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Analyzing Objective and Subjective Data in Social Sciences: Implications for Smart Cities

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ABSTRACT The ease of deployment of digital technologies and the Internet of Things gives us the opportunity to carry out large-scale social studies and to collect vast amounts of data from our cities. In this paper, we investigate a novel way of analyzing data from social sciences studies by employing machine learning and data science techniques. This enables us to maximize the insight gained from this type of studies by fusing both objective (sensor information) and subjective data (direct input from the users). The pilot study is concerned with better understanding the interactions between citizens and urban green spaces. A field experiment was carried out in Sheffield, U.K., involving 1870 participants for two different time periods (7 and 30 days). With the help of a smartphone app, both objective and subjective data were collected. Location tracking was recorded as people entered any of the publicly accessible green spaces. This was complemented by textual and photographic information that users could insert spontaneously or when prompted (when entering a green space). By employing data science and machine learning techniques, we identify the main features observed by the citizens through both text and images. Furthermore, we analyze the time spent by people in parks as well as the top interaction areas. This paper allows us to gain an overview of certain patterns and the behavior of the citizens within their surroundings and it proves the capabilities of integrating technology into large-scale social studies.

INDEX TERMS Data analysis, data science, smart cities, social science, urban analytics, urban planning.

I. INTRODUCTION

The advancements in technology and the digitalisation of the physical world, allows the Internet of Things (IoT) to encourage a variety of multidisciplinary studies, part of which focuses on the human interaction with cyber-physical systems [1]. This is due to the desire of harmonizing the interaction between society and the smart things. Furthermore, a paradigm focusing on the social side of IoT emerges [2]. The Internet of Things vision for a Smart City employs advanced technologies to foster the administration of cities with the aim of providing better utilization of public infrastructure, improved quality of service to the citizens, while operating at minimal administrative budget [3]. The end goal is to create an integrated approach for managing and

analyzing the data to help in planning, policy, and decision making for a smarter environment and improved quality of life for the citizens [4]. Key interventions are possible to directly influence urban health and well-being [5]. In this work we are looking at a real-world pilot study on how data science and machine learning techniques can enable us to gain insight into social science studies. Social science studies have conventionally been based on data gathered from paper diaries, stand-alone electronic devices or self-administered forms [23], and have employed traditional methods of data analysis which are laborious, time consuming and can limit the insight that can be achieved through the study. In one such crowdsourcing research, Ruiz-Correa *et al.* [10] investigate the perception of young people about a city in a developing country using descriptive statistics. Our work is different in the sense that it employs data science tools to uncover patterns, and make correlations in a way that may not be

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easily identified with traditional statistical tools. Furthermore, by taking advantage of the increase in technology use, besides the subjective data directly collected from the study participants, objective data can also be obtained (as recorded by sensors in the used devices).

This pilot study is concerned with better understanding the interaction of citizens with green spaces and improving well-being through engaging with urban nature. The insights from these interactions can be used to help stakeholders in planning, policy and decision making, in addition to improvement of the citizens' experience and life quality. The study involved tracking 1,870 subjects for two different periods (7 and 30 days), covering 760 digitally geo-fenced green spaces in Sheffield, UK. To collect data, we used Shmapped, a smartphone app developed by the IWUN project [6], which allows measuring the human experience of city living. The app serves as a dual data-collection tool for both subjective data (well-being, personal feelings, type of social interaction, the users' observations about their surroundings) and objective data (location tracking for when a user enters a digitally geo-fenced green space in the city and activity detection). The app is also used as an intervention tool that prompts participants to notice and record the good things in their environment, using either text or/and photographs. This is theorized to improve their well-being, as research has shown links between exposure to green space and well-being [7], [12]. Moving beyond exposure, Richardson and Sheffield [11] and Richardson *et al.* [20] outline the benefits of improving nature connectedness through noticing the good things in nature. Such research has led to much interest in the design of smart city management frameworks for improved quality of life [13], [14]. The research in this line of interest can be a major challenge due to the complex processes involved in planning, collecting and analyzing vast amounts of data. Clearly, a large-scale IoT infrastructure can improve this process by automating data collection, storage, processing and analytics [5].

We are looking at a novel model of analyzing the information obtained from data driven social applications in order to maximize the insight gain. Through the use of technology, particularly smartphones, we aim at complementing the traditional way of gathering data in social sciences. Furthermore, this also allows the collection of objective data (sensors' information) which can open the study to new dimensions of analysis. Through information fusion we can find new links between a citizen's interaction with the surrounding environment and the features of the city. This kind of study enables a smart city approach and allows for a better and accurate representation of a citizen's interaction with the city, because users are asked for information or interrogated about their observations and behavior in moments of action. This difference to the traditional way of gathering people to fill out a questionnaire, allows for monitoring in the moment of interaction, collecting both subjective and objective information about the specific time. For example, when users enter a geo-fenced green space, they are prompted to answer a

series of questions specific to that moment: who is accompanying them in the visit; what good things do they notice about the surroundings; how would they grade this interaction etc. Simultaneously, the location and other sensor specific information (from the accelerometer) are tracked and can be used to determine the time spent in the green space, speed etc. Furthermore, this approach allows for scaling up social studies and collecting information from multiple subjects at the same time. In a smart city scenario this can be used to monitor and improve existing infrastructure, as well as quality of life. We use several data science and machine learning techniques in order to gain insight from the data generated by the users in Sheffield, UK. First, we clean and pre-process the raw information, and then we proceed into a further analysis of the text observations, the images taken, as well as the location points. We identify the clusters of topics in the observations and we automatically map the observations against the categories of themes from previous research into noticing the good things in nature [20]. We identify the features in the images taken by the users and compare the top labels with the text data. Based on the location points, we look at the time spent in the green spaces from different perspectives and compare it against the location data derived from the observations. These types of information fusion allow us to gain a better understanding of the interactions between the users and their surroundings, as well as plan the next steps for extending and improving the present work.

This paper is organized as follows: Section II gives an overview of the related work; Section III describes the methods used for this work; Section IV characterizes the dataset we used; Section V outlines which features were noticed by the users; Section VI looks at the time users spent in green spaces; in Section VII an analysis of the park use based on gender and age is being done; and in Section VIII we draw the conclusions and indicate future research directions.

II. RELATED WORK

A. DATA CHALLENGES IN SOCIAL SCIENCE STUDIES

Most definitions and studies of Big Data in cities are limited by the volume attribute of Big Data. It has become a trite definition that anything which does not fit into an Excel spreadsheet or cannot be stored in a single machine is Big Data [16]. For instance, the study in [17] analyzed half a million waste fractions to identify inefficiencies in waste collection routes. Anantharam *et al.* [24] analyzed social textual streams comprising 8 million tweets to extract traffic events in the city of San Francisco Bay Area. Though our study may not fit the volume bracket based on the number of participants of our study, we cope with other inherent characteristics of Big Data which make it challenging such as its variety (composing of structured and unstructured data), exhaustivity (attempts to capture all the population), scalability (can rapidly expand in size), and relationality (has common fields that can be correlated) and messiness [15].

B. MINING OBJECTIVE AND SUBJECTIVE DATA

Based on the method of data collection, data could be broadly classed as objective data or subjective data. From the IoT perspective, objective data can be obtained from the things in the IoT, such as sensors, GPS receivers and smartphones, while subjective data is collected directly from humans. Technology has made it easier and faster to collect objective data, and such research can boast of large volume of data for analysis. In one such study [26], data collected from accelerometers is used to control gaming mechanisms that encourage metabolic activities. Calabrese *et al.* [27] performed real-time monitoring of urban mobility (traffic conditions and movement of pedestrians) using data collected from the GPS of mobile phone users, buses and taxis. While such objective studies may perform better at collecting information faster and at a larger scale, they hardly account for the harmonious interaction between these smart objects and the humans, an important element in smart cities [21]. Again one has to deal with issues of data quality in objective data like uncertainty (sensor precision, missing readings), inconsistency and redundancy in data [29]. Subjective data presents the problem of being limited in volume, and diminishing in quality over time (people start a study with high response at the start and then get tired - law of diminishing returns). Social networks have made it easier and faster to collect subjective data like event tweets [30], however they tend to be noisy, messy and get thinner when filtered down to specific interests. Though the process of collecting subjective data may limit the volume for Big Data studies, it could make for richer, diverse and complementary analytics for smart cities [25].

