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Studies in Small Scale Data: Three Case Studies on Describing Individuals' Spatial Behaviour in Cities

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Abstract

Big Data has been effectively mined to understand behavioural patterns in cities and to map large-scale trends predicated upon the repeated actions of many aggregated individuals. While acknowledging the vital role that this work has played in harnessing the Urban Internet of Things as a means to ensure efficient and sustainable urban systems, our work seeks to recover a scale of behavioural research associated with earlier, empirical studies on urban networks. UrbanIOT data expands the depth and precision of intimate behavioural analysis; small-scale analysis lends insight into important anomalies not explained by large-scale trends.
The three case studies at stake here combined empirical journaling with data from mobile devices, tracking both automatically and through user reporting. Each produced diverse information and visualizations for describing the interaction of individual citizens, resources and urban systems. These are: a description of behaviours relative to food stores and shopping habits in New York City, US; a description of the correlation between mobility and food waste likelihood in Providence, RI, US; and a study of mobility patterns and personal choices in Copenhagen, DK.

Keywords: Resource Flows, Transportation, Human Factors, Visualization, Design Thinking, Apps, GIS, GPS.

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1. Introduction

Traditionally, the ability to manage urban flows has been challenged by the unpredictability with which people respond to spatial cues. In certain sectors, such as traffic and public transport planning, stochastic studies [1] have rendered some degree of predictability by interpolating from relatively large sample groups. In other contexts largely within the social sciences, painstaking interview and observation has been applied to statistically meaningful but numerically small sample groups [2]. Although quantitative and sociological approaches have each produced a rich literature, the methodological divide between the two continues to limit the understanding of spatial behaviours as simultaneously generalizable and highly individualistic. Traditional research offers few bridges between the two. As cities grow at unprecedented rates and increasingly constrained infrastructure requires unprecedented efficiency, the need to understand human behaviour as both mass and individual phenomenon in an urban context has gained new urgency.

Developments in Urban Internet of Things have created new opportunities to understand cities. Bridging between the quantitative and the qualitative is facilitated by the ability to map and track the movements of goods and people through the use of GPS and GIS at multiple scales. [3] At the same time, the use of mobile devices for social research has seen a surge in interest. In this context, we understand our work to augment and cross-fertilize impulses taken from the Ethno-Mining movement in the social sciences [4] and the efforts of Situated

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Technologies research [5]. Our platform-agnostic approach has deployed off-the-shelf apps and software intended for diverse purposes: personal fitness tracking, 3-d architectural modelling, social media and GIS. We also continue to develop bespoke approaches to correct for the inaccuracies uncovered progressively. At the same time, we retain methods endemic to social science research such as observation, journaling and interview.

The three case studies discussed in this paper made use of many different digital data collection tools, each with a different degree of technical finesse, user interaction, accuracy and mappability. As our interdisciplinary work has progressed, the expertise of the researchers involved has diversified; in this sense, the three case studies also represent an evolution ranging from off-the-shelf use to customized app development.

The first case study, which explored the relationship between habituated movement through a city and food shopping patterns, used the mass-market app *Instagram*, in its out-of-the-box form, GIS-based open source data, journaling and interviews. The second, which considered the correlation between student meal habits and the amount of food-related waste they produced, undertook modifications to a downloadable GPS fitness tracking app, *MyTracks* used in conjunction with architectural and GIS mapping software. The third case study is the most technologically robust. It was developed during a multiday workshop sponsored by the Design Modelling Symposium 2015 in Copenhagen, and required the development of a bespoke GPS tracking app, and the customization of a software developed for interior spaces.

2. (re-)Defining the ‘City’ and the ‘Sample’: Literature Review and Scope Definition

Cities can be defined by both their stable and ephemeral characteristics. They may be said to comprise the designed flows of streets, infrastructure and built environment overlaid with the incalculable contribution of human spatial behaviour. Resource flows thus form the tacit spatial backbone of cities: dominant in the early stages of settlement, these spaces become increasingly invisible as other, stronger market and cultural forces appropriate limited land. The need for greater intelligence in the way resources are used in a city requires that these flows be acknowledged as spatial and social, not purely logistical, entities. A robust definition of the city considers the interplay of its traditional static, physical dimensions and those in constant flux.

The complexity of motivations behind human spatial behaviours in cities is a broad research area that has been subjected to both older empirical study methods and to contemporary UrbanIOT-based mapping methods. One foundational example of the former is the pioneering 1975 study by the socio-linguists Linde and Labov [6], which used analysis of the narratives by which New Yorkers described their apartments to identify how habit, perspective and convention determine the ways their subjects construct movement through space. Their findings have often been extrapolated to an urban scale, most famously by Michele Decerteau [7] to support the conception that cities are experienced as movement paths, not merely “tableaux”. Decerteau, arguing in his writings for the individual “culturally creative” acts that define the experience of urban space, used the idiosyncratic ways in which urban space was cognitively mapped to provide evidence for the complexity and multiplicity of how urban dwellers charted their everyday courses in cities.

