Supporting smart citizens: Design templates for co-designing data-intensive technologies

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DOI: 10.1016/j.cities.2020.102695

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The design of interactive technologies for smart cities requires understanding the interactions between diverse data, physical objects, existing services and different stakeholders. Yet there is a lack of supporting methods and tools for modelling the complex interaction processes, especially between humans and data. This can inhibit engagement with smart city applications and services design, particularly for those who are not experts in developing smart technologies. This paper describes the development of a typology and a set of design templates, derived from analysis of both existing and proposed examples of smart apps and services. In the process, it highlights the capability of citizens to contribute to smart city design, if given appropriate support as part of a co-design process. In this regard, we contribute a common language for both professional and non-professional designers to discuss how smart city technologies turn data into services.

Keywords: Smart city; citizens; co-design; typology; data; design templates

Introduction

Cities face great challenges from rapid urbanization, climate change and increasing pressures on services such as transport, housing and healthcare (United Nations, 2014). Smart cities is a widely used concept that seeks to address such challenges through an intelligent use of information communication technologies (ICT), although there is no agreed definition of what a smart city is (Angelidou, 2015; Ruhlandt, 2018). However, increasingly a range of digital infrastructure and networks, devices and sensors are being embedded within cities, which collect large volumes of data about the city and its citizens. This data can offer city governments opportunities for more efficient management of the city and related services, for companies it can create new business opportunities to sell products and services, and for citizens it might offer insights into city life, support everyday living and decision making, and empower alternative visions of city development (Kitchin, 2014).

An important issue in the design of smart technologies and services is the fact that cities have specific needs and are different from one another. They are shaped by their politics, history and socio-economic characteristics (Angelidou, 2014). The large range of contexts has led to the emergence of a highly challenging smart city design space with a high diversity of user experiences.

Studies have focused on bringing some clarity to the smart city design space by categorizing how cities negotiate physical space (Angelidou, 2014), generate and manage development policy (Nam and Pardo, 2011) and balance off their human, technological and institutional dimensions (Chourabi et al., 2011). These approaches provide a valuable outline of the common features of smart cities, which has helped to map out how smart city planning and management can be broached in different contexts. More recently, the smart city concept has also been recast with a more *citizen-centric approa*ch (Marsal-Llacuna & Segal, 2017; Nesta et al. 2015), that aims to give greater agency to citizens in framing problems and ideating solutions. This citizen involvement can take different forms, depending on the focus and also on the true agency of the citizen, being framed variously as *civic tech* (Boehner and DiSalvo, 2016; Patel et al., 2013), *civic hacking* (Levitas, 2013; Schrock, 2016) and *participatory urban informatics* (Foth, 2018), to name a few.

The approaches above provide both an awareness and understanding of the smart city and its potential for supporting new ways of problem-solving. But the large diversity of the design space and the lack of a unifying model for describing the possible interactions between people, sensors, data and systems and services, is a major barrier to citizen engagement and bottom-up design. Communities are unlikely to engage with, identify and then design solutions for civic problems if they do not understand what is meant by smart technology and how these large, complex datasets can be used for problem-solving, or large-scale citizen-led scientific experimentation.

Our position is that innovation requires creating a design space that helps to support design with – and for - citizens. In this case, citizens should be seen as more than a source of data that is farmed and then used by other people to decide services for them, or just data collectors for citizen-science experiments. They are key stakeholders in the design space with the capacity to act as true collaborators to city-making (Foth, 2018). To this end, participatory and co-design approaches have much to offer in facilitating citizen innovation within complex systems such as a smart city, as they bring together stakeholders with differing expertise. However, an emerging problem is that there is a lack of appropriate tools to support them in many parts of the process (for examples, see Balestrini et al., 2015; Coulson et al., 2018).

To this end, this paper focuses on *one specific problem*, that of *how to mediate conversations around data flows and end user interaction when designing smart solutions that utilize such infrastructure*. We describe the development of a typology and framing of a design space intended to support co-design of smart city applications and services. The outputs are intended to support citizens who are actively involved in smart city design activities to conceptualise the smart city design space, as a first step in ideating solutions.