We address the limitation and leverage the strength of the two using a hybrid data collection approach. On the one hand we collect data from GPS and sensors, and on the other, we put in the human element through text and image information collected from participants. There are similar works that have employed the concept of objective and subjective data mining. In [8], the participants are asked to report their well-being at random times during the day, whilst having their location tracked. The response of participants in the app is then correlated with the GPS and weather information. In our work we show that the text and image entries collected from participants can be harnessed in the context of smart cities to complement other modalities such as the location data from the GPS, thus providing a comprehensive view of the green space in the city.

C. APP-BASED STUDIES ON THE CONNECTION BETWEEN WELL-BEING AND NATURE

With IoT and smartphones, it is now possible to automatically collect much larger sample data, both subjective and objective. This is more cost-effective and involves larger datasets and, in turn, yields more statistically robust findings [22]. Mappiness [8] is a social app designed as an intervention tool to enhance happiness as an element of well-being. In Mappiness, participants are asked to report their well-being at

random times during the day, whilst having their location tracked. Urban Mind [9] is another social app, designed to examine how exposure to green spaces impacts mental well-being in real-time. In that study, there were seven prompts a day for assessing well-being in urban areas. The set of questions the users had to answer was dependent on their location (indoors/outdoors). In both cases, most of the collected data was done when the participants were indoors, as they only spent at most 14 percent of their time outdoors, making it challenging to collect the data in green spaces, where the reported level of happiness is actually higher. This was seen as a major limitation in these two apps. In an attempt to address this issue and optimize Shmapped for data collection, the green spaces were structured into geo-fences and the users were prompted to observe their environment upon entering one. Thus, the reliability of the study concerning the interaction with nature is improved as people are prompted to give details of their experience when in green spaces.

III. METHODS

A. SHMAPPED

Given the spread of smartphones in today's digitalised world, it is reasonable to employ apps in order to gain insight into the users' interaction with nature. For this study the app dubbed Shmapped (Sheffield Mapped) was developed [6]. Shmapped uses a chatbot to achieve a human friendly and engaging interaction with the participants. It collects both subjective and objective data, by means of two main tools:

- The intervention tool, prompts the users to notice something good about their environment and to translate any observations into text, image or both. This prompt can also be snoozed and the users are reminded of it in the evening. In the latter case, we can assume that the users' comments are made retrospectively rather than during the moment of interaction. Since this data is generated directly by the users, we consider it to be subjective. In the remainder, we will refer to this as the "observations" or the "comments data."
- The data collection tool tracks the participants' movement whilst they are within geo-fenced green spaces. We collect the user's GPS location and derive their activity from the device sensors. Therefore, we can discern among different users: stationary, walking, running, etc. In the remainder, we refer to this data as "objective," since no user intervention is involved.

The data described above were collected throughout different testing periods, considering two cases: 7 and 30 days, respectively. Besides this data, there were three other questionnaires a user had to complete as part of the study: one at the beginning (containing the demographic data as well as assessment of individual differences and well-being); one immediately after completing the study and a third one at follow-up (1 month for the 7 days version or 3 months for the 30 days version). The last two are used to measure aspects of well-being and nature connectedness. In this way, we could

establish how the participants' well-being changed throughout the study.

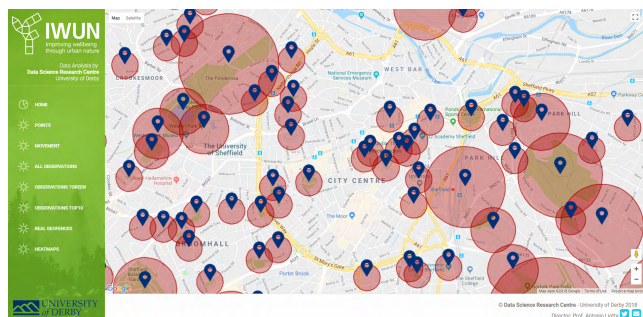


FIGURE 1. Preview of the extracted geo-fences.

B. DATA COLLECTION

As mentioned earlier, there are two main types of data gathered from the users: Subjective Data and Objective Data. GPS locations of participants were tracked within digital geo-fences (circular areas comprising the green spaces of interest as shown in Fig. 1), with data then being recorded once participants entered the more detailed geography of publicly accessible green spaces (provided by Sheffield City Council). The use of the geo-fences allowed phones to be woken from standby alongside more accurate GPS recording. Specific information about the data collected are:

- Locations (Objective Data)
 - GPS Data
Location and speed data, used to analyze the users' dwelling time in the green spaces.
 - Derived Data
Based on the information provided by sensors the app also evaluates the user activity: it creates and updates fields like `is_moving` and `activity_type`. The latter is classified in four main categories: still, on foot, in vehicle and unknown.
- Observations (Subjective Data)
During the study, the app asks the users for input. They introduce observations about the "good things they noticed" in their surroundings. When they insert their comment, the app asks for additional information. This aims at obtaining an overview of their experience. The collected data are:
 - Comment about what they noticed
 - Picture (optional)
 - Why they are in that place ('whyThere')
 - With whom they spend time ('whomWith')
 - How built-up the place is ('howMuch')
 - How they feel in the moment ('howFelt')

C. DATA CLEANING AND PRE-PROCESSING

One of the first steps we had to take at the beginning of our interaction with the dataset was data cleaning. Parts of the collected data were irrelevant for the study and problem at hand. For example, there were users who registered and took

part in the study but were not living in Sheffield, UK. As the study was focused on this specific city, their data had to be filtered out.

The subjective user responses included free text, images, or a mix of both, but also controlled input such as: whom they were with, how they felt, why they went there, how built-up the environment was. The information were fused through a mix of semantic text and image analysis as well as correlating the whom, why and how.

The objective data includes mainly the location points and other sensor information, which were used as the starting point to infer things like dwelling time and type of activity.

The types of cleaning or filtering which were undertaken are shortly described below based on the category of data they belong to.

1) USERS

For the study, participants were split into two categories: the green (70%) and the built (30%). The former group was prompted to notice good things about nature. The latter group recorded their observations regarding the built environment, a condition which was included by the psychology researchers as a control group. For our analysis, parts of the data were split according to the built/green criteria, with an emphasis on the green. This is due to the focus being on gaining insight in the citizens' interaction with the natural surroundings. The total number of registered users in the app was 1870. Out of these, 580 were part of the built group and 1290 of the green group (69%). It is important to note that the numbers of unique users in the different types of analysis turned out to be lower. This is because not all people who registered went on to use the app or provide data. Furthermore, some of the users who signed up were not living in Sheffield. They were filtered out by using the postal code provided at registration.

2) OBSERVATIONS

By observations we refer to the text comments and the images taken by the users. It is important to note that only 418 entries out of 5626 had a time stamp associated, meaning that they were recorded at the time of the observation (when the user was prompted to notice the surrounding and input the data). The rest, were entries made later during the day, mainly in the evening after the reminder given by the app. The app asked the users to manually input their location, but in most cases the field was left blank. Some of the earlier analysis we conducted was focused on these 418 entries, i.e. the parks with the most registered observations. We did not find an optimal way to reconnect the remainder of the observations with their location. The possible ways of achieving this could be: looking at the comments to check if there is mentioned a location and seeing what parks were visited by the users during the day. The problems that arise are required knowledge about the names of the parks and the possible variations, multiple parks visited in one day, as well as general comments or sum-ups of the day which cannot be tied to one specific area. For the

text analysis, we looked at the data provided by the green group. This accounts to 4226 entries from 718 users. Location was not taken into account here as the focus was rather on classification and feature extraction. To have a better clustering performance, we filtered text to only include the green users. The data used to train the model for text classification was specifically about nature, hence it was necessary to filter out the observations which were gathered for built users. The number of images used for analysis was 1641; 1020 belonged to the green group and 621 to the built group.

