen prototype will therefore not be installed. A website and screen prototype will be evaluated by using explorative user interviews, which will be reported on in the evaluation part of the report. The requirement pertaining to loading time is still evaluated, because during interviews it would be nice if users can access the website prototype on their own phone. Because no working AI has to be made to evaluate the initial designs, two versions of the website with a simple or advanced AI can be evaluated. Therefore, a number of Functional and nonfunctional requirements are changed. The final lists of requirements are found in tables 5 and 6, the changed and added requirements are in green, and the removed requirements are in red.

Number	Requirement	Importance
FR 1	The system needs to give an estimate of how many people are in the room at any time	Must have
FR 2	There is a prototype of a system that lets users check the number of people in the Tower Room from anywhere.	Must have
FR 3	There is a prototype of a system that lets users check the expected number of people in the Tower Room from anywhere.	Must have
FR 4	There is a prototype of a system that displays the amount of people in the Interaction Lab ground floor	Must have
FR 5	The system needs to provide privacy	Must have
FR 6	The system needs to be able to be connected to the Interaction Lab home system	Must have

Table 5: Functional Requirements of the System

Number	Requirement	Importance
NFR 1	When there are ten or fewer people, the system needs to know how many people are in the room with a maximum error of 2	Should have
NFR 2	When there are ten or more people, the system needs to know how many people are in the room with a 20% error range	Should have
NFR 3	The system needs to know whether the room is empty 90% of the time.	Should have
NFR 4	The system uses colours in the theme of the interaction lab	Should have
NFR 5	The system has colours with enough contrast	Should have
NFR X	The system in the lab space automatically turns on when the Interaction Lab is open	
NFR 6	The system must not discriminate against people.	Should have
NFR 7	One version of the system prototype shows the expected amount of people by showing the data of last week	Must have
NFR 8	Another version of the system prototype shows the expected amount of people by simulating a smart AI	Must have

Table 6: Non-Functional Requirements of the system

6 Realisation

In this chapter, the research question "How to realise the specified project idea and design requirements?" is answered by considering the technology and software that is needed for this, and picking a best option.

To make the system run, three major software components are needed: a sensing AI, a communication program, and a database. All major software components are run on a Raspberry Pi. The software is structured as can be seen in figure 5.

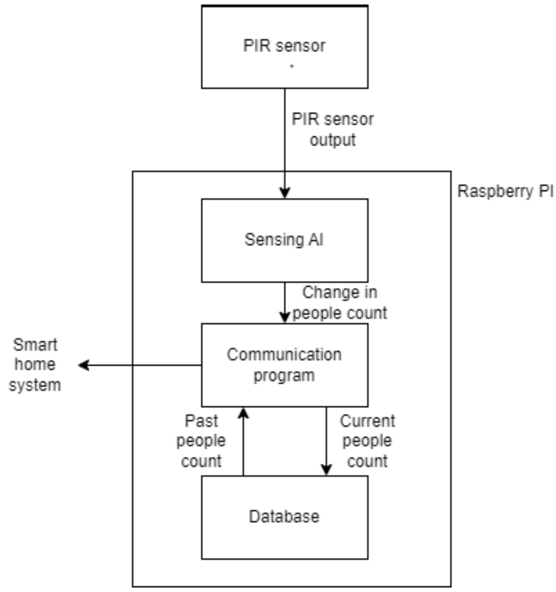


Figure 5: Structure of the software of the system

6.1 Sensor and sensing algorithm

To sense people, the system needs a sensor. For one, this sensor needs to be accurate: It is important the sensor knows roughly how many people there are and whether the room is empty. Also, the sensor needs to not be too expensive or hard to install, otherwise it falls outside the scope of this project. The PIR sensor is perfect for this. It performs great on all aspects, and though it may be easily fooled by malevolent users, this is not expected to happen, as it is not expected users have a reason to do this. A Panasonic Grid-eye sensor is used, which was also used in a similar report by Perra et al. An image of the sensor can be found in Figure 6. Because they described a very high accuracy with a simple AI, and reported clearly on this AI, this seems like a good option.

Figure 6: Panasonic grid-eye sensor []

The grid-eye sensor measure the temperature of passing users in an 8x8 grid, as shown in figures 7 and 8. The sensing AI by Perra et al [1], divides every frame from the 8x8 PIR sensor into 4 2x8 bins, and calculates the power of each bin based on what the temperature is in the bin. If the bin with the highest power passes a calibrated threshold, it logs the location of a presumably measured user. There are six possible readings based on what the user does when being measured, described in table 7.

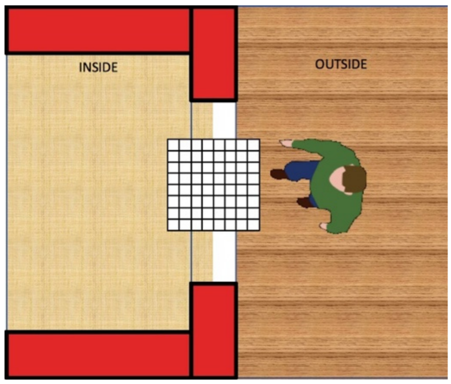


Figure 7: User entering doorway [1]

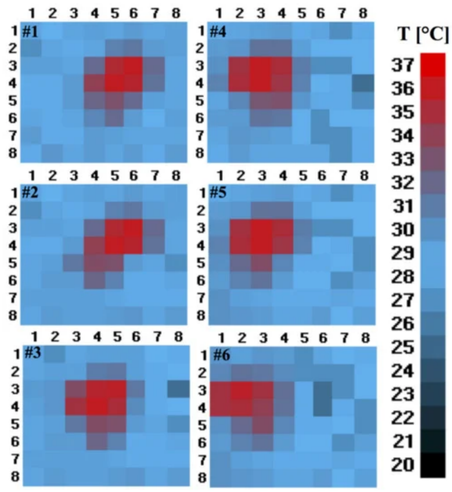


Figure 8: six frames of user entering doorway [1]

Reading	**Measured**
“I”	The user goes inside, in bin order 1234
“O”	The user goes outside, in bin order 4321
“IHI”	The user goes inside the doorframe from the outside, holds, and ends up going inside, in order 12. . . 34
“OHO”	The user goes inside the doorframe from the inside, holds, and ends up going outside, in order 12. . . 34
“IHO”	The user goes inside the doorframe from the outside, holds, but ends up going back outside, in order 43. . . .34
“OHI”	The user goes inside the doorframe from the inside, holds, but ends up going back outside, in order 12. . . 21

Table 7: Codes of user interaction

For the Panasonic grid-eye sensor, the AMG8854M01 version was ordered, as this version allows for easy connection using an i2c protocol and a JST ZHR 5-pin socket. This version has a more narrow viewing angle than used in Perra: 35.6° as opposed to 60°. This means that for every metre below the ceiling, about 0.64 metres are covered by the viewing angle. The installed sensor is shown in picture 9. After doing tests in the Tower

Figure 9: The sensor attached above the doorway

Room entrance, it turned out the user did not fit in 4 bins as described by Perra et al.. Therefore, less bins needed to be used, so three bins were used instead Because the sensor has 8x8 pixels, which cannot be easily divided by three, the bins overlap, having the first four columns make up bin 1, the third to sixth columns make up bin 2, and the fifth to eighth column make up bin three, as shown in figure 10.