Within the emerging literature drawing upon UrbanIOT, urban mobility and its drivers have received significant attention. As with the Linde and Labov study, urban mobility research seeks not only to ascertain patterns of movement but also to understand the motivations to behaviour, which results in that movement. A seminal example is the study by Noulas, et al [8], which used social media data to interrogate the assumption that urban mobility could be characterized universally based upon physical distance between points. Mobile data allowed researchers to map the location of social media events onto the physical city and its assets to produce a new hypothesis – that mobility behaviour is related to the density of urban amenities, and not only proximity. Here, too, the subjective factors, which determine the nature of path in complex urban environments could be accounted for, albeit differently than in earlier empirical studies.

To give equal credence to traditional observational and contemporary analytical studies is to beg the question of the statistically meaningful sample. Although not explicitly stated in the article, Linde and Labov reference only ten participants in their study. By contrast, as Noulas et al state in the introduction to their study, “the scale of the datasets is planetary” when access to smartphone user data is permitted. We were motivated to envision a hybrid research approach, in which the assets of social media were seen as a means to augment a study rooted in the highly individuated, observationally based tradition of earlier urban sociological undertakings. Thus, in the three case studies discussed here, sample size and experiment duration vary based upon participant logistics, data availability and the validity of proxy data used to interpolate between observed and tracked information. Where smartphone apps used as intended were unable to offer the desired interactions, alternative apps were appropriated from their intended use. As additional challenges emerged, bespoke apps were developed to provide individuated information that could be set against larger statistical data sets. The interplay between sample size for collected data– always relatively small in the case of our studies – and publicly available urban data, such as census or infrastructure information, offered opportunities for innovative visual representation from which hypotheses about the city as flows could be derived.

As we continue to codify our methodological processes and better adapt mobile device interfaces, we foresee this area of study as an enormous opportunity for research at the nexus of social science, urban studies and architecture, expanding what has been achieved traditionally.

2.1. Testing the Value of Hybrid Research

In the past decade, food has become a bellwether for societal changes in the US, with research on both supply and waste production components. There is, however, a blind spot in food resource tracking between point of sale and waste stream. This moment in the resource chain is by nature diffuse and individuated, related to myriad factors endemic to the diverse ways in which urban dwellers live. Kitchen size, shopping opportunities, transportation, lifestyle and taste may all influence the transition between food as commodity and waste as output. These complex parameters offered an attractive challenge to test a hybrid observational/individuated and data/mapping driven approach to urban flows.

Visualization in the form of maps, graphs and photography served as a valuable touchstone with which to bridge the methodological differences in approach. Therefore, each study is copiously illustrated as a means to compensate for the gap between very small, observed sample groups and very much larger statistical data used to describe the urban context in which these groups operated.

3. Case Study New York: City as Path, City as Shopping Opportunity

In this early study, we favoured an empirical, participant-driven method of data collection via journaling and user-initiated social media. Each participant used the *Instagram* app, photographing and uploading all grocery shopping events. A journal documented contextualizing information such as means of transportation and whether the purchase was made en route or as a dedicated trip. *Instagram*'s date, time and geolocational stamps could also be verified against the journal. Our goal was to track consumer shopping behaviour relative to both a Linde and Labov-inspired account of the urban experience and a critical assessment of the behavioural component of food-related environmental impact.

The rhetoric of environmental sustainability often assumes that urban spaces are inherently more efficient because they are compact. Market and policy forces optimize and streamline in order to deal with the small spaces they are allocated for resource provision. But in high-density cities such as New York City in which space is at a premium, the value placed on resource efficiency pales in relation to property value drivers. Domestic spaces are small, on average less than 50 m^2 per capita and much less in poorer neighbourhoods. One desired research outcome was therefore an attempt to apply a series of sustainability indicators to the implications of scaling down food distribution to fit these small domestic and public spaces. From waste-to-packaging ratio to delivery practices, purchasing habits, and waste produced, both urban and private spaces and individual shopping habits impact urban food efficiency.

A growing body of research and visual modelling using GIS techniques has documented and speculated on New York City's food shed. [9] New York's goal of zero landfill by 2030 [10] has driven extensive data collection on waste streams. The data derived from these studies and from tax maps was mined to provide context.

	ITEM	OUTCOMES	SOURCE/METHOD
LARGE	1. Understanding NY Food Stores Typologically	Type by Size Dostribution by Neighborhood Celivery Practices and Impacts	Tax Data/GIS Tax Data/GIS Empirical (Observation)
MEDIUM	2. Product Size and Variety	Relative to Store Type	Empirical (Survey)
SMALL	3. Corresponding Behaviours in Consumers	Shopping Patterns	Empirical (Journal, Interview) Social Media
	4. Case Study	Food Waste Tracking	Empirical (Journal, Weighing) Social Media

Figure 1. Three scales of research

3.1. Characterizing Food Resources: Store Typologies and Concentrations, Life without Loading Docks

The distribution of food stores within New York City speaks volumes about the city's neighbourhoods' affluence and food habits. Using public GIS data sets, we characterized the distribution of stores throughout the city by size. Known in New York by the Spanish term *bodega*, although the owners of these stores could as easily be Yemeni or Korean, small corner stores are found almost everywhere in the city, but are prevalent in less affluent areas. Most neighbourhoods also feature one or two medium-sized supermarkets, but the city has only few large supermarkets. Not included on this map are the outdoor weekly or biweekly farmers markets that have become significant fresh food sources in affluent and less affluent neighbourhoods throughout the city.