3) LOCATION POINTS

As mentioned earlier, users were tracked while inside green spaces. In the app, there were mapped 949 green spaces falling within 760 geo-fences. First, we filtered out location data points falling within the circular geo-fence but outside the actual green spaces. Particular attention was needed to avoid excessive filtering. For instance, people walking along the paths surrounding the green space were kept. We decided to select the location points with an associated accuracy lower than 10 meters. This means that we take into account the edge cases. The location data was used to infer the dwelling time in the green spaces. For the time analysis we restricted ourselves to green spaces contained within the 5 kilometers radius circle centered in the city center of Sheffield as shown in Fig. 2. This resulted in 539 green spaces that were analyzed. This corresponds to approximately 78 square kilometers and 1184702 location points.



FIGURE 2. Study area for time analysis.

D. TEXT ANALYSIS

To have an initial understanding of the data, we performed an exploratory analysis to understand the key topics in the observations. We used the K-means clustering algorithm to partition the observations into chunks of related data points based on some similarity measure such as the euclidean distance, using as parameter the number of clusters, K. This number is typically determined experimentally, aiming to satisfy a given metric such as a distortion and silhouette score. An optimal number of K clusters is chosen such that it minimizes the distortion and maximizes the silhouette. We found

this to be $K=40$, which leads to the minimum steepness of the distortion and silhouette. This means that the users' entries were divided into 40 separate clusters. Next was to map the Shmapped data against earlier studies of human connection to nature conducted by Richardson *et al.* [20]. This study was conducted with 65 participants who were asked to record three good things in nature each day for five days. Using an emergent coding, the information was then hand-coded into 11 themes using content analysis, a systematic technique used to code large volumes of data [33], [34]. Table 1 shows the list of themes of the training data, the description and distribution in the dataset. We used the Fasttext API [19] to train a classifier with the training data. Using the trained classifier, the model outputs the most likely labels for our observation data. As the training data are few, we train on 100,000 epochs. We recognize this as a multi-label classification problem where an input instance can be mapped to multiple output classes [28]. Hence, we extract the predicted labels alongside the probability. We set the threshold such that the predicted labels with probability below 50% are eliminated from the count. Semantic analysis as was done on social tweets in [30] does not work with our dataset because the people had been asked to notice the 'positive' things about their environment. So, nearly all the texts had positive sentiment except for very few outliers.

E. IMAGE ANALYSIS

When the users were prompted to insert an observation about the good things in their environment they had the option to also take a picture. The approach undertook for analyzing them was object recognition. We used the Google Cloud Platform, namely the Google Cloud Vision API [18]. For each image we identified a set of associated labels and their corresponding scores. An example is provided in Table 2. Afterwards, we carried out a frequency analysis and counted all uniquely identified labels for all images, and for each of the two groups. Furthermore, we filtered the labels in order to reduce their number and lower the amount of redundant information. This was done in the following way: for each image, its set of labels was analyzed; if any of the labels contained another label, the contained label was discarded; the explanation for this action is that the "shorter label" is the "parent" of the composed label. For the example in Table 2, the labels "flowering plant" and "annual plant" would be discarded after the compression. An additional frequency count was carried out. Further compressing of the resulted labels with similar meanings (e.g. 'flower' and 'flora') would be possible with specific dictionaries of words (such as WordNet) or by manual categorisation.

F. TIME ANALYSIS

One of the goals for the present analysis was to compute the time spent by the users inside the green spaces. In order to achieve this, further filtering of the location points was required. The procedure we followed is described in the following. First, we selected all the points inside the

TABLE 1. Labels from training data [20].

S/N	Theme	Description	Example	Distribution
1	Specific part of nature	When an example of specific plant, animal or feature of nature was given with no or very little context	A bumble bee; Bluebell wood; Bright rainbow; Beach	100
2	Animals being active in their habitat	When animals were discussed in terms of some activity in their habitat	Pigeons walking in a group together like a family; A buzzard being mobbed by crows; watching 2 birds dance together; Squirrels running up a tree together	109
3	Animals interacting together	Reference to animals engaging in an activity with at least one other animal such as playing/chasing/hunting	Pigeons walking in a group together like a family; A buzzard being mobbed by crows; watching 2 birds dance together; Squirrels running up a tree together	47
4	Sensation of nature	Items which focus on the sensations of nature; smell, sound (including bird song) or touch.	Sun on my skin; Birds tweeting in the trees; Sound of long grass in the wind; hearing the birds singing to one another	159
5	Colour	Items which had a specific emphasis on colour	Bright pink blossom on the trees; The slug that I removed from my sage plant had quite a fetching orange belly; The grass looks very green in the rain; Green on the leaves	76
6	Effect of weather on something	When the weather has an effect on a plant or another aspect of the environment	The breeze in the trees; Sunlight streaming in through my window; The long grass on the bank if the stream had been flattened beneath the weight of the rain drops hanging from it this morning	93
7	Growth/temporal changes	Reference to new buds, things in coming into bloom and changes associated with the seasons	The soft new leaves emerging on our beech hedge; Purple flowers starting to bloom; Budding leaves on the trees outside my window at work; Regeneration across the seasons	124
8	Reflections on the weather	Judgement/observation on the weather or a reflection on the dynamic weather	How nice the weather was; dramatic hail storm this morning; The constantly changing weather, from rain to bright sunshine and back	72
9	Beauty/appreciation/wonder of a particular landscape or aspect of nature	Items which refer to beauty or a specific landscape the person appreciates. Expression of the wonder of nature or the resilience and diversity of nature	The beauty of a magnolia tree in someones garden; Mist shrouding the trees first thing in the morning; Cow parsley in the grass verge lining the road for miles on my way home	98
10	Good feelings	Reference to nature creating positive feelings or state of mind	Walking by the brook at university was very peaceful; The sun was shining, walked past the park, everyone was smiling;); However I could hear the dawn chorus through my open bedroom windows and it immediately lightened my mood	40
11	Other	Statements that didn't fit into themes but didn't form a theme of their own	A nice house made of wood. The beautiful wood texture and its functions are so great; The threat of rain in the air	20

green spaces. Then for each area and for each user we checked if two consecutive recorded points in a day were created within a time limit of five minutes. We assumed that if two consecutive location points are farther apart in time, it would be erroneous to consider that the user spent the time there. This is because while in a green space, a user's location should be continuously recorded within a small time span. Furthermore, some parks are very small and the crossing time is very low, requiring a threshold for the minimum time distance between two consecutive location points. An example for this is Dial Way Garden depicted in Fig. 3 covering an area of 37 square meters. The five minutes imposed

check helps us in correctly discriminating the user presence in the determined park. We consider the points satisfying the imposed condition relevant. Based on that, we increase associated counters that take notice of the time spent by the user inside that area, the number of visits inside the different parks and the number of days in which the users were tracked. The procedure is repeated for every user inside all the considered areas. It enabled us to obtain the data for all the time spent. After this phase, we grouped and filtered that data to obtain different overviews, such as the total time spent by users in the different areas, the parks with the most time spent inside etc.

TABLE 2. Example of labeling for an image.

Image example	Labels
	plant: 0.98 flower: 0.96 flowering plant: 0.89 flora: 0.79 garden: 0.77 shrub: 0.75 annual plant: 0.69 herb: 0.67 groundcover: 0.65 yard: 0.59



FIGURE 3. Dial Way Garden: one of the smallest green spaces taken into account in the study.

IV. DATASET CHARACTERISATION

In this section we provide an overview of the dataset. We compiled this based on the demographic information provided by the users when registering.

A. PARTICIPANTS' DESCRIPTION

As it can be seen in Fig. 4 the average age of the participants is 35 years old. The age ranges between 18 and 72. We grouped the users in three classes. This was done to establish how different categories interacted with green spaces, considering young people (age 18 - 35 years), middle-aged people (age 36 - 53 years) and senior people (age 54 - 72 years). Each class has the same age range (18 years). It can be noticed that the young people group was considerably larger, possibly due to a greater digital engagement of this category. To reduce the bias across categories, we have normalized all results, so as

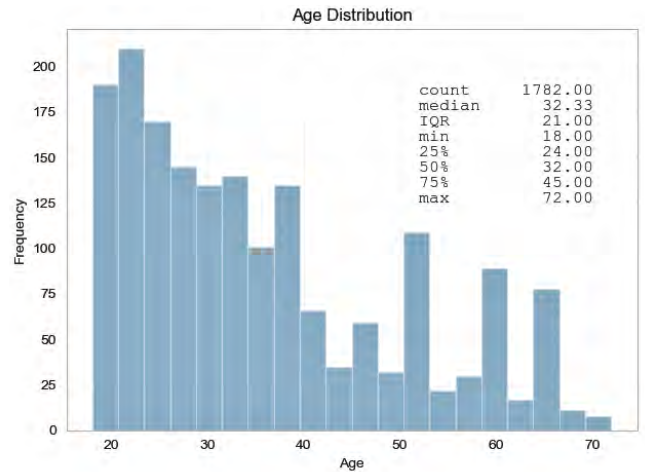


FIGURE 4. Age distribution of the sample dataset.

to achieve directly comparable results.