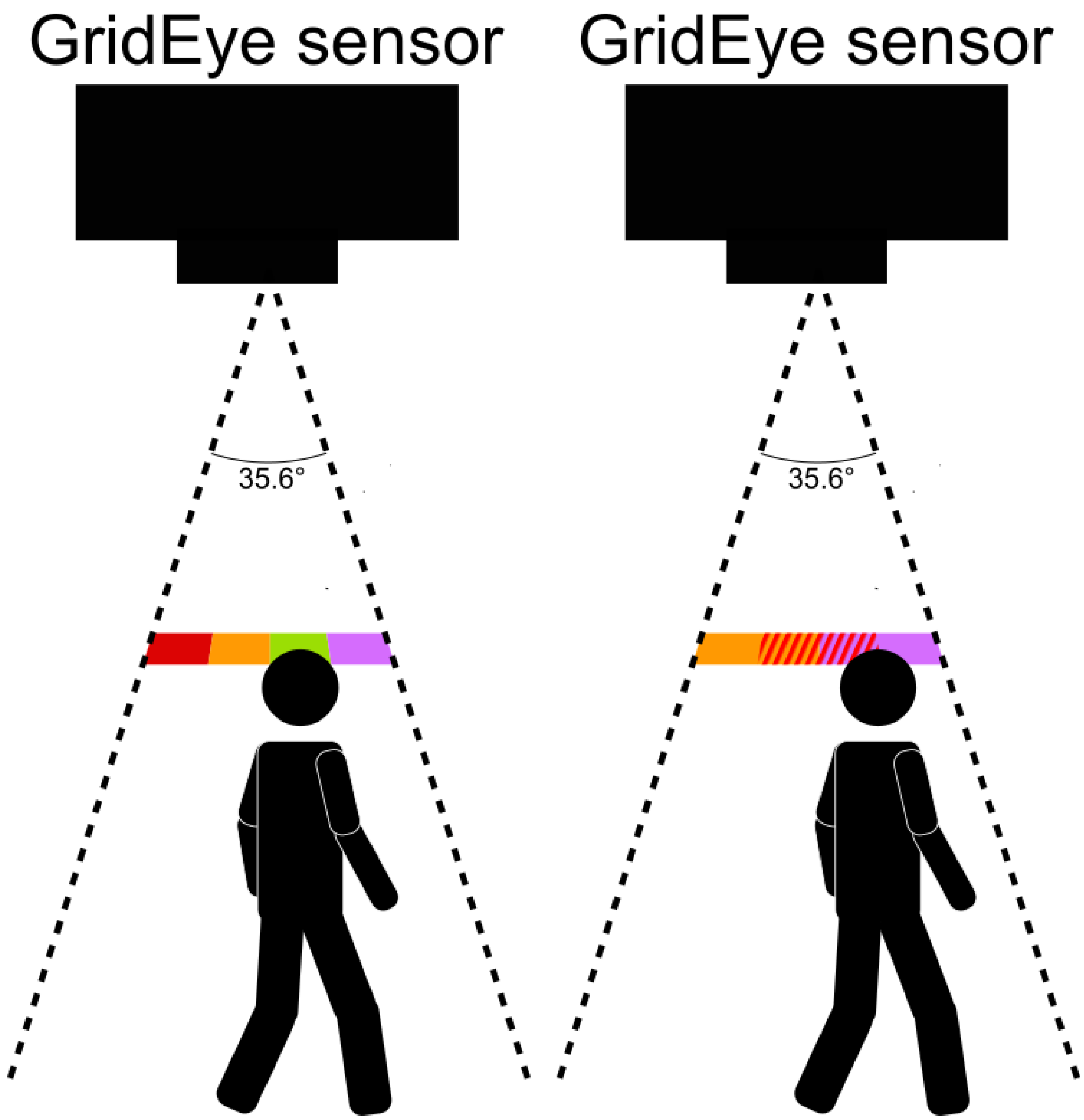


Figure 10: User entering the doorway. The head does not fit in one of 4 bins. When bins are combined into three bins of equal size that overlap, they do fit.

Perra has an algorithm that calculates the expected location of a user by comparing each pixel to the average of all pixels of the last four frames. However, the sensor used in this report covers a smaller area due to a more narrow view angle. This means the average of the pixels goes up more when a user passes, because the user covers a larger area. Therefore, the average is taken over 15 frames instead, so that it is not affected too much by the more narrow angle.

6.2 Circuit Board

To process the information of the sensor, a circuit board is needed. This circuit board needs to be able to process the input of the sensor to find out when a user enters or exits the room. It would be nice if it can also store data to show the data of last week, is able to host a website and connect to the smart home system of the interaction lab. A Raspberry Pi seems perfect for this. The Interaction Lab has some available for use, they have plenty of processing power and with a WiFi connection it may connect to the smart home system. A raspberry pi has pins dedicated to i2c communication with the sensor. Finally, a Raspberry Pi is advanced enough to host a database.

When the raspberry pi was installed on the ceiling, it warmed up a lot, because the heat could not go up. This caused the system to throttle, using less processing power. To help the raspberry pi lose heat, heatsinks were installed, and the raspberry pi was installed vertically, so the heat could go up a few centimetres. This was sufficient for proper heat transfer. Also, the sensor was attached to the ceiling away from the circuit board, because when it warmed up it became uncalibrated. An image of how the raspberry pi was installed can be found in picture 11.

Figure 11: the sensor installation

6.3 Database

The data base has two parts, an updates part, where it is recorded when a user leaves or enter the room, and a count part. Every five minutes, the count part is updates with with the logged changes since the last people count update. The count is reset to zero every night at 4 am, when it is not expected anyone is in the room.

The database is run on the circuit board as well, using Maria-db, a program for creating an SQL database. It stores the Unix timestamp of every change log and people count, so it would be easily accessible by the website and possible future projects.

6.4 python program

As could be seen in figure 5 at the start of this chapter, the python program consists of 2 main parts: an image analysis program and a communication program. There is another smaller part, the sensor program, for retrieving the sensor output from the sensor using i2c. These parts are controlled by a main script, which activates the programs when necessary. The python program is automatically started using crontab when the raspberry pi is booted. The full programs can be found in appendix B.

The sensor program uses the smbus2 library to retrieve information from the sensor program, and converts the data to temperatures. The image analysis program applies the algorithm described before on the images by estimating whether and where a user is, and deciding what has happened when a user leaves the sensing field by looking where the user is estimated to have been. The communication program uses the MySQLdb library to communicate with the database, by sending an update every time the program notices a user entering or leaving, and updates the people count in the database by finding the updates since the last people count recording. Finally, it is also capable of finding when the count needs to be reset, so it can be reset at midnight.

6.5 Website

To allow users to access the people count remotely, two website prototypes were made: one shows the amount of people the sensor measured last week, and the other shows the amount of people the sensor predicts using an AI. For both versions, the light-blue colours of the interaction lab are used, in a way that satisfies the accessibility guidelines. Because the prototype is made in figma, users can open it on their own phone, but it takes quite some time to load. There is a progress indicator, however. The two versions are displayed in figure 12. The website shows in a big widget how many people are in the room, because this is expected to be the main functionality. The widget with AI and data from last week are simple, so they can be understood fast.

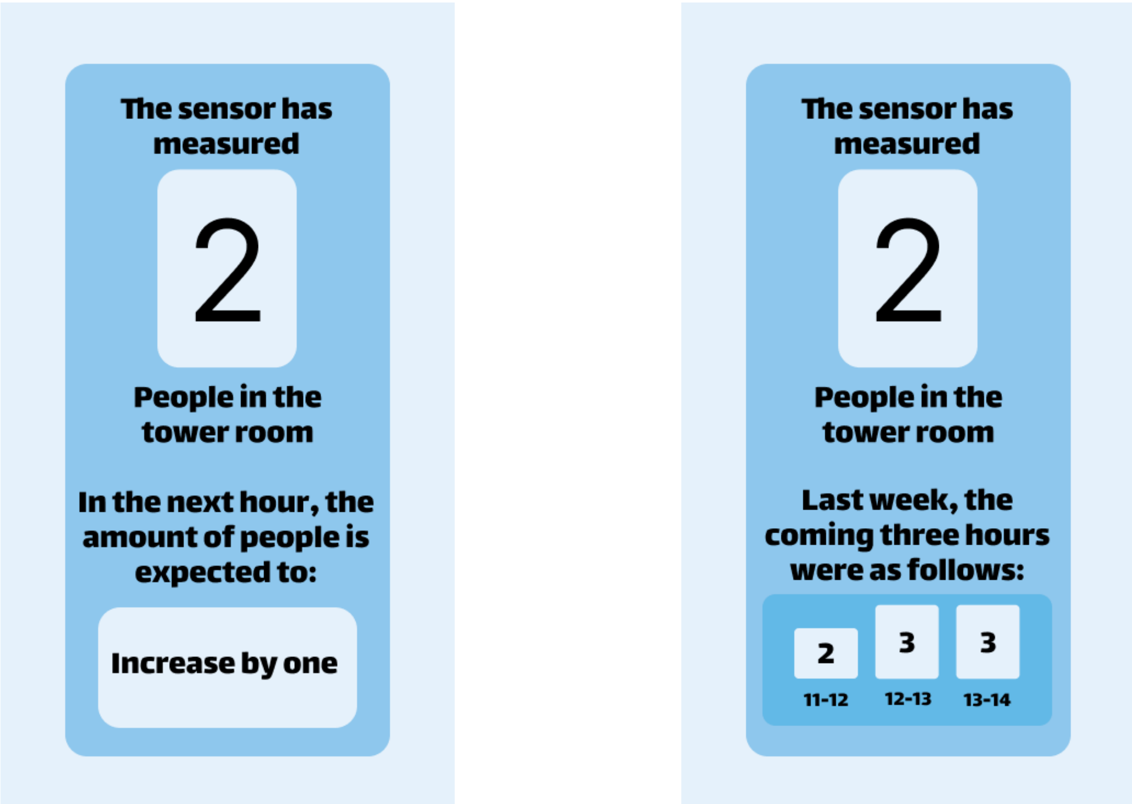


Figure 12: The two versions of the website. Left is the version that shows the last week, right is the AI