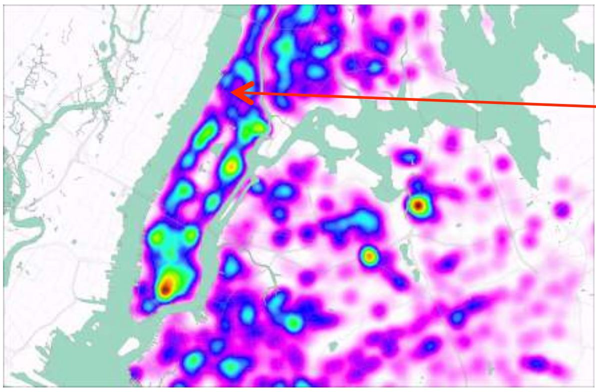

Figure 2. (top) Distribution of food stores throughout New York City, size indicated by diameter (bottom) Proximity to food stores by size as false color rendering. White: no store in 1000 ft. radius. Maps by Cezar Nicolescu

New York City has few service roads or alleys. This makes for frictions and congestion during deliveries. The public sidewalk serves as loading dock, trash station, receiving and hand truck gangway. In the area of upper Manhattan we studied, the street outside food markets was double-lined with trucks, vans, recycling and garbage vehicles each day. At one 4,000 ft^2 supermarket within our study (fig. 3), double parking occurred for some 100 feet, causing traffic congestion during rush hour. To quantify the impact of this congestion, we note that an idling diesel truck emits 94.6 g/hr of CO and 56.7 g/hr of NOx; an idling passenger car emits 371 g/hr of CO and 6.16 of NOx. [11]

Through observation and mapping, we developed a typology of the food markets within our study area. At the lowest end of the scale were *bodegas*, under 1,500 ft^2 in area. At the highest end was a 25,000 ft^2 supermarket with access to customer parking and a dedicated delivery zone, an anomaly in Manhattan. Figure 4 shows the four food types, their square footage and their locations within the sample Morningside Heights neighbourhood.

Figure 3. Typical sidewalk and street congestion for food store logistics. 8:00 AM October 5, 2014.

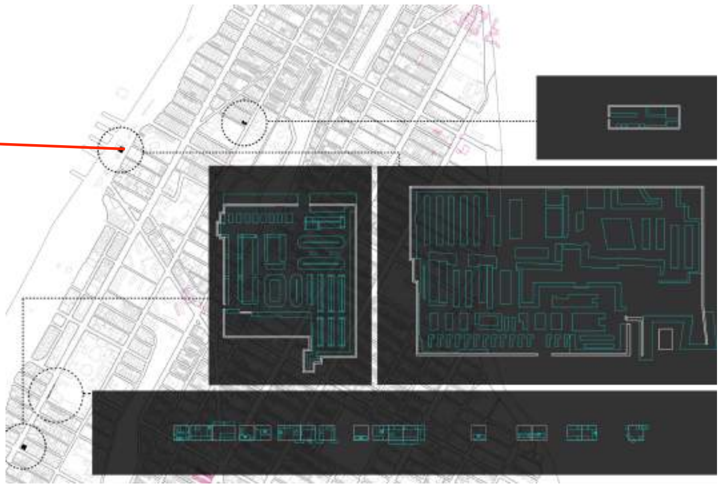

Figure 4. Food retail by size, type and location, Morningside Heights, NYC. Clockwise from top: Bodega, 900 ft^2; Supermarket on marginal land, 16,000 ft^2 retail/ 6,000 ft^2 storage; Biweekly farmers' market 400 ft long; Standard supermarket, 9,800 ft^2/3,000 ft^2 storage.
Drawing by Elizabeth Cohn-Martin.

3.2. Packaging and Variety as Factors in Waste Stream Impact

We used our store typology to test the hypothesis that there was a correlation between store size and the variety of package size, brand and type of product offered, which would register in consumer waste. We surveyed four food retailers of different sizes in the Morningside Heights neighbourhood as well as a biweekly open-air market, and compared their offerings of two proxy staples, milk and honey. Through journaling and measurement, we documented the impact of content to packaging ratios on the food-related waste streams of our four subjects. To evaluate the implications of the non-organic waste measured, we note that New York City has a dual stream recycling program for uncoated paper and cardboard; and for glass, metals and rigid plastics. Glass bottles are collected but not reused: all deposit and recycled bottles are crushed. Everything else is landfilled.

In addition, each size of market demonstrated unique potential environmental efficiencies and inefficiencies. The smaller packages in a *bodega* had poor content to packaging ratio but small-scale stocking practices limited impact on urban traffic congestion. The farmers market uniquely offered the reuse of packaging by returning empties to farmers and minimized organic waste by calibrating to consumer demand and soup kitchen donation but used an inefficient, decentralized delivery system. The medium sized supermarket offered great variety by using smaller packages and fewer articles for sale, also limiting potential food waste; but its delivery system created enormous traffic congestion. Finally, the largest supermarket has optimized its delivery system but favoured long life packaging that must be landfilled and has high-embodied energy. We thus concluded that product sizing and packaging may translate into valuable parameters for assessing and predicting the environmental cost of non-organic waste from the food supply stream. A further study which inventoried waste packaging by neighbourhood could extrapolated from this kind of assessment to assist in scaling policy to hyper-local need.