TABLE 3. Gender distribution.

Gender	Number of users	Percentage
Female	894	64.64%
Male	489	35.36%

Table 3 illustrates the gender distribution of the participants. Again, in the carried analysis the results were normalized as to have a fair comparison between the two categories.

B. PARTICIPANTS' INTERACTION WITH SHMAPPED

One of the questions the users had to answer when prompted was 'who they were with.' Overall, 5626 entries were taken into consideration. The distribution of social interaction types is shown in Fig. 5. It is indicating that the majority of participants were either alone or with 'friends & family'. The group 'Other' comprises also free-text responses or a multiple selection. The most common multiple selection was 'with friends, family or partner' and 'pet'.

Besides the question regarding social interaction, the users were also grading their interaction with the surrounding environment, namely how they were feeling in the situation. The histogram in Fig. 6 shows the aggregated answers. It can be noticed that the interaction was mainly positive. Fig. 7 shows a part of the area under examination, also including suburban parks. It shows the density of the grades they assigned. The feelings of the participants are represented by using a color scale that varies from blue (medium) to red (high).

C. PARTICIPANTS' WELL-BEING

Participants' well-being was evaluated based on a specialized psychometric scale which quantifies the response for each item on the scale. As a result, each user has an associated well-being score. The number of participants was restricted to those who completed the initial and the after-study questionnaires. As a result, the number of users decreased from the

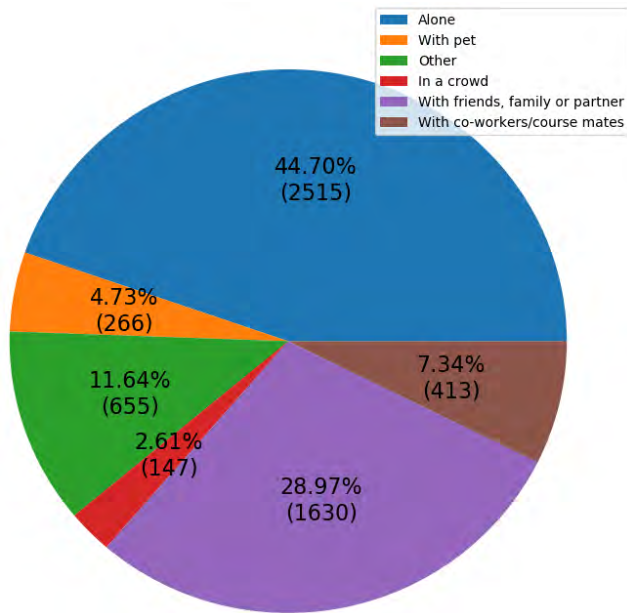


FIGURE 5. Participants' companionship / social interactions.

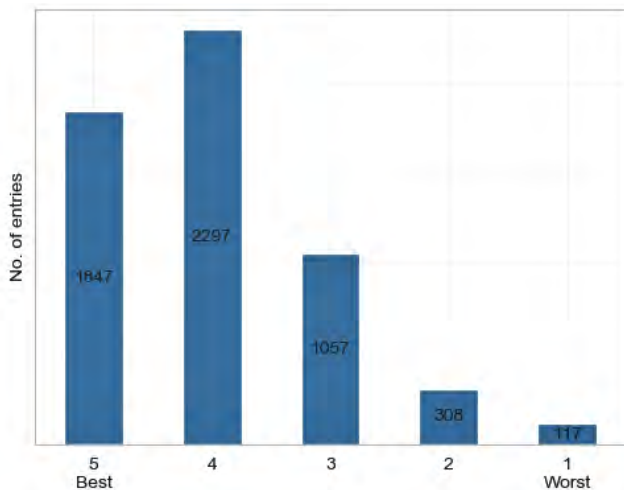


FIGURE 6. How the participants felt while interacting with their surrounding on a scale from 5 (positive) to 1 (negative).

initial of 1870 to 403, because the participants either chose not to complete the after study form or they disengaged with using the app. To give an overview, for the 403 participants at the beginning of the study, 22% had a well-being classed as clinical cases, while the rest of 78% had a well-being above the threshold. The impact of noticing the good things in urban nature on well-being is reported in a separate paper, however statistical analysis revealed clinically significant improvements in mental health for clinical cases along with significant improvements in mental health for the whole sample.

V. FEATURES NOTICED BY THE USERS

In order to find out which elements of nature get the attention of the users, we analyzed the observations data, namely the text entries and the uploaded pictures.

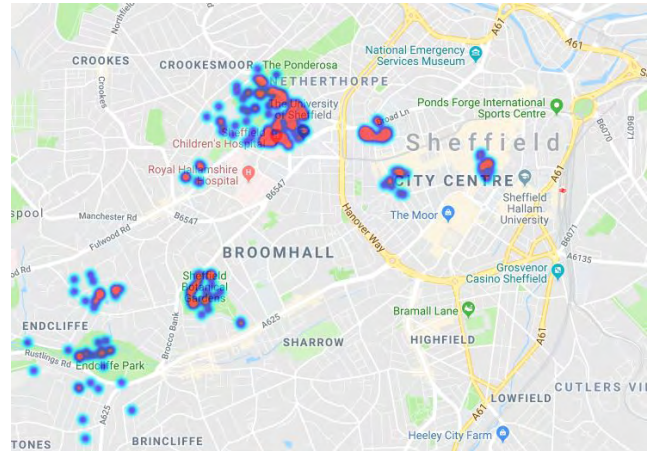


FIGURE 7. Heat-map representing the density of the users' feelings and the associated grades. The scale varies from blue (medium) to red (high).

TABLE 4. Number of labels for participant categories.

User group	No. of labels	No. of unique labels	No. of labels after filtering	No. of unique labels after filtering
Green	9610	804	8450	676
Built	5630	640	5012	530

A. WHAT DO THE IMAGES SAY?

For the images, we filtered the identified labels and did a count analysis as described in Section III-E. Table 4 gives an overview of the number of labels for the two participant groups. The column "No. of labels" gives the total number of labels identified across all pictures, while the following column tells us how many of those labels are actually unique. After we apply the filtering described in Section III-E, we can see that these numbers reduce.

Top 10 labels for each category of pictures

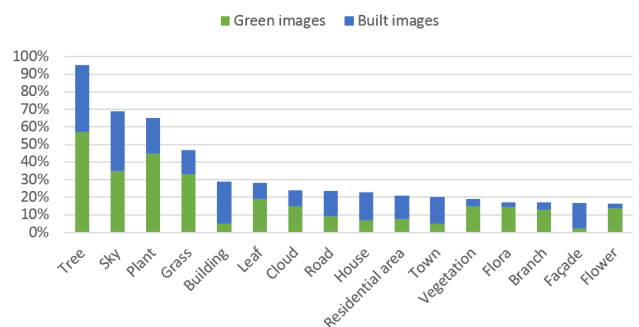


FIGURE 8. Top 10 labels for each category of images.

Afterwards, the filtered unique labels were used for continuing the analysis. We chose the first ten most encountered labels for each of the two groups and looked at the overlap between them. To be able to have a fair view of the overlap, we first normalized the number of occurrences of a label by dividing this number with the total number of pictures in the category. Fig. 8 depicts the overlap. The x-axis identifies the

TABLE 5. Text clustering.

