Solution Document

CSC4008

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# Background

Digital transformation is leveraging technology of the 21st centaury to create new or modify existing business processes and customer experience. It integrates digital technology into all areas of the business to fundamentally change how you operate and deliver to customers. The term ‘Internet of things’ was not coined until 1999 by Kevin Ashton executive director of Auto-ID. One of the earliest examples of using the internet and sensors to gather information was in the early 1980’s in Carnegie Melon University. Local programmers would connect the internet to a coca cola machine to check if there was any stock left and whether it was cold, before making the trip to the machine. The introduction of powerful smart devices and development of communication technologies like 5G, is currently integrating IoT devices into societies life. In 2017 the market size of IoT was 109 billion U.S. dollars, two years later, in 2019 the market size of IoT nearly doubled, which increased to 212 billion U.S. dollars [1]. In recent years the Internet of things has grown into a network of multiple technologies ranging from Internet to wireless communication and embedded systems. With the reduction in size of a computer chip it is now possible to turn nearly anything into an IoT device. Devices with inbuilt sensors will be connected to an internet of things platform which integrates data from different devices and will apply analytics to the data. These analytics can be used to give recommendations, detect inefficiencies and possible faults before they occur. The integration can be as small as a wearable device such as Fitbit being connected to your phone, to a plethora of sensors in a building connected together.

Our team proposed a smart building system for QUB Computer Science Building which will utilise many existing resources, the design of re-using existing resources matches contexts mentioned in [3]. The advantage of this early design is that the initial set up costs for smart building deployment are low which most customers will be satisfied with as they see results without heavy investment. This can increase the confidence of the customer in IoT solutions and this can stimulate them into investing more into IoT solutions, this is a win-win for the business developing IoT solutions and the customers who will receive the benefits of the solutions. Our system will consist of several features such as map of building, route analysis between different rooms, display room status, alert any changes of room status and environment statistics monitoring such as heating, electricity and occupancy. Our system contains majority of basic functionalities of smart building solutions, so it is portable to different smart building scenarios such as school, shopping mall, office, hotel etc. Our system can be extended easily because of our de-coupled architecture between front-end, server, business logic and database, it only needs relatively small effort to deploy and it’s not hard for troubleshooting and maintenance.

This document will first specify and evaluate target markets of our system by combining experience gathered from background research. Next, we will explain steps to develop our project according to our background research, start from project planning to project implementation and share the challenges we experienced during this project. Then, we will detail how our system works, what components it has and what’s the difference between design and reality. Lastly, we will explain the real-world use of the system, share what we learn from this project and a product plan about maintenance and further improvement of the product. In the future, different functionalities of our system can have different advanced features. Our model of building will provide real time navigation for users instead of preview of route [5]. Users will be able to check room status online, book free room if they want, receive message if rooms they interest become free [6]. Our environment monitoring system will be able to control HVAC system automatically, predict future occupancy, and manage resources consumption more properly [7][8].

# Scoping and Market Evaluation

Smart buildings and the wider Internet of things network has seen a year on year increase in Market size over the past decade. The companies that are entering the market range from start-ups with personal seed money to pre-existing multi-national corporations establishing new divisions in their organisation to leverage IOT devices for their customers. The pricing potential for the market is one of the reasons that such disparity can be seen in the size of the businesses. The top of the range solutions incorporate advanced machine learning algorithim and state of the art sensors on the other end of the scale a simple sensor sending environment information to a database will satisfy some customer’s needs. The full potential of this market has yet to be realised, the uniqueness of what a business can offer to a client compared to its competitor is not distinct. At the time of writing the core components of a smart building solution are space utilization and HVAC management. Fortunately these two features are very easily sold to clients as the cost savings that they catalyse are straightforward to understand, making the cost of customer acquisition low, these core components will continue to result in an increase in the sector.

Queen’s university is one of the leading institutions in the world with a reputation for excellent research. The expectation would be that its computer science building is state of the art and is a reflection of the research that occurs in the university. However at the present moment there is very little elements that everyday regular users will interact with that would indicate that the CSB is a smart building. In our proposed smart solution we aim to deliver a system that is state-of-the-art and will attract the next generation of talent to choose Queen’s university over other institutions. A key target is not only to attract new students with the system but also to reduce the cost of running the building. In the past decade Queen’s university has seen their budget cut by 16 percent from public funding. This has led to a reduction in the number of jobs that Queen’s offers, the number of places that the university can offer students and strikes in the past two years over fair compensation, though it must be noted the latter is a nationwide problem. Through the analytics of our system the cost of running the building will be optimised. This reduction of cost will of course not solve all the issues that are outlined below but it will do its part and hopefully will prevent drastic measures such as increasing fees for students.