6.6 screen

To display the people count in the Lab Space, a screen prototype was made. The same light-blue colours are used, according to accessibility guidelines. It shows the amount of people in the Tower Room, on a widget and in a visualisation. The visualisation is a drawing of the tower room that shows people working inside of it. It was decided to do

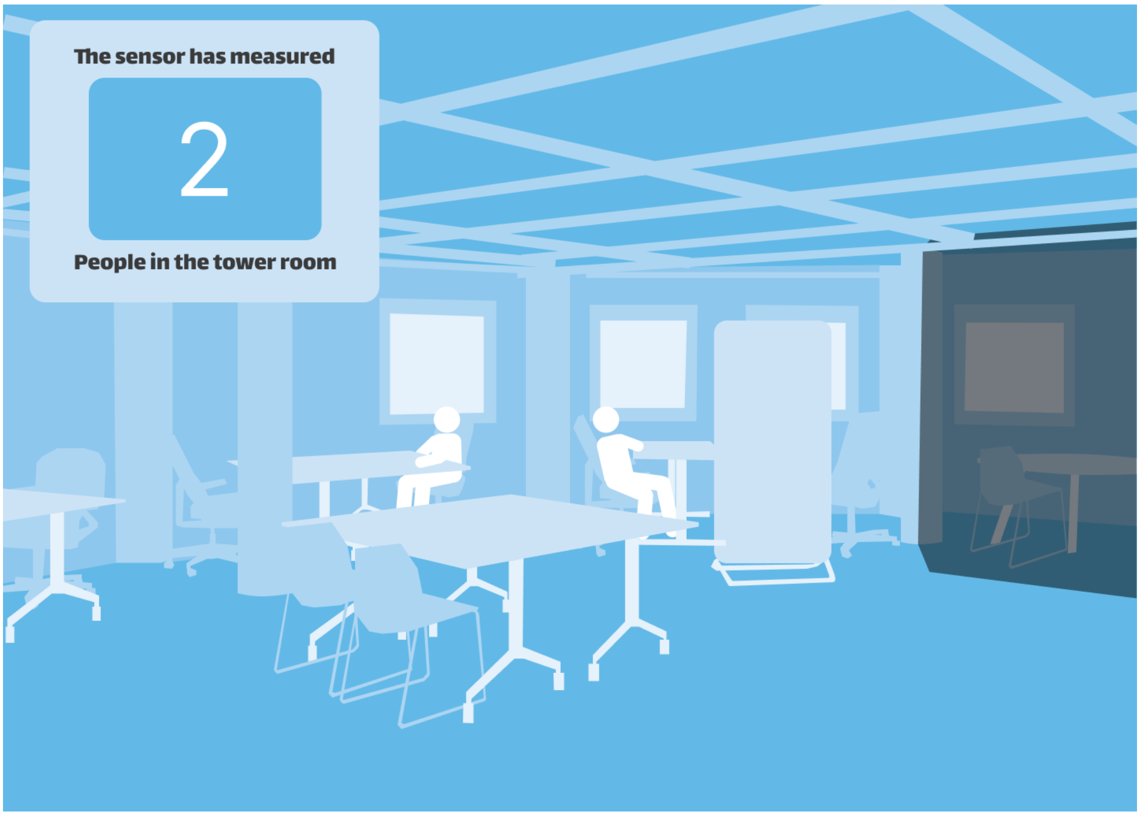


Figure 13: The first variation of the screen

a drawing to make the Tower Room more connected to the Interaction Lab ground floor when it is hung inside of it. An example of the screen is shown in figure 13.

This version of the screen raises a few concerns. Because an image is shown, users might think activity tracking is happening, and it is measured what people are in what chairs, which would deceive the user. They might think a camera is used, which might raise privacy concerns. Finally, the amount of people that are visualised might not communicate well how busy the environment truly is. These concerns are evaluated in chapter 7.

7 Evaluation

In this chapter, the system is first evaluated using a functional evaluation to see whether the functional and nonfunctional requirements are met. Then, research questions are set up based on the goals of the system, which are evaluated using an interview.

7.1 Functional evaluation

To evaluate the functional and nonfunctional requirements of the system, some sensor accuracy measurements have to be done. Two types of accuracy tests are performed to test the accuracy of the sensor. First, tests are performed to learn whether the sensor registers people going in and out with headwear. Secondly, a longform test is run to test the accuracy of the sensor in real use.

The headwear test is performed because the sensor might cause discrimination against people. It was decided to use a PIR sensor, which has been shown to have a worse performance on people wearing headwear, because it does not measure the temperature of the head as well. This might introduce a bias to groups of people wearing headwear, which is often done by people of marginalised religions. Users that are not measured by the prototype because of their headwear could be discriminated against in future use of the sensor. Therefore, to learn whether the technology performs worse on people wearing headwear, experiments are performed. With different types of headwear, the room is exited and entered 30 times in succession, for a total of 60 updates. The configurations were: Without headwear, Wearing a flat cap, wearing a sunhat, wearing a headscarf and wearing winter jacket with hood up. The results can be found in table 8. As can be seen

Test	Entrances measured	Exits measured	Percentage measured
Without headwear	29	27	93%
Flat cap	21	16	61%
Sunhat	7	11	30%
Headscarf	29	28	95%
Winter jacket	4	7	18%

Table 8: Measurement Results for Different Types of Headwear

in the table, the more insulating the material, the less updates are measured. This was enhanced by the fact that the headwear was not worn for long before starting testing. If headwear was worn for longer, perhaps the outside of the insulating material would be a bit warmer and easier to measure. During testing, it was noticed that none of the users wear headgear when entering the tower room, for religious reasons or otherwise.

Because people do not often wear insulating headwear for religious reasons, and since the measured data does not affect people since the website and screen are not made, users with headwear are not negatively affected as per the nonfunctional requirement. However, because people with headwear are less noticed, this is a flaw of the system if it were to be used where headwear is more often worn, like closer to the entrance of a building.

To do the longform tests, the sensor is installed for four days. At multiple times in a day, the researcher enters the tower room and counts the number of people in the room. This is then compared with the results the sensor has measured to see whether they are accurate.

Eighteen measurements were made. The result may be found in figure 14 and table 9.

Day 1	Actual	3	3	4	5		
	Sensor	3	4	4	5		
	Error	0	1	0	0		
Day 2	Actual	3	4	3	4	3	
	Sensor	3	3	3	2	3	
	Error	0	-1	0	-2	0	
Day 3	Actual	2	2	2			
	Sensor	2	5	5			
	Error	0	3	3			
Day 4	Actual	3	2	1	3	2	2
	Sensor	3	3	3	6	5	5
	Error	0	1	2	3	3	3

Table 9: All measurements made. The results with errors not fitting the requirements are in red

