KING'S College LONDON

# 7CCSMGPR Impact Accelerator 22/23

*Final Report: Smarter Recycling Service Platform*

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**Abstract**

Searching for and extracting information in the most effective manner can be daunting, especially for performing essential tasks in people's life. The six priority ambitions recently elicited in the London Borough of Hounslow with the "Greener Hounslow" emphasis stimulate a re-investigation of the council's recycling service website by transforming repeated, scattered content into more streamlined and engaging one that boosts residents' joyfulness during consumption. This project establishes a web application that strives to make an impact in maximising the borough's overall recycling rate by enhancing the content visualisation using a range of AWS services including Amplify, Lambda and Amazon Rekognition. Upon completion, the application has undergone various evaluation techniques, which involve running 4 user studies against university students as an evaluation of the overall usability and end-user experience, computing ML performance metrics of the Amazon Rekognition model, and evaluating two-sided impacts.

# 1 Background Research

*"Our specific challenge for you relates to a Greener Hounslow as one of our high-level priorities."*

*"The objective is to enhance existing channels of communication to our residents by the provision of clear, engaging, enhanced (potentially interactive) promotion and signposting of services available and how to access them with the objective of increasing resident uptake and minimising misuse of bin types, fly-tipping etc."*

The above two quotes originate from Neil Gordon, data and development manager for Hounslow council. He is the main Challenge Sponsor of this project, in cooperation with Jennifer Colgan (engagement manager) and Cindy Gardener (head of waste and recycling and circular economy). The quotes depict the main focus of their current work. This prompts us to investigate further "A Greener Hounslow" which forms one out of six priority ambitions for the council (Policy 2023a). In particular, the goals of "A Greener Hounslow" include:

1. Developing a user-device strategy based on the circular economy, ensuring that **all equipment is properly recycled and that reusable components and materials are recovered for reuse**.
2. Using **a wide variety of state-of-the-art technologies** such as Machine Learning and Internet of Things to **develop new insights and decision-making opportunities that ultimately lead to a more sustainable borough**.
3. Building tools to **enhance residents' access to information including garbage collection dates and its corresponding guidance** (Policy 2023b).

In this borough, there are several recycling services available to residents. These services can be located on the council's official website (*London Borough of Hounslow* 2023). For instance:

- **Plastic and metal** is collected using the **red recycling box** (*Plastic and metal cans recycling in your Red Box* 2023).
- **Garden waste** is collected using the **brown wheeled bin** (*Garden waste collections 2023/24* 2023).
- **Large household items** that cannot fit into the normal sized bin are collected using the **bulky waste collection service** (*Bulky Waste Collection Service* 2023).

Moreover, there are additional recycling services that exist outside the official website, two of which have been placed in HounslowConnect (*Hounslow Connect* 2023):

- **The Hounslow furniture recycling project** redistributes furniture and electrical appliances at reasonable prices to people who may have difficulty affording such items (*Furniture recycling* 2021).
- **The Brentford recycling action group** organises monthly meetings to spread awareness of recycling issues and promote activities in which everyone has opportunities to get involved (*Brentford Recycling Action Group* 2021).

The wide variety of services offers residents many options to pick from when recycling their waste. However, information regarding these services is not very readable/usable in most cases. In particular, **services being displayed on multiple, separate websites** and **duplicated content appearing across several subsections** potentially require users to make more effort to interpret and understand the service they intend to select (Westbrook 2006). The conceptual model of the overall system in this case does not align well with the mental model users have built as the system's representation in their minds (Slovak 2021a), such that their mental models may be incomplete, easily confusable, and based on unnecessary clutter on the website (Helen Sharp and Rogers 2019). This leads to a relatively "large" size of the gulf of execution - amount of effort users have to make to perform a task in order to reach a specific goal (Helen Sharp and Rogers 2019; Whitenton 2018) and the gulf of evaluation - amount of effort users have to make to interpret the system's displayed information (Helen Sharp and Rogers 2019; Whitenton 2018) between the user and the services, depicted in Figure 1 (Chris Quintana and Soloway 2013).

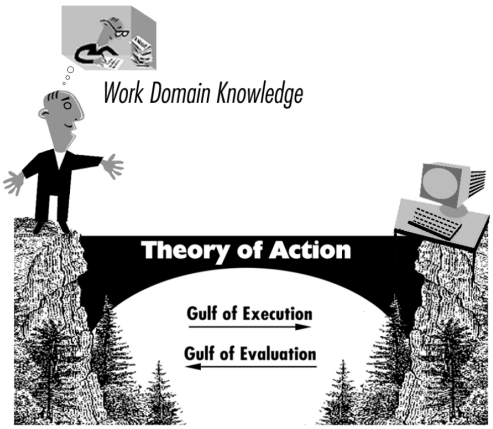


Figure 1: A visual representation of the "large" gulfs scenario arose in User-centred Design (Chris Quintana and Soloway 2013).

In early 2014, Orland Hoeber proposed a Visual Search Analytics Framework (Figure 2) that explores machine learning, visualisation, etc. to facilitate quicker information interpretation and easier manipulation in a human-centred manner (Hoeber 2014). This aligns with the second and third goals of the "Greener Hounslow" initiative.

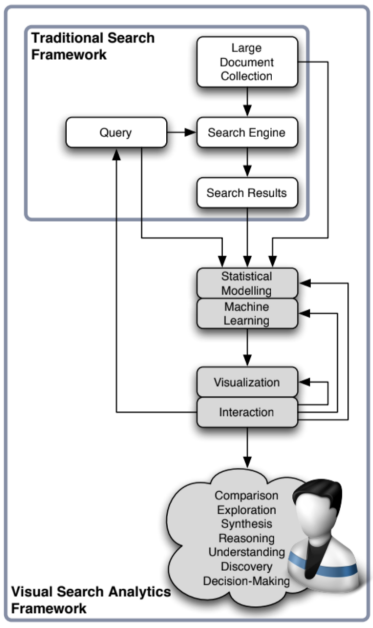


Figure 2: A framework for Visual Search Analytics (Hoeber 2014).

Before discussing the current website's problem space, it might be worth having a brief look at the council websites of the top 3 boroughs in terms of recycling in 2019 - 54.1% for Bexley, 52.6% for Ealing and 50.1% for Bromley (*Recycling household waste in London 'impossible'* 2020).


Figure 3: Extract of recycling service webpage for London Borough of Bexley (*Rubbish and recycling* 2023).

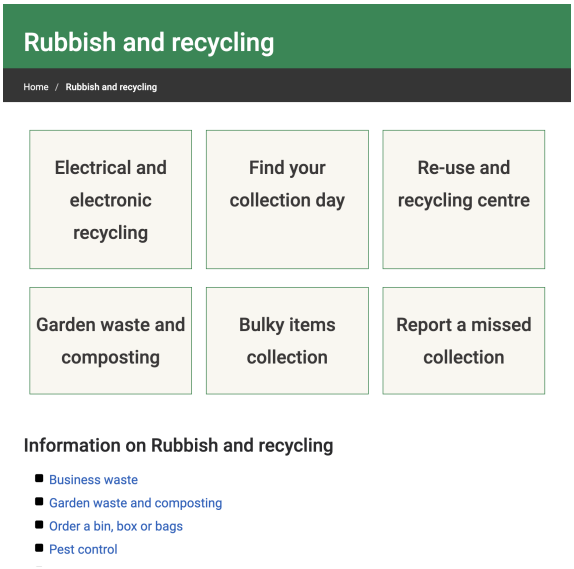


Figure 4: Extract of recycling service webpage for London Borough of Ealing (*Rubbish and recycling* 2023).