3.3. Mobility and Consumer Behaviour: City as Path, City as Shopping

In a largely pedestrian city such as New York, urban life experience involves what we called 'opportunistic shopping', done in smaller quantities when passing a store. Within our research collective were four different kinds of households. Our participants (fig. 5) represented four different kinds of households: communal living (purple), a single living alone (blue), a couple (green) and a family (red). Two participants (purple and green) were car owners, and two were regular cyclists (purple and red). We found that the frequency and intensity of shopping for the car owners differed markedly from the other two.) Car owners, one of whom had the longest commute among participants, tended to shop for food infrequently. Large and bulk purchases were made on a weekly basis. By contrast, the non-car-owning Subject whose range of daily activities were the most far-ranging by virtue of bicycling (red) shopped at 11 different locations, and on three days of the seven, shopped more than once a day. All purchases by the two non-car-owners were made en route rather than as a dedicated activity. The results were plotted on a *google* map of New York City by moving data to spread sheet form and GIS software.

Drawing upon the mapped results, we hypothesize that each type of city dweller could be represented by the route connecting his or her food shopping habits – a kind of urban food fingerprint. The implications of understanding these fingerprints for the optimization of urban efficiency could add a significant dimension to considerations of public health, diet and food availability by location. The results also argue strongly for the sociospatial embeddedness of food shopping and the importance of deeper study into the spatial patterns around urban "foraging." The study also pointed to the limitations of data culled from self-reporting and spurred further experimentation with automated apps and tracking methods.

Shopping habits also resulted in different waste regimes. Infrequent, bulk shoppers produced less non-organic waste by volume, but that waste was largely landfilled. Farmers Market shoppers produced almost no non-organic waste because of the ability to return packaging to the farmers for reuse. Frequent shoppers tended to have much less food waste from fresh food, and to avoid frozen foods, which require more storage energy in supply chain, supermarket and home.

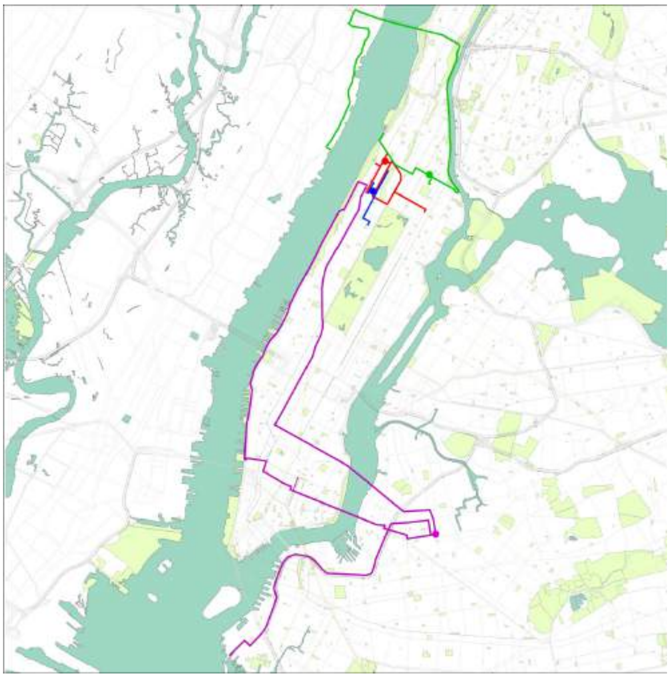

Figure 5: Mapping Urban Tracks and Shopping Purple and green tracks are car owners; red and blue walk or bike. Image: Cezar Nicolescu, Lynnette Widder

4. Case Study, Providence Rhode Island: Work/Life Balance and Urban Mobility

Our subsequent case study expanded upon our questions on urban resource flows and food-related behaviour by leveraging more extensive mobile tracking in combination with mapping and three-dimensional architectural modelling platforms. We again used a small sample group, all students at the Rhode Island School of Design in downtown Providence, RI. Data collection occurred through three distinct channels: interviews, journal entries and digital tracking via mobile device using automated trajectory tracking and user-initiated photographic upload with associated date and location-stamp (*MyTracks)*. Spatial and social characterizations were captured in photos and subsequent interviews with subjects. Journaling provided narrative descriptions of food consumption trajectories and daily practices.

The study's premise was that each subject's food habits would describe a unique set of spatial practices, which would correspond to different types and quantities of food-related non-organic wastes. Our findings verify that there is a distinct spectrum of behaviours arising from social, temporal and spatial preferences, which are expressed in the production of both recyclable and non-recyclable waste generating by the act of eating.

Ultimately, two salient parameters emerged through which to characterize initially the correspondence between behavioural choices and food waste: the distance a subject was willing to travel in order to have a meal and whether the meal was eaten alone or in company. These parameters were, we ascertained, dependent upon the urban context and its density and type of food outlets, a finding that argues for the need to reflect and represent accurately the city in which a study such as this is undertaken. Responding to this insight, we used two different visualization techniques, one derived from architectural representation (*Rhino)* and the other from GPS-based mapping (*OpenStreetMaps* and *Carto db*).