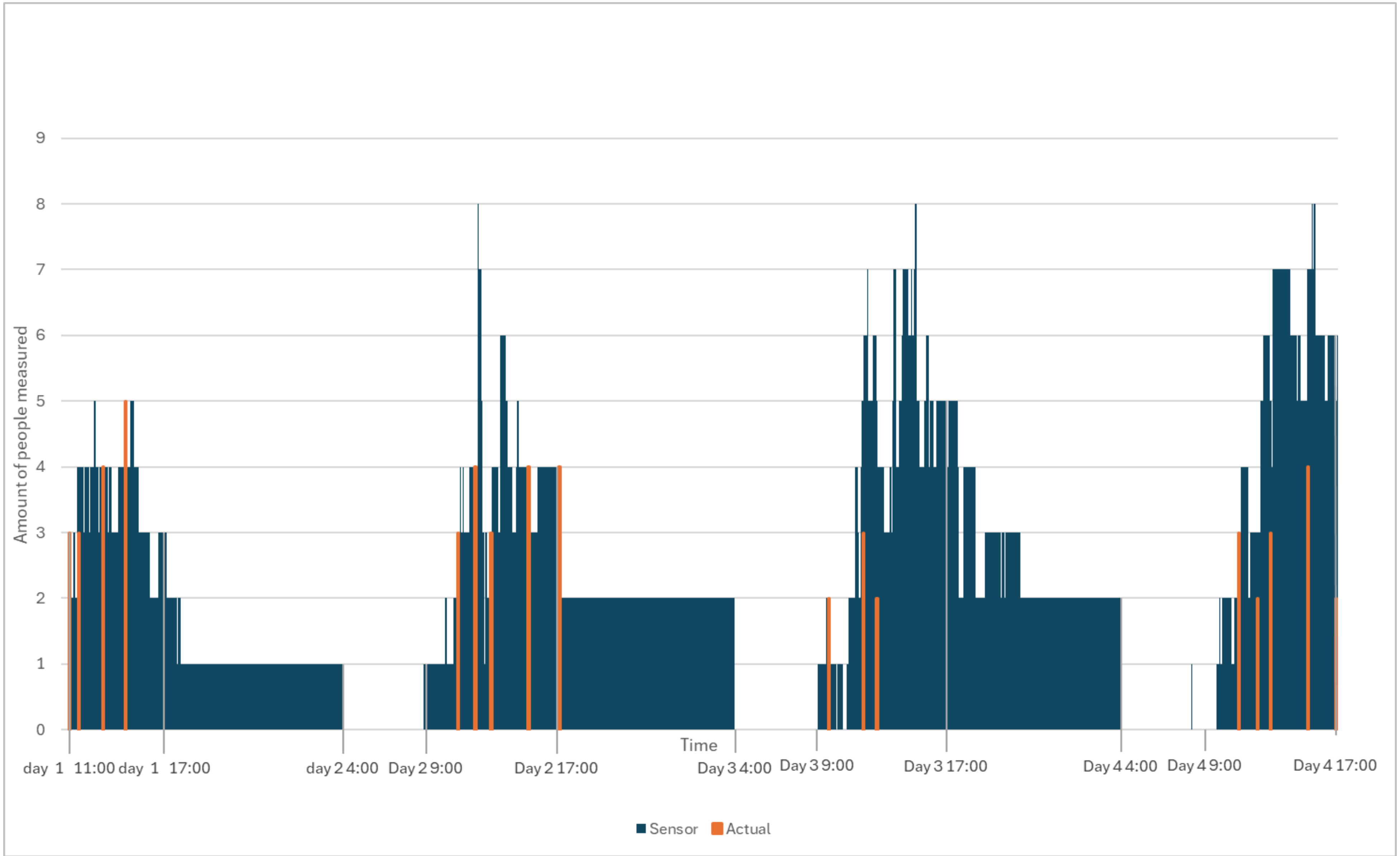


Figure 14: Measurements of Sensor compared to actual measurements

The test was not very accurate. Because the sensor might make a mistake every time a user enters or leaves, the data at the end of days is less accurate than at the start of days, when the count is reset. Generally, the data was higher than expected, because if a user leaves when the counter is at 0, the counter stays at 0, after which the user might enter again. In the table it can be seen that 28% of the measurements have an error that is bigger than required.

Theoretically, having an accuracy of 93% as was measured in the headwear test, and assuming the probability of missing an entry or exit is the same, 7% of the updates would occur into the error going up or down by one. This results in a symmetric one dimensional random walk where, $E[x]$ is the expected amount of mistakes to reach 3 or -3 from x.

$$E[x] = 1 + \frac{1}{2}E[x+1] + \frac{1}{2}E[x-1]$$

$$E[3] = 0$$

$$E[2] = 1 + \frac{1}{2}E[3] + \frac{1}{2}E[1] = 1 + \frac{1}{2}E[1]$$

$$E[1] = 1 + \frac{1}{2}E[2] + \frac{1}{2}E[0]$$

Since the random walk is symmetric, $E[x] = E[-x]$, so

$$E[0] = 1 + \frac{1}{2}E[1] + \frac{1}{2}E[-1] = 1 + E[1]$$

Substituting $E[1]$ gives

$$E[0] = 2 + \frac{1}{2}E[2] + \frac{1}{2}E[0]$$

$$\frac{1}{2}E[0] = 2 + \frac{1}{2}E[2]$$

$$E[0] = 4 + E[2]$$

substituting $E[2]$ gives

$$E[0] = 4 + 1 + \frac{1}{2}E[1] = 4 + \frac{1}{2}(2 + E[1])$$

$E[0] = 1 + E[1]$, so:

$$E[0] = 4 + \frac{1}{2}(1 + E[0])$$

$$\frac{1}{2}E[0] = 4\frac{1}{2}$$

$$E[0] = 9$$

Therefore, it is expected to make 9 mistakes before the error boundary is crossed. Since the system only makes a mistake 7% of the time, this is expected to happen after 129 updates. This would explain the error on day 3, when there were 189 measured occurrences of people entering and leaving the room, but not on day 4, when there were 52 occurrences. It is worth noting that since around 7% of occurrences might not be measured, the actual number of occurrences might be higher. This was likely because the ideal testing situation during the headwear test does not apply in real life, where it was observed that users may enter or exit together, or enter or exit to or from the side of the sensing zone, where jackets are stored.

Though it was not recorded that the sensor measured an empty room when it was not empty or vice versa, in the figure it can be seen that after closing time, the sensor sometimes still thinks there are people in the room until it is reset at 4 AM, so it may sometimes give a false positive.

In table 10, all the functional and nonfunctional requirements are displayed, and it is noted whether they were completed.

Number	Requirement	Result	Importance
FR 1	The system needs to give an estimate of how many people are in the room at any time	Completed	Must have
FR 2	There is a prototype of a system that lets users check the number of people in the Tower Room from anywhere.	Completed	Must have
FR 3	There is a prototype of a system that lets users check the expected number of people in the Tower Room from anywhere.	Completed	Must have
FR 4	There is a prototype of a system that displays the amount of people in the Interaction Lab ground floor	Completed	Must have
FR 5	The system needs to provide privacy	Completed. The system uses anonymity provided by PIR sensor to provide privacy	Must have
FR 6	The system needs to be able to be connected to the Interaction Lab home system	Completed. The system uses an SQL database that can be accessed by the Interaction Lab home system.	Must have
NFR 1	When there are ten or less people, the system needs to know how many people are in the room with a maximum error of 2	Not completed, the sensor makes too many mistakes in practice.	Should have
NFR 2	When there are ten or more people, the system needs to know how many people are in the room with a 20% error range	Not tested, there were never more than 10 people in the room during the testing period.	Should have
NFR 3	The system needs to know whether the room is empty 90% of the time	Partly completed: During testing, no errors were noticed, but after closing time, the sensor sometimes thinks there are users in the room until it is reset at 4 AM.	Should have
NFR 4	The system uses colours in the theme of the interaction lab	Completed	Should have
NFR 5	The system has colours with enough contrast	Completed	Should have
NFR 6	The system must not discriminate against people	Completed	Should have
NFR 7	One version of the system prototype shows the expected amount of people by showing the data of last week	Completed	Must have
NFR 8	Another version of the system prototype shows the expected amount of people by simulating a smart AI	Completed	Must have

Table 10: results of functional and nonfunctional requirements

7.2 Research questions

To guide the interview process, a list of exploratory research questions are made:

1. In what circumstances does the website encourage or discourage users to go to the tower room?
2. In what circumstances does the screen encourage or discourage users to go to the tower room?
3. How do users think the screen affects the connection between the tower room and the lab space?
4. How do users think the screen sensor works?
5. What privacy concerns do users have?
6. How well does the screen visualisation reflect business?
7. How do users think the website prototype expectation widgets work, and what do they think about the options?
8. What would users like to change about the website prototype?

The first two questions are made to learn whether the website and screen work as envisioned, and in what unexpected ways they might work. The third question is also to see whether the screen works as envisioned. The fourth question is to learn about whether the users think the screen uses a camera, since it shows an accurate visualisation of the tower room. If they do, or they think the system uses another invasive sensor, this would have an effect on the privacy users think is offered by the system. The fifth question is to learn about whether users have privacy concerns with the way the system is set up now. The sixth question is to see whether the visualisations made accurately reflect how busy it feels in the tower room, so users may be well informed before going there. The seventh question is made to evaluate what widget might work better and how to change them. The last question is made to learn what else users would like to see on the website.

7.3 Prototype interviews

In order to answer the research questions, a Prototype interview is performed. In this interview, the users are introduced to the prototype that shows what the screen and website look like, and what their functions are.