The rest of the paper is organised as follows. First, we explore the differences in how smart cities have been conceived over time, the emergence of the citizen-centric smart city and how participatory and co-design approaches are supporting the development of this. Next, we examine data flows in a city, showing common ways in which data is captured, stored and transformed to provide intelligence to the people living in them. Using this knowledge as a starting point, we introduce a method for creating a typology through the examination of 113 smart city applications that utilise data, which we then present in the form of design templates intended to support ideating new smart city technologies. Finally, we explore how these design templates might be used and discuss the opportunities and barriers of using them within a co-design process with citizens.

The emergence of the citizen-centred smart city.

The term smart city has appeared in a diverse range of contexts over the last decade, leading to the emergence of many differing definitions. Fuzziness in its practical applications are paralleled in academia, where research teams from diverse disciplines have been unable to agree on a single, shared meaning (See Hollands, 2008 for in depth discussion about the various definitions). Some of the discontinuity is related to a general confusion over the meaning of smart technology. This terminology has been applied liberally by a disparate set of public and private organizations (Klein and Kaefer, 2008), in a range of contexts. Digitally augmented e-governance systems, homes, education, clothes and electronic entertainment products have all shared the Smart label. As Hollands (2008) notes, this liberal usage is testament to its somewhat "self-congratulatory quality", which helps to market systems and emphasize their intelligence.

Although the specific objective of a given system seems to have little bearing on whether the term smart can be used to describe it, the ability of a device to sense an environment and respond to change does seem to be loosely shared across applications. This meaning can be traced back to the 1980's when the American Military was examining the potential of combining advanced materials and sensors with powerful computers to monitor the environment. Drawing on these origins, Goddard et al. (1997) sought to define a smart system in the early 1990's as "one which has 'an inherent ability to gather information on its operating environment or history, to process that information in order to draw intelligent inferences from it and to act on those inferences by changing its characteristics in an advantageous manner" (pg.130).

More recently, smart has become synonymous with the interconnected objects as well as intelligent ones. This is a key aspect of many smart city visions. In an early attempt to define a vision for what a smart city should consist of, Hall (2000) stated that it should use technology to monitor all of its key infrastructures, defining the smart city as key data gathering and dissemination processes for *instrumentation*, *interconnection* and *intelligence*:

- Instrumentation: sources of near-real-time, real-world data from both physical and virtual sensors.
- Interconnection: the integration of those data into an enterprise computing platform and the communication of such information among the various city services.
- Intelligence: the inclusion of complex analytics, modelling, optimization, and visualization in the operational business processes to make better operational decisions. (pg. 1) (Harrison et al., 2010)

However, a variety of concerns were identified with respect to this 'real-time city', including the politics of such data, technocratic governance, the corporatization and neoliberalisation of city management, the possibility of technological lock-in and ethical issues regarding surveillance and control (Kitchin, 2014). It is for these reasons that many commentators (Boehner and DiSalvo; 2018; Foth, 2018; Gooch et al. 2018) have called for a more *bottom-up, citizen-facing* approach to smart city design than this. One which places more value on the knowledge and skills of its citizens, and where they are enabled to solve the urban problems themselves, with the aid of technology. As Nam and Pardo (2011) put it, while technology advancement is without doubt a prerequisite for any smart city, 'without real engagement and willingness to collaborate and cooperate between diverse people from public institutions, private sector, voluntary organizations, schools and citizens there is no smart city'.

However, there is currently a disconnect between the intent and the reality, as limited forms of citizen engagement and citizen power have actually been enacted within smart city initiatives (Cardullo & Kitchen, 2019). Cowley et al. (2018) found a dominance of the 'service user' (citizens framed as consumers of services) and 'entrepreneurial' (citizens actively involved in co-creating and innovating) modes of the public in smart cities, but a lack of 'civic' (citizens taking part in grass root activities not directly orientated towards market activity) and 'political' (active role in decision making) modes.