There were a plethora of ideas that could have addressed the problem areas that have been outlined above, some of the ideas that did not make it into the solution are described below and their justification of why they didn’t make it. A staple of IoT solutions is to have a space utilization feature, where throughout the day, week, term the use of desks and spaces are tracked. This feature was decided not to be incorporated into the system for two reasons: the first being that it is a passive feature, users of the building would not know that analytics are being used in the building for space utilization. This does not address one of goals to attract new talent to the building with a smart solution. The second reason was that we felt that in our infancy we would not be able to deliver a space optimization solution that would be distinct and outperform our competitors. Currently access to the building is regulated by the use of student cards, a facial recognition feature was proposed for an alternative access to the building however this was quickly disregarded because of the advanced algorithim needed to provide accurate authentication, the increase in cost of hardware needed to capture the image and the increase in administration that Queen’s would have to go through each year to calibrate facial recognition for each student. Other features such as visitor management and office assets meta-data collection were also considered.

The solution delivered by our system will address the problem domain through three main components: Wayfinding, HVAC management and Room alerts. Wayfinding will offer the users the ability to select the room that they need to visit. The system will then get the users current position and then calculate the shortest possible route to the room. This feature was incorporated because in a building that spans a large square footage and multiple floors it can be hard to navigate to a room you haven’t visited before. It was also felt that this feature could easily be demonstrated to visitors to the building. The system could be run on a kiosk at the front door and the visitor could then select their destination from that. HVAC management while not the wow factor feature, the benefits that it can offer were felt to be too great not to incorporate. Sensors will be installed in the building and will continuously keep track environmental features, some of the metrics it will track include, temperature, electricity, emission and occupancy. The sensor will feed this data into a database and from this data decisions will be made to regulate the building environment to reduce the energy expenditure and cost. This will save the university money and will go part of the way of addressing the funding cuts Queens have had to face. The final component does not necessarily address the problems stated before however it does address a problem for the stakeholders that use the building the most. An alert system will be incorporated for when group study rooms become available in the building. Occupancy sensors will be installed in the group study rooms, if for 10 minutes there is no occupancy detected then the room will become available to book again on Queens online. The study rooms are in demand, this feature will allow for more use, as there are occasions where the room is only needed for 15 minutes of the hour or the group does not turn up for the meeting. With this feature we believe that the study rooms will see more use throughout the day. The features outlined above will deliver a positive experience to the main stakeholders of the building. A feature that could be built upon in the future is the wayfinding, instead of showing a route on a map, it could be possible to use Augmented reality to overlay the route on the image of the building.

The main stakeholder of the computer science building include students, building management and Queen’s administration. The primary features that the student of the building will see the benefit from is the wayfinding feature and the room booking. The wayfinding will be of primary importance to new students at the beginning of the semester or when they are trying to find a new room they have not visited before. The students will see the benefit of the room alert feature throughout the entire year especially when there are group assignments due. The building management will primarily benefit from the HVAC management while the system will automatically change the environment equipment such as radiators, lights and air conditioning for example, human intervention can still be achieved if the management believe a different setting will achieve a more optimum environment. The final stakeholders is Queen’s administration it is the hope that through this system they will receive secondary benefits, those being the attraction of new students and the reduction in running cost.

It has previously been stated the sector has a variety of different sizes of business, through research we have identified several businesses that we believe are our direct competitors in the solutions that they deliver and the customers that they will target. These businesses include: Beco Inc, CoWorkr, Inovu and Spaceti. These businesses are delivering solutions that are on par to our system as well in the case of Spaceti they have features that we have not yet implemented. The size of customer and price point that they offer their solution at is also in the same ballpark as our solution. These businesses offer a benchmark to comparing the performance of our business.

# Project Planning

The first item to note in the planning and execution of the project is that during the first week of development one of the three team members was no longer able to contribute to the project. This resulted in the planning up to that point becoming largely irrelevant, how the two remaining members of the group adapted to this will be outline below later. It is worthy to note that the development experience in the group was not substantial with two of the members not having worked in industry. This meant that exposure to proper project planning was minimal. In conceiving the system the ideation session using design thinking techniques was fruitful, it allowed the group to quickly prioritize the features that they would be most beneficial to the stakeholders of the building. Having this easily understood framework that was not time consuming was beneficial to getting the project off the ground.

Developing an Iteration plan was probably the hardest part of the whole process. This was because fundamental lack of knowledge or experience in several areas. There was no standout member who knew about web application development, if there had been then it would have been easier to plan as some of the problems encountered in the development stage could have been avoided. For example the templating engine that was being used was changed from pug to ejs during development. The development methodology that we used cannot be boxed into one category. It was always going to be hard to follow one methodology due to the small-time constraints and the fact that it is a prototype being delivered rather than a full system. Agile is the closet method that we followed; sprint plans were outlined, and the division of tasks also assigned. It was at this point in the project that a team member was lost. At this point it was obvious that rescoping of the project had to take place. Three features had been in the initial design as this nicely separated between the three members, now an evaluation of the features were carried out and the two that felt carried the most value were kept. The third feature was relegated to a point that if it was time allowing that it would be implemented with the acknowledgement that it would not be the full feature that was initially conceived.