Figure 5: Extract of recycling service webpage for London Borough of Bromley (*Recycling, rubbish and waste* 2023).

It is easy to spot that the top tasks for all three web pages really stand out from the rest of the content and are displayed in an extremely concise manner, which matches 2 of the 10 usability heuristics of UI design derived by Jakob Nielsen (Slovak 2021a; Nielsen 2020):

1. **Recognition rather than recall:** Due to the limited short-term memories that humans possess, reducing the information that users have to remember is essential, especially for key tasks, via making them visible (Nielsen 2020).
2. **Aesthetic and minimalist design:** It is vital to keep the content and visual design of UI focused on the essentials: any unnecessary content distracts users from performing intended tasks and hence diminishes the overall visibility (Nielsen 2020; Fessenden 2021).

Looking back at the recycling service webpage for the borough of Hounslow (*Recycling and rubbish* 2023), the plain-text description under each service adds extra cognitive load to the users. Inserting a background image below the section title seems to add extra decorations to the webpage, but in fact it is unnecessary visual clutter that makes users less likely to concentrate on the key tasks that they wish to perform.

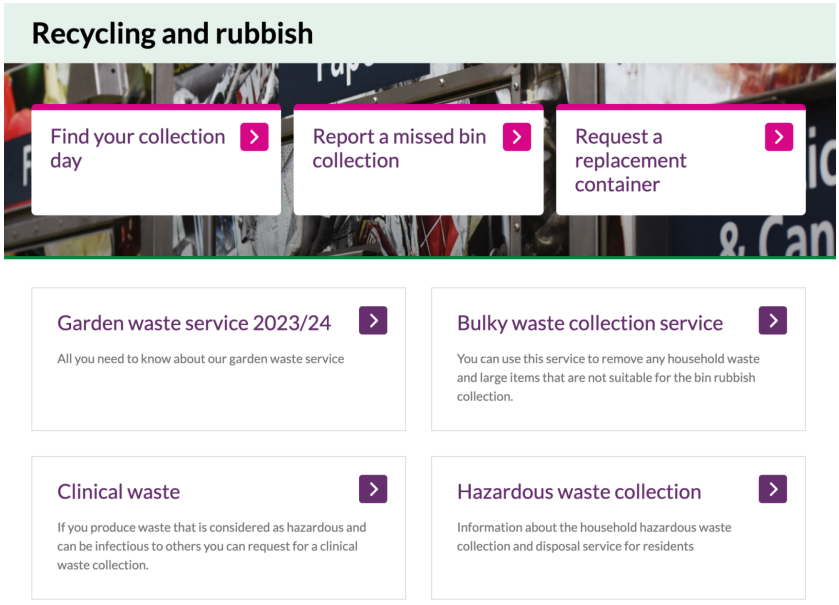


Figure 6: Extract of recycling service webpage for London Borough of Hounslow (*Recycling and rubbish* 2023).

In addition to the points discussed above, it has been shown by Ferronato et al. (2019) and Wilson et al. (2012) that the recycling rate correlates with the income level of a specific region. In Hounslow, approximately 62.7% of the population in 2019 experienced deprivation relating to low income (*Deprivation Report for Hounslow* 2019), resulting in only 31.4% of Household waste in that year being recycled, which ranks 18th out of all 33 boroughs and 12.1% below England's average recycling rate (*Recycling household waste in London 'impossible'* 2020). Despite the residents' widely distributed age range, with female population 0.6% higher than male, no explicit trends have been discovered regarding the correlation between the demographics and the recycling rate (*Population Report for Hounslow* 2021).

In the following section, more details with regard to difficulties residents might face when interacting with the website will be discussed together with concrete examples.

## 2 Problem Description

To understand the problem with recycling in general, we researched the barriers that prevent people from recycling across the UK. According to wrap.org.uk (*Recycling Tracker Report Spring 2022* 2022; *84% of UK households are unintentionally contaminating their recycling bins* 2022), data has shown trends of "wish-cycling[1]" amongst UK citizens. Some of the key findings are:

- **The top barrier to recycling items correctly is uncertainty.**
- UK citizens dispose of 5.6 items incorrectly on average – a significant improvement in 2021 (6.2 items).
- 52% of the residents miss opportunities to recycle common items from home.
- 84% of the residents dispose of an item in the recycling that is not accepted.
- Glass is the number one contaminant with many households mistakenly adding old/broken drinking glasses to their recycling.

Next, we moved our attention to the Hounslow website. The first problem we found is that not all information about waste and recycling is located there. Indeed, it is currently spread over multiple websites. Most of the services are described on the main council platform (*London Borough of Hounslow* 2023). However, some information can only be found on other websites such as HounslowConnect (for example, information about how to join the Brentford Recycling Action Group) (*Hounslow Connect* 2023).

Another problem is that the same information can be found in multiple places on the council website. For instance, the page about the bulky waste collection service contains three different sections:

1. Bulky Waste Collection Service
2. FAQs
3. Bulky Waste Terms and Conditions

However, most of the information - including the items that can and cannot be collected, the collection hours and the price - can be found in all three sections. This makes the volume of information seemingly large which often overwhelms the user. Residents trying to find out how to recycle large items would much rather spend five minutes to find the solution instead of searching through the website for half an hour, reading all the information about the bulky waste collection service. When such confusion and time waste are caused repeatedly, people start to avoid using the website (and even the services themselves) altogether. Instead, they direct their questions to their neighbours or just guess the answers, causing rejected waste collection and spreading of incorrect or partially correct information.

Moreover, the current design of the website is not very user-friendly and the information is presented in a way that is not easily consumable. Walls of text, insufficient use of icons/imagery and a lack of interactive features result in a user experience that fails to engage residents. This makes them uninterested in recycling activities and initiatives throughout the borough.

Overall, **the incoherence and repetitiveness cause confusion and frustration among the residents** leading to a lower portion of the waste being recycled, low participation in recycling events organised by the Hounslow council, and potentially even fly-tipping. All these negative impacts can be reduced by **creating a more engaging, well-structured platform that contains all the practical information about recycling waste in one place**.

[1]The practice of recycling items that cannot be recycled.

# 3 Solution and Implementation

## 3.1 Strategy

To select and implement the most appropriate solution to the assigned challenge, we followed the Double Diamond design thinking process (Humble 2023). The main arguments behind this choice are that it fits well with the structure of the GPR module and that it is a proven approach to the development of successful products. According to it, we first concentrated on solving the right problem (selecting the best solution), and then on solving the problem right (correct implementation).

In the first term, we started from the challenge description provided by the Challenge Sponsor and through divergent thinking discovered creative and innovative ideas for a solution. Then, using convergent thinking, we analyzed them and selected the most appropriate ones to refine into a focused idea, which was then used to define the solution described in the section below. In the second term, we worked on the implementation by first developing various features and producing a prototype. Then, the process converged as we concentrated on delivery - we evaluated the implemented features and improved the most valuable ones to come up with the final product.

To facilitate our working process, we used several widely known tools and frameworks. At the end of the first term, we created a Gantt chart[2] with all the main features we were planning to implement at that time. At the beginning of the implementation phase, we created a Trello board[3] to keep track of our tasks, responsibilities and progress. We also used a GitHub repository to store our source code and provide us with version control. We agreed that before any changes can be merged into the main branch, they must first go through a pull request, which must be reviewed and approved by a different team member. For the actual code, we used Prettier (a code formatter) (*Prettier* 2023) to ensure a consistent coding style between all team members. Lastly, we took advantage of additional tools such as a Miro board[4] and Google Drive[5] to store our ideas, resources, documentation and records from meetings with our Challenge Sponsor. All this allowed us to organize our work better and maintain a high level of quality.

