Framework for studying the flow of people at campus Johanneberg

A way to streamline the resource use

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1. Introduction

1.1 The project team

Emilia is a 25 year old engineer student with a bachelor in Bioengineering from Chalmers University of Technology. She is currently studying her last year at the master program Industrial Ecology which has given her extensive knowledge in tools needed to analyse environmental impacts and resource constraints. The education has equipped Emilia with competence in planning, leading and evaluating the effects of measures related to product development, land and resource use, energy systems and large-scale urban planning processes. During both the bachelor and master she has been provided with a solution-oriented engineering approach to environmental and sustainability problems as well as gained knowledge in chemical processes. Her interest in the course is mainly connected to the sustainability aspects and how we as humans can live in harmony with nature while still fulfilling our and our future generation's needs.

Felix is a 23 years old computer science student at Goethe-Universität Frankfurt am Main, Germany. He just started his master program and is spending a semester abroad in Sweden at Chalmers University of Technology. During his studies he learnt abstract thinking, analytical skills as well as working with teams and stakeholders. His bachelor program provided a broad background of computer science theory like algorithms, communication technology but only little practical application. This course is a great opportunity to apply this knowledge to a practical project, and learn more about working in cross disciplinary groups.

Elena is 23 years old and is currently studying the second year of a master programme in Industrial Design Engineering at Chalmers University of Technology. This field of studies is very broad. It deals with situations that range from complex interdisciplinary problem-solving, to creative-thinking and to graphical design visualizations, what makes Elena an individual that can handle a variety of situations, even those new to her. As a consequence, her years of studies and projects have made her used to looking at projects from different angles and finding a common ground between different perspectives and stakeholders. She is particularly interested in sustainable and user-centered design, since she believes that anything new we build needs to add value, rather than only aggravating even more the current environmental issue. Therefore, her interest in this course was to enter a yet new area of knowledge regarding the kind of problems and solutions that could try to generate value, rather than just consume even more resources.

Johnny is a 26 year old aspiring designer, who is currently attending the second year of the Interaction Design and Technologies (IxD) master program at Chalmers University of Technology. As interaction design is a broad topic that involves how we design and develop interactive systems, the IxD discipline ranges from design-focused areas such as game design, industrial design and human-computer interaction, to more advanced computer science concepts such as simulation engines, mobile and tangible computing, and computer graphics. He aims to become a modern renaissance man of information technology, and finds a great interest in the diverse areas of IxD where the diverse aspects of the applied computer sciences can be gathered in a toolbox and applied in a user-centered context to add actual value. Studying both design and computer sciences to become an interaction designer have made him a jack-of-all-trades and a master of none, but in a modern interdisciplinary and multidisciplinary context of digital innovations, he sees bigger potentials in that than a master of one.

1.2 Campus Johanneberg

Campus Johanneberg was built in 1926 and at first there was a comprehensive plan on how to expand the campus area. However, during the mid 18th century new buildings were built and the architecture style had changed since the campus plan was made in the 1920s. Now, the focus was more on the functionality of the buildings and less on the overall architectural perception of the area. The campus plan was changed due to the new city plan and the buildings we see today are the ones built during this time, with some adjustments (Chalmers tekniska högskola et al., 2019).

A lot has changed since the mid 18th century and a few problems have arisen. The largest challenge we have identified is the large amount of people visiting campus during the weekdays. Campus is getting crowded and the buildings are not suited for this amount of people. Currently, there are about 11 000 students and 3 000 employees at Chalmers' three campuses, whereof Johanneberg is the largest one. The ventilation systems are getting old and the way students study has changed a lot. Only two decades ago, students did not have their own laptop on campus. Therefore, there was a great demand for computer rooms. However, this is not the case today. We see that the use of the facilities can be more efficient if we can map out how and when the facilities are used.

Today, there are two main actors when it comes to facility management on campus Johanneberg, Akademiska Hus AB and Chalmers Fastigheter AB, see figure 1 below.