Initially the communication channel that was to be used was Slack, this was chosen due to its wide use in industry and accessibility. However when the group was reduced from three to two it was felt that direct messages were an adequate way of communicating. Throughout the development process communication was frequent and clear, the implementation of a feature was reported quickly to avoid any redundancy as well as issues encountered were also helpfully dealt with. Meetings occurred regularly throughout the development process this was to ensure constant development was occurring as well as to increase stewardship of the features the members were meant to be developing. The meetings were conducted similarly to how daily scrum meetings occur in business however in a longer form as the meetings were not as frequent. Progress was reported, any problems encountered were brainstormed and to finish a short planning session used to determine what features should be developed by the next meeting. Some tools that were used to keep the development process clear was a Kanban board, and a Gantt chart to keep track of development time and deliverables. Communication has been agreed upon as a strong point in the product development.

The greatest risk was that through our lack of experience the time to develop features had been underestimated and the system would not be complete by the deadline. This was a worry from the start and was carefully managed. It was mitigated by having in each meeting that occurred an assessment for how the project was currently progressing. This meant that some components that were meant to be in the system had to left out but overall the estimation for development time was sound and the majority of features outlined in the planning phase were implemented. The overall project planning was a positive experience that was carried out well considering the lack of experience and disruption caused by losing a team member. Lessons were also learnt that will carry onto future projects.

# Software Realisation

## Requirements

Our system included different functional requirements:

1. The Front end can display static pages and change web pages’ layout according to stylesheets.
2. The Front end can understand user’s activities such as select and click and send correspond requests to back end.
3. The Front end can display forms, graphs and render dynamic pages.
4. The Front end can execute JavaScript functions, record and submit user inputs to back end and update pages according to server’s responds.
5. The Back end can listen to assigned port and receive requests from clients.
6. The Back end can execute corresponding code according to requested URL and HTTP GET, POST parameters.
7. The Back end can send requested static resources, parameters and template pages to front end.
8. The Back end can pass parameters to template engine to generate dynamic pages.
9. The Back end can execute query in database and receive result from database.
10. The Back end can parse and filter received user inputs and validate login credentials with database.
11. The Back end can generate cookie for logged users.
12. The Back end can keep session active for logged users before logging out or session timeout.
13. The Back end can validate cookies and sessions, refuse requests from unauthorized users and clients.
14. The Back end can handle both known and uncaught errors of server and business logics.
15. The Back end can send encrypted requests to third-party mail servers and waiting for response messages.
16. The Database can handle request from back end and convert it to correspond SQL queries.
17. The Database can execute queries and send results back.
18. The Database can read and modified by back end.

Our system also includes different non-functional requirements:

1. The Architecture of our project should keep de-coupled and in layered architecture.
2. System can response user’s requests without long wait.
3. Server can be set in different computers which installed require environment correctly.
4. Service can keep available when uncaught errors have been thrown.
5. Communication with third-party services should be non-blocking in non-agent network (no integration of proxy).
6. Database is available at any time even though server is not running.
7. Database cannot be accessed by unauthorized users.
8. Database can be easily backed up.
9. Functions can be tested individually.
10. Components can be easily re-engineered and replaced individually.
11. Components are easy to portable to other systems.
12. Program output and error messages can display in console to help troubleshooting.
13. Program won’t display error message in front end because of security reasons.
14. User data won’t be shared to third party individuals and companies without user’s permission.
15. Project is open source and hosted by third party platform GitLab.

## System and Architecture

In the design stage of the system it was decided that a layer style would be the most straightforward design for the system. The layers in the system would consist of a presentation layer, Business logic and database. The coupling between the layers will be high to low, meaning high level layers will depend on those lower than itself and not vice versa. This design had other benefits, separation of concerns as it reduces coupling and promotes cohesion this makes it easier to maintain and understand. The division of work is easy to achieve although this can have its drawbacks, in our case with such a small team if a problem is encountered then it can be difficult to seek help from a team member who has not been working on that part of the system. The modifiability of a layer architecture is beneficial to us as at the moment since only a prototype is being developed, new features are likely to be added for when the final system is produced, changes to any layer should not affect other layers making it perfect for this stage of development where there are likely to be many changes.