During development, we used an iterative approach - continuous development of our product through feature implementation, followed by repeatedly gathering feedback and making improvements. This allowed us to be flexible and to respond to suggestions and feedback easily.

The nature of our solution (containing many independent or loosely dependent features) made a horizontal prototyping strategy viable - a type of iterative development approach where the features are partially implemented in parallel and then continuously improved while being fully implemented (Slovak 2021b).

## 3.2 Solution and Project Scope

Based on the insights gained from the research described in the previous chapters, our solution to the problem is an easily accessible web application which provides concise and useful information about the state of recycling in the borough of Hounslow. As requested by the Challenge Sponsor, the proposed solution is not a replacement of the Hounslow website: rather, it complements the existing websites used by the council. Although it seems that this may strengthen the problem with information being spread over many different platforms, it instead allows us to centralize all recycling-related content, present it in an innovative way and link it to existing information sources (which provide more detailed guidance). To achieve this aim, maintaining up-to-date content is vital. Hence, we included a content management system (CMS) in order to allow the council members to update the web application with ease and without any need for technical

[2] https://docs.google.com/spreadsheets/d/1xtm4aoa2F8KDk3cIen_8IOvej0F1aYQU/edit?usp=sharing&ouid=104282261329986077898&rtpof=true&sd=true

[3] https://trello.com/invite/b/IFOVkjyK/ATTI350a4845cd8ba76996ba976adbc718acDA3F6A79/mgpr-team-black

[4] https://miro.com/app/board/uXjVPBItx48=/?share_link_id=16215614995

[5] https://drive.google.com/drive/folders/1KPcggfkhhchGbgfx4_SyyvHZRWu3TPhI?usp=sharing

assistance.

Hence, the objectives of our web application are as follows:

- Become the primary source for recycling-related information in Hounslow.
- Allow easy access to necessary recycling content with minimal user effort.
- Increase awareness of the recycling services available and the benefits of recycling.
- Allow maintainability through the use of a content management system with a user-friendly interface.

These objectives are reflected in the AWS Press Release, which is located in the Appendix. This one-page document acts as a short summary of the previous three chapters: it describes what problem we are trying to solve, for whom, and how we plan to solve it. The exact solution is described in more detail in the following sections, which follow the implementation process and the decisions made during it.

## 3.3 Responsibilities

After the solution was defined, we assigned main areas of responsibility to each team member:

- Kacper - feature implementation, CMS
- Mirela - feature implementation, machine learning
- Ai - UI design
- Zihao - content and research
- Fatlir - AWS architecture
- Haoxuan - statistics

However, to support a smooth workflow, the areas of responsibility defined above were not exhaustive and often a student took part in more than one type of task throughout the implementation process. We also used the Trello board to keep track of who is the main person responsible for each task, although it was common for team members to help each other with tasks.

## 3.4 Risk Assessment

A risk assessment is an important part of any project. For our challenge, we analysed the following risks:

Table 1: Risk Assessment.

| **Risk description** | **Likelihood** | **Impact** | **Severity** | **Mitigation** |
|---|---|---|---|---|
| The project's goals are misunderstood. | Medium | High | High | The team should communicate with the challenge sponsor to ensure a shared understanding of project goals. |
| The project's goals change. | Low | Medium | Low | The team should adopt a flexible methodology in order to be able to respond to changes in goals and requirements. |

| | | | | |
|---|---|---|---|---|
| The solution produced does not match the project sponsor's expectations. | Medium | High | High | Throughout development, the team should check in with the challenge sponsor to ensure the developed solution is on the right track to meet their expectations (and make changes if it is not). |
| The project is not completed (to a satisfactory level) in the allocated time. | Low | High | Medium | A reasonable project plan should be created prior to the start of development. Progress should be regularly monitored and checked against the plan. Changes to the plan or project should be made if schedule issues arise. |
| One or more team members lose a significant amount of work hours. | Medium | Low | Low | If the cause is foreseeable, i.e. coursework deadlines, then the team member should plan ahead to avoid it. For unforeseeable circumstances, i.e. illness, the team should take this into account when making the project plan and include additional time for such events. The work should be split between the remaining team members. |
| The project involves using new technologies that team members are not familiar with. | High | High | Very High | Team members should dedicate time prior to and during development to learn the required technologies. Team members should support each other by sharing expertise and helping with any problems. |

## 3.5 Implementation

### 3.5.1 Initial design

We started development by creating a fast prototype of the structure of our web application. The first version can be seen in Figure 7.

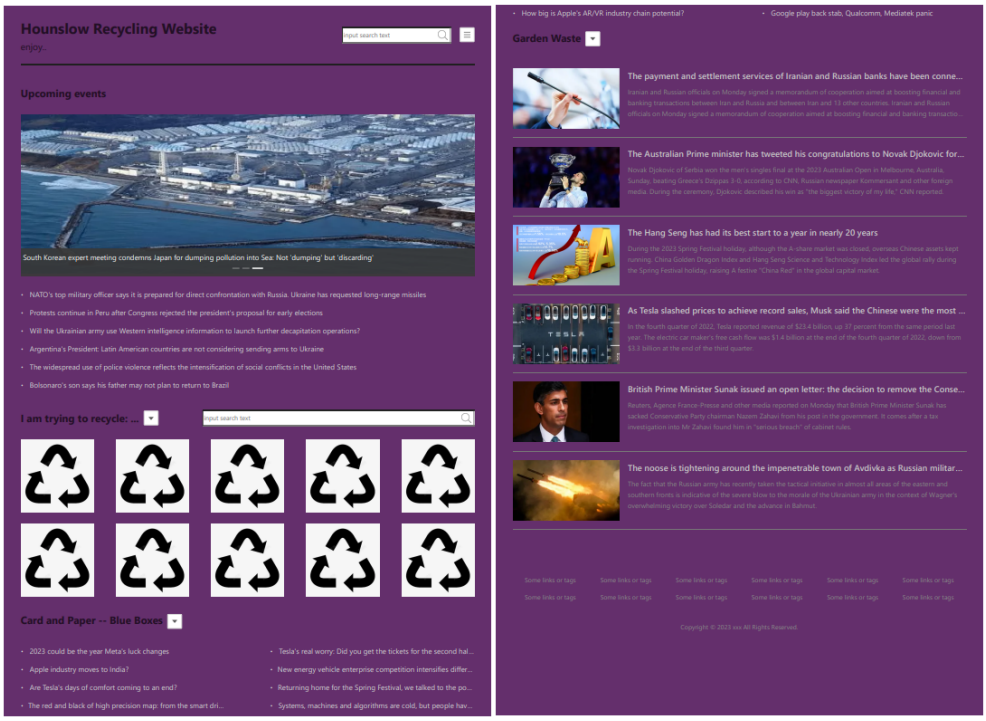


Figure 7: The first version of our web application.

We chose a one-page design to facilitate navigation throughout the application. This decision was based on the fact that the existing recycling information in the original website of the Hounslow borough is spread across multiple pages. This makes it hard for the users to find the content they are looking for. It can also cause redundancy, which unnecessarily increases the volume of information and makes maintenance more difficult (increasing the probability of inconsistency). In addition, research shows that pop-ups and transitions through many pages are perceived with a "high degree of irritation and dissatisfaction" (Willermark and Sigridur Islind 2020). Through the one-page design we aim to minimise this type of interaction and at the same time keep the content minimal which leads to easier and more intuitive navigation through the web application.

The colour scheme we selected is similar to the one used in the original Hounslow website. This should speed up the adoption of the new platform as it can be perceived as an extension of the original website, which residents are already used to.