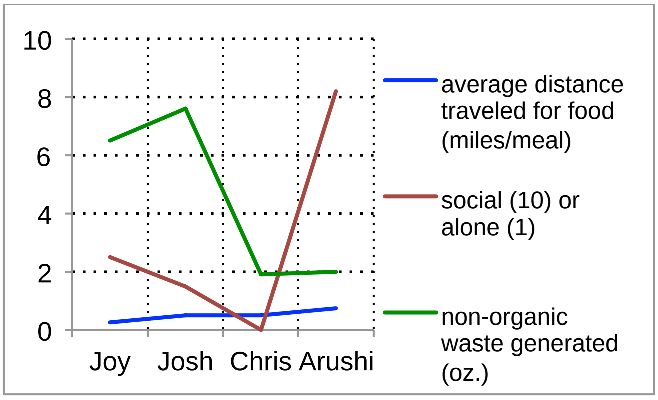

Figure 6: Graphic representation of all four subjects relative to distance per meal travelled, social engagement while eating and the non-organic weight generated in ounces. The parameters of mobility (average distance travelled) and meals as social or work events (social vs. alone) are measured against the amount of non-organic waste from food that each subject generated.

4.1. Urban Context: Food and Waste in Providence, RI

Our sample group and location offer a microcosm of the forces that influence waste from food consumption in urban environments, where such factors as convenience, constrained time, social milieu and spatial preference influence how food as resource and as potential waste makes its way through the consumer's life world.

RISD is located in Providence, Rhode Island, a city with a strong coalition of local government, NGOs and universities dedicated to food equity, local farming and more sustainable solid waste management. In 2011, the city's mayor appointed the first Director of Sustainability and funded an Office of Sustainability to set goals and take action on energy, transportation, waste, water, food and land use. Rhode Island has invested in solid waste management, including a state-wide transition in 2012 to single stream recycling and the construction of New England's largest Materials Recycling Facility (MRF) about 8 miles east of Providence. Baled post-consumer materials – paper, cardboard, metals and plastics – are sold internationally. [12]

Nonetheless, the intent to capture and resell all potentially recyclable packaging is difficult to realize. Spring, 2014 statistics from the RI Resource Recovery Corporation indicate that 15% of RI's waste from packaging, which accounts for 28% of the total statewide solid waste stream, is recycled. In other words, only half of the waste generated from plastic, paper and metal containers is recaptured. Because incineration of waste for energy is considered recycling by RI code, some recaptured waste may be simply be downgraded to fuel. [13] The rate of recapture in Providence is even lower than statewide averages, around 13%. [14] These factors help to understand the impact accruing to waste from the subjects' food consumption practices.

Spatial maps of Providence's food and waste streams spatially are few, mostly focused on food equity. Although Providence has significant food deserts, the RISD neighborhood has between 49% and 95% market basket access, an indicator defined as the physical and economic accessibility of items contained in a USCA standard "market basket". [15] However, students like those in this study have little opportunity to shop and cook at home without recourse to car transportation. Our findings show that food prepared and eaten at home or leftovers brought to school generated the least amount of packaging waste per serving. The school's immediate neighborhood offers only inexpensive take-away options or much higher priced sit-down restaurants.

4.2. Technology and Mapping

This study used *myTracks*, a GPS logger, which automatically records a .gpx file with timestamp and geographic coordinates (longitude, latitude, altitude) at a desired interval. This app also provides the option to take photos during the log, which are then time-stamped. Recruits were instructed to make recordings throughout the day, taking photos at the purchase, consumption and disposal of every food item. Further instructions were to document more information in photos that capture details of food item, packaging and socio-spatial context (where they are eating, whether they are eating with a friend, etc) and to keep a brief written log of these details. Efforts to preserve battery life were made by downgrading the resolution to every 15 seconds and to pause the recording when in any given location for more than 20 minutes.

Daily tracks were then collected and imported into a parametric 3d-modeling environment (*Rhino* and its parametric plug-in *Grasshopper*, workhorse applications in the architecture world) and overlaid on a site model that included building models provided by RISD and the City of Providence as well as topographical and urban context from *LiDAR* and *OpenStreetMap*s respectively. For comparison, two separate 2d-mapping formats were also used: *Carto db* animation and *OpenStreetMaps*. Necessary conversions from geographic coordinates to the Euclidean coordinates were required for the overlay of this information. By integrating mapping tools, 3-D modelling software and customized processing platforms, a hybridized analysis was possible that correlates linear pathways and nuanced spatialization.