There is emerging evidence, through examples in practice, that demonstrate the benefits of a more citizen-centred approach to smart city design (Balestrini et al., 2017; Boehner and DiSalvo, 2018; Gooch et al. 2018;. Participatory and co-design approaches, across the triad of people, place and technology, have the potential to offer a framework through which different stakeholders (including both citizens and city planners) can be supported to engage with shaping the smart city. Such approaches have an important role to play in fostering more productive, sustainable and livable smart cities (Foth and Brynskov, 2016). For example, involving city inhabitants in the co-design of a smart city service prototype using a living lab approach (Alam and Porrus, 2018). Whilst Citizen Design Science has been presented as a strategy for cities to integrate citizens' ideas in the urban planning process with online design tools (Mueller et al., 2018), other researchers are involved in civically engaged projects, empowering communities to find solutions to their own problems using technology (Boehner and DiSalvo, 2018; Gooch et al. 2018). Balestrini et al. (2017) developed and tested a City Commons Framework for Citizen Sensing, a conceptual model that builds upon Participatory Action Research, designed to orchestrate large scale citizen engagement around urban issues. Expanding on these approaches, Fredericks et al. (2016) propose a 'middle-out' design approach that utilizes the knowledge of stakeholders from both the top (government) and bottom (the general public) through a participatory process that takes place not in co-design environments but within the urban space itself, with a continuing participation even during deployment and testing of solutions.

However, a common barrier in citizen innovation is the general public's lack of technical skills, as well as access to tools, to enable them to convert their ideas into technology applications. For example, a smart citizen crowdsourcing project found that technical skills were often not held by the originator of the idea and the citizen would be unable to implement them without assistance (Gooch et al., 2018). Whilst Balestrini et al. (2017) found that a lack of technical skills and data literacy was a source of tension in their citizen sensing project.

Understanding the smart city through human and data interactions

We focus on understanding the smart city through the complex interactions that occur between people and the data produced both by them and from the environment in which they live and work. We propose that this understanding is a key part of a solution towards bridging the potential knowledge gaps between the bottom-up, top-down or middle-out approaches (Fredericks et al., 2016) to smart city development, and in supporting a co-design process for innovating smart technologies. Figure 1 portrays possible data flows that might occur in smart services (a similar representation of this space can be found from Robinson et al., 2012). It highlights a range of different possible touch-points and types of interaction throughout the processes of collecting, aggregating, analysing and deploying smart services to end users. Although it is a simplified schematic, it is indeed a complex space for design of the interactions and the services.

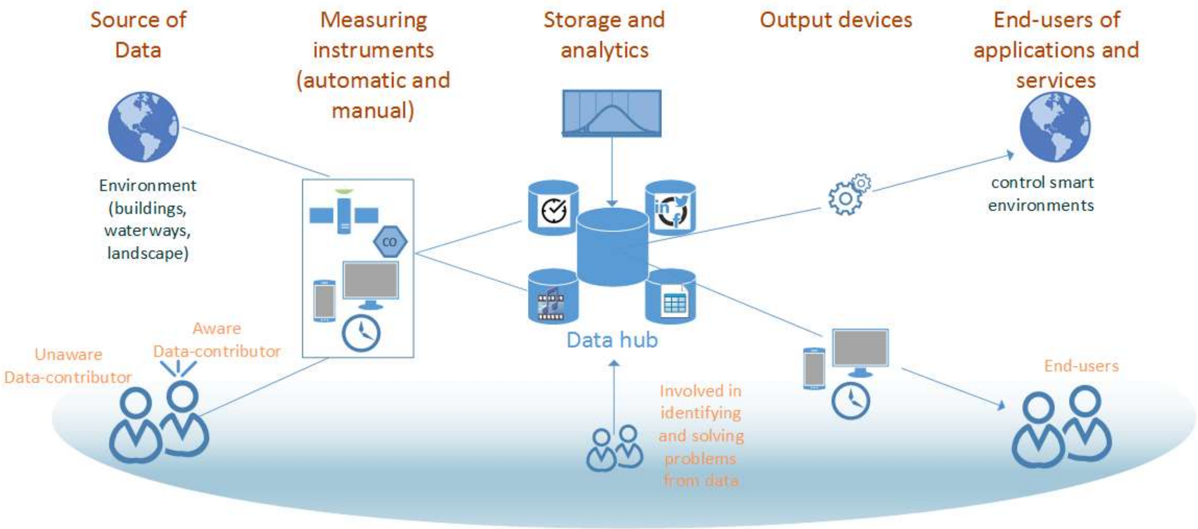


Figure 1. Data flows in smart services design

Overview of approach and introduction to concepts

In order to more fully explore the data flows shown in figure 1, we have conducted a broad analysis of smart city technologies pooled from a number of different sources and then narrowed down to focus on those that use data. These comprise our sample cases. We have analysed both real and imagined examples originating from a range of different stakeholders to fully explore the space of design possibilities. We included imagined cases as we wanted to understand how people conceptualized smart city apps as well as how they were realized, as this would reveal what sorts of technologies people want and need and what could be the likely future cases. Through this process, we have tried to understand:

- How the technologies capture data, in the form of citizen's input on public displays, mobile devices, or through sensors connected to the environment;
- How data and users are connected; how data is analysed; and how and when it is used to create 'intelligence' and through which type of interface.