There are three layers in our system, the presentation layer focuses on the user interface, supported by HTML language, which used to generate static pages, JavaScript help to deal with dynamic contents and receive update from lower layer. Then Business logic layer, this layer contains different business logics and communication infrastructures, business logic layer get metadata from data collection layer or database layer, process them, and send to presentation layer Data collection layer integrates required APIs of sensor and database queries to help this layer collect data and write data to database. Finally the database layer supports send and receive operations and acts as a storage unit in whole system.

The layer design has changed from the design phase to the implementation phase. Initially there was another layer which was used to control the data received from the sensors however once implementation has stated it was quickly realised that this layer as surplus to requirements and that its functionality could be achieved in the business logic.

|  |
| --- |
| logical view(re) |
| Figure 1: Logical View of Layered Architecture |

The system will be deployed as a web application hosted on an application server. The DBMS and database will be hosted on a database server. The application server communicates with the database server via TCP/IP. The user will use a web browser on their PC to connect to the application server via HTTPS. The application server will serve static and dynamic content to the user, communicating with the database server when data is required for necessary calculations. This has stayed the same throughout the design to implementation stage.

A picture containing screenshot

Description automatically generated

## Design Components

Our project consists of three components: front end is responsible for UI and receive some response from the server; a server include business logics and processes data; a database for data storage. The map has dedicated map data. The front end can display map without communicating with server. Because the map reads data from files, it only needs an interpreter to execute JavaScript functions and no need to connect to the database. The map will record where the user initially clicks on the map and then the second click will correspond to the destination, integrated scripts will receive this information, calculate route, and display route in front end. In our project, every page contains a navigation bar and a footer. Through the use of a template engine we were able to minimize the amount of repeated code in the project. With the use of an ejs template engine we were able to create the navigation bar and footer once and be able to reuse them in all the webpages. Additionally, template engine can display those data which need to be pre-processed before displaying. For example, our room status page will display room status in different times of the day, however, we can’t use static page to display room status because room status is constantly changing, when requesting room status, our server fetches data from server, store it in a variable and pass it in template engine for generating pages, template engine makes us able to separate front end and business logic and make our pages change dynamically. The business logic of the system serves as the bridge between the presentation layer and the database. It handles request from the user and renders the pages for the frontend. It receives login credentials from the frontend and will validate these credentials for what is held in the database and will then generate a session with cookies and maintain the session for the logged in user.

The server is equipped with different security procedures, we added code for handling uncaught exceptions to ensure the server can continue running when an unknown error occurs. This will improve the availability of our system, but it will also increase the risk of denial of service and memory leak at the same time. To retrieve data we need to communicate with database by SQL queries. Queries are vulnerable for SQL injection, so we use prepared statements in SQL query these security procedures can slow down attacker’s speed and mitigate database attack.

Our database receives queries, executes and send results back to server. In the current stage of development the database allows us to manage our data efficiently. it’s more reliable because data in database can easily backed up. In the future, when more types of data need to store in database, it will become more important, use database can and can decrease redundancy of data and make our implementation more efficient.

## Implementation

It has been stated before that the majority of the team didn’t have experience in developing medium web applications. Each member carried out research into the best practices of how to build a web application. Two possible stacks were proposed, these were FLASK and MEAN stack. The MEAN stack was agreed upon to be the software stack that the web application would be built upon as it had dedicated JavaScript support through each aspect of the stack. MEAN consisted of MongoDB for the database, Express and Node for the backend and AngularJS for the frontend. This plan was accepted by all team members because it requires fewer learning cost and can save more time for implementation stage. After one of the team members as not able to continue with the project it was felt that to learn an entire new stack would be too time consuming. We simplified the front end by using the express JS templating engine, this meant that the frontend was very closely written in vanilla HTML. The database was changed to MySQL as both remaining team members were familiar with the setup and interaction with this style of database management system.

ExpressJS was used for handling the HTTP requests. The webpage routes were initialized for different web requests and ExpressJS was used as a template engine to generate dynamic webpages. The login credentials of a user are received from the frontend of the website. In the backend we set a middleware to parse the incoming request. The input data is validated to ensure no malicious script is trying to be injected in the database. The input data will be submitted to the database unless the validation step is passed. Once a user’s login credentials have been authenticated a session is created for the user. A unique ID for the user session is created and to mitigate against a session fixation attack the session is given a time limit.

In the current stage of the project the Room Alert function has not been fully implemented. In the current form the alert that a room has become free is implemented by email. In the full system the user will be alerted in the web application. A mailer module was added to our system along with another library for message encryption. Emails will be sent to the users who have requested the room at the time it has become free. The use of different software libraries means the implementation time for a project can be decreased, however, the choice of software libraries and then the learning how to use them correctly and integrating them into the system can be time consuming. The overuse of software libraries can also make unit testing harder and limit the time that the development team has for making improvements to the system.