7.3.1 Interview setup

The goal of this interview is to get insight into the perceived usefulness of the various functions of the prototype. A persona is introduced and discussed, to see how interviewees relate to the target group. Questions in the interview are tried to be asked in a neutral manner, to avoid pushing the interviewee to answer in a positive or negative way. Because new topics might come up, the interview will be semi-structured. The questions and interview guideline can be found in Appendix C.

Interview Introduction The interview starts with an introduction and signing the consent form, in which the goal of the project and the interview is introduced to the interviewee, after which some questions are asked about demographics and data points. Because the expected number of interviewees is not big, and to learn information about the interviewees, a persona is introduced. This persona represents the target audience, and it is asked whether the interviewees relate to them. In case the interviewee is not part of the target audience, they are asked to answer questions from the perspective of the persona too, to gather more insights.

In order to make sure all kinds of stakeholders are represented, and to find differences between groups, questions about demographics are asked. When a group has significantly different desires from another group, knowing about these differences allows for better inclusion by catering to the needs of groups that may otherwise be in the minority. To protect the identity of users, the raw interview data is not shown to the supervisor.

Three questions about demographics are asked: Whether the participant is a student or researcher, and if they are a student, what study they do and whether they are working on a thesis. Participants are asked whether they are students or employees, because students and employees play a very different role in the university and in the Interaction Lab. Because it is expected that students that do different studies which are either bachelor or master studies have different needs and wishes, questions about this are asked. Finally, it is also expected that students that are working on a thesis use the Interaction Lab differently from those that don't work on their thesis.

Two data points are asked as well: How often they use the Interaction Lab ground floor and how often they use the tower room. These data points are important as they are expected to influence the participants' opinion on the website and screen. If a participant uses the tower room, additional questions about the website are asked.

Finally, a persona is introduced. This persona resembles a member of the target user group for whom the website would be very useful. Because not all users may want to use the website in the same way as this persona, it is asked how they do and don't relate to the persona. Later in the interview, the users will be asked how they think the persona would use the prototype, if they do not relate to the persona as much.

Website prototype The website is shown to participants on their own phone using Figma prototype links, provided with QR codes. Both versions of the website are shown, one which shows the amount of people from last week and one with an AI. When the prototype is shown, using the thinking out loud method, users are asked what they see, and what function they think it has. This method is useful to learn about prototypes in an objective way. These questions are asked to learn about the clarity of information and its perceived usefulness. Then, the user is asked whether and how they would use it. If they answer they would use it in a different way than is envisioned for the persona, they are also asked how they think the persona would use it.

Finally, some questions are asked to find out whether the website encourages users to go to the tower room. The website is shown with different variations of information, when there are different amounts of people, when there are no people, and when the amount of people is expected to increase, lower, or stay the same. Every time a variation is shown, it is asked whether the user is encouraged to go to the tower room, and why. Up to six variations are prepared and shown, if the interviewer thinks they might offer useful insight. The variations can be found in appendix D.

Screen prototype The screen is also shown to participants, this time on a monitor in the interview space. It is explained that the screen will be put in the main Interaction Lab room. Similarly to the website, users are asked what they see, and what function they think it has. Then, users are asked how they think the system works. This is because it may happen that users think the system works with a camera, since the screen shows the room. They may also think it is being tracked what chairs are being used. They may be asked about privacy concerns or whether they expect people to be in the exact spot the system shows them, if this is the case. This is because it should be avoided that users have any privacy concerns with the system, or think it uses accurate people tracking which might disappoint them. Then, people are neutrally asked about how seeing this in the Lab Space would make them feel about the tower room. They are then asked about whether it would make them feel like going to the tower room, with up to three variations, just like the website. Finally, they are asked how they think this would affect the sense of connection between the tower room and the Lab Space.

Finally, it can be expected that the visualisation the screen uses visualises the ambience in the tower room wrongly, since it is expected the visualisation looks way busier than what it looks like in reality. For three different amounts of people, users that regularly use the tower room are asked about what the ambience is in the tower room. Then, they are shown the visualisation, and asked whether this visualises the ambience accurately. This is to learn whether the visualisations should be adjusted. All the shown variations of the screen can be found in appendix E.

Interview ending At the end of the interview, there is room for discussion, and users are thanked for their contribution to the project.

7.3.2 Interview results

In the end, nine users were interviewed. Just like the ethnographic interview, the interviews were analysed using a latent inductive thematic analysis. For example, it was found that the same user found the screen more inviting than the website with the same amount of people displayed, and users could generally be split up into people that use the tower room and people that use the lab space. The interview results are discussed here, and a new proposal for the website is made here. Every research question is answered here.

In what circumstances does the website encourage or discourage users to go to the tower room? Users that like to use the tower room for studying generally still go when it is empty, but they all prefer not being alone. Users that mainly use the Lab space like to go to the tower room for socialising or finding volunteers for research, so they like to go when it is not empty. They prefer there to be as many people as possible. One user that didn't go to Interaction Lab often remarked that if the room was empty it was probably closed. Many users also commented on spaces: if it seemed like there would be no good spaces left, users would go somewhere else. This happens when about five to six spaces are occupied. Finally, one user would like to use the room when it's empty, for calling.

In what circumstances does the screen encourage or discourage users to go to the tower room? The screen is generally used in the same way as the website. However, the amount of occupied spaces gave users the idea that it showed how much spaces were left. Therefore, the amount of spaces shown should be carefully considered. One user remarked that when the lab space is full, people looking for a spot could easily see whether there is space in the Tower Room. One Lab space user remarked that having the website show the people made it more inviting to socialise than the website. Having two people was not inviting on the website, but it was on the screen.

> "I know I said no to the website, but somehow having a visual makes it more inviting" -Participant 7

How do users think the screen affects the connection between the tower room and the lab space? Users thought it would make the rooms belong together and encourage socialising. Some users remarked that having a screen the other way would also be nice, because a lot of people that often use the tower room never go to the lab space.

How do users think the screen sensor works? Some users guessed correctly there was a sensor in the door. Some users didn't know what to expect. Some users initially considered there was a camera. Users remarked that having a visualisation like this hints towards there being a camera. They said that if the visualisation was static, and after visiting the tower room, they would learn whether it uses a camera. One user remarked that it was weird to use a visualisation of people in chairs when they are not in those actual chairs.

What privacy concerns do users have? One user said the data should be secure. Besides that, no users had privacy concerns if there was no camera and the data was anonymous.

How do users think the website prototype expectation widgets work, and what do they like about the options? Most users assumed that the graph used data from multiple weeks, and that the AI was another way to show the graph. Users prefer the graph for the amount of extra data it shows and the clarity of how the data is generated. Some users thought the graph was easier to understand, and some users thought the text was easier to understand.

How well does the screen visualisation reflect business? Most users thought the screen accurately reflected business, except for one, who thought the visualisation of 5 people was too busy and reflected how busy it was with 8 people more.

What would users like to change about the website prototype? Users would have liked to see more data so they may plan ahead. Three users compared it to the business charts from google maps. One user thought it would be a nice function to show when the tower room is closed.

8 Discussion and Future Work

In this chapter, the evaluation is discussed and plans are made for how the technology should be used in the future. First, the results of the functional evaluation are discussed, and then the results of the interviews.

8.1 Functional evaluation

To allow for extra accuracy and less mistakes at the end of the day, hybrid sensors could be used. Since the sensor in the door is event-based, it can't calibrate itself during the day: If a mistake happens, it stays for the rest of the day. On busy days, this will likely occur in an error that is too big. Having a sensor that measures the amount of people using a technology that makes an estimate that is not based on past events, the combination could make for an accurate measurement. These sensors sometimes have a delay, but since event-based sensors don't, they make up for each other's weaknesses. There is much opportunity in combining them, because there is a lot of room for a smart AI that combines the information into an accurate count.

Although it did not pose a problem during this research, having a hybrid sensing system could also solve potential problems posed by headwear and reliability. Though it might not lead to discrimination, being able to measure people wearing insulating headwear could be important in other applications of a people-counting system. It could also increase reliability by making the sensor harder to fool, if that's necessary.

8.2 prototype interviews

Perhaps data can be shown in a bar graph that shows the entire day, and how busy it is right now with an extra bar at the current time. This way, it is clear to users how the data is manipulated, and how they can compare what goes on right now to what normally happened. This also shows users more data, and to show even more data, a button could be added to show the graphs of other days.