The first step in our approach has involved constructing a typology. A typology allows things to be classified according to commonalities or distinguished from one another according to their differences. Previous research has sought to understand different aspects of the smart city through typology construction. Mainka et al. (2015) analysed a large number of mobile apps that used open urban data. Their focus was on identifying the types of problem that the apps were solving. They identified six broad categories: mobility, points of interest, education, health, public safety, and information awareness. They additionally identified common mobile app features: map, GPS, game, payment, user feed, real time information, problem identification, and problem resolution.

Subsequently, other typologies have emerged which apply a similar methodology. Desouza and Bhagwatwar (2012) sorted a set of smart city apps according to their data source, goal motivation, and range. Lee and Lee (2014) sorted them by technology type, service, purpose, authority level, and delivery method. In our case, we use the typology to understand better how data is collected, analysed and presented to users – in other words, the human and data interactions. Therefore, we used our original ideas about interaction and data flows in smart services (figure 1) to guide the initial analysis and then refined it by looking at the real cases. Figure 2 shows an overview of this process. The first step in creating a typology is to derive attributes, from across all sample cases, and a range of possible values for these attributes. These values either show commonalities between instances or allow their differentiation. These attributes and values are then used to formally describe each sample case for the clustering stage. The clustering process reveals similar groupings. By analysing each cluster it is possible to identify distinct archetypes, which in our case we present as design templates, which are visual representations of the important values that differentiate them from other archetypes, framed by the attributes to provide a common structure.

Finally, the set of attributes and values, and these design templates form part of the design space to foster innovation of new products and services, either by using existing templates or creating novel combinations of features to create a new product or service.

Materials and Methods

There are various methods available for constructing a typology from sample cases. We have chosen to use the model of empirically grounded type construction proposed by Kluge (2000). It includes a number of different analysing methods and techniques to support each of the four stages of the model and can therefore be easily tailored to different contexts. These four stages are:

(1) Development of relevant analysing dimensions

(2) Grouping the cases and analysis of empirical regularities

(3) Analysis of meaningful relationships and type construction

(4) Characterization of the constructed types

We first describe how cases were selected for analysis. We then describe the method chosen for implementing each of the four stages, which included both human and computational analysis.