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## Data Gathering

For a user to be able to use the wayfinding feature they must opt in to having their location tracked while using the system, without this the system will not be able to establish routes to the desired destination. The location will be gathered using the HTML5 geolocation API which will return the most accurate location possible which could be a GPS or Wi-Fi Location. This data will be stored in the user account table. The user’s location will be updated every time they access the app, each time they use the wayfinding feature and every minute if they remain on the app. This data will obviously be used to generate the shortest route between the current location and the desired destination. It is also possible that the data could be used as another way to gain insight into the where people gather in the building however to gather enough data for this to make business decisions the collection would have to change from the previously outlined points of collection to always collecting the location even while the user is not using the app. This type of data collection introduces new legal and ethical concerns and if adopted would have to be made clear to the user what data is being gather.

The other data being gathered by the system has less legal and ethical concerns in what and how often the data is being gathered. The data being gather is primarily the environmental metrics of the building, such as heat, light, air conditioning electricity and emission usage. This data will be gathered by the sensors that will be installed in the computer science building. The frequency of the data collection will depend on what metric is being captured. Data like heat is unlikely to have drastic changes minute by minute, however occupancy of the building can have drastic changes. If a lab class finishes, then the occupancy of a lab can go from near capacity to nearly empty in the space of a few minutes. Hence occupancy will be the metric that is captured very five minutes and the other metrics being tracked will be captured every ten minutes. The data gathered will be used for the HVAC management system to optimise the energy usage of the building, this data can be broken up into different levels for example the energy usage of a room can be viewed or if a more macro view is needed the entire floors energy usage can be viewed. The data will also be used for the room occupancy to detect if there is anyone in a group study room when it has been booked. If not, then the room will be made available for booking.

The model that will be used for the database that the captured data will be stored in is a relational model. This model is based on a first order predicate logic. It describes the database as a collection of predicates over finite set of predicate variables, describing constraints on the possible values and combinations of values. The power of the model lies in its mathematical foundations and a simple user-level paradigm. This model will be implemented in MySQL this was selected as it is quite an easy database management system to use and understand and a relational model is easily implemented in MySQL.

The data storage have been accessed to be adequate for the amount and type of data that the system will gather when it is put into production. However if the requirements of the system change or the amount of users that system has to accommodate increases dramatically then in the future the storage of data may have to be handled by an application such as Apache Hadoop which is an open source distributed processing framework that manages data processing and storage for big data applications.

# Documentation

## Preface

This brief user guide is here to highlight the main components of the software system, it is not meant to be an extensive guide on all the capabilities of the system that would usually accompany a software release. The main components that will be highlighted will be logging on, Wayfinding, Environmental statistics and Room Alerts.

## Logging on:

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| --- |
| A screen shot of a smart phone  Description automatically generated A screenshot of a cell phone  Description automatically generated |
| User steps:   1. Enter in the username 2. Enter your password 3. Click the login button   Process:  If the user’s username and password credential are verified, then the user will be logged on and redirected to the homepage. If the credentials are incorrect then the user will have to log in again. |

## Room status:

|  |
| --- |
| A picture containing monitor, indoor, screen, black  Description automatically generated  A screenshot of a cell phone  Description automatically generated |
| Process:  A table displays the status of the bookable rooms in the computer science building. A request for a room can be made on queens online. If the motion detectors in the room do not register any activity for 10 minutes, then the room will be made available and an email alert will be sent if you have requested the room at that time. |

## Wayfinding:

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| A screen shot of a computer  Description automatically generated  A screen shot of a computer  Description automatically generated |
| User steps:  Click on the map the point that relates to your current location.  Click on the point in the building that you would like to go to.  Process:  The shorted possible route to your destination marker will be displayed on the map. This is possible across multiple floors. The other floors can be accessed via the menu bar on the left of the pane. A 3D perspective can also be shown of the building. Environment Dashboards:  |  | | --- | |  | | Process:  The environmental dashboards will display the data gathered from the sensors for: Heat, Light, Air conditioning, Electricity and Emissions. The data is updated every ten minutes and various breakdowns of the usage are displayed such as by floor, room etc. The occupancy of the rooms in the building are shown. An overview of the yearly contribution of each metric is also available | |

# Legal, Social and Ethical Implications

In more traditional and longstanding professions there is usually a governing body that sets out a standard that must be adhered to. In law there is the Bar association and in medicine we have the medicine association. The Hippocratic oath made by doctors can be seen as following a correct set of standards. The ethical issues that IT professionals confront have not been codified into law nor is there a global regulation body that oversees the conduct of IT professionals. However that is not to say that the influential bodies that are found within the IT sector have not had their say about correct conduct. The British computing society and the IEEE have both published a code of conduct that professionals should adhere to.