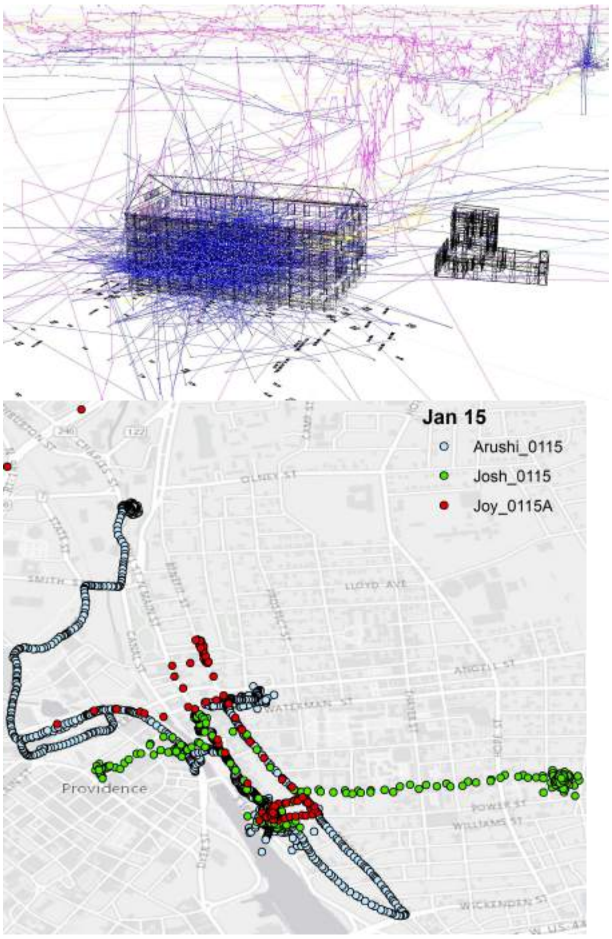

Figure 7: Overlay of local movement by all four subjects around the BEB Architecture building. Top rendering in a 3-d Rhino environment; Bottom rendering, Open Street Maps, in which each point represents the 15 second interval data logged.

4.3. Findings: Workaholics and Waste

Our intuition was that each subject would generate a unique three-dimensional hieroglyph based solely upon where and when they purchased and/or consumed food. The ability to identify precisely what space a subject occupied while eating, as corroborated by a photograph, facilitated our analysis of spatial behaviours; the ability to identify the subjects' trajectories as linear or looping indicated the value placed on efficiency, measured in distance invested in procuring a meal. The resolution of the tracking program allowed us to recognize the difference between the choice to eat alone at work, or elsewhere, in the company of other people. Precise time stamps, accompanied by photographs, indicated whether students were using breaks for lunch more generously or simply slipping out for the mid-afternoon coffee. Our findings verified the uniqueness of each subject's path and periodicity. Closer readings of the photographs and logs revealed how such parameters as time, work rhythm, food culture and social interactions contributed to each of those hieroglyphs. The tracking results of two subjects in particular, Josh and Arushi, bear further explication since they came to represent two markedly different attitudes and resulting waste patterns.

Josh's food patterns represented the anticipated norm for a workaholic architecture student: a diet of take-out food, eaten on the run or at a desk – not a single meal was treated as a social opportunity. His breakfast was a protein shake consumed while biking to school. With the exception of his shake bottle, he used disposable containers: aluminium, #5 plastic, steel sheeting cans. His routes were proscribed by home, work and food procurement. His distance travelled per meal was the least and his non-organic food waste production was highest over the course of the weeks tracked (Fig. 6 and 8).

For Arushi, eating was an activity in itself. Her behaviours and associated food packaging waste results scale high relative to social contact and mobility (see Fig. 6): only three meals involved disposal receptacles. A laptop computer appears only once in the images but other people were frequently pictured, indicating that eating was treated as a social event. Her low waste to meal ratio suggests that the a greater sense of freedom in moving away from the place of work, and the high value she placed on eating as a social or dedicated activity will positively impact waste type and quantity. This finding is significant for sustainable resource regimes, since it indicates that eating as a stand-alone activity may be less resource intensive.

Figure 8: Images typical of Josh's eating and a map showing his four primary points. The two foreground points are home and school, the other less intense points are food purchase locations. The tracks form a continuous loop, with no redundancies, indicating value placed on efficiency.

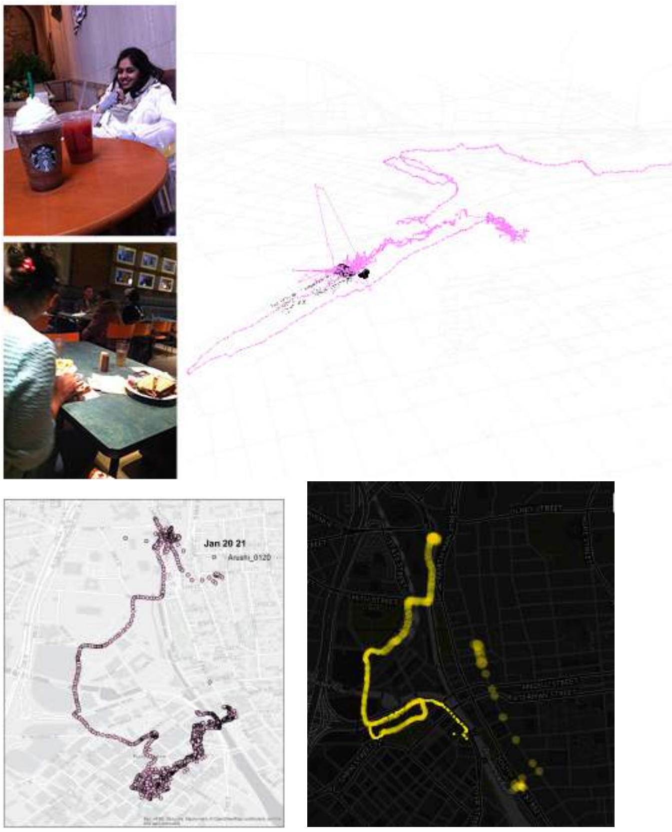

Figure 10: Typical images from Arushi's tracking, in which friends figure prominently. Her tracks typically double back on themselves, indicating less regard for efficiency. Each rendering – in Rhino, in Open Street Maps, and as an animated trajectory - tells a different version of the same story, based on trajectory, frequency, duration and clustering.