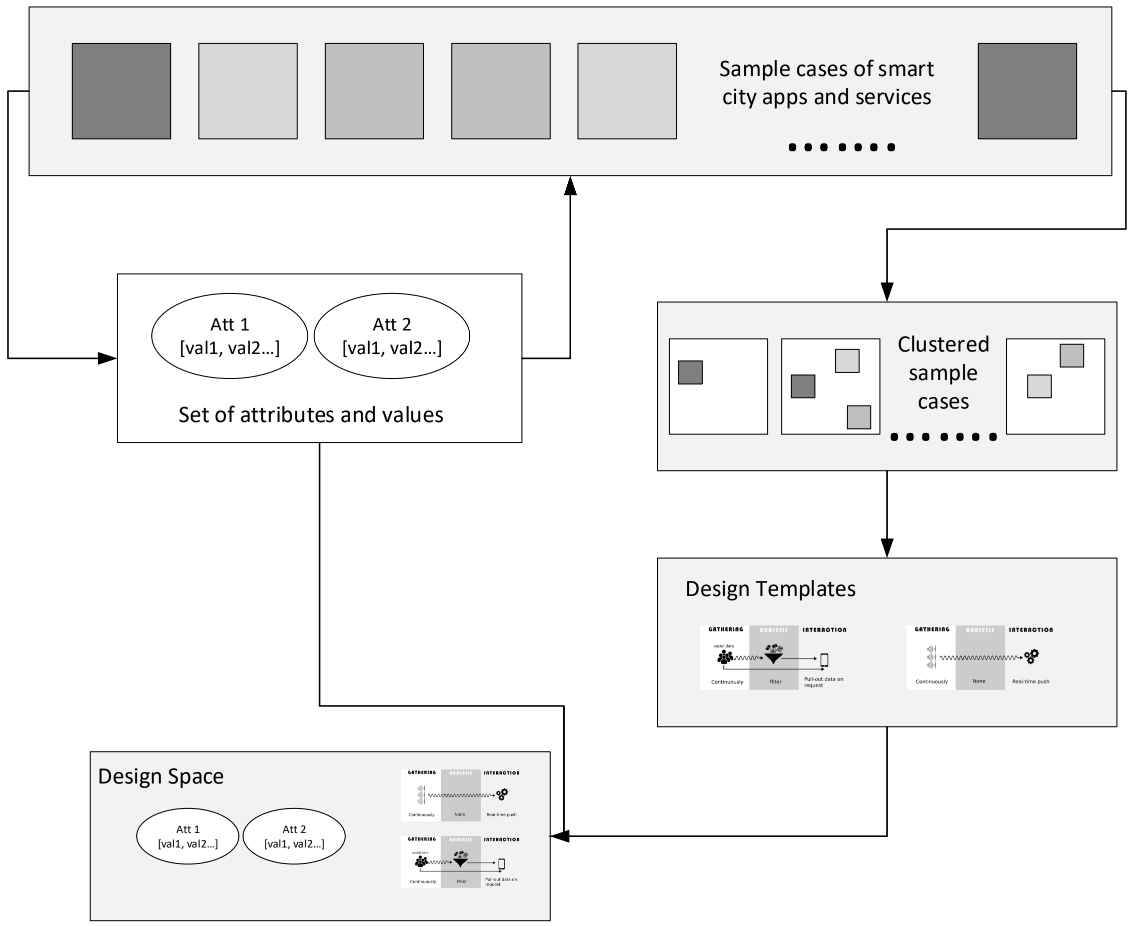


Figure 2. An overview of the typology and design space construction process. For details of attributes, cases and templates refer to later sections.

Selecting cases for analysis

A range of smart city applications were selected for analysis. These were either examples of bottom-up or top-down design. The bottom-up design examples are ideas that have been proposed by citizens but not necessarily built. The top-down designs are mainly real life examples of services that have been built and instrumented in smart cities, or that are at least in a trial planning stage. We chose to include both of these types in our analysis to reflect the thinking of both practitioners who have the resources to realise their visions and non-professionals, who are generating ideas to solve genuine problems within their cities and communities. The six sources are summarised below.

The first source of examples were derived from 6 smart city projects. These were selected for the analysis in accordance with Angelidou’s (2014) classification of smart city types. They included **Rio Smart Operations Centre** (hard infrastructure-oriented strategy), **Songdo International Business District**, (new city), **Amsterdam Smart City** (existing city), **OneNYC**, New York (local strategy), **SmartCity Malta** (national strategy), **Barcelona Digital City** (soft infrastructure-oriented strategy), and **Intelligent Thessaloniki** (geography-based strategy).

The second source was the internet news media. To find these, a search using the Google search engine was made, using the term ‘smart city technologies’. Any smart city project ideas listed on the first three pages of the Google search were added to the list of technologies for analysis. Several of the returned pages were of the type ‘top X smart city technologies’. The search produced 27 technologies from a mix of private and public organisations. There were no examples from citizens. These news media sources were included, because it was seen as a good way to find examples from private enterprise and business.

The third source was the Apple and Android app stores. These each feature a search box function and a review ranking function. The most-highly-rated apps (4 stars and above) that were outputted by the search engines for the search term ‘smart city’ were chosen for the analysis. If an app was available from both stores then only one version was included in the compiled list of technologies. The smart cities term was not included as this did not return any relevant additional results. This produced 12 iTunes apps and 32 android apps.