At the heart of the system that we have developed, data gathering is the essential component. Without being able to continuously gather data relating to, the building environment, user location and user account information then our system would not be fit for purpose. With the gathering of this data there also comes responsibility of keeping the data secure and complying with regulations. In recent years GDPR has been introduced as the new standard of keeping data secure. The previous regulations for managing data, the Data protection act was felt to be not fit for the digital age. The GDPR regulations outline seven principles relating to personal data some of them being: Integrity, confidentiality and purpose limitation. The open university has received scrutiny by analysing the access logs of student to the library to predict whether they are likely to pass their examinations or not. This could be said to be breaking the spirit of the purpose limitation principal.

The data that is stored and gathered by the system is quite sensitive, a user’s email, username and password are all stored in the database the system uses. These usernames and passwords are also linked to the wider queen’s network. If the security of our database was compromised, then the users account across all queen’s system would then also be compromised. Security measures have been implemented to prevent against SQL injection and the user’s sensitive data has been encrypted. As a whole the data gathered by our system is mainly concerned with the environment of the building and will not be of concern to the users of the system.

The gathering and collection of data has become quite a sensitive topic in society and the potential use of it. The Cambridge Analytica meddling in the United states presidential election demonstrated to people the power of data in a way it hasn’t before. This resonated with people and made them want more transparency in what data companies are gathering about them. Specifically to our system the tracking of a user’s location is a feature that will leave some users feeling uncomfortable and the feeling of big brother watching. To use the wayfinding feature the users will have to opt in to having their location data tracked and stored. This is to make it as transparent as possible. As well as the location data will only be collected when the user is on the app and while on the university campus. These measures have been considered it is felt that there is a societal shift towards the protection of personal privacy. A number of data misuse incidents and security breaches have occurred in the past number of years that have made people more aware of what is being tracked however the security breach that will massively affect the lives of public and make them demand for better data protection has yet to occur. The regulations for data protection have largely been driven by governments and institutions rather than the court of public opinion.

There are some positives to the gathering of data, if for the moment we take the smart solution being outlined in this document in isolation. The data that it gathers relates to the energy wasted by the building. This wasted energy has a negative effect on the environment, however by tracking this wasted and through the use of our system we can make the energy usage more efficient and this will have a positive effect on the environment. This is just one small use case where we can demonstrate where gathering data can have a positive impact.

# Critical Analysis and Lessons Learnt

The features included in the software at this prototype phase is very close to the expected deliverable that was outlined in the design phase. The map that was developed is a very accurate representation of the computer science building, this is mainly down to the use of the architectural floorplans that were acquired. This is a drawback of the current system in that there is no automatic way to generate a software representation of the building. For each building that the system would be deployed in floorplans would have to be acquired and then the time-consuming process of creating the map would begin. Further there is a lack of finite detail in the current mapping system, room features are hard to incorporate, even doors were a struggle to adequately represent on the map. In the research for choosing how to create the map another tool was discovered which would have allowed us to create a very accurate representation of the building, such as including desks, chairs and even sensors in the map. However this tool did not come with the functionality of wayfinding. In this case substance was prioritized over style. The functionality of the wayfinding does transfer over to real life use cases and its value to a user speaks for itself.

The environmental statistics that are displayed are more of a demonstration of the type of data that will be gathered by the sensors rather than an actionable feature. In its current state the admins can only observe the environmental factors. The machine learning algorithm that would manage the building environment has not been implemented in this prototype. In the future a feature that would let the building management take manual control of the environment settings within the application would be of benefit, as while the hope would be that the ML algorithim would find the optimum balance between comfort and cost savings, it is still of benefit to be able to have human intervention.

The room status alert is the feature that has not been fully realised from the design. In the design the alert would have come from within the application. In its current form the alert is given via email. Whether this is an improvement, or a regression is hard to say and would depend on the preference of the user. Some users may be more attached to their phones than others and never check their email, and for others it could be the reverse. In the future it may be of benefit to allow the user to select how they would like to receive notifications about room occupancy. This feature the development team feel will be received well in real world application of the system, as currently there are only a limited number of group study rooms for over a thousand students to make use of. The team see this feature as the one that will generate the greatest use of the app.