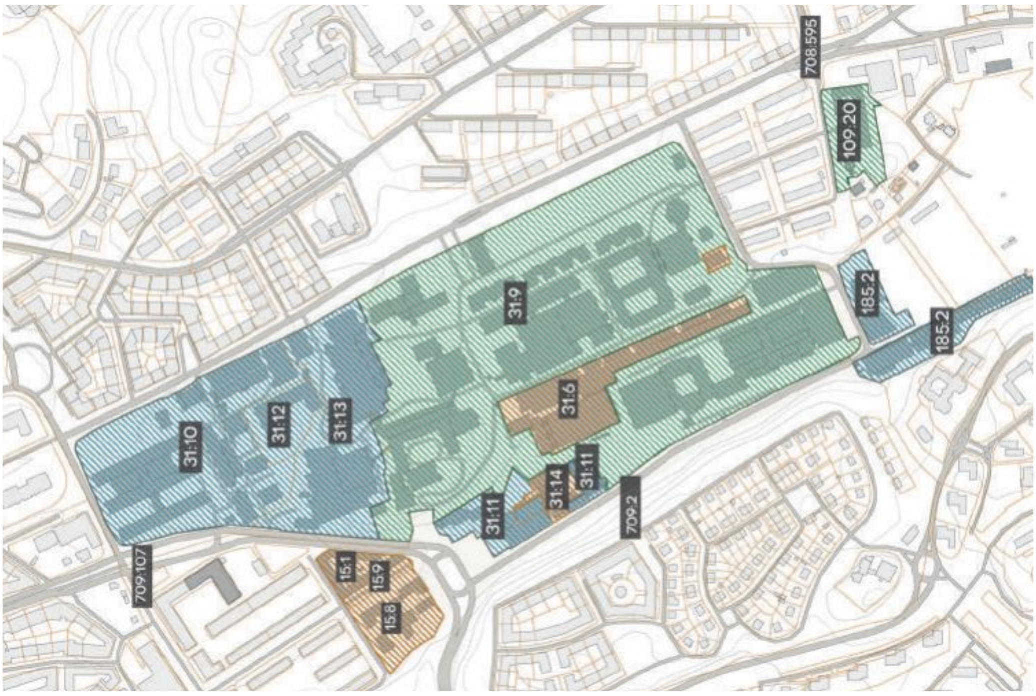

Figure 1. *Property division of campus Johanneberg where blue is Chalmers Fastigheter AB, green is Akademiska Hus and orange is others such as the student union and SSPA.*

The actors on campus have together formed a plan for the development of the campus until 2050 (Chalmers tekniska högskola et al., 2019). Included in this plan are some overall goals for the campus area, see figure 2.

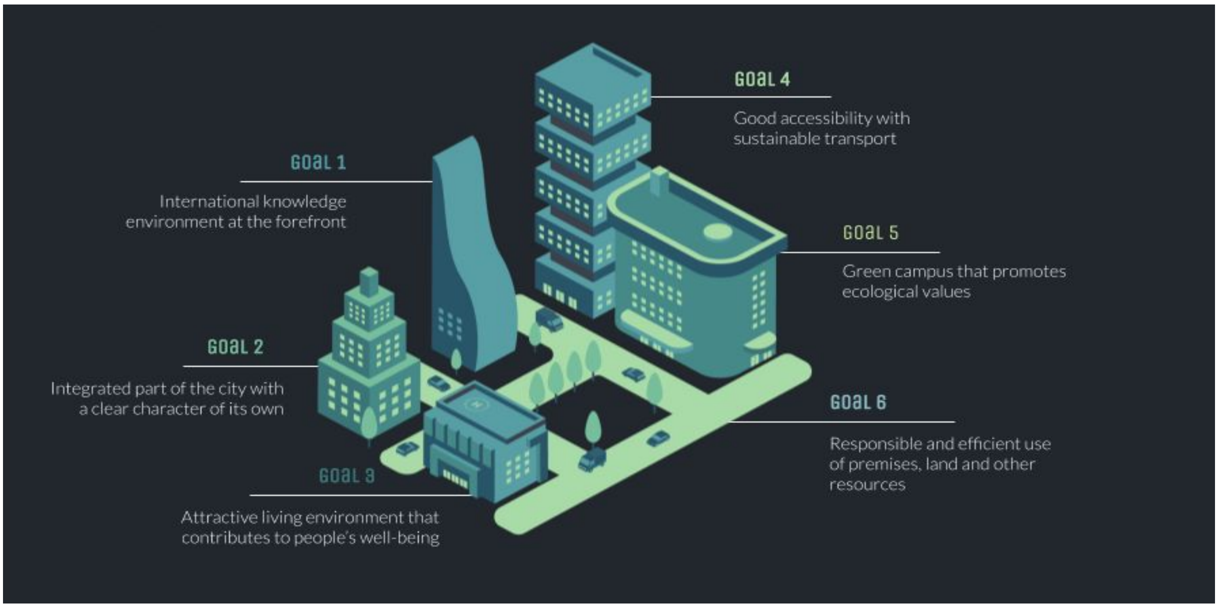

Figure 2. *The six goals of the campus plan for Chalmers University of Technology 2019-2050.*

Our project is mainly connected to goal 6; Responsible and efficient use of premises, land and other resources. We think this can be achieved by focusing on gathering information of how people use the premises at campus.

1.3 Studying flow of people

Through using information about how people move around in campus Johanneberg one can plan the use of facilities and other resources connected to those, in a more efficient way. A project connected to this has been conducted by Ioanna Stavroulaki, associate professor at Spatial Morphology Group who visited us during the first part of the course (Stavroulaki et al., 2020). Pedestrian movements were tracked through wi-fi signals and sensors counting people passing by with the aim to understand how the flow of people relate to the spatial structure of campus Johanneberg and how the plan for developing campus will affect these patterns. Inspired by this study, we will propose a solution for how to measure the flow of people on campus as well as how to use this information to improve the resource use on campus, with focus on premises. Additionally, we will present other ideas on how this information could be used. This information can come in handy for several applications and especially in the times of the covid-19 pandemic when large crowds of people should be avoided.