The fourth source of examples derived from different types of citizen ideation around the design of smart city apps and solutions. The first set of examples came from a Smart Cities Massive Open Online Course (MOOC) -

https://www.futurelearn.com/courses/smart-cities which was written by one the authors of this paper, who therefore had access to content created by the course participants (Hudson et al., 2019). The second set of citizen examples, derived from an online crowd- sourcing platform that encouraged citizens to contribute smart city ideas as part of OurMK, a Milton Keynes (UK) based smart city project (http://ourmk.org/discover/index.html). Citizens in the town could compete to win funding for their project ideas within their local communities (Gooch et al., 2018). The third set of citizen examples derived from young adults who took part in school-based Appathon design challenges, devised to help students increase their understanding of how data can be used as part of smart city design (Wolff et al., 2017). These activities were organized as part of the Urban Data School initiative, which devised methods for teaching data literacy and smart city concepts in primary and secondary schools in the UK. An example, that the young designers named 'Taxis on the Axis' can be seen in Figure 3.

Figure 3. Taxis on the Axis.

This yielded a total of 264 examples from which to begin the coding analysis. Next, some examples were discounted as being out of scope. These were classed as behaviour-driven rather than technology-driven initiatives. These were excluded because the focus for this paper was in identifying apps that utilized data and finding ways to support designing with complex data flows. However, it is important to realise that not all smart city apps are data driven and that ideating and creating such technologies may require different types of support. Next, some samples were reduced, using random sampling method, to make the overall numbers more manageable for analysis. A secondary check was conducted on the outcome to ensure that the remaining examples reflected a good cross section of the larger sample. The final figures for each source of examples are found in Table 1. This gave a total of 101 cases used for analysis.

Source Type	Total number
MOOC	23
Crowd Sourcing platform	33
School Appathon	12
App store	13
Media	10
Smart City programs	10

Table 1. Breakdown of smart city technologies used for the analysis

Applying the four stages of Kluge typology development

Stage One: Development of relevant analysing dimensions

This stage involved the identification of the dimensions along which smart city technologies might be analysed, using a combination of collected data and theoretical knowledge (utilizing the literature review and expert knowledge on how smart cities are normally conceptualized) and through a process of iterative refinement. The activities were as follows:

(1) Two researchers – who were both experts in smart city technologies and one of whom was also an expert in designing products from data – generated a first version of the attribute/value list based on their own knowledge (gained from working with a large smart city project on citizen co-design activities) and an initial reading of the compiled examples of smart city technologies.

(2) The same researchers iteratively refined the list by taking turns to apply it to the entire sample and modifying it each time by adding or removing attributes and values. This process was continued until the researchers reached a consensus on

coding the sample.

(3) This final set of attributes and values was validated by applying it to a number of new cases that were not part of the initial development. 12 new projects were drawn at random from the initial set of 264 examples, none of which had been included in any analysis thus far. This sample was coded by one of the researchers who had developed the initial set of attributes and values and a third coder, who was also an expert in data analysis and smart city technologies. These additional cases were combined with 101 examples from the previous step, which resulted in a total of 113 fully annotated examples for the following stages of analysis. Given the small sample size, it was not appropriate to do a formal inter-rater test, however the percentage difference of rating for the values of each attribute was calculated. The mean difference across all attributes was 80%, which indicates a good agreement between the coders.

Stage Two: Grouping the cases and analysis of empirical regularities

Grouping the cases to derive common, overarching themes was performed using the k-modes clustering method, which is a variant of k-means that is adapted for categorical data (Gan et al., 2009). This was applied to help in the identification of different generic classes and subclasses of smart city problems. Computational clustering was chosen for this initial procedure in order to eliminate potential researcher bias in creating the groupings.

Stage Three: Analysis of meaningful relationships and type construction

Clustering results were analysed manually by the researchers. Their task was to identify which common relationships the k-modes algorithm had drawn between the technologies to construct the clusters. Through this process it was possible to identify outliers in the data that could not be wholly explained or captured by the results.