Cluster	Dominant term	No. Observations	Example Text	Cluster cont.	Dominant term cont.	No. Observations cont.	Example Text cont.
1	General	1324	Shepherd wheel moss	15	autumn	54	I admired the autumn leaves on the trees
10, 27	tree	395	Trees in nether edge	11	field	52	Sheep in the fields
34,37	park	302	Nice park (weston park)	25	weather	48	Nice weather, breezy not rainy and not too cold
29	birds	195	Loads of birds in the park	35	peak district	41	Beautiful views over the peak district
20	garden	192	Insect life in our garden	12	sunset	37	The sunset when i woke up was beautiful
0, 7	walk	186	Went for a walk to devonshire green	30	morning	36	Birds making noises in the morning
28	saw	158	Saw a heron in flight	17	city	29	City centre greenery in the rain
2	love	152	Flowers are lovely	3	heather	20	Heather covered in snow
9	sky	126	The sky when not fully dark	14	snowdrops	19	Snowdrops are starting to appear
26	flower	124	My honeysuckle flowers coming out	36	nest	9	Saw a nest of birds in a big tree
18	green	122	Green grass instead of brick or concrete greys	4	flowing	7	Fast flowing river
38	morning	113	Morning dew on the grass	8	-	1	-
13	leaves	112	Rain droplets on leaves	6	-	1	-
39	duck	93	Ducks eating carrots is pretty awesome	5	-	1	-
23	beautiful	91	Beautiful flat landscapes as I travelled back into York	16	-	1	-
19	river	68	Light dappled on the river	21	-	1	-
31	singing	55	Birds singing in the trees	37	-	1	-

labels, whereas the y-axis gives the percentage describing the presence of a label in the pictures. It can be observed that 4 of the top 10 labels are common for the two groups: “tree,” “plant,” “sky” and “grass.” As a result, the figure only has 16 labels described. For each of the labels in the top of one group we checked if a corresponding value exists in the other group. It is interesting to note that the highest ranking label is in both cases “tree,” while the third for the green and the second for the built is “sky.” This shows that despite the group that the users belonged to, nature is salient and meaningful to people. Furthermore, trees and sky are natural elements which are the easiest to encounter in a city. For the labels that are not in the top 10 for both groups, we can notice a differentiation based on the category with built images containing building structures such as building, house etc., whereas the elements for green images include flora, flowers etc. The total count of the represented labels (for the top 10) in the green category is 2694, while for the built it is 1317. This represents approximately 32% of the total for the former and 26% for the latter, respectively. A better view could be obtained with a compression of synonymous labels in just a few clusters. However, this would require a dictionary for each cluster or a human expert for manual categorisation of the labels.

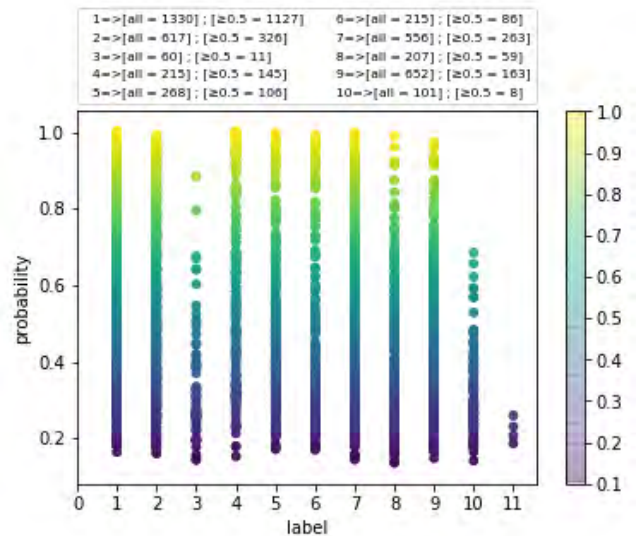


FIGURE 9. Classification of the textual observations into the themes of Table 1 with the FastText algorithm.

B. WHAT DOES THE TEXT SAY?

Using the text clustering API of [31], we obtained the result in Table 5 which contains the count of the number of obser-

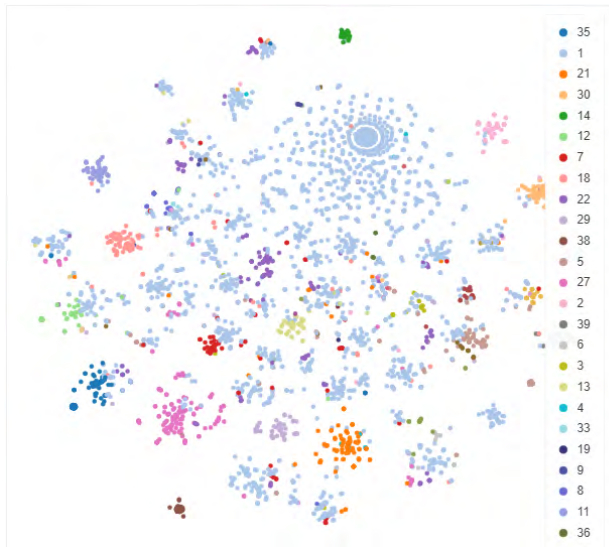


FIGURE 10. Clusters produced from k-means clustering ($k=40$) of textual observations. Legend captures 25 clusters.

variations for each cluster and an example from the dataset. A visualization of the clustering using a simple technique, which generated twice the number of observations of the general category (cluster 1) is shown in Fig. 10 with a snippet of some of the cluster labels. There were clusters formed for observations with specific parks mentioned which enabled us to have an idea of the location of the citizens. Cluster 32 and 34 were observations about parks including those in Sheffield like the Weston Park, Meersbrook Park and Hillsborough Park. It was earlier mentioned that the app did not produce some expected result for the data analysis, with only 418 observations being recorded at the time of the observation. The users were allowed to record their observations at the end of the day. This was supposed to be an advantage to give people flexibility and convenience and allow for more entries to be recorded. However, since most of the observations could not be tagged to a location, we could not carry out analysis mapping locations with observations. This introduced errors as some observations were made and tagged to wrong locations. In the text analysis results, we found some clusters around predominantly mentioned parks. This could be used further to match missing information from the study.

The clustering gave an idea of the kind of activities people were engaging in. Clusters 0 and 7 related to walking activities. A relation with the ‘whyThere’ field was observed. Most of the text observations clustered around walking; (Cluster 0 and 7) received ‘Walking’ as the response to why the people were there. Other reasons were traveling and exercising. The clusters with only one observation count contained rather long text which could fit into multiple themes. Some other clusters give us an insight into the kind of the biodiversity of the park - birds, ducks, bird’s nest, flowers. The category “tree“ has the highest number of cluster elements for a specific dominant term and is represented in two clusters (Clusters 10 and 27). It is interesting to note that in the case of

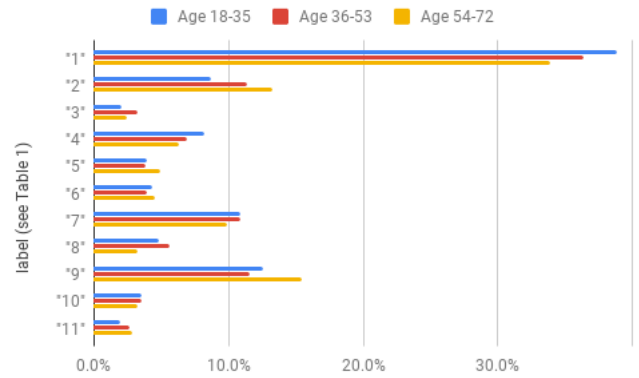


FIGURE 11. Age classification of textual observations.

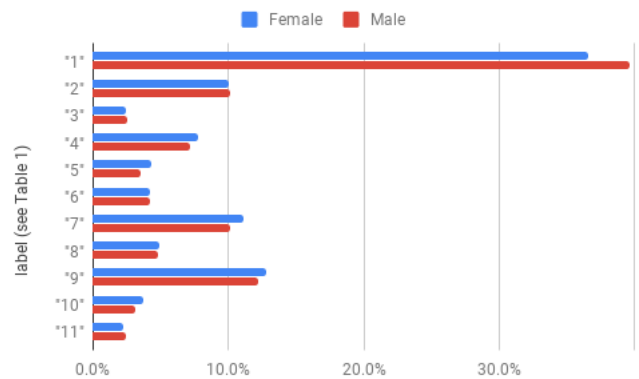


FIGURE 12. Gender classification of textual observations.

the image analysis, the highest count for the labels extracted was also “tree.”