2. Goal and scope

The aim of this project is to create a framework for gathering and visualising information about the distribution of people on campus in order to use available resources in an efficient way. We find that it is strongly connected to mainly four global sustainable development goals, see figure 3 (United Nations, 2020).

Figure 3. *The four SDGs connected to the project aim, goal 7, 12, 13 and 15.*

The framework may be able to support the development of affordable and clean energy. If connected to the energy source, the use of this energy can be optimised and not wasted and the excess energy can be made available for others to use. In the same way, the project is connected to goal 12; responsible consumption and production. The goal is to use all resources in the most efficient way, and through our framework we will move towards that goal. It will support the planning of resources and may also be directly connected to the control of some resources such as energy.

Following this, the more efficient use of our resources will also have an impact on climate change mitigation. The less resources that are wasted, the less greenhouse gases are emitted unnecessarily. We may not have to warm up premises that are not used a lot, and we may reduce the food waste through better planning of how much food is going to be cooked each day. This will also influence the life on land, goal 15, through the efficient use of our resources on campus, particularly the use of premises. While we today feel that there is not enough space for everyone on campus, we may find that optimising how we use the space reduces the need for expanding the campus. In this way, we are able to keep the green areas on campus and not destroy the environment around us by building new facilities.

3. Process

The whole process of forming a project idea started with the selection of the three thematic blocks that we want to base our project on. Thanks to our common interests, we were able to quickly agree on the thematic blocks **Information**, **Flows**, and **Resources**.
Inspired by the pedestrian study presented by Ioanna Stavroulaki (Stavroulaki et al., 2020) during the first study visit we came up with the idea to measure the number of people that are present on the campus and how they move. We thought this was an excellent connection of the two areas *Information* and *Flows*, while also involving the thematic area *Space*. By brainstorming how we can combine this first concept with the thematic area of resources, we came up with plenty of ideas. The many brilliant but different ideas led us to decide to present our project as a framework that allows for a smarter use of resources on campus, by providing real time information about the number of people on campus. For this course we want to focus on 4 possible use-cases:

- **Food preparation**: If the restaurants on campus knew how many people are on campus in the morning, they might be able to make a more accurate prediction for how much lunch needs to be prepared that day. This could reduce food waste.
- **Heat and ventilation:** The heating and ventilation of buildings and individual rooms could be regulated according to the amount of people inside those.
- **Safety:** If it was known how many people are inside a building or room, it could make it easier to follow Covid-19-regulations but also regulations regarding fire protection.
- **Student information:** Students could be informed about empty study rooms, available places in computer rooms, etc.. This could lead to a more efficient use of premises on the campus.

In order to assess how useful our ideas were, we decided to talk to different stakeholders. Each group member contacted a different stakeholder for each of our ideas. We did interviews with the Food & Beverage Manager of Chalmers Studentkårs Restaurang, the crisis management group and a survey among students. Unfortunately we were still not able to get a reply from Chalmersfastigheter regarding our heating and ventilation ideas.

As we got overall positive replies from the stakeholders we moved on to the questions of how this project could be implemented. Based on our different competences within the group, we split our research into the areas *visualization* and *counting people*. In regular meetings we exchanged our new insights to develop our concept. Especially the feedback from our teachers was very helpful along the whole process.

4. Proposed solution

4.1 Areas of application

4.1.1 Chalmersfastigheter: heat and ventilation

This user-case would consist of using the number of people at a room to automatically adjust heat and ventilation, thus reducing the energy wasted in these aspects. An idea is to connect the system to timeedit and the schedule could then give a prediction for the heat and ventilation systems on what to expect. It would not only be a beneficial feature for Chalmersfastigheter and Akademiska Hus, which right now is responsible for the infrastructure of the buildings, as well as their maintenance, electricity, water, heating and ventilation systems, but also for the great number of individuals that spend time in Chalmer´s facilities. It would assure a comfortable temperature in departments, offices and classes being used throughout the whole campus, while at the same time saving energy from those empty or more crowded spaces.

Sadly, we could not contact Chalmersfastigheter, but still, we believe that this area has great potential as a means to reduce energy use at campus.

4.1.2 Food: Restaurants and Cafes at Campus

We hope that our proposed framework can help the kitchen staff at campus to better estimate the amount of food that needs to be prepared for lunch in order to avoid food waste. As our framework cannot predict the amount of people that will be on campus at lunchtime and rather provides just a snapshot of the people that are currently on campus we were critically thinking about how helpful this information might be. To assess how our system can help the restaurants on campus, we talked to the Food & Beverage Manager of Chalmers Studentkårs Restaurang.

Especially now during the Corona pandemic, it is not very easy to estimate the amount of food that needs to be prepared for the lunch at campus. Even though the staff in the kitchen has gained a lot of experience predicting the amount of portions to be prepared, they would still benefit from knowing the number of people currently on campus.
The restaurants order the food from the suppliers approximately 1-3 working days before serving it. However, the decision on how much food will be prepared for the day is done on the same morning. Knowing how much people are on campus in the morning would make these predictions easier.