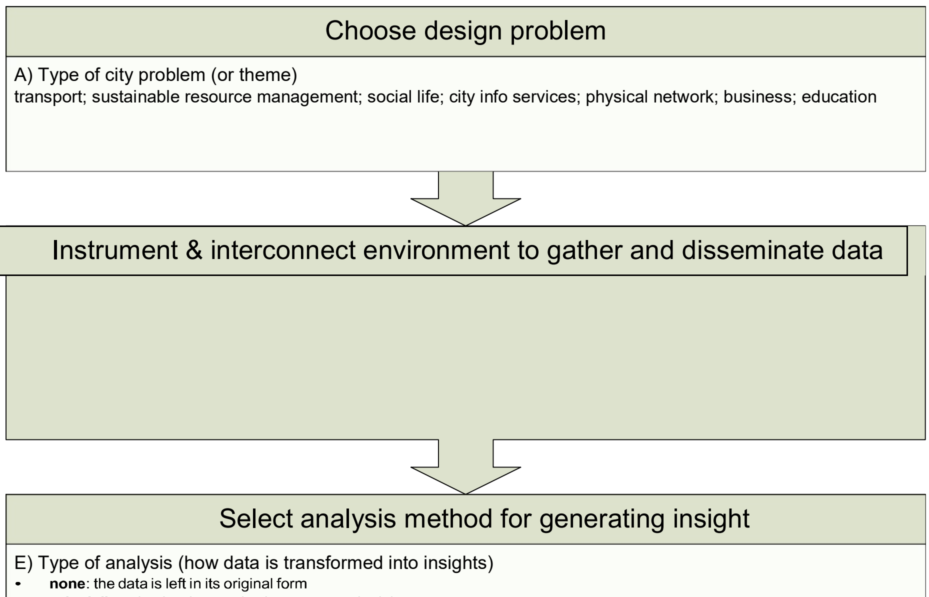
Outliers are quite normal in this type of analysis. These particular outliers will be revisited later in the discussion section.

Stage Four: Characterization of the constructed types

In this stage, labels were assigned to the common prototypes identified in the previous stage. These were then presented as common design templates for creating data-driven smart city technologies. They were then converted to visual templates, in which the processes of data flow were also made clear.

Results

The results of the iterative coding of the 101 smart city technologies (stage one of the typology construction method) are displayed in Figure 4. The method produced 10 different attributes for describing smart technologies and services (A- I). Each aspect has an identified range of values. It should be noted that these values are representative rather than exhaustive, e.g there are many more themes than are listed here. It can also be expected that the types of interface an end-user might use will continue to grow as new innovations become available. One example would be peripheral displays, such as smart watches, which were not used in any of our examples. These 10 criteria fit into 4 overarching processes, which mark out the stepwise procedure by which data is turned into intelligence in a smart technology.



B) Primary source of data	C) Latency of Output	D) Type of data inputted
• **static sensor**: A sensor placed in the environment • **mobile sensor**: a sensor in a moving vehicle or on a person • **human**: data is input by a human	• **once**: data is added once only • **periodic**: data is added periodically, in batches, or after authorisation • **real-time**: data is added continuously	• **social data**: news stories, opinions, comments • **machine data**: sensor readings • **transactional data**: customer purchases • **images/video**

End-user interaction with insights derived from data			
F) insights accessed by same population from which they derive?	G) interface type	H) Primary end user	I) access method
• **yes** • **no**	• **PC** • **Mobile device** • **public display** • **ambient display** • **embedded city infrastructure** (e.g. lamp post)	• **humans** • **machines**	• **static**: unchanging physical object, e.g. document, non-digital noticeboard • **real-time**: insights appear in (or very close to) real-time • **on-request**: insights appear on request by end-user • **context-dependent push**: algorithm instructs interface to output insights when a condition is met, e.g. when a user's mobile phone is in certain area.

Figure 4. Attributes and values derived from stage one typology analysis

Clustering

The 113 cases were formally annotated using the attributes and values derived in stage one. Clustering was done using the K-modes algorithm implemented through the klaR library (in R studio). K-modes is a variant of the K-means clustering algorithm which is optimized for working with categorical, rather than numerical data. These algorithms cluster data into a specified number (*k*) of clusters based on similarity of data within the clusters and dissimilarity of data between clusters. Two approaches were taken to selecting an appropriate value for K, which indicates the number of clusters that should be returned by the algorithm, and which needs to be specified before-hand. A good value of K means that there are not too many clusters that are over-specific or too few large clusters that fail to discriminate well between different clusters. An appropriate value for

K should therefore lead to clusters that discriminate well between cases that are clearly different whilst allowing some ambiguity on ones that are closely related but not identical.