We can see some level of correspondence between the clusters and the themes recurring in the study [20]. There is a clustering around color with most of the comments being about the green color of leaves or grass. We can see the effect of weather on different elements, as well as reflections about the weather in most of the observations containing the word ‘morning’. There is also the beauty/appreciation/wonder in the cluster about love and beauty. Most of the clusters about animals were referring to the ‘animals being active in their habitat’. Some clusters hint at the specific actions that occur naturally in the environment and which people notice: i.e. in cluster 4 (‘flowing’) people are mostly observing how the river is flowing, and in cluster 31 (‘singing’) the depicted activity is concerning birds singing on the trees.

The result of the text classification as described in Section III-D is shown in Fig. 9. The “specific aspect of nature“ theme happened to be the dominating theme regardless of the used threshold. For a threshold of above 50%, the “animals being active in their habitat theme“ is the second highest. The top 5 themes with probability above 50% in this study, interestingly corresponds to the top 5 themes of the study in [20] gathered by a traditional, and time consuming approach to content analysis. The present analysis demonstrates that automated approaches to content analysis are pos-

TABLE 6. Average time spent in parks, by user.

User	Period Study	Tracked Days	N. Visit	Visits for day	N. Parks	Total Time	Avg Daily Time	Avg Visit Time
1	35 Days	30	106	4	10	5 days 20:40:01	04:41:20	01:19:37
2	70 Days	23	64	3	14	2 days 00:31:09	02:06:34	00:45:29
3	38 Days	20	47	2	7	1 days 07:22:15	01:34:07	00:40:03
4	8 Days	7	25	4	6	0 days 08:17:29	01:11:04	00:19:54
5	11 Days	11	48	4	11	0 days 12:54:22	01:10:24	00:16:08
6	43 Days	19	37	2	8	0 days 21:55:20	01:09:14	00:35:33
7	69 Days	24	37	2	7	1 days 03:19:41	01:08:19	00:44:19
8	114 Days	41	168	4	8	1 days 20:00:32	01:04:24	00:15:43
9	122 Days	74	154	2	26	3 days 04:23:51	01:01:57	00:29:46
10	24 Days	16	94	6	25	0 days 16:18:26	01:01:09	00:10:25

TABLE 7. Average time spent inside green spaces, by park.

Rank	Park	Tracked Days	N.Visit	N.Users	Visits for Day	Visits for Device	Total Time	Avg Daily Time	Avg Visit Time
1	Endcliffe Park	124	358	68	2.89	5.26	10 days 19:28:10	02:05:33	00:43:29
2	Whiteley Woods	71	111	23	1.56	4.83	2 days 20:24:10	00:57:48	00:36:58
3	Weston Park	149	807	170	5.42	4.75	5 days 19:31:05	00:56:11	00:10:22
4	Botanical Gardens	97	191	39	1.97	4.90	2 days 22:46:01	00:43:46	00:22:14
5	Ponderosa Park	82	231	46	2.82	5.02	2 days 00:13:41	00:35:17	00:12:32
6	Hillsborough Park	52	165	29	3.17	5.69	1 days 02:24:19	00:30:28	00:09:36
7	Hallam Square	117	287	56	2.45	5.13	1 days 09:53:09	00:17:23	00:07:05
8	Crookes Valley Park	90	246	76	2.73	3.24	0 days 23:20:11	00:15:33	00:05:42
9	St. Georges Lecture Park	109	310	76	2.84	4.08	0 days 20:05:13	00:11:03	00:03:53
10	Peace Gardens	135	334	91	2.47	3.67	1 days 00:09:48	00:10:44	00:04:20

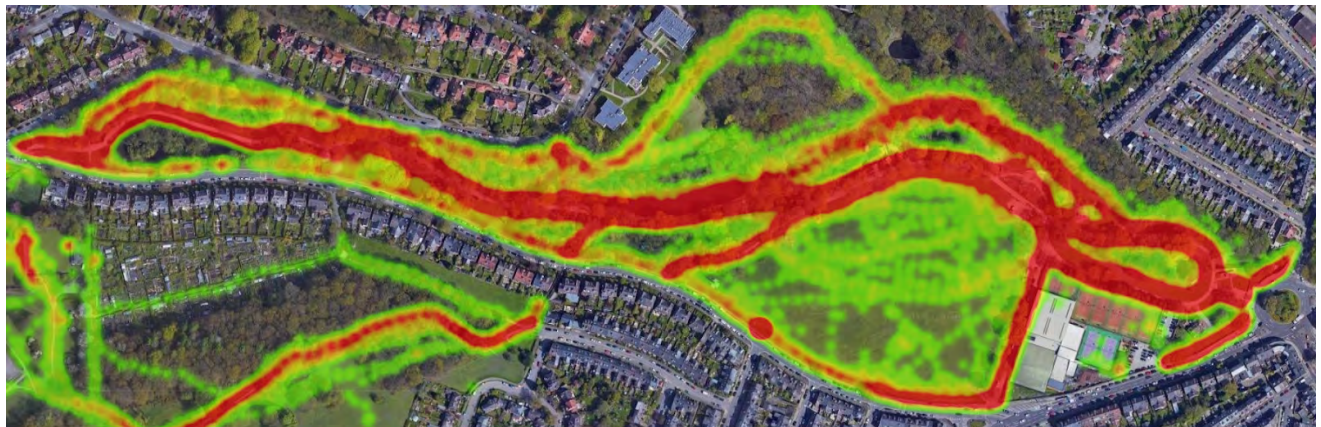


FIGURE 13. Endcliffe Park utilization based on the concentration of location points (green - low number, red - high number).

sible. However, unlike their study which has the “sensations of nature“ theme as the dominating theme, this study has the “specific aspect of nature“ as the top theme.

Fig. 11 shows the result obtained from classification for the various age groups. Theme 1 and 9 happen to be the most popular in each group as expected from the general classification. For the younger group, there is less interest in the activity of animals in their habitat than in other age groups, as growth and temporal changes appear to be more interesting to them. In Fig. 11, the female and male gender seem to vary only slightly, with the females scoring only a little higher for some themes like the sensations of nature, color and beauty. In summary, understanding the good things in nature inform the design of future interventions to engage

and connect people with nature for their well-being, for example, by prompting people to notice trees and birds, or adapting prompts based on gender and age. Future developments could allow real-time text analysis to vary the prompts away from aspects which are being frequently recorded, or towards those known to be associated with improvements in well-being.

C. HOW DO IMAGE AND TEXT CORRESPOND?

By looking at the results from the text and image analysis, we can see that the most encountered label in both cases is “tree.” Furthermore, for the green users, 4 of the top 10 image labels have a direct correspondent in the identified clusters, namely “sky,” “tree,” “leaf“ and “flower.” If we were to

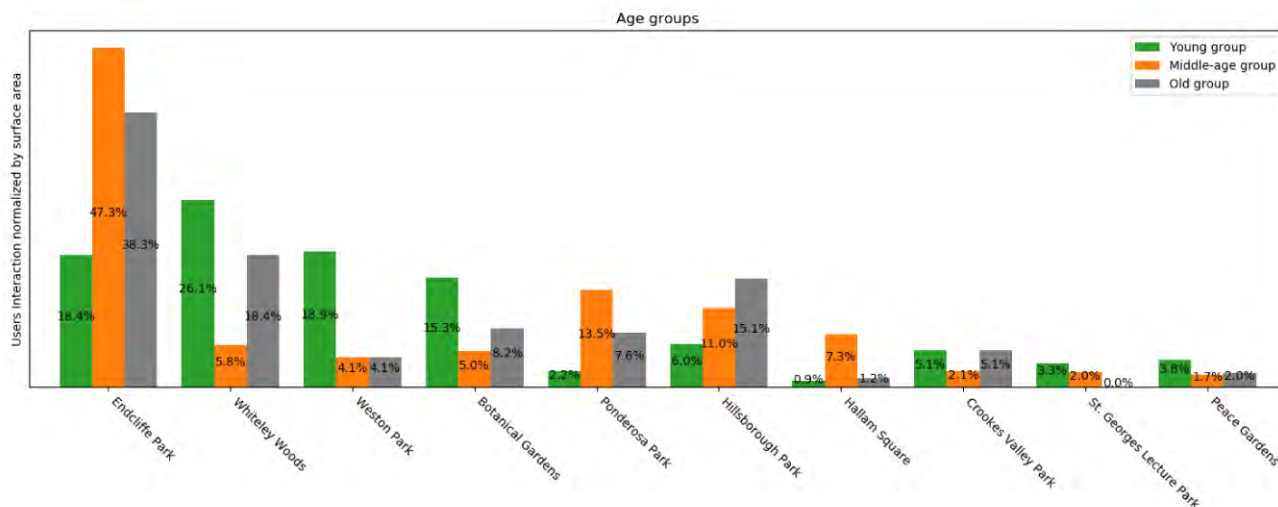


FIGURE 14. Age groups interactions with top 10 most visited green spaces. The percentages are computed only on the samples in these top areas. The amount of interaction decreased by going to the right.