The Food and Beverage Manager mentioned that our framework providing real time information would assist the kitchen team enormously and that "it would help us to be more efficient in a lot of ways, everything from food preparation, logistics in the kitchen and also reduce food waste".

4.1.3 Safety

The information about how many people are visiting the premises can be used in order to assess the risk of different situations. One example is when the members in the crisis management group are assessing the risk connected to visiting campus in educational situations during the pandemic. It could also be used for fire safety planning. If there are a lot of people visiting some specific areas, there might be a need for improving the fire safety like adding multiple emergency exits or rearranging the furniture.

We asked a representative for the crisis management group if this kind of information would be useful and how it should be presented in that case. The answers we got where mostly very positive and we got some new insights in how the information may support the employees working with safety on campus.

4.1.4 Streamlining use information of premises

This case is special, since it is not directly connected to the efficient use of resources, but rather to make available the information already gathered for a stakeholder that would find it useful. The main idea is to give students and staff at Chalmers the capacity to see real time information of rooms/study places available. This would also be useful for the pubs, restaurants and cafeterias, where one could find out if there is room, or check other available options.

In addition, we thought it might be relevant in the current pandemic situation, since this kind of information might help some students assess the "risk of going to campus". One could know if there are lots of students using the department study places, or if there are usually a lot of people in a given silent room. This will also help improve the study and work environment, reducing the risk of being in a loud and crowded room.

We carried out a student survey and we got a very positive answer to all of the application cases that we suggested. The topic of data protection proved to be a matter of concern amongst students, which stressed its importance and the need to target this issue in particular. Moreover, the surveys on this case were very useful regarding the decision of which platform would be most convenient to share this information for students, since Chalmers provides several kinds of platforms like The Student Portal, Canvas, Campus Maps, etc. Based on the survey, it was decided that Campus maps should be used and we find that it could easily adopt this feature. For the staff, we think the most convenient platform is the Intranet since that is used almost daily by everyone that is employed by Chalmers.

4.2 Methods for measuring flow of people

Our project suggests different use cases that could benefit from the information about the amount of people on campus. In order to provide helpful data for each of the use cases, we need to consider at which resolution our system has to detect the amount or presence of people. Therefore we decided to conduct our data gathering in three different resolutions:

1. **Small:** Individual desks and workspaces
2. **Medium:** Group rooms
3. **Large**: Campus and Buildings

4.2.1 Small Resolution

Is an individual workspace currently occupied or free to use?

In order to detect whether a workspace is currently occupied, we came up with many different ideas to detect the presence of a person. However, it seems to be quite a challenge to accurately tell whether a desk is currently being used, even when the person went away from the desk for a short break.
We decided for the use of wireless under desk sensors. They are small, easy to install and considerably cheap. Those sensors detect the passive infrared radiation emitted by people and can therefore tell whether a person is present sitting at the desk. Configured correctly, it can allow for a short absence of the person before the desk is considered as unoccupied again.

***Figure 4**. Wireless under desk sensors detect the presence of a person sitting at the desk.*

4.2.2 Medium Resolution

Is a group room currently in use or is it free?

When it comes to detecting individual rooms, there's less of a need to understand how many occupants are utilizing a group room, as it would be enough to define whether or not the room has more than one occupant or not. This could however be defined with the same type of method as the lower resolution design, as it would be enough with sensors that detect whether or not there are still potential occupants in a room.

4.2.3 Large Resolution

How many people are currently on campus, in which buildings, and how do they distribute?

For counting the amount of people on campus we propose two possible methods. In both cases we rely on the infrastructure of wireless access points all over the campus and the ubiquitous use of mobile devices. The first method does not require any change to the current WiFi infrastructure and therefore keeps the costs and effort low. The second method requires some additional hardware that is placed in certain points on the campus, but would probably increase the accuracy of the predicted amount of people. In this section we will briefly introduce both methods.

METHOD 1: COUNTING EDUROAM CONNECTIONS

The campus Johanneberg provides a wide and comprehensive network of wireless access points (see Figure X). We assume that most of the people that regularly visit the campus, i.e. students and staff, have their mobile devices connected to the eduroam network.

Figure 5. *The campus Johanneberg already has a comprehensive Wifi infrastructure that can be used to determine the number of mobile devices on campus. (Exemplary figure)*

The Dynamic Host Control Protocol (DHCP) is used by routers to lease IP addresses for a temporary period of time to non-permanent devices connected to the network. This includes mobile phones and laptops, but excludes computers and workstations that are permanently installed on campus. Each access point maintains a table of the IP addresses leased out with DHCP and is therefore a measure for the number of mobile and temporary devices on the campus. We expect this number to correlate strongly with the ground truth amount of people on campus. Melfi et al. showed that this method can be used as an indicator for building occupancy (Melfi et al., 2011). As we know the location of each access point, it is possible to make a rough estimate on the location of the connected devices.