After these decisions were finalised, we created a basic empty web page and deployed it using AWS Amplify. Next.js and Typescript were chosen for the front-end implementation because of the wide range of opportunities and flexibility they provide.

### 3.5.2 Main Features

The next steps were focused on implementing the main features of the web application.

With the help of empathy maps, we came up with the most common scenarios for using a recycling web application:

- Residents want to use a recycling bin in the right way but need information about what can and cannot be disposed of using it.

- Residents want to recycle an item but do not know what bin/service they can use.

Given the research discussed in section 2, where we discovered that the greatest barrier to recycling is uncertainty, we focused on providing clear and concise guidance about the different recycling services available. We decided to extract the most important information about each recycling bin/service (how it is used, what can and cannot be recycled using it, when the collection takes place) and put it in accordions in one section of our web application.

An accordion is simply a container that can be opened to display more information. Since we are using a single-page design, it is important that we don't overwhelm the user with too much at once. By using accordions, we can hide most of the information - except the name of the bin/service and a short description - until the user requires it. This allows only the most relevant information to be displayed.

Each accordion is also linked to the corresponding page on the original Hounslow website to provide additional details. This approach helps fulfil the request for complementarity between the platforms. It also serves to make our platform a central source of recycling information (as mentioned in subsection 3.2).

The recycling service accordions solved the first common use case mentioned above (residents want to use a recycling bin in the right way). The initial version of the recycling service accordions is presented in Figure 8.

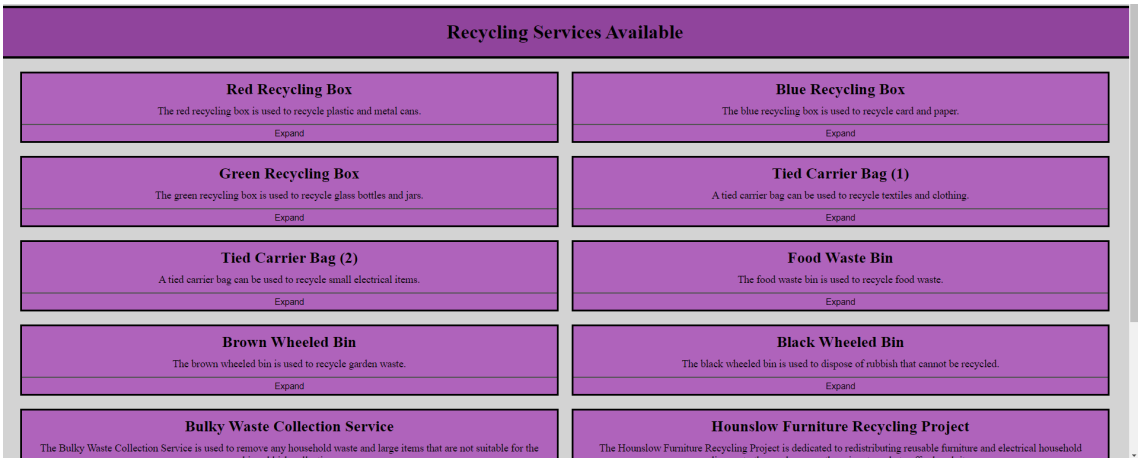


Figure 8: The first version of the recycling service accordions.

For the other main use case (users want to recycle an item and do not know what service or bin they can use), we implemented a grid of item-type cards, representing different types of items. On the front of each card was the name and picture of the item type. When clicked, the cards would flip to show the name and picture of the correct bin to use.

The idea behind the cards was to allow the user to easily see all the different types of items that can be recycled (by presenting them in a grid). The user could also easily find out how to recycle each type of item (by flipping the card). The flipping functionality meant that once again only relevant information is shown to the user. Moreover, it was a more interactive method of information retrieval, which is one of the goals set by our Challenge Sponsor (see the quote in the first chapter). The first iteration of the item-type cards can be found in Figure 9.


Figure 9: The first iteration of the item-type cards.

The importance of the problem of uncertainty as well as the desire to make the website even more interactive made us implement a feature that we called "recycling assistant". It provides an interactive way to determine the correct recycling service for a specific item. In order to find out which bin they should use, the user answers a series of short questions about the item they want to recycle (Figure 10). Although it may seem that the recycling assistant has similar functionality to the item-type cards described above, it actually provides guidance for items that are harder to categorise directly. Additionally, the question-and-answer process can have a positive impact by helping residents build better decision-making habits so that they are able to choose the correct service even without using the app.

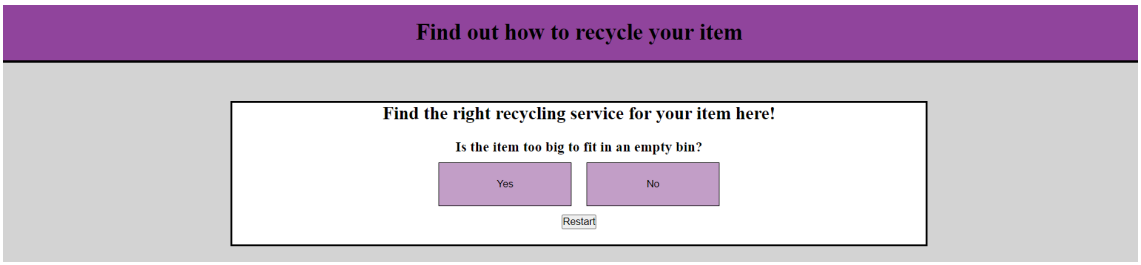


Figure 10: The "recycling assistant" feature.

The last basic feature we chose to implement is related to the problem of information being spread over multiple websites and the need for better communication channels. While exploring the existing platforms, we discovered that there is no dedicated section for announcements of cancelled collection days. Also, some events promoting recycling awareness in the borough (e.g. the Brentford Recycling Action Group) are not located on the main council website. To solve this problem, we implemented a section containing a carousel of recycling-related events (Figure 11). Once again, we stood by our commitment to display minimal and relevant content, and each event card was designed to show only the name and date of the event. However, similar to the item-type cards, each card is flippable and more information can be found on the back. Like before, this makes the process more interactive for the user.


Figure 11: The first iteration of the events cards.

These features created the first draft of our product. As per our iterative development approach, during this phase we mainly concentrated on creating functionality and not on delivering style.

### 3.5.3 Prototype

In the middle of the second term, we polished the functionalities we had implemented and added several enhancements to produce a prototype. In this stage, we also started to refine the user interface by unifying the style of the web page and making each section clearly separated and noticeable.

Based on the feedback we got from the Blue team during one of the lab sessions, we made the following changes to the design of the accordions:

- We made the accordions bigger.
  - This makes them easier to read, especially for older people.
- We removed the buttons that open/close the accordions. Instead, clicking anywhere on an accordion will have this functionality.
  - The other alternative was to make the buttons bigger and therefore easier to click, but we thought removing them was the more user-friendly option.
- We changed the way the accordions open, so that they slide past each other.
  - Initially, expanding one accordion would change the corresponding accordion in the other column to have the same size. However, this resulted in a lot of redundant whitespace. On the other hand, when we made it so that both accordions expanded together, it looked unnatural. These two options can be seen in Figure 12. The Blue team suggested a third option, where the accordions can slide past each other rather than be in strict rows. The updated version of the accordions is shown in Figure 13.