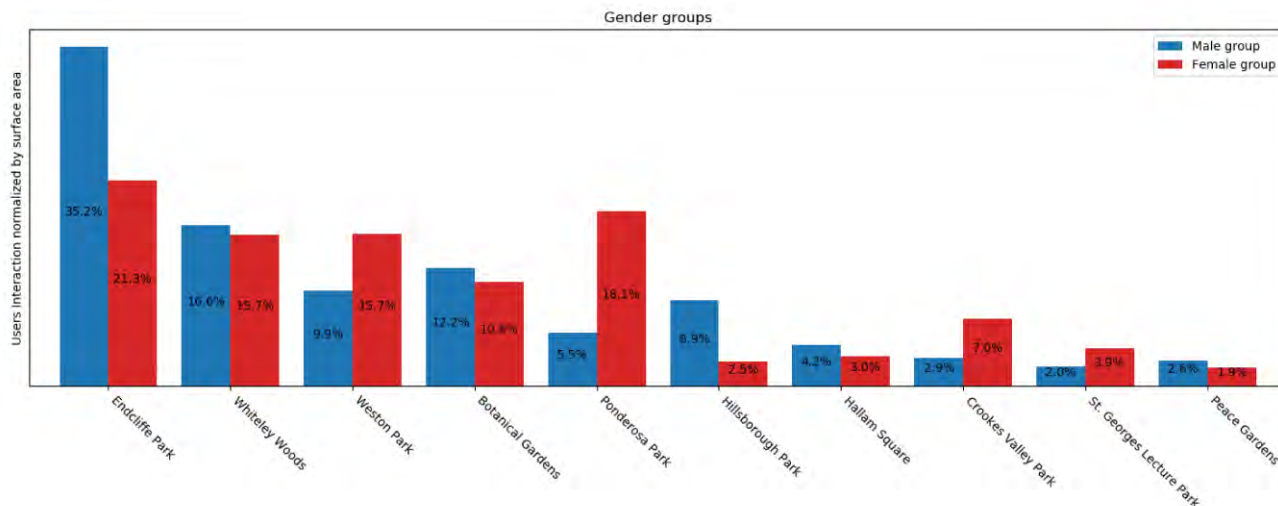


FIGURE 15. Gender groups interactions with top 10 most visited green spaces. The percentages are computed only on the samples in these top areas. The amount of interaction decreased by going to the right.

look at the other unique labels identified for the images outside the top 10, we would find other direct correspondents for some clusters, such as park, city, field etc. It is important to note that we can link image and text based on elements of nature that are rather static and do not involve movement, emotion, action nor specific time of day. This is due to the static nature of an image which makes it hard for an algorithm to pick dynamism, as well as the emotion or feeling felt by a person which can be more easily expressed through text. As an experiment, we used the technique for the text classification described in Section III-E for labeling the set of labels for each image. In other words, each set of labels associated to one image was treated as a text observation. The result was overwhelmingly “label 1“ (approximately 90%) which represents a specific part of nature. This is not surprising and

just reinforces the idea mentioned above regarding the rather static nature of an image.

VI. TIME SPENT IN GREEN SPACES

In this section we report the time users spent in the green spaces computed as described in Section III-F.

A. TOP USERS AND PARKS BASED ON AVERAGE TIME SPENT IN GREEN SPACES

Tables 6 and 7 offer a view of the top 10 users and parks, focused on the average time spent. It is important to note that, although the study period was defined, users were able to continue using the app for longer due to follow-up requirements. Therefore, the total time spent for different users cannot be directly compared, so average time is considered. For Table 6

the column ‘‘Period Study’’ presents how many days the users were part of the study, while the column ‘‘Tracked days’’ identifies the number of days the users were using the app and had location data recorded, meaning days in which there were associated entries. What is interesting here is the number of parks which users interact with. Considering that the average number of parks where the participants spent their time is 7, this indicates that throughout their daily routines, people tend to interact with a variety of green spaces. Therefore, it is important to offer a high variety of parks, such as number, size and location with which citizens can interact, rather than having only large suburban parks. The average daily time spent in green space by a user is calculated as the average of all the time spent values for each day in which users have some interaction with a park. This analysis was carried out taking into consideration only the days in which the person actually interacted with the parks, shown in the table as tracked days. In other words, we looked only at the days where there were location points recorded for the specific user. On average the users spent around 20 minutes in green spaces for every day in which they interacted with at least one park. The top 10 users shown in Table 6 have a time spent in nature higher than average and, excluding user 4, also the number of parks with which users interact is higher. Then there are some borderline situations, for example, user 1 spent an average of 4 hours a day in green spaces. By analyzing their data we noticed that they spent almost all their time in a park. This suggests that they are connected to this park for a specific reason, i.e. it may be that they work in the park (an example could be park maintenance, a dog-sitter or fitness instructor).

The top ten parks users interact with in terms of average time spent can also be observed. Using heat-maps (also called density maps) it is possible to see how the people interact with parks, where they go and what paths are the most used. Fig. 13 shows the users’ interactions with ‘‘Endcliffe Park.’’ The heat map evolves from green (fewer location points) to red (higher number of location points). The red path identifies with the actual built path in the park which can be identified by the light colored thin line. The green paths are rather in green spaces where there are no built paths and the users freely walk around. It can be seen that this view allows us to identify the most used paths in a green space, as well as the less explored parts. This can act as a trigger for administration and local authorities to decide in which areas should the new interventions in that park be focused.

B. AGE AND GENDER DISTRIBUTION IN PARK UTILIZATION

In Fig. 14 and Fig. 15 we can see a depiction of how the different age and gender groups interact in terms of time spent with the top 10 green spaces. Focusing on the age distribution, it can be noticed that the middle-age group prefers to spend more time inside big parks like Endcliffe Park, Ponderosa Park and Hillsborough Park. The younger group instead prefers parks like Endcliffe Park, Whitley Woods, Weston

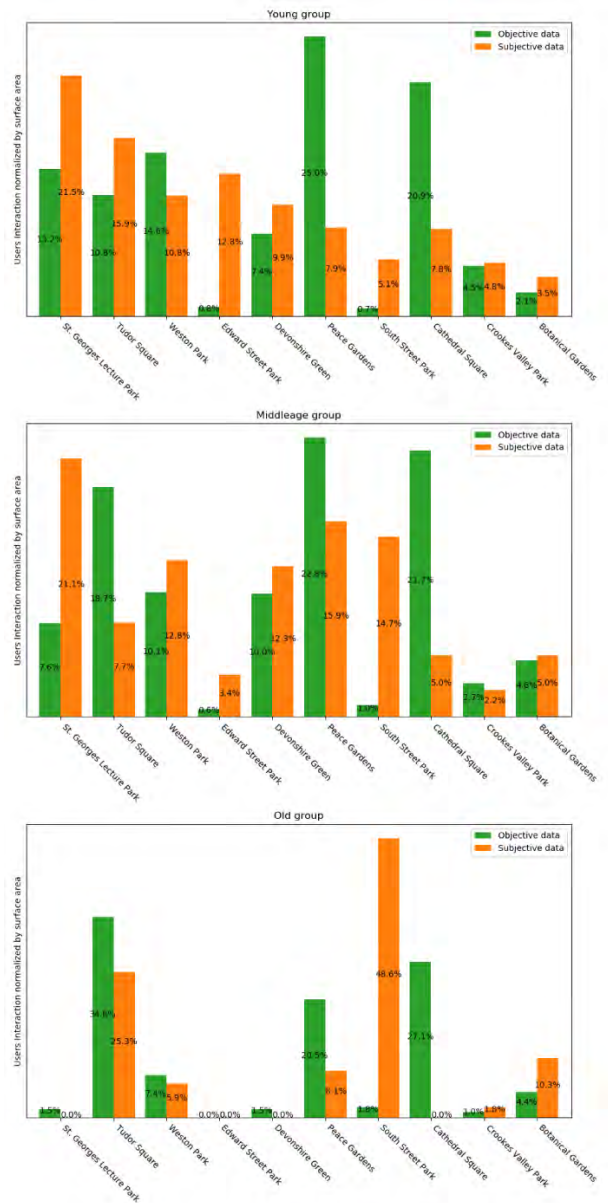


FIGURE 16. Age groups objective (green) and subjective (orange) interactions with top 10 most visited green spaces. The percentages are computed only on the samples in these top areas.