4.4. Analysis and Technical Challenges

Our findings reinforce the hypothesis that each individual creates a unique pattern in navigating space relative to the parameters associated with meals: time allocated, efficiency, social interaction, primacy of work. The development of a prepared food 'Market Basket Index' could also assist in ascertaining whether economic factors influence the choice homemade versus purchased food. There is little doubt, however, that the culture of efficiency and prioritizing work above all results in greater quantities of non-organic, unrecovered food waste.

It is also important to integrate larger supply and waste flow systems in evaluating these individual findings (Figs. 3 and 5). Because shipping demands efficient packaging, to quantify non-organic food waste by volume or weight is misleading since it misses the resource intensity of packaging variants. The development of a factor that integrates embodied energy, local recyclability and resource intensity would help to qualify the true environmental costs of each disposable container.

The technical challenges involved in this study were myriad but instructive. Interfaces between various software – *Revit, Rhino, My Tracks, Carto db* – were stymied by different basic unit measures and methods for registering three dimensions. Hybrid automated and agent-driven data produced heterogeneous data types and thorough data cleaning. Future studies can also better exploit three-dimensional and temporal tracking to reveal behaviours motivated by spatial situations.

5. Case Study, Copenhagen, Denmark: Some Potentials of Automated Mobility Tracking and Mapping

We used a workshop in Copenhagen [16] to test tailored data collection and representation to describe how spatial characteristics relate to urban behaviours. Since our purpose was to test a bespoke approach to tracking apps, we considered only behavioural choice relative to mobility, eliminating the focus on food. We had access to volunteer-collected mobility data as well as municipal and open source data, including geographic data about the city (i.e. green spaces, trees, streets, average pedestrian counts). The analysis of volunteers' tracks interrogated assumptions around why any one route was favoured relative to urban features that could motivate choices.

5.1 Advantages of Bespoke Data Collection

The development of a bespoke technology we called *Lillebrot* afforded certain opportunities not offered by existing platforms in terms of the collection, storage, and querying of spatial data.

- Passive rather than active tracking;
- Access to a variety of means for tracking position;
- The inclusion of data other than position made available by the platform of the mobile device;
- Easy integration with desktop mapping and visualization software;
- Live Feeds;
- Participants could make individual inquiries of collective data;
- Diversity of visualization methods, including *Lillebrot* live map for visual exploration and easy track mapping in the web platform *Carto db*;
- Spatial analysis of track data compared to municipal datasets in ArcGIS.

Hooks were developed for *ArcGIS, Carto db, Mapbox, Processing, D3*, and *Grasshopper*.

5.2 The Lillebrot Platform

The goal of developing our own platform was to address inadequacies around human error (ie forgetting to turn on/off an app, need for manual upload of data) and data accuracy (i.e. limitations to GPS-based apps). The

Lillebrot application required no intervention once activated. It recorded position, movement and speed, as well as activity levels, such as data transmission, screen activation and user-prompts based upon certain triggers, such as arrival at a pre-defined location or time of day. Using the former feature, for example, we were able to record not only the position of volunteers, but also their level of activity both in terms of data transmission and active engagement with the mobile device.

Recording positional data used GPS satellites for understanding at a coarse ("macro") level. To understand fine level data, the program used a technique developed by *IndoorAtlas* that utilizes a building's pre-recorded magnetic signature. The accuracy of GPS positioning is dependent upon the subject's mobility: subjects stationary in indoor locations or in city streets bounded by tall buildings offer less accuracy. During this study, the range of accuracies experienced by subjects ranged from 3- 40m uncertainty on average. On the other hand, the magnetic positioning system developed by *IndoorAtlas* requires access to a venue in advance. Once mapped, however, *IndoorAtlas* claims accuracies as low as 1m. Although not entirely achieved during initial tests, accurate indoor data collection could assist in scaling up spatial analysis for which we otherwise used visual reading of photographs.

Lillebrot data was registered in .csv and geojson formats and included fields for message number, latitude/ longitude, frequency/speed and the screen message at transmission. Because these data formats are easily incorporated into web mapping, desktop GIS and CAD environments, they could be used in combination with existing spatial data for Copenhagen.

5.3 Resulting Studies

Workshop participants performed three different analysis and visualization mini-studies using *Lillebrot* data. The first group sought to determine data accuracy. The other two groups addressed hypotheses about the interaction between mobility and choice-driven human behaviour.

The first group, 'In Or Out' juxtaposed empirically verified and remotely tracked data to ascertain accuracy. The map contrasts accurate (blue, green) and inaccurate (orange, red) data.

Figure 11: Dots show whether the GPS collection via Google SDK using *Lillebrot* correctly predicted whether a user was inside or outside. In this ground truth exercise, participants manually logged when they were inside or outside while also using the tracking software. Image: A. Bjerre-Nielsen, K. Ray Minor, A. Tabatabai

The second group, 'Blue/Green', speculated that city dwellers would be more likely to choose travel routes along greenery or water, given the choice. The third, 'Biking the City', proposed that biking as a form of mobility would register distinct ways of accessing parts of the city, in contrast to the experience of more efficient or habituated routes traced by public transportation.

'Blue/Green' compared the actual routes travelled with the shortest possible routes, computed as the shortest traversable path between two points using a Dijkstra type algorithm. Along both routes, the degree of overlap with adjacent parks, green spaces and waterways was measured. Fig. 12 depicts the shortest route (black) and the actual route taken (ochre) relative to the intensity of street trees (green), parks (yellow) and waterways (blue) as a potential way of accounting for less direct route.