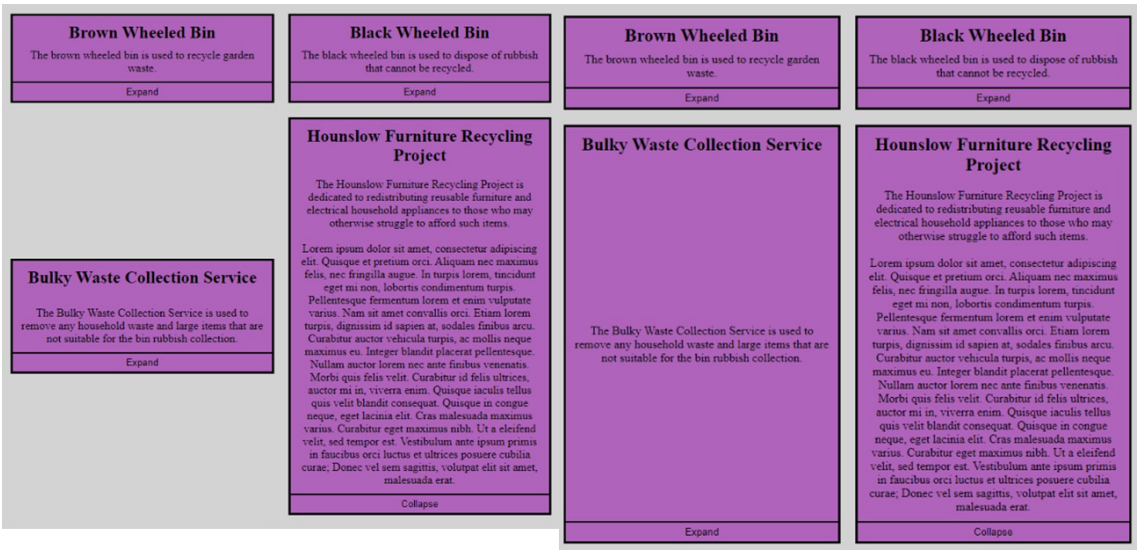


Figure 12: Some potential issues of the recycling service accordions.


Figure 13: The updated version of the recycling service accordions.

Finally, we added one more feature to our application in order to make it more engaging and to increase interest in recycling. Recycling appeals more to people who have a better understanding of the process and its benefits. The Hounslow website already contains this sort of information, but it is presented as several paragraphs of text, which is not very appealing to casual users. We decided to extract this information (plus additional data from the Internet) and create a list of so-called "fun facts", each one only 2-3 brief sentences long. By presenting one of these facts (chosen at random each time the page is loaded), at the top of the page, we provide a low-effort way for users to learn more about recycling.

In addition to the facts, to increase interaction even further, we came up with a list of simple multiple-choice quiz questions. Here, we took advantage of a simple psychological trick - people love clicking buttons! We didn't want to distract the users from the main functionality of the website too much, so we decided not to display both a fact and quiz question at the same time, but to choose one or the other every time the page is loaded (see Figure 14 and Figure 15). By being embedded directly into the page, it is easily noticeable and does not require more effort or interaction than reading some sentences or clicking a button. We believe that this will naturally draw users' attention and will help educate them about recycling.


Figure 14: The fun fact box.

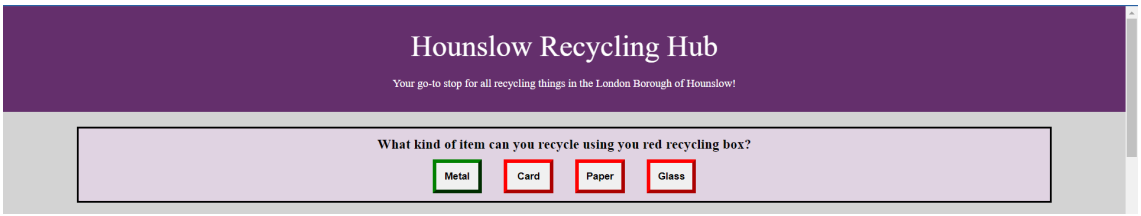


Figure 15: The quiz box.

### 3.5.4 Improvements

After the prototype demonstration, we collected useful feedback which we integrated during the next phase of our iterative development process.

We started by addressing a comment stating that we still have too many sections on the page. As a result, we refined our initial plan. Since the main function of the item-type cards was to lead the user to the appropriate recycling service, we decided to merge these two sections together. We added pictures of the items to be recycled to each accordion (Figure 16). We also changed the accordion names to focus on the actual services instead of the bins, to make it easier to find the required service. When an accordion is expanded, in addition to the old information, we added a picture of the bin to be used.


Figure 16: The recycling service accordions with the addition of pictures.

Another very important point that the feedback from our Challenge Sponsor emphasised was that there is a difference between the recycling services (and containers) available for residents living in flats compared to those living in houses. As a result, we researched this further. Keeping in line with our commitment to only show information that is relevant to the user at any given time, we decided to create two versions of our page: one for residents living in houses and one for residents living in flats. When a user opens the webpage for the very first time, a small popup (Figure 17) will appear asking them what type of home they live in. This preference will be saved in their browser for the next time they visit the page. Users can easily change between the two versions using a toggle button at the top of the page. In addition to providing more accurate content, this feature allows us to personalise the user experience to some extent.

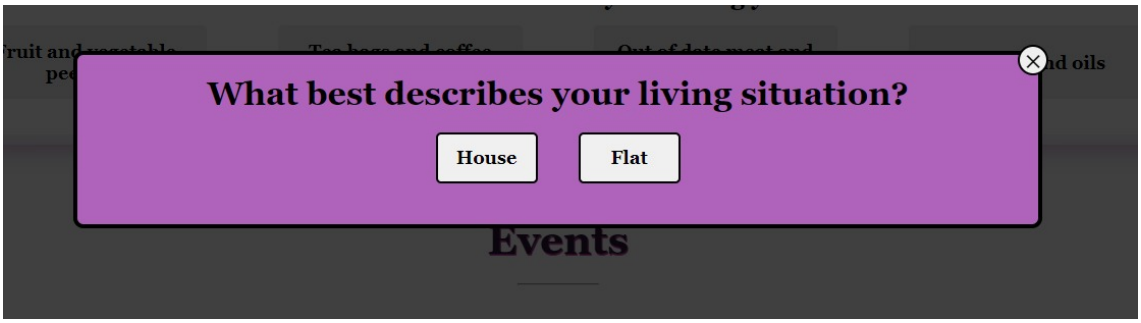


Figure 17: The small popup window when users visit our webpage for the first time.

Apart from that, based on peer reviews, we made further improvements to our user interface. We went through another iteration of refinements to the overall design (including font and borders). We also added a navigation bar that says on the screen while scrolling to provide direct access to each section of our website.

The last feature we worked on during this stage was the creation of a DynamoDB database to store the content of the website and fetch it when the web page is accessed. This is a vital feature as the content of the web application should be kept up-to-date to be usable. API Gateway and AWS Lambda functions were used to implement the functionality needed for the application to communicate with the database (Figure 18). A REST API was developed to support basic CRUD requests.