Park and Botanical Gardens. The older group spent more time inside parks like Endcliffe Park, Whitley Woods and Hillsborough Park. Analyzing Fig. 15 we can assert that some parks are used in an unbalanced way by the different genders. Examples are Endcliffe Park and Hillsborough Park where there is a higher presence of male users. The opposite happens in Weston Park, Ponderosa Park and Crookes Valley Park, where there is a higher use by the female participants. This basic analysis shows how the data collection methodology could provide data of interest to local authorities and inform the design and provision of urban green spaces. More detailed analysis can explore the park characteristics and relationships to outcomes such as well-being.

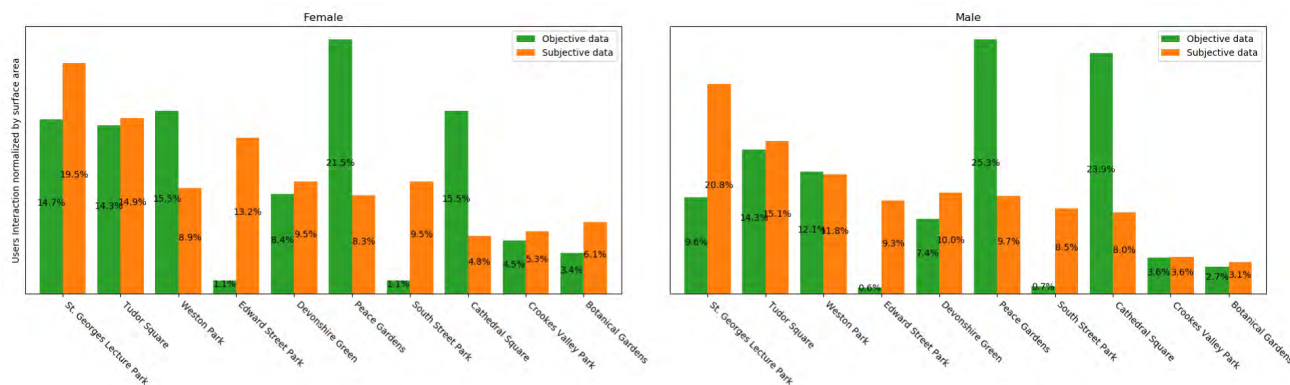


FIGURE 17. Gender groups objective (green) and subjective (orange) interactions with top 10 most visited green spaces. The percentages are computed only on the samples in these top areas.

VII. COMPARISON BETWEEN OBJECTIVE AND SUBJECTIVE INTERACTION

In [32], we analyzed the interaction of users with the green spaces through the app utilization and we did a chart of the top 10 areas based on the number of observations. In this paper we look at a similar analysis. We compare the interaction based on the number of observations with the interaction based on the location points. We analyze these data and subdivide it according to demographic characteristics such as age and gender, so as to be able to compare the different behaviors of the users as shown in Fig. 16 and 17. These graphs are based on the top parks according to overall subjective interaction (density of recorded observations). We add the analysis of location points density in these top parks for the comparison and the results are different from Fig. 14 and 15 where the order and the data is based on the time spent. In these graphs the x-axis is ordered based on the total interaction density, so the interaction is higher in the first park on the left and then decreases in the parks to its right. The most interesting thing here is to notice how the subjective and objective data differ. In some cases, the users who interacted more with some parks in terms of time spent did not interact with the app in the same way. Checking the graphs, on the age distribution we could say that St. George Lecture Park is actually one of the parks less frequented by the old group both for the interaction with the app and for the interaction with the park itself. In this area, the young and middle-aged groups are more consistent due to the presence of the university site. Peace Gardens appears to be a park where the interaction based on location points outnumbers the interaction based on observations in all age and gender categories. This is probably due to the area being in the heart of the city, surrounded by cafes and working spaces. Because of this it is likely that a high number of people often pass by due to engaging in other activities such as hanging out with friends, going to work etc. The central position, accessibility and present features seem to trigger a high objective interaction. The opposite situation appears to be recorded in South Street Park where the subjective data highly outnumbers the objective data in

all age categories. Also, the features of the area seem rather different to those in Peace Gardens. Furthermore, the area is considerably larger, along a street, in an area with residential buildings. Therefore, it is more likely that people are returning home, passing by the park. This could trigger a subjective interaction as people notice green features from the distance. At the same time, the interaction concerning location points is limited as the persons do not actually go into or pass through the park.

VIII. CONCLUSIONS

The aim of this work was to present how data science and machine learning techniques can be used in social science studies in order to maximize the insight gained. In order to do this we made use of a pilot study in which the problem at hand consists of understanding the interaction of citizens with green spaces. By making use of smartphones, data about the interaction is collected as it happens. This allows for monitoring of the exact moments in time. The data can be split into two main categories: subjective and objective. This allows for multiple levels of analysis and comparison. Problems that occur are incomplete data, lack of data or erroneous data which can impact on statistical significance. In this work we looked at better understanding the behavior of the inhabitants of Sheffield, UK. We cleaned and pre-processed the initial data set and proceeded towards a deeper analysis. The main types of data we used concern text observations, images taken by the users, as well as participants' location points in the geo-fenced green spaces. Machine learning techniques allowed us to automatically extract the main topics of interest in the text, as well as categorization of the comments in 11 classes as described in previous research using traditional methodologies, showing how content analysis can be automated with similar results. Furthermore, it enabled us to identify features noticed by the users based on the pictures they uploaded. The output from the text and the images were compared and some similarities could be pinpointed regarding what the citizens notice as the good things in their green surroundings. The location points provided us with the

time spent in various green spaces and allowed us to identify the most active users, as well as the most popular parks. In order to broaden the analysis we compared the interaction based on inputted observations with the interaction based on automatically recorded location points when in green spaces. The challenge in this type of study comes from fusing the information and finding the relationships between different variables.

The lessons learned from undertaking this work allowed for a better understanding of how to carry out large-scale social studies and which techniques can be employed in order to target results from both objective and subjective data. This opens the door to how this work can be extended and improved. The first step would be designing a new app which takes advantage of artificial intelligence. In this context, the chat bot that prompts the user for information would be smart, meaning that based on the information it already has, it will decide which questions it should ask in order to maximize the knowledge gain. This is different from the static approach where each user always gets asked the same questions. The aim is to manage the asking of questions in order to build statistical significance and to minimize intrusion. This also implies that we are moving from an offline approach to an online one. The data is to be analyzed as it comes and depending on the present results and the current statistical significance, the system decides which questions should be addressed to which user. This approach can also be applied to the 'green prescription' element of the app, with real-time text and image analysis used to vary the prompts towards those known to be associated with improvements in well-being. Thus, in the future the app may actively stimulate the improvement of well-being based on known causes of well-being variation; work in this direction is only preliminary at the moment. This kind of app fits into the framework of a smart city and can be used for both social studies, as well as city planning and improving the quality of life for citizens. It represents a scenario where technology, IoT and artificial intelligence can be used in order to improve current conditions in cities and to implement and monitor large-scale studies.

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