METHOD 2: COUNTING BY DETECTING WIFI PROBE REQUESTS

Every device with an enabled WiFi interface sends out periodically so-called “probe requests”. Wireless access points in range reply to these broadcasts and send back information about the wireless network, see figure 6. The actual purpose of this procedure is for the mobile device to detect nearby networks available for connection. This scanning process is performed whenever the device’s WiFi interface is enabled, regardless of whether or not the device is already connected to a network.

Figure 6. *Mobile devices regularly send out probe request to gather information about access points nearby. The access points reply with information about the network.*

The probe requests are transmitted wirelessly and therefore can be captured by a detection device and analysed. Along with the probe request, the devices send out their unique physical address (MAC address) which can then be used for counting. Oliveira et al. implemented a system that uses this technique to monitor the amount of people inside a room. They showed that the number of detected devices predict the ground truth number of people with a Pearson’s correlation coefficient of 0.896 (Oliveira et al., 2019). We expect that a network of those detection devices, spread all over the campus and buildings, can accurately predict the presence and number of people on campus. As probe requests might be picked up by multiple detection devices it might even be possible to predict the position of each device with triangulation.

Both methods for large resolution counting have their strengths. However, it is to consider that the measurements will not be totally accurate due to multiple reasons. Some people might carry more than one device with a WiFi interface while others do not carry a device at all or have their WiFi interface disabled. Which of the proposed methods is suited better for the campus environment could be shown in future research. We think that a mix of both methods, Method 1 outdoors and Method 2 indoors, could be a good tradeoff between accuracy and costs.

4.2.4 Joining, storing & interfacing data

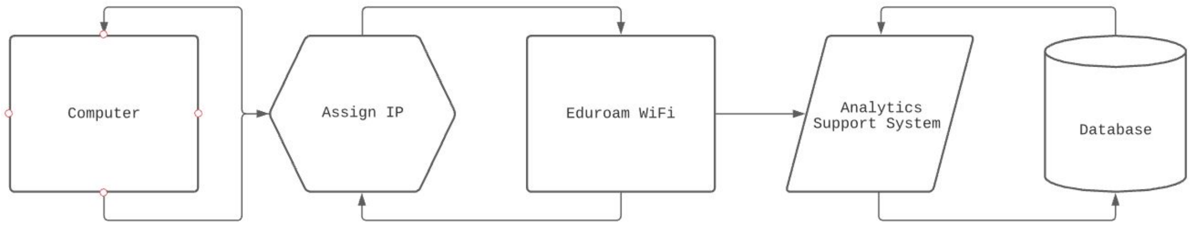

Figure 7 - WiFi solution system diagram

As the initial vision of the data collection is to analyze it, there exists a need for it to be securely stored where it would be easy to access. We need to take into account the public availability and the security of the storage of this data. This could however be accomplished by either self-hosting the analytics data through Chalmers IT, or by utilizing cloud storage providers to minimize downtime. However, since the software architecture would allow buffering of the real-time data stream, the upkeep time of the storage of the data system would not be a priority.

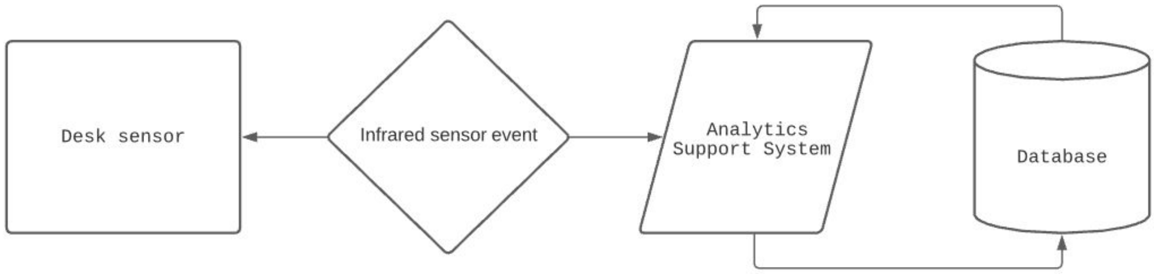

Figure 8 - Infrared desk sensor system diagram

Our design concept involves the lower resolution solution for analyzing the number of participants sharing a similar system architecture, where the main data is collected from the desk sensors collecting user data and is sent to the processing unit (dubbed the Analytics Support System).

Now, how the DBMS in itself would be designed is of less importance in this stage of design, but it would be designed for maximum upkeep operability due to this system's potential to become the backbone of a larger environmental support system. The query type it would be stored in is of less speculative importance. However, it would be most probable for the system to be utilizing MySQL for stability and scalability, as lighter alternatives such as SQLite would be easier to implement at the start but would suffer in the long term. The front-end query interface would preferably be written in Python, as it could offer interoperability with other potential systems that could benefit from this data.