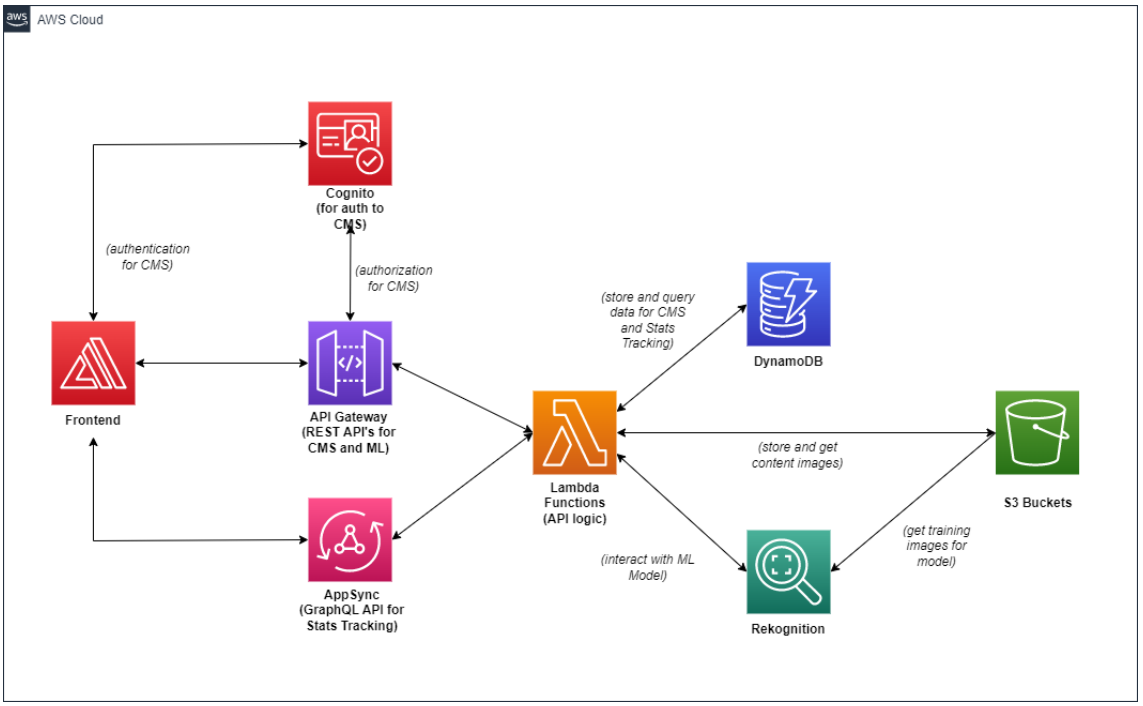


Figure 18: An overview of the project's architecture.

### 3.5.5 Extra Features

Finally, we implemented some extra features which enhance the capabilities of our product and allow for a better user experience.

Firstly, we focused on achieving the objective of "using a wide variety of state-of-the-art technologies such as Machine Learning and Internet of Things to develop new insights and decision-making opportunities that ultimately lead to a more sustainable borough" as stated by "A Greener Hounslow" (see section 1).

Through the different phases of our project, we came to the conclusion that the main goal of our web application is to make the process of choosing the correct recycling service easier (again helping to reduce the uncertainty in users) and more interactive. Hence, we decided to extend the recycling assistant feature by using a machine learning model to analyse user-uploaded images of items and determine their category (Figure 19):

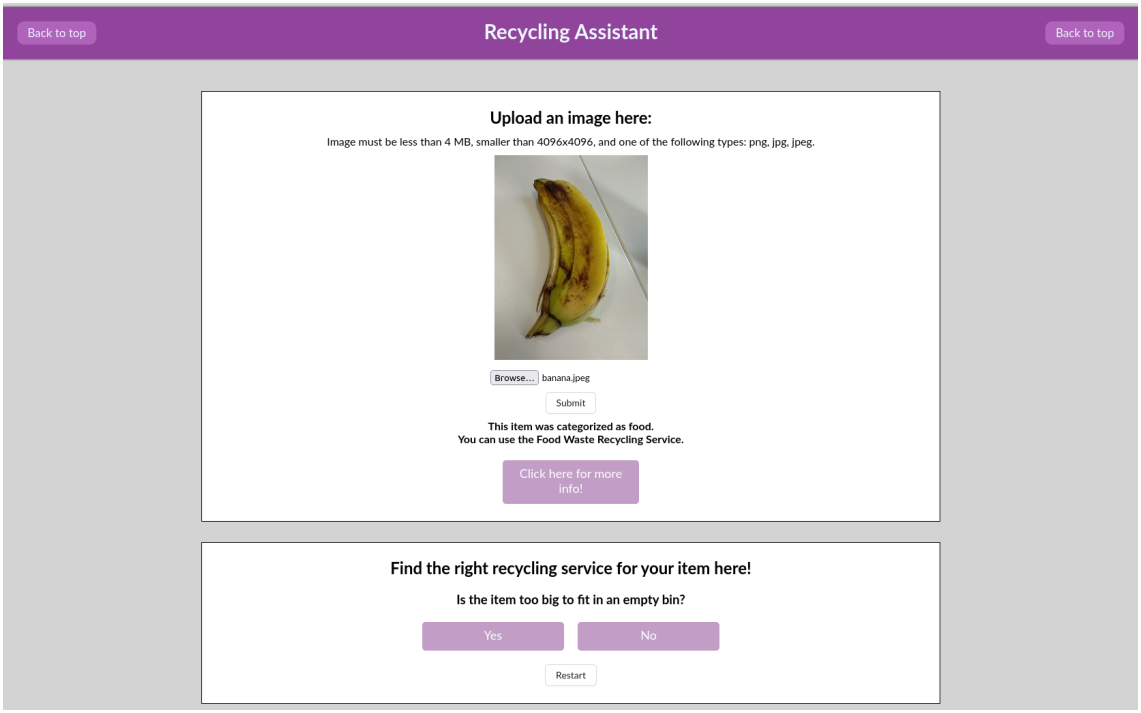


Figure 19: The Machine Learning model that analyses user-uploaded images and determines the item category.

To create the machine learning model, we used Amazon Rekognition. Firstly, we needed to collect a dataset of images of items in different recycling categories. For the most common categories (e.g., plastic, paper, rubbish) we used open-source datasets found on Kaggle (Mohamed 2021; Cchangcs 2019). For the remaining categories (including garden, clinical and bulky waste), we collected images manually from the open-source platform Unsplash (*Unsplash* 2023). In the end, we had 12 different categories of items with about 600 images each[6]:

- plastic
- metal
- paper
- cardboard
- glass
- food
- textile
- small electrical
- bulky waste
- garden waste

[6]Here, it should be noted that there was significant variance in the data quantity between the services. For some of them like clinical waste, bulky waste and small electrical items, the images we managed to collect were much fewer: 58, 132 and 212 respectively.

- clinical waste
- rubbish

We utilised an AWS S3 Bucket to upload the dataset and used the category of each item as a label. Next, we trained an Amazon Rekognition multinomial classification model with our custom labels. Then, we needed to make a decision about the way images will be passed from the UI of our web application to the ML model. We had to choose between two options - either to pass the raw image directly to the model through an AWS Lambda function or to upload it to an S3 Bucket which then connects to Amazon Rekognition to send the image for analysis. The first option imposed a 4MB file size limit, while the second one required us to store users' images. Valuing data privacy and given the fact that image size can be reduced with compression, we chose to pass the image directly. This was implemented through a request sent from the application to a simple HTTP API Gateway which triggers an AWS Lambda function connecting to the Amazon Rekognition client. The result of the analysis is then displayed to the user. In the event that the confidence of the classification result is not high enough, or if an error occurs, the default category to be displayed is rubbish. While categorising items that can be recycled as rubbish is of course unfortunate, it is preferable in comparison to categorising rubbish as items that can be recycled, as this can contaminate the whole recycling bin and cause its rejection. This also values availability of the service by providing users with a result at all times.