For the screen, the visualisation had benefits and drawbacks. Multiple users really like the visualisation, and having a visualisation seems to make the room more inviting. However, one user remarked it was weird to use a visualisation of people in spots they are not in, and the visualised study spots gives users the sense that the study spots are limited to what was shown. Perhaps the visualisation can be made more abstract, to show it is not a camera, but still reflect the tower room. This could for example be done by making a 2d interpretation of the Tower Room, which shows the full amount of desks

A lot of users cared about how many and what desks were available. In a more advanced prototype, this could be measured using a sensor that allows for location tracking. Although this doesn't mean that people may be identified, this information would be more private, so it would need to be protected well. Having this information would provide users with the information they want to know before going to the Tower Room, as they might be scared off when they learn there are six people, when there is no guarantee that these six people are occupying all the good spots. Also, it would make the tower room even more connected to the Lab Space, as people in the Lab Space would have an even better idea of what is going on.

9 Conclusion

In the information revolution, privacy is very important [38]. Therefore, providing users with anonymity protects their data against unethical use. Crowd counting has often been done with cameras, which can't do this [6]. This project applies less used privacy-friendly crowd counting technology to make a system that counts people and uses it to transform a study location into a smart environment in a privacy-friendly way.

First background research was done into what crowd counting technology is available, and what is needed for a good study location. Then, interviews were conducted to find what is important for this particular study location. Using the knowledge of the interviews and background research, ideas are generated, and one is picked. This idea is further specified, and realised. Then, the resulting prototypes were evaluated. Finally, the results and progress are discussed and future work is proposed.

Whenever making a new technology, it is important to realise how this may discriminate against people. [39] In this research, it was found that the sensor does not work as well on people with headwear. This might seem like an accuracy issue at first, but it is also an ethical issue since people wear headwear for religious reasons.

According to Tromp, Hekkert & Verbeek [40], technology serves as a driver for change. The technology developed in this research adds to society's knowledge about privacy, and reiterates how important it is to make sure there is no discrimination in creating new technologies. It is the responsibility of any engineer to make sure there is a more ethical future.

A Ethnographic interview questions

1. Demographics
   (a) Are you a student or an employee?
   (b) What study do you do?
   (c) Do you use the Interaction Lab regularly?
   (d) What gender do you identify with?
2. Questions about how the Interaction Lab is used
   (a) How do you use the Interaction Lab?
   (b) How do you think others use it?
3. Questions about activities in the Interaction Lab
   (a) Studying alone
   (b) Studying in groups
   (c) Group project work
   (d) Spend breaks
   (e) Meet with friends/hang out
   (f) Perform user testing/interviews for projects
   (g) For each topic it may be asked where they do it, why they do or don't do it in the interaction lab, how often they do it, and what factors are important in their decisions to do it.
4. Questions about early ideas
   (a) How would you feel about an application that shows you the crowdedness/occupancy/noise level/temperature/light level/air quality/what furnishing/what devices are available in the Interaction Lab before you decide to go there?
   (b) How would you feel about an application that corrects the noise level in the Interaction Lab when people talk too loud?
5. Question about what participants would change about the Interaction Lab
   (a) What would you change about the Interaction Lab?
6. Discussion of project
   (a) Do you have anything to add about this interview?
   (b) Do you have anything to add about this project?

B Code

B.1 main.py

```
import time as tim
import datetime
from analyze_image import Analyze_Image
from communication import Communication
from sensor import Sensor

analyze_image = Analyze_Image(0.0210)
communication = Communication()
sensor = Sensor(tim.time())



def AnalyzeFrame(time, datetime, frame, startup):
    analyze_image.update(analyze_image.t, frame)
    if analyze_image.Output[analyze_image.t] == 4 and not startup:
        analyze_image.idle += 1
        if analyze_image.Output[analyze_image.t - 1] != analyze_image.Output[analyze_imag
            code = analyze_image.getCode(analyze_image.t - 1, analyze_image.Output[analyz
            communication.communicate(datetime, time, code)
    else:
        analyze_image.idle = 0
    analyze_image.t += 1
    if analyze_image.idle >= 50 or analyze_image.t >= 900:
        analyze_image.reset(data=True)



def loop(time, datetime, startup):
    if time >= sensor.takeFrameTime + 0.1:
        frame = sensor.getFrame()
        sensor.takeFrameTime = time
        AnalyzeFrame(time, datetime, frame, startup)
    if time >= communication.setCountTime + 240 and datetime.minute % 5:
        reset = time >= communication.resetTime
        communication.SetCount(datetime, time, reset)



while analyze_image.t <= 50:
    loop(tim.time(), datetime.datetime.now(), startup=True)

while True:
    loop(tim.time(), datetime.datetime.now(), startup=False)
```

B.2 sensor.py

```
import smbus2 as smbus
import numpy as np


class Sensor:
    def __init__(self, time):
        self.bus = smbus.SMBus(1)
        self.takeFrameTime = time

    def getFrame(self):
        frame = np.zeros((8, 8))
        for i in range(8):
            data = self.bus.read_i2c_block_data(104, 128 + i * 16, 16)
            for j in range(8):
                frame[i][j] = (data[2 * j] + 256*data[2 * j + 1]) *0.25
        return frame
```

B.3 analyze_image.py

```
import numpy as np


class Analyze_Image:
    def __init__(self, normalizing_coefficient):
        self.k = normalizing_coefficient
        self.reset()

    def reset(self, data: bool = False):
        if data:
            self.Frame[0:49] = self.Frame[self.t - 49:self.t]  # time row column
            self.Frame[50:] = 0
            for i in range(3):
                self.Power[i][0:49] = self.Power[i][self.t - 49:self.t]
                self.Power[i][50:] = 0
            self.t = 49
            self.Output[0:49] = self.Output[self.t - 49:self.t]
            self.Output[50:999] = [0] * 949
        else:
            self.Frame = np.zeros((1000, 8, 8))
            self.t = 0
            self.Power = np.zeros((3, 1000))
            self.Output = [0] * 1000  # time
            self.Output[0] = 4
```

```
        self.Image = np.zeros((3, 1000, 8, 4))  # bin time row column
        self.Image_bin = np.zeros((3, 1000, 8, 4))  # bin time rows columns
        self.Threshold = np.zeros((3, 1000))  # bin time
        self.idle = 0

    def update(self, t, frame):
        self.Frame[t, :, :] = frame
        for i in range(3):
            self.Image_bin[i, t, :, :] = self.I_bin(t, i)
            self.Image[i, t, :, :] = self.I_bin(t, i)
            self.Power[i, t] = self.P(t, i)
            self.Threshold[i, t] = self.T(t, i)
            print(str(i) + ": " + str(self.Power[i, t] / self.Threshold[i, t]))
        self.Output[t] = self.O(t)

    def I(self, t: int, bin: int):
        return (self.I_bin[bin, t, :, :] - self.I_bin[bin, t].min()) / (
                    self.I_bin[bin, t].max() - self.I_bin[bin].min())

    def I_bin(self, t: int, bin: int):
        return self.Frame[t, :, bin * 2:bin * 2 + 4]

    def P(self, t: int, bin: int):
        return np.sum(np.square(self.Image_bin[bin, t, :, :])) / 32

    def T(self, t: int, bin: int):
        thresh = 0
        if t >= 50:
            for frame in range(t - 50, t):
                thresh += np.sum(self.Power[bin, frame])
        else:
            thresh += np.sum(self.Power[bin, t]) * 50
        return thresh * self.k

    def O(self, t: int):
        maximi = [0] * 3
        for i in range(3):
            maximi[i] = self.Power[i, t] / self.Threshold[i, t]
        if max(maximi) > 1:
            return np.argmax(maximi)

        return 4
```

```
    def getCode(self, index: int, last, middle: bool = False):
        if (self.Output[index] == 4 or index == 1):
            if middle:
                if last == self.Output[index + 1]: return "Hold"
                if last == 0 and self.Output[index + 1] == 2: return "I"
                if last == 2 and self.Output[index + 1] == 0: return "O"
            return "Wrong Output"
        if self.Output[index] == 1:
            middle = True
        return self.getCode(index - 1, last, middle)
```