4.3 Visualising data

Once there is a database with the information received by the different kinds of methods that comprise the data gathering infrastructure, it is of the utmost importance for the stakeholders, to have the kind of data they need accessible and in a comprehensible display. During the studies, it was clear that there are two main groups of stakeholders: corporate and non-corporate. The first group comprises a variety of companies like Chalmers, Chalmersfastigheter or Akademiska Huset, which would need direct access to the data gathered to improve their performance. Secondly, the non-corporate group would be students and academics who would only use the information for informative purposes. This group would not need the exact numbers, but would benefit from having access to useful information expressed in intervals.

Both groups of stakeholders have different kinds of needs and aims. They do not need the same information, nor do they need the information displayed in the same way. Thus, the solution has two different kinds of visualizations, one for each group.

4.3.1 Data access for employees

The raw data can be accessed by employees on the intranet. The intranet at Chalmers is role-controlled and hence only people that need the information will be able to access it. An example on where the information could be found on the intranet is presented in figure 9.

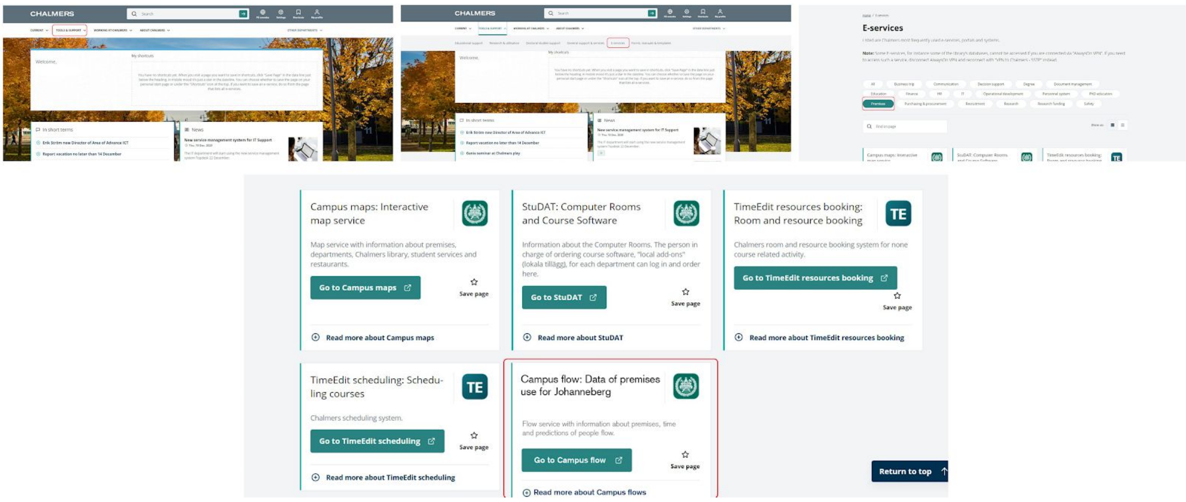

Figure 9. *Where one will be able to find the data on campus flows through the intranet.*

The raw data will be presented in tables and there will be historical data presented in average, peak and bottom notations for a selected time period, see table 1.

__Table 1.__ Number of people visiting the chemistry entrance at different time periods during the day in a span of days.

Chemistry entrance *2021-12-10 - 2021-12-15*			
Time period	Average	Peak notation	Bottom notation
8:00-9:59 am	373	527	113
10:00-11:59 am	452	698	231
12:00-2:59 pm	594	767	344
2:59-5:00 pm	147	379	87

Another idea is to visualise the real time data with bars in a diagram. When the number of people that are currently present in a room exceeds the fire safety limit or optimal ventilation limit one can send an alarm warning people or the janitor that there are too many in the room at the moment. This could be visualised in the way as you may see in figure 10.