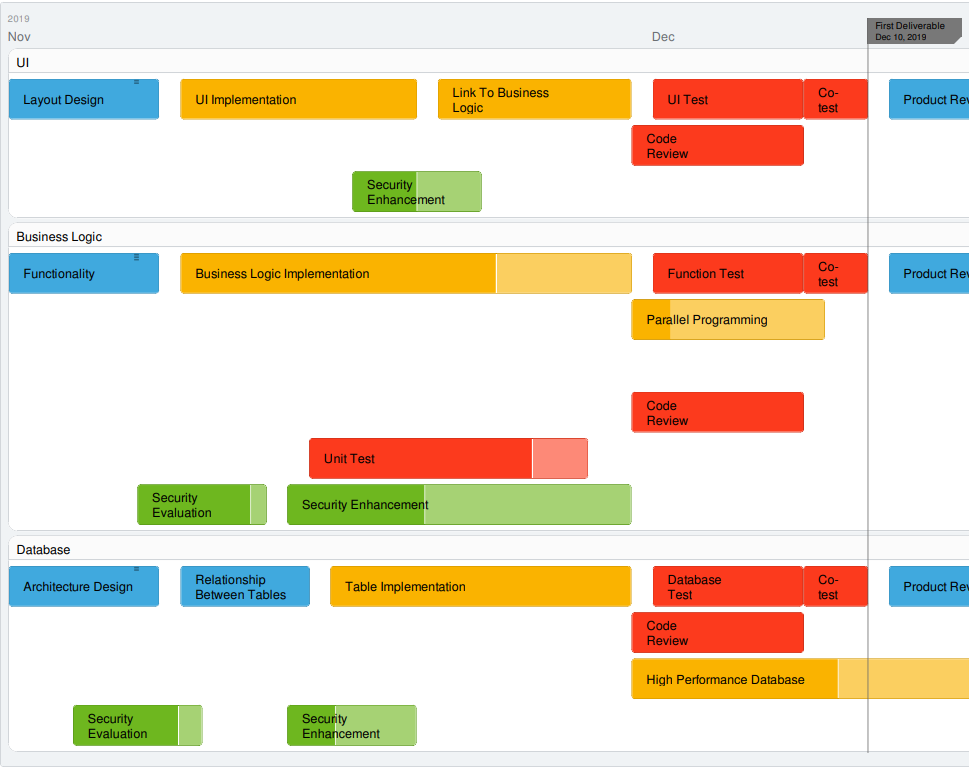
The software design that we started with has mostly held true throughout the development process. It has already been discussed that the software stack was changed after one of the development team was lost. However apart from this change the design has stayed much the same. The layered architecture was a good choice as it meant when development began the division of work was easy to achieve as well as an error that occurred in one layer did not propagate through to the other layers. The key lesson learned for all team members in this process is how to cope with the sudden absence of a team member as this is a scenario that is not unique to university, it can easily occur in industry and probably does with greater frequency. The team’s overall development experience has also increased, this was an area that was lacking at the start of the process and the extra responsibility that was taken on with only two members in the group has only increased this experience. In the future for organising meetings it may be better to establish at the start of the week the meetings that would occur during the week instead of scheduling the next meetings at the end of the current meeting. There has already been some discussion about what features could be incorporated in the existing system, One feature that would make the system be high tech and premium was if the wayfinding incorporated Augmented reality, in that the route was overlaid on the users screen which was also displaying their current surroundings in the building.