Another feature we implemented that could help achieve a better recycling culture and a cleaner borough was a section for reporting dumped rubbish (Figure 20). Similar information is available on the original Hounslow website (*Report dumped rubbish on streets* 2023). However, it is not well structured and refers to some outdated or useless web pages which we fixed:

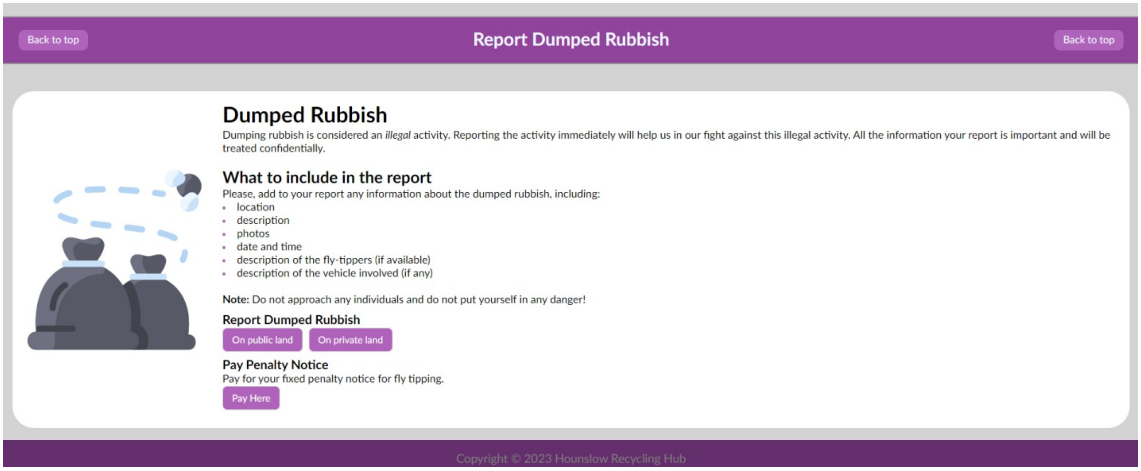


Figure 20: The 'report dumped rubbish' section at the bottom of our webpage.

While we mainly concentrated on the residents of Hounslow as our main target users, we also considered the borough's council members, who will need to support the website and provide relevant and up-to-date content. To make this process as smooth and easy as possible, we created a content management system (Figure 21), which allows anyone with an administrative account to create, update and delete content from the database by using an intuitive dashboard, without the need for assistance from IT specialists. By making information maintenance easy, we hope to ensure that information on the website stays valid.

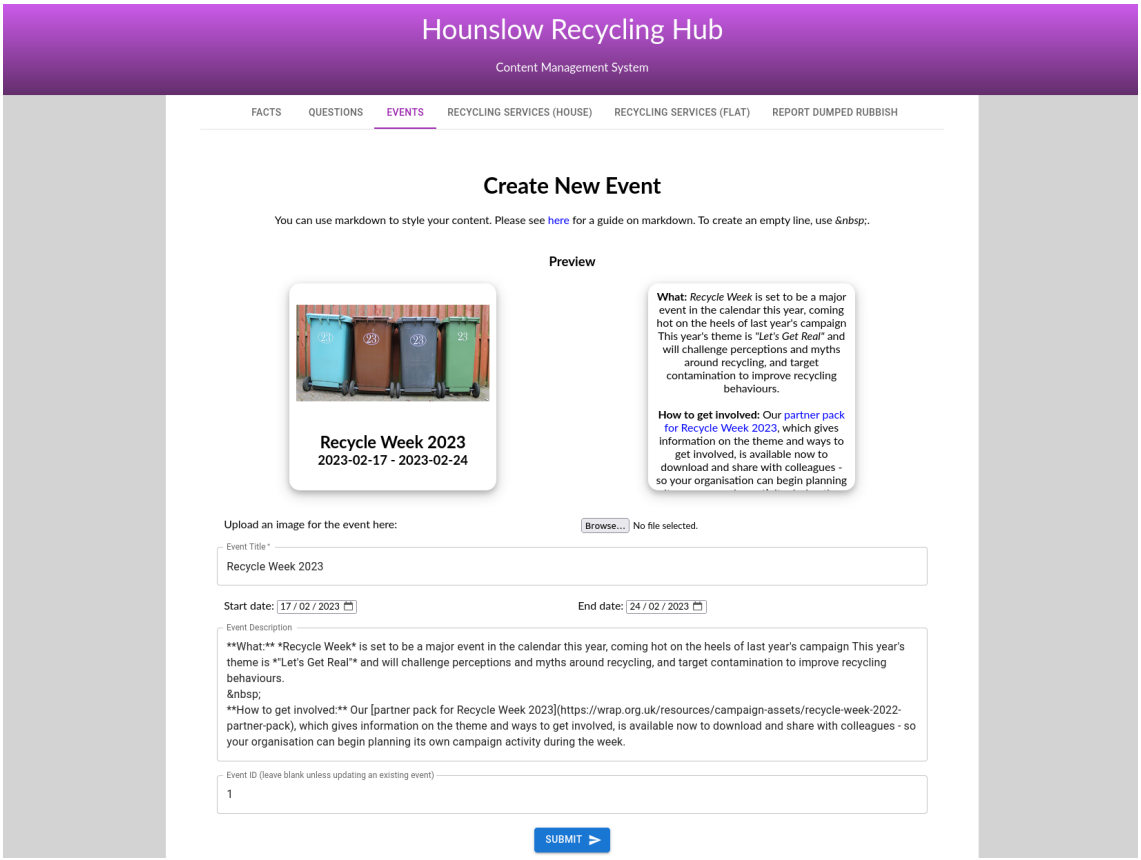


Figure 21: The Content Management System.

Apart from that, after discussions with our Challenge Sponsor, we agreed that keeping track of statistics related to the use of the web application may be useful to them in identifying trends and common problems with recycling in the borough. These statistics include the number of page visits (to analyse the popularity of the application), the number of answers to quiz questions (to track user engagement and knowledge), the number of accordion expansions (to check which services are needed most often) and the number of times an event card is flipped (noting the events popular amongst the residents). To accomplish this, we used AWS AppSync.

Lastly, we polished the design of our website to finalise the UI and make it as appealing and clear as possible (Figure 22).


Figure 22: The final layout of the web application.

# 4 Testing and Evaluation

## 4.1 Usability Testing

In order to capture behavioural data (both qualitative and quantitative) (Loranger 2016) from design-related questions being asked to users, we tested usability according to the 5 aspects below at the end of the project:

- Users can understand how the fun fact/quiz box works and what to do when they need more information.
- Users can use the recycling assistant section to find out the right recycling service for a given item.
- Users can understand how the event cards and recycling service accordions work, and recognise options to explore each service further.
- Users can easily navigate to various sections of the website by utilising the navigation bar.
- Users enjoy using the application overall and find it useful when they have items they need to be recycled in real life.

This project was not tested against the actual end users (i.e. residents living in Hounslow) due to the length of time it would take to secure ethical clearance. Instead, a relatively small participant pool was used (i.e. 4 university students). Each participant was given a scenario of moving into a house/flat in the Hounslow borough, and was asked to perform some tasks on the website, giving verbal responses to some hypothetical questions. The study took place online and was recorded in Microsoft Teams in order to take advantage of the transcripts. By extracting meaningful quotes, we could use them as a gauge for the user experience and for insights for the project's future work areas.

Overall, our web application left all participants with a good aftertaste. They all agreed that our webpage helped them more compared to the council's existing one when finding the right recycling services. They also enjoyed interacting with the visualisations, such as the changing fun facts/quiz questions as well as the card flipping and accordion expanding effects. The most recognised component of our website turns out to be the recycling services section, as it received the most votes (i.e. three-quarters of the entire participant pool). At the end, all participants gave useful and constructive feedback regarding improvements to make our project more interactive and user-friendly, which will be discussed in section 5. More details of the study (including test guide plus qualitative and quantitative data analysis) can be accessed via the Miro board.

## 4.2 ML Evaluation

The user studies we conducted did not cover the image classification feature due to the time limit imposed by the research. Given that, we will discuss here the results of testing the Amazon Rekognition model we trained. The model was tested automatically with 20% of the dataset.