B.4 communication.py

```
import MySQLdb as mc
import datetime as dt



class Communication:
    def __init__(self):
        self.meanings = {"Wrong Output": 0, "I": 1, "O": -1, "IHO": -1, "Hold": 0}

        self.db = mc.connect(host="localhost", user="root", password="Bb!24Paumysq")
        self.cursor = self.db.cursor()
        self.running = True

        self.cursor.execute("USE peoplecounter2")
        self.cursor.execute("SELECT time FROM count ORDER BY time DESC LIMIT 1")
        self.setCountTime = 0
        self.setCountTime = self.cursor.fetchall()[0][0]
        self.resetTime = self.getResetTime()

    def getResetTime(self):
        date = dt.datetime.fromtimestamp(self.setCountTime)
        if date.hour >= 3:
            date += dt.timedelta(days=1)
        date = date.replace(hour=3, minute=0, second=0, microsecond=0)
        return date.timestamp()

    def SetCount(self, date, time, reset):
        if reset:
            count = 0
            self.resetTime = self.getResetTime()
        else:
            self.cursor.execute("SELECT count FROM count ORDER BY time DESC LIMIT 1")
            count = self.cursor.fetchall()[0][0]
```

```
            self.cursor.execute("SELECT code FROM updates WHERE time >" + str(self.setCou
            for x in self.cursor.fetchall():
                count += self.meanings[x[0]]

        self.cursor.execute(
            "INSERT INTO count (time, count) VALUES (" + str(time) + "," + str(count) + "

        self.db.commit()
        self.setCountTime = time

    def communicate(self, date, time, code):
        if code == "": code = "Wrong Output"
        print(code)
        if code == "I" or code == "O":
            self.cursor.execute("INSERT INTO updates (time, code) VALUES (" + str(time) +
            self.db.commit()
```

C Prototype Interview

Make sure the interviewee is ready for the interview

1. Make they are comfortable
2. Tell people we are not testing them, but the prototype

Explain what the interview will look like

1. Explain goal of research
2. Ethics form
3. Questions about demographics and persona
4. Show prototypes and questions about prototypes
5. Closing

read/sign the ethics form Goal of project

1. The goal of the project is to make an application that invites people to go to the tower room more often and make it more connected to the main room. For this, two prototypes are created, which are meant to work in parallel, and which you will be introduced to in time. The goal of the interview is to find out what might be improved about these prototypes

Persona

1. To guide the interview, interviewees are introduced to a non-existent persona, using the following text and giving them a picture: "This persona is Frederik, Dutch, 25 years old. He studies Interaction Technology at the UT and is currently working on his thesis. Before, he was a CreaTe student. In his free time, he likes to use his 3d printer and do bouldering. He likes to use the tower room, because it is a comfortable place and his fellow students are also working there. Sometimes he takes breaks with them. Sometimes, he arrives in the tower room, but there is no one there yet, which disappoints him."

Demographics: Questions will be asked about demographics and compared to Persona

1. Whether they are students or employees
   (a) What study they do
   (b) Whether they are doing a thesis
2. Per week on average how often they use Interaction Lab ground floor
3. Per week on average how often they use the tower room
4. This is Persona. In what way do you relate to them? In what ways do you not?

Questions will be asked about the website.

1. Can you describe what you see? What function does it have?
2. How would you use this?
3. How would PERSONA use this?
4. Would you want to go to the tower room if you see this?
   (a) Ask the same question with different variations
5. If you could change anything about this website, what would it be?

1. Questions will be asked about the screen.
2. Can you describe what you see?
3. How do you think this system works?
   (a) If you see this and go to the tower room, what do you expect to find? Do you think the people are in these exact chairs? Would you be disappointed if what you find looks different from this?
   (b) Do you think you have any privacy concerns regarding the screens?
4. If you are in the Lab Space, how would seeing this make you feel about the tower room?
   (a) Would this make you feel like going to the tower room?
      i. Ask the same question when there is two people
      ii. Ask the same question when there is 0 people
      iii. Ask the same question when there is 5 people
   (b) How would this affect the sense of connection between the tower room and the Lab Space?

If people use the tower room, questions about business will be asked.

1. If there are 5 people, what is the atmosphere like in the tower room?
   (a) Does this image reflect the atmosphere when there are 5 people?
2. If there are 8 people, what is the atmosphere like in the tower room?
   (a) Does this image reflect the atmosphere when there are 8 people?
3. If there are 11 people, what is the atmosphere like in the tower room?
   (a) Does this image reflect the atmosphere when there are 11 people?

Closing

1. Do you have any other questions or comments about the project?

D Website Prototype variations

The sensor has measured

5

People in the tower room

Last week, the coming three hours were as follows:

11-12	12-13	13-14
5	6	6

The sensor has measured

8

People in the tower room

Last week, the coming three hours were as follows:

11-12	12-13	13-14
8	8	7

The sensor has measured

1

Person in the tower room

Last week, the coming three hours were as follows:

11-12	12-13	13-14
1	0	0

The sensor has measured

0

People in the tower room

In the next hour, the amount of people is expected to:

Increase by one

The sensor has measured

0

People in the tower room

In the next hour, the amount of people is expected to:

Stay the same

The sensor has measured

5

People in the tower room

In the next hour, the amount of people is expected to:

Increase by one

The sensor has measured

8

People in the tower room

In the next hour, the amount of people is expected to:

Stay the same

The sensor has measured

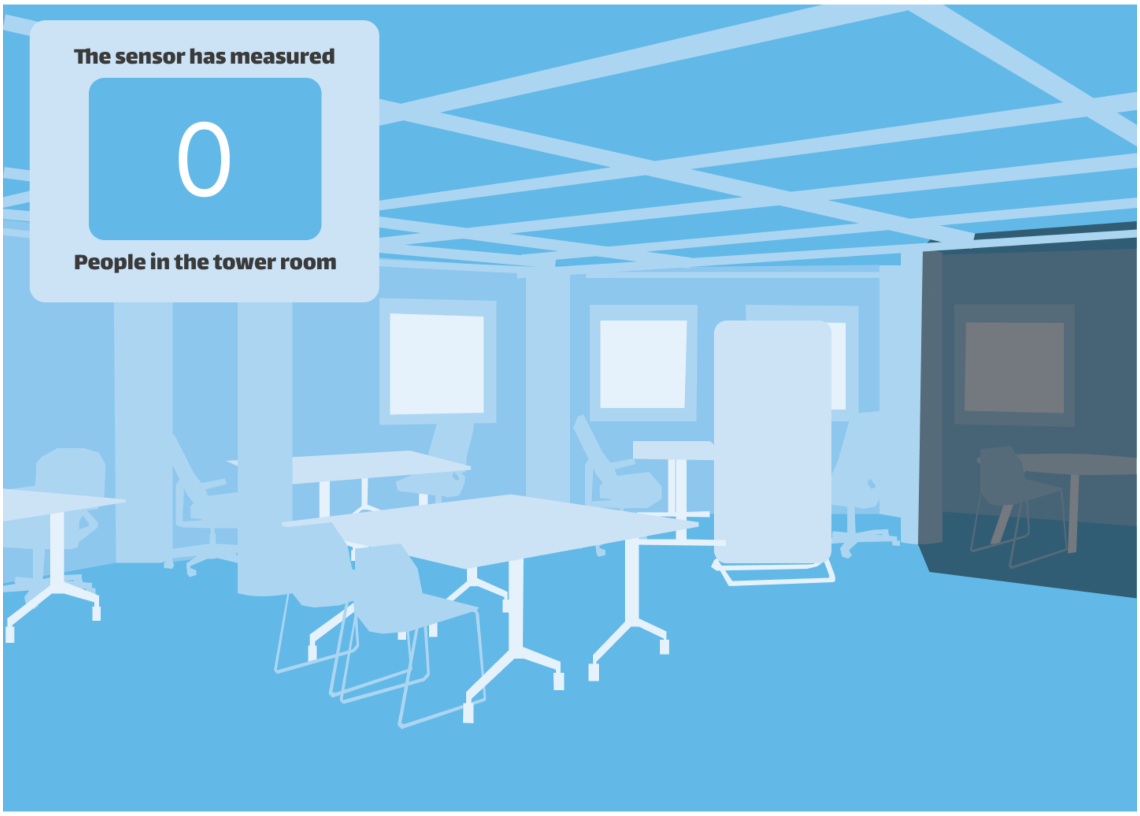
1

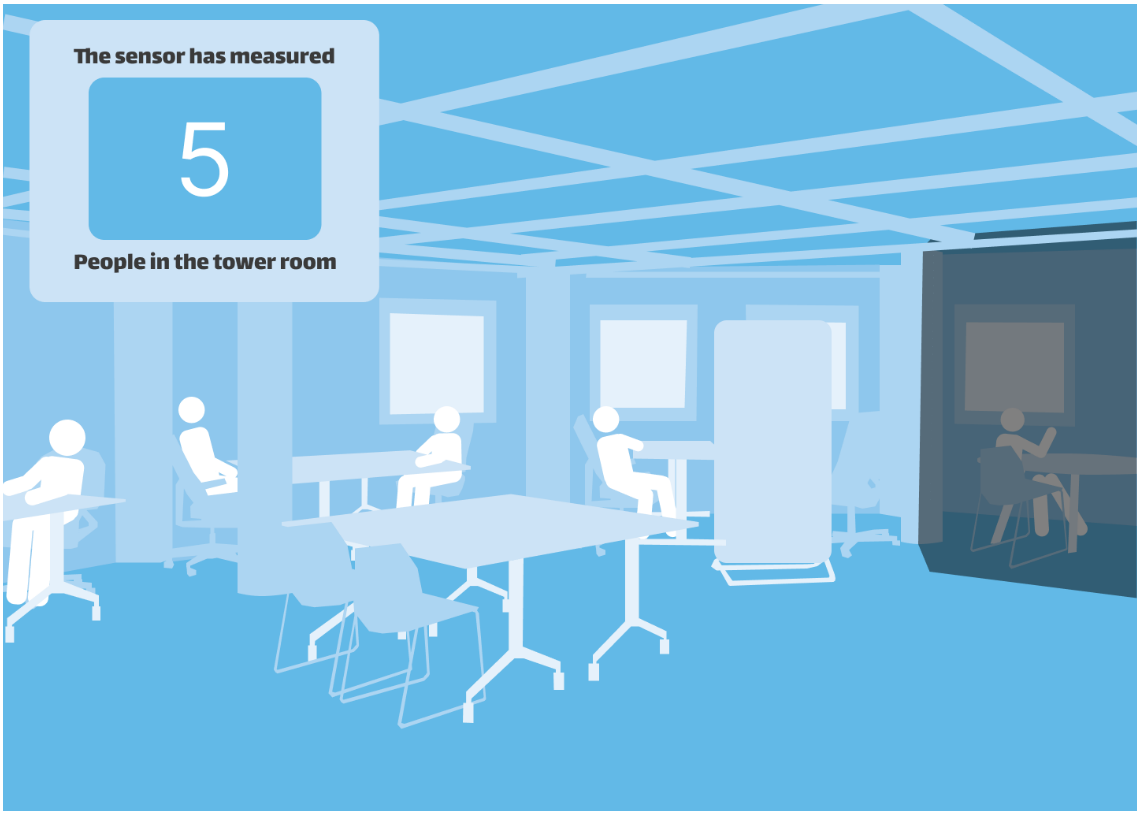
Person in the tower room

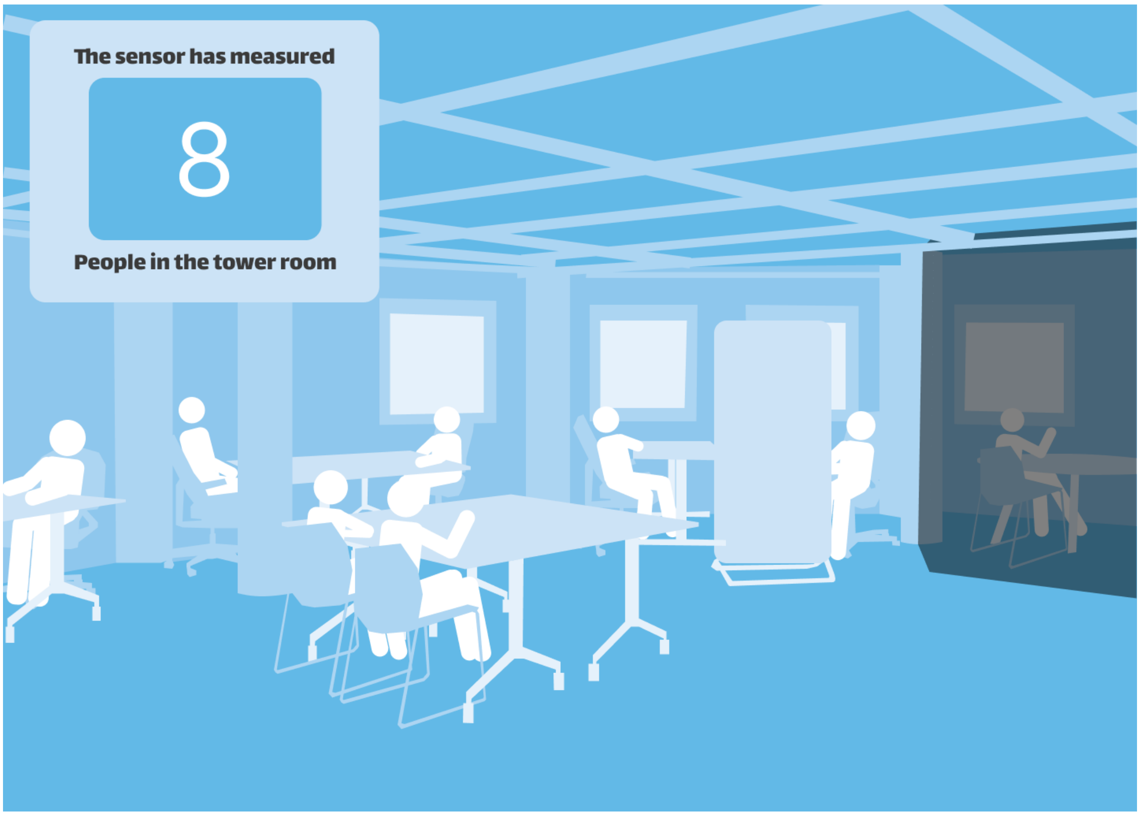
In the next hour, the amount of people is expected to:

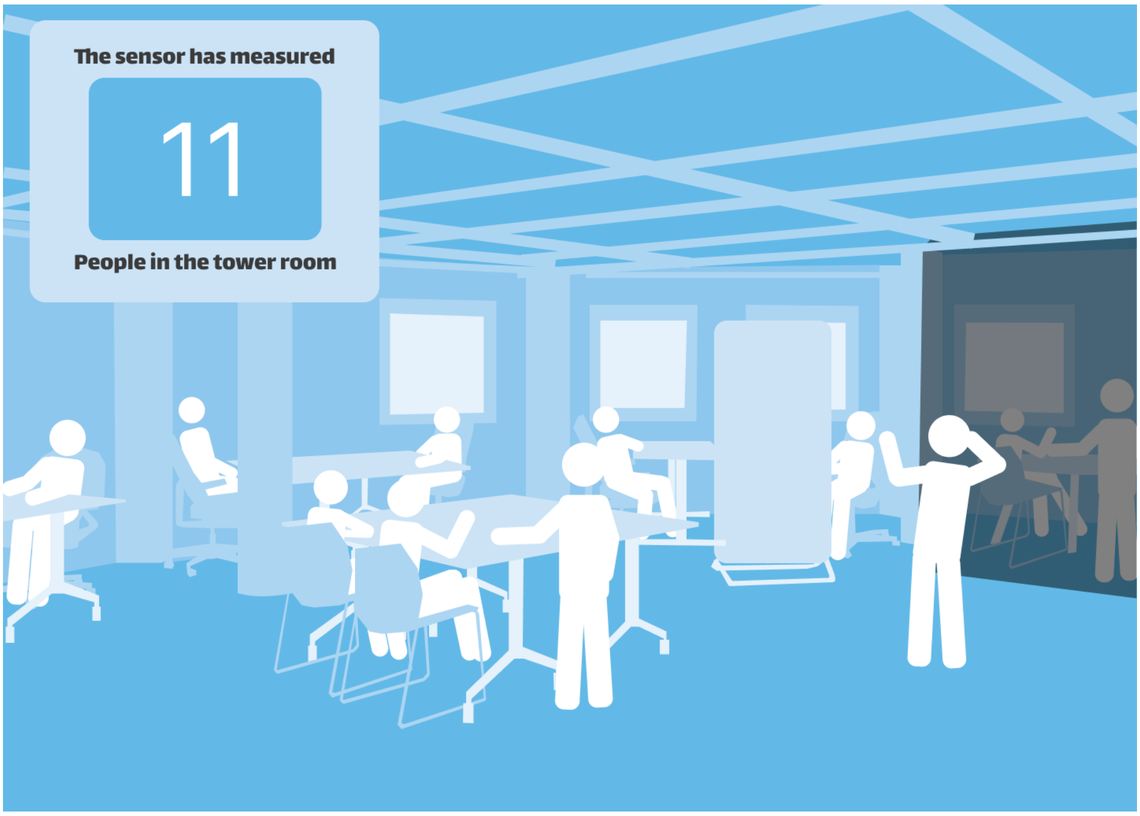
Decrease by one

E Screen Prototype variations






The sensor has measured
8
People in the tower room


The sensor has measured
11
People in the tower room

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