# Product Roadmap, Potential Business Context and Future Planning

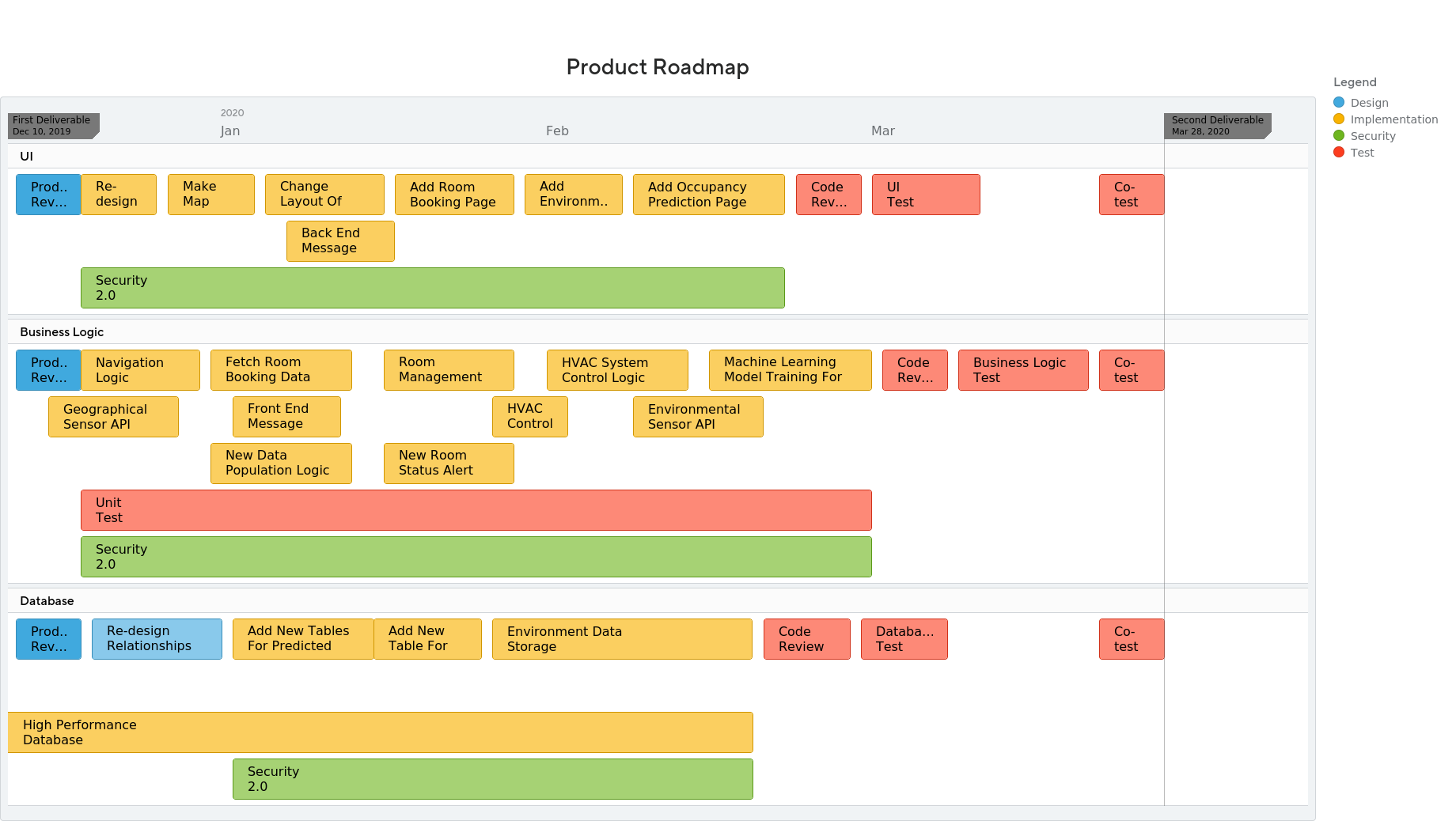
It has been well stated that the system that has been produced for this deliverable consists of three features. In researching other business operating in this sector it is a recurring theme to see the features in our system be offered as a standalone product. If we take for example the wayfinding and the Room alert features these are two quite distinct features a customer may only want one of these and would feel put out by having to also pay for the other. In the future as the business matures it is quite likely that the current system would be partitioned into separate products. For this to happen all the features in the current system would have to advance and offer more value to the customer, the augmented reality for the wayfinding has already been discussed, similar advancements to the other features would be needed for them to be offered as a standalone product. In creating a portfolio of products it is key that to integrate one product with another must be modular, the requirements of individual customers are likely to be very different. It must be easy for the business to implement a customer’s request of having the wayfinding product and the HVAC management product together for example. This will expand the offerings we can deliver to customers.

The software that has been developed so far is the beginning steps in the realisation of a business vision. The software will be used as a proof of concept to customers about what the business can potential deliver rather than a full example of what the business has delivered in the past for other customers. This decision has been made because it is felt that the products are not mature enough to be brought to market and generate sales for the business. If this were done it is felt that the reputation of the business would suffer.

Picture below is the roadmap of our project’s first deliverable. In the first deliverable, we separated architecture into different levels, created a skeleton of each component, and implemented a prototype for our project. Future development will build upon this prototype of the system.



Pictured below is the road map for our project in the future. The current features that we have developed will become more advanced. The user experience of using the map will be improved. Room details will be given such as temperature, maximum occupancy and equipment housed within the room. APIs for geographical sensors will be used for real time navigation instead of the route preview that is currently implemented. Next, we will complete our unfinished logic about fetching data logic and data populate logic, database will be able to be updated automatically and regularly; we will also add message box to room status page to display latest room status information; additionally, we will implement a prototype for room booking system, people will be able to book room online if they want. Finally, we will provide a more fine-grained environment manage system, managers can not only get environment statistics online, but also get advice to control HVAC system to balance comfort level and power consumption. With the help or machine learning, a prediction model will be trained by using historical environment and occupancy data, people will be able to get information about future occupancy in different areas, managers will be able to manage free space easier. Our second deliverable will add new features to old system, make it more user-friendly and increase competitiveness in market.



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Appendix

Table 1: Partition of work completed

|  |  |
| --- | --- |
| Background | BaibingJi |
| Scoping and Market Evaluation | Mark Friel |
| Project Planning | Mark Friel |
| Software realisation | Mark Friel & Baibing Ji |
| Documentation | Mark Friel |
| Legal, social and Ethical concerns | Mark Friel |
| Critical Analysis and Lessons learned | Mark Friel & BaibingJi |
| Product RoadMap | BaibingJi |