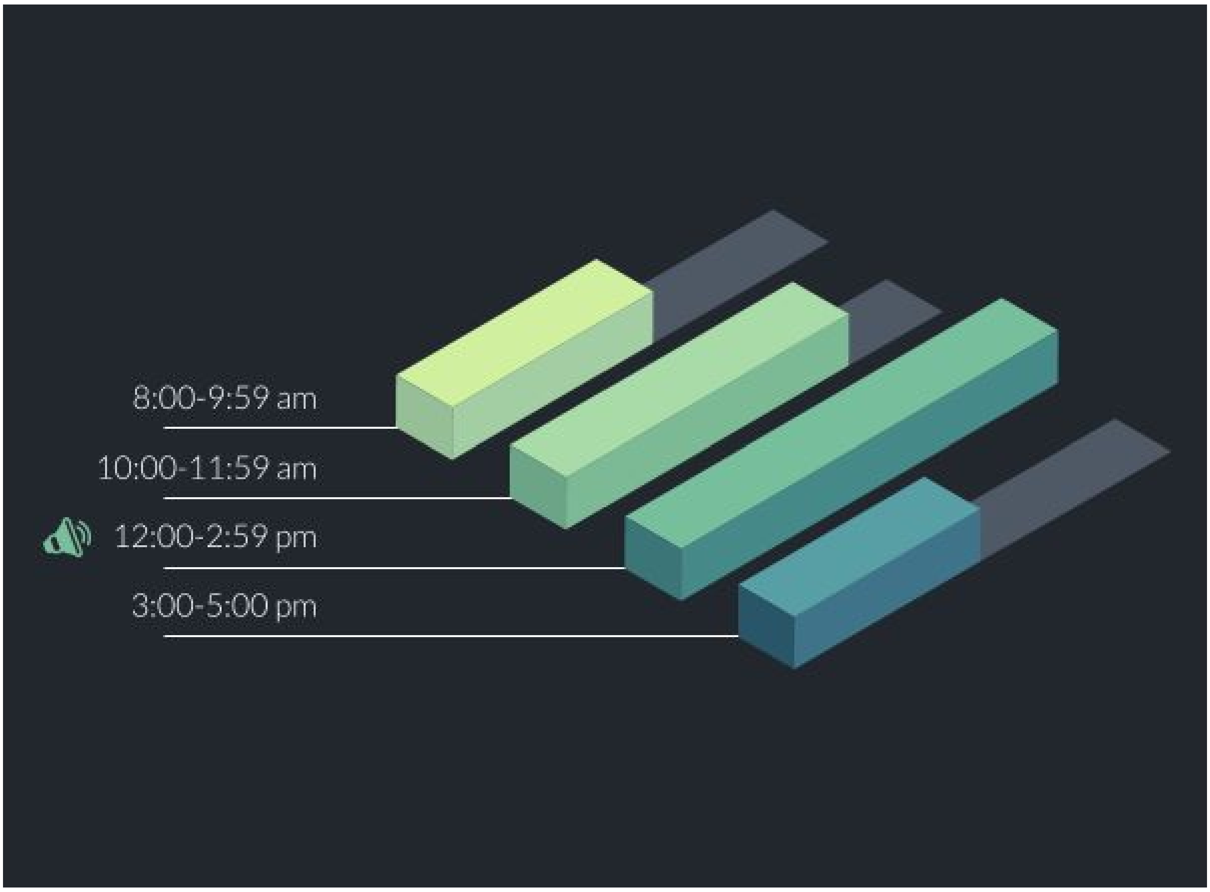

__Figure 10.__ Bar graph representation of real time number of people in a specific time period.

4.3.2 Data access for students

Students´s data access needs not only to consider what kind of information would be useful for them or where to find it, but also other aspects like safety or privacy. Safety in the sense that not just anyone should have access to the information displayed about how many people are at a given moment at a given place at campus, but also that it should not be displayed if someone is alone. And privacy, meaning that the movements of one individual should not be used to track them down, or to know who that one person might be.

To tackle these issues, the user research was essential. On the student survey, options were provided as to where would be useful to find the information, As well as some considerations regarding the possible different uses and safety. As a combination of the answers of the user research and the use of our own judgement, we thought the most convenient platform to display the results was an updated version of Campus Maps. This app is already owned by Chalmers and students use it to find rooms, computers and people throughout campus. It is a very suitable platform to support this kind of service extension. Furthermore, regarding the accessibility of the data, it would be very simple to add a login feature, so that only users with Chalmers credentials could access this information.

Campus maps is an ideal platform because it already has information of the different locations on all of Chalmer´s campus and counts with a database and search engine. Our proposed framework would provide information that could be seen as an update of the features provided now by the app.

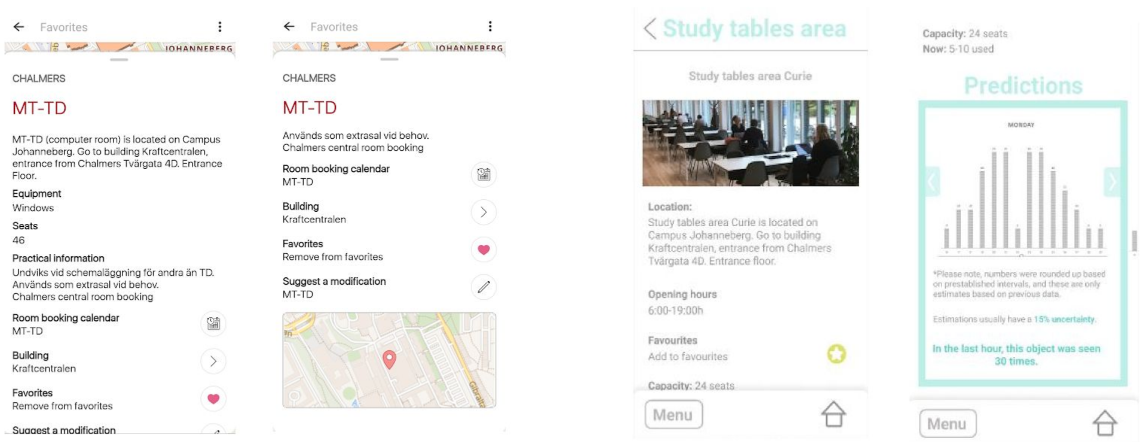

Figure 11. *Comparison between current campus maps app and the new proposal.*

On figure 11, one can see that a prototype of the Campus Maps v2.0 (the screenshots on the right) would be based on the current one (the screenshots on the left), but it includes the information regarding the capacity of the space, and the number of people currently at the location, expressed in intervals. The fact that information is given in intervals is to avoid showing information of who is alone at a given place. Another feature would be that one could find interactive predictions of how many people might be, based on the data gathered through time, as well as its estimated uncertainty. How many people have seen that object in the last hour, could be added as well, to help students estimate how many people are thinking of going in the near future or to provide information about how popular a spot is.