The overall performance was significantly high with the average confidence of predictions at 95.6%. The other statistics were also high with a precision of 95.6%, a recall of 96.0% and an F1 score of 95.6%. For the different categories, the highest result measured was for the garden waste category with an F1 score of 100%, while the lowest result was for the clinical waste category with an F1 score of 83.3%. It should be noted that both of these categories contained significantly smaller data sets compared to the others, which probably impacted the performance of the model.

Another important point to discuss is the minimal confidence score for which the model should return results. Using manual testing, we started at a confidence score of 90% for which we got too few results (but with accuracy of 100% for all of them). This means that in many cases we just automatically categorised items as rubbish because the model was not confident enough to label them otherwise. Lowering the confidence score to maximise the portion of returned results that are correct, we settled on a confidence score of 70%.

## 4.3 Impact Evaluation

It is important to consider potential impacts that our solution could have as well as ways that the impact could be measured. According to UK Research and Innovation (UKRI) agency, impact is defined as "an effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia" (*How Research England supports research excellence* 2022). Impacts can be positive or negative. Moreover, impacts may differ for different groups of people. The table below shows the anticipated impacts of our solution:

Table 2: Potential Impacts.

| **Stakeholder** | **Impact description** | **Positive/Negative** | **Likelihood** |
|---|---|---|---|
| Residents of the Hounslow Borough, members of Hounslow Council (potentially the whole planet). | Increase in recycling in the Hounslow Borough. This can benefit the economy (recyclable material can be sold), society (sustainable for future generations) and the environment. | Positive | Medium |
| Residents of the Hounslow Borough, members of Hounslow Council. | Decrease in fly-tipping in the Hounslow Borough, resulting in cleaner streets and a cleaner environment. | Positive | Low |
| Residents and waste collection agents in the Hounslow Borough. | Decrease in misuse of bin types, resulting in fewer problems/hassles for residents and waste collection workers. | Positive | High |
| Residents of the Hounslow Borough who do not have access to the Internet. | As the solution requires access to the Internet to access the website, residents who do not have such access will be disadvantaged. | Negative | Low |
| Residents of the Hounslow Borough who are visually impaired, colour blind or have any other disability which prevents them from accessing information. | As the solution was not designed with this user group in mind as the main intended audience, these users might potentially find themselves disadvantaged when it comes to accessing information on the web app. | Negative | Low |

Next, we propose several ways of measuring the impact of our solution once it has been released to the public:

- Our website tracks various statistics such as the number of visitors, responses to quiz questions, event cards flipped, accordions opened etc. Hounslow borough tracks the volume and percentage of waste that is recycled. Statistical analysis could be carried out to see if these numbers are related. For example, it is expected that as the number of visitors to our site increases, the recycling rate should also increase. However, it is important to note a caveat: the more people use our website, the less they need to use it. As such, it would not be unexpected if the visitor numbers fall after some period of time, but the recycling rate stays constant.
  - Additional metrics that could be observed are the number of fly-tipping reports, the number of refused collections due to residents not following recycling guidelines and the number of items that

have been incorrectly recycled.

- A study could be carried out to assess residents' recycling knowledge during the initial rollout of the website and then again after a period of time. It is expected that resident knowledge will have increased over this time period.

We also got an indication of what the potential impact could be during the user studies. When asked to find the correct bin to use to recycle a specific item using both our product and the Hounslow website, all participants were able to quickly find the answer using our website but found it more difficult using the Hounslow one. This shows that our website does make a difference in the ability to access recycling information efficiently, which should ultimately translate to an increase in recycling.

# 5 Conclusion and Future Work

## 5.1 Conclusion

This project itself lies interdisciplinarily between Information Visualisation and Human-Computer Interaction (HCI), which are equally weighted throughout the development phase as enhancing content visualisation requires introducing additional user interactions to the website.

> *"A project is usually deemed to be a success if it achieves the objectives according to their acceptance criteria, within an agreed timescale and budget (You 2022; Cunha 2019; APM 2022)."*

Considering the quote defined by APM (Association for Project Management), an average score of 7.125 across all participants and at least 50% less time spent by participants searching for services (in comparison with the council's website), the project is an overall success, despite still having room for improvement as suggested by participants. The remainder of this chapter is dedicated to these improvements.

## 5.2 Future Work

In terms of specific application components, several further tweaks can be carried out. For instance, making the event cards and the "Top" navigation button stand out even more ( *"I would have like, maybe enjoyed more looking at these events in like a different page to be more interested and to give it its own space, because they feel very small and like unimportant." "Maybe the top button to make it into an arrow just so that it's obvious that we're going to the top."* - **Participant 2**).

In terms of the overall content, one participant mentioned some additional visualisations that may be useful to consider ( *"The use of images would be great, and then I also think potentially if you did some videos that would be cool. And then I also like this table. So I think you should try and integrate this table somewhere because it's just very straightforward what to put in what container."* - **Participant 3**). Another has proposed a rearrangement of the website sections based on how much they liked each of them ( *"I think the recycling assistant is the best thing. So I would just put that at the forefront and then probably have the recycling services be next. I'd rearrange the website. And then maybe the events and then the report dumped rubbish as well, at the end."* - **Participant 4**).

Some of the other limitations of the project include:

- A map of the borough showing the recycling rates and collection days could not be implemented because the council does not collect data about recycling in different areas.
- A tool for identifying the collection dates for users based on their location could not be implemented because not enough information was available.
- The recycling assistant has a 4 MB file size limit for images because of the software architecture used for connecting to Amazon Rekognition.
- A dashboard displaying statistics collected from the website was not implemented due to time constraints.
- Email notifications for events were not implemented due to time constraints.

One last potential improvement would be to integrate our CMS with existing ones that are already widely used by various councils. This is to allow for easier extensibility of the app.

Our product can be extended to cover these aspects in the future, which could improve the user experience and recycling in general.

# 6 Appendix

## 6.1 AWS Press Release

**Recycle your waste without wasting your time!**

Residents in the London Borough of Hounslow struggle to find the information they need to recycle effectively. Although such information is available online, it is often buried in massive walls of text filled with excessive detail and presented in a dry and unappealing manner. Currently, the council recycles only about 36% of its waste, with a target of hitting 50% by 2030. In order for this to happen, residents need to be able to easily access information about recycling services available to them that maximise the amount of waste they can recycle.

Residents want to do their part and act in a sustainable manner. They believe recycling household waste should be a simple way to contribute to a greener and cleaner Hounslow. However, many feel discouraged and frustrated as they try to navigate the dos and don'ts of recycling. Finding relevant information on the council's website feels overwhelming and difficult.

*"I care about our planet and my borough. Recycling is one of the easiest ways for people to make a difference - or so I thought. I've had my recycling bins rejected on multiple occasions because I've included the wrong thing, or placed them in the wrong location or at the wrong time. I understand that there are rules about these things, but I shouldn't have to read pages and pages of text just to make sense of them!"* - David from Feltham, Hounslow.

The council's new website, HounslowRecyclingHub, hopes to make recycling easier for residents by providing them with a central access point for all recycling-related information. Infographics are used to quickly convey key points while further details are presented in short and concise sentences using simple and understandable terminology. Interactive elements (such as buttons, quizzes and even machine learning) are utilised to make the website more engaging. With just a few clicks, residents can find exactly what they need to know.

*"As part of our Greener Hounslow strategy, we want to improve residents' access to information such as their waste and recycling collection days, and advice about what can be recycled. Recycling will not only result in a decrease in fly-tipping in the borough, but it is also our duty as citizens of this planet."* – Neil Gordon, Data & Development Manager at London Borough of Hounslow.

Visit HounslowRecyclingHub.co.uk for more information.

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