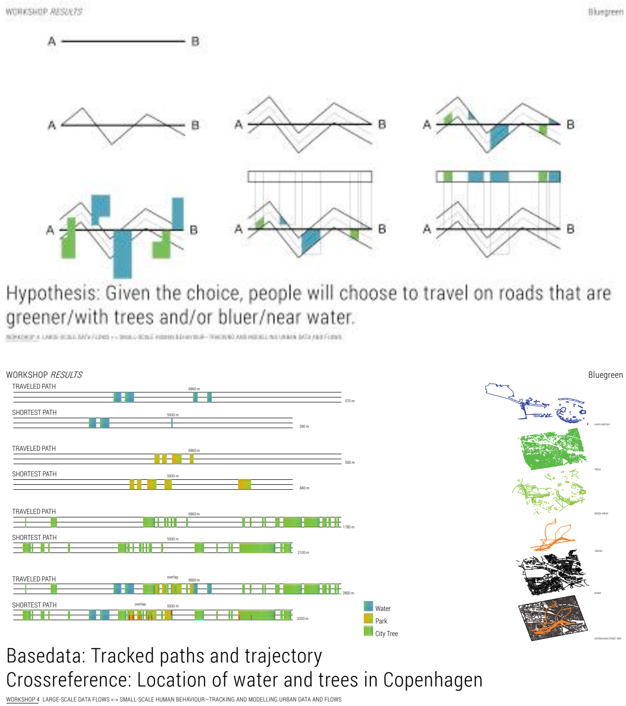

Figure 12: (top to bottom) Conceptual diagram of shortest/actual routes; scaled juxtapositions of shortest/actual routes; mapped trajectories (shortest black, actual in ochre) showing parks (yellow), waterways (blue) and street trees (green). Image: Z. Aksöz, A. Mararoiu, L. Vinther, P. Bus

The third group, 'Biking the City', tested the observation that the bike riders among our sample group showed a distinctive pattern of travel that was both more varied and more circuitous than those who took public transportation or walked. An overlay of tracking data and municipal traffic data showed the divergence between bicyclists' routes and heavily trafficked streets on which buses run.

The map uses clouds to represent the scope of areas that can be seen by bicyclists, but not bus riders, relative to speed of travel.

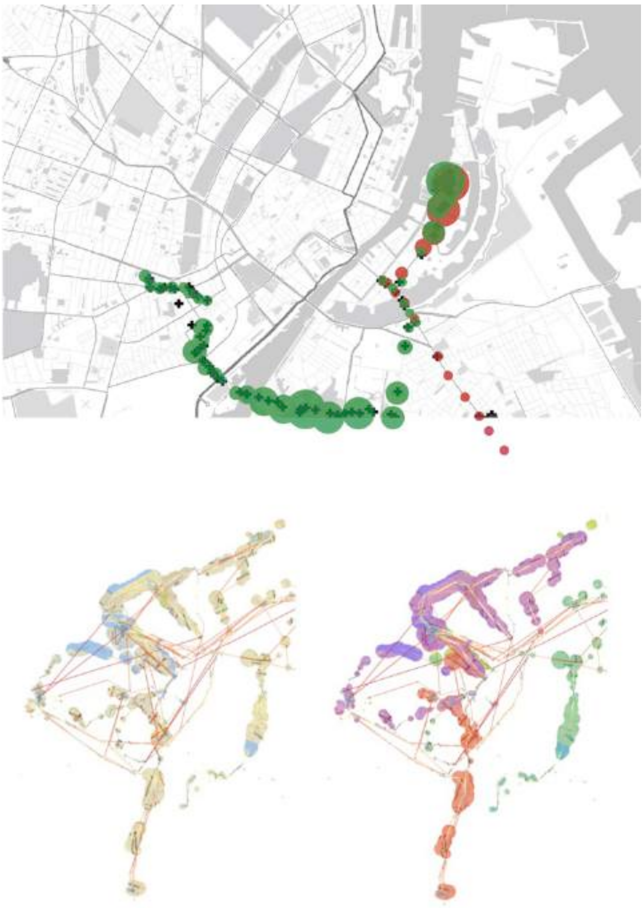

Figure 8: Bikers' paths (clouds) and public transportation routes (red). The left-hand map juxtaposes public transportation routes on heavily trafficked streets with bike routes used to access the same locations. Colors on the right-hand map show different participants; gradations and hues indicate speed of travel. Image: N. Azel, G. Bouron, A. Devi Garla, S. Leinweber, I. Maksimovich

4.0 (Provisional) Conclusion

The decision to embrace highly complex problems in order to test a series of technical and methodological approaches has produced intriguing hypotheses relevant both to sociological and efficiency/sustainability agendas. At the same time, the need to develop both technical and methodological means while considering topical areas has presented challenges that limit the conclusiveness of our findings. We remain convinced that a hybrid method using Urban IOT in conjunction with empirical methods can address in entirely new ways such "wicked" problems as individual spatial behavioural choices and their relation to larger statistically graspable trends. The desire to create timely, relevant and differentiated research while testing new data technologies as they become available is, we believe, one that will result in true reciprocity between method and topic.

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