But this proposed solution not only displays the capacity information and surveillance, but the way in which that information is visualized needs to be user-friendly, smart and coherent.

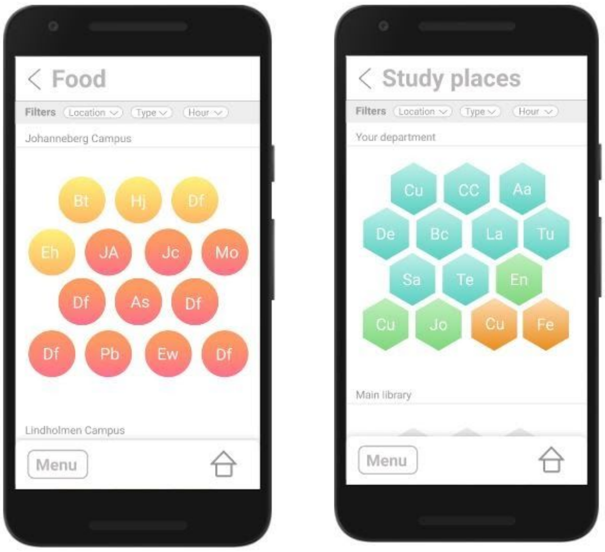

Figure 12. *Prototypes for finding food and study places in the new campus maps app.*

The proposed visualization of the available objects is through an eye-catching but easy-to-use interface with simple geometrical objects standing for the objects. Different colors would mean different types of objects, and the different objects could also be recognisable for their names. For example, in figure 12 one can see yellow and orange circular buttons: yellow would mean it is only a cafe and orange that it also has a kitchen and provides proper lunch. As for the letters, on the first object one can read “JA”, which would be the shortened version of “J.A. Pripps”, so that it is easy to recognize and to know the names of the different services available at campus. This would also help in some cases, where some facilities are “hidden” for people that study in different departments.

Regarding the objects shown, the software would prioritize the options in the user's department, then main common areas, and finally other objects in different departments. Furthermore, in the case of study places/rooms/group work rooms it would automatically show only available options at the moment. But it would also offer a search engine that allows search by location, type of object and time of the day, which would give the option to see or book places in the future too.

You are most welcome to use the prototype and explore the visualizations we created for the [Campus Maps v2.0, click here.]

5. Conclusions

The framework created in this project might be able to help streamlining the resource use on campus Johanneberg, which in turn will contribute toward the sustainable development goals presented in chapter 2. The most important thing is probably to use the premises in a more efficient way than what we do today. This also connects to one of the goals in the campus plan that were presented in chapter 1.2. While identifying the premises that are not used as much as expected, one may be able to convert these into more flexible spaces that could be used for several different purposes.

Another important aspect is the one of reducing food waste and how this technology could be a great tool for the kitchen staff at campus. However, this probably needs to be based on predictions of the data. In this case, we need to gather some data before in order to make correct predictions.

To conclude, our work probably has the ability to impact the economy of Chalmers as well as the societal contexts. We may be able to help people find new places to study and meet new people while at the same time making sure that the premises are used in an efficient way, reducing the costs of renting premises.

6. Reflections

One of the major pitfalls with storing this type of data is whether or not this data can be tracked to those who it initially originates from. This refers to the type of data that specifically could be used to identify individual users, the analytics concerning the data, and the accessibility of this. As we noted in the responses from our questionnaire, there exists concerns among the affected target group, i.e. the individuals that would be the target of these analytics. This means both types of users in the form of those being subject to generating the data, and the expert users who would be processing the collected data. When analyzing the data collected from the user research phase, we realized that there were concerns regarding the privacy and accessibility features of the concept. There is an inherent fear from the common user that the accessibility of the collected data could be used in unintended ways by unauthorized third parties.

Along our work on the project we learnt how important and helpful it can be to include the stakeholders in the design process. For instance, suggestions from students in our survey led to more insights from different perspectives and made us change our plans regarding the visualization of capacities with color codes. Students pointed out better approaches that might be less deceptive and rather neutral.

When we look back at how the project was conducted, we realized that there's value in a multidisciplinary approach. When we as individuals come together with different perspectives, that's when we can apply design thinking methods and look at the problem with a solution-oriented approach. However, it can definitely be noted that we earlier on would benefit from establishing a basic understanding of how our disciplines can synergize. By more openly sharing the methodologies that define our respective fields at the inception of the project phase, we could have had the opportunity to workshop and brainstorm how our different skill sets and toolboxes could better synergize.

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