Firstly, each researcher independently stated the number of distinct groupings they would expect to find, based on their familiarity with the sample and knowledge of the domain, both agreeing that 7 was the number they expected to find. This provided a starting point around which to try and find the optimal solution. Secondly, the cases were clustered using a variety of values for K, from 4 up until 14. Values of K below 5 were found to produce clusters that were disproportionately large to the size of the dataset, such that one cluster contained an entire third of the total cases. Those above K=10 showed evidence of over- fitting the data by producing clusters of 1. Taking this into consideration. A cluster size of 7 was deemed most appropriate as it fell within a suitable range of observed clustering results and was consistent with the independent assessment of two researchers. The theme attribute (from 1: choose design problem) was omitted from the dataset for clustering as the goal was to find common types based on information collection, analysis and dissemination of outputs, independent of the problem context.

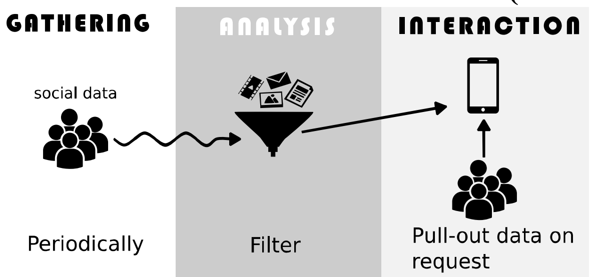
Whilst it was interesting to find which design problems were most popular, this had been covered in previous research (DeSouza and Bhagwatwar, 2012; Lee and Lee, 2014) and was not a focus of this work.

Clustering the cases with K=7 and 10 iterations created 7 clusters with the sizes 27, 7, 30, 22, 5, 9 and 13. Each cluster was then assessed to identify the common properties of the smart city technologies within the cluster as well as to identify outliers. Each cluster was labelled with a single type label. Cluster data is available from Zenodo (https://zenodo.org/record/3585334#.XoGdi6gzb-g).

Seven Templates for designing around complex data

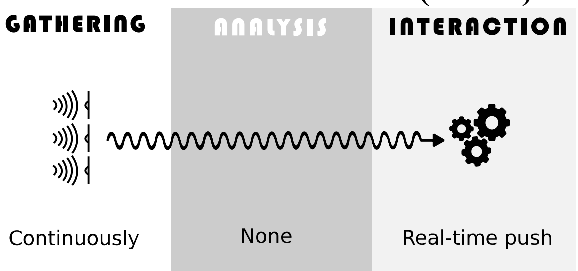
The seven design templates derived from the described process are visualised to represent how intelligence is generated from data through the processes articulated in figure 4. Along with the visualisation we state how many of the 113 cases fit the parameters, explain what the diagram shows and list some common examples.

Cluster 1: Information Dissemination (27 cases)



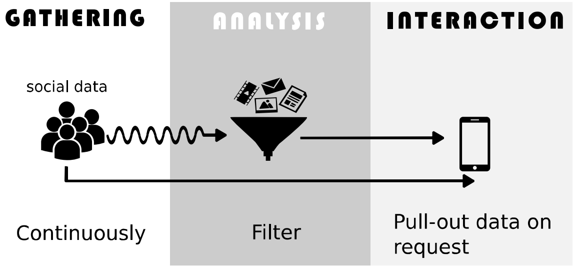
Description: Data is shared from one group of people to another group, who pull it out of the system on request via a mobile interface where it is typically filtered according to some search parameters that narrow what is shown for each user. In this case, the type of users who create the data and the type who use it are different. Examples include problem reporting apps, such as Fixmystreet or the issue-logging app of Foth et al.(2011) where citizens report problems and councils act on them.

Cluster 2: Machine to Machine (7 cases)



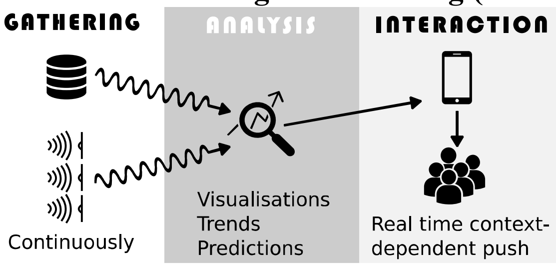
Description: A recipient machine responds to raw data in real-time. An example is smart light that turn on or off based on light sensor readings for time of day (e.g., Smart Lighting in Amsterdam).

Cluster 3: Sharing Economy (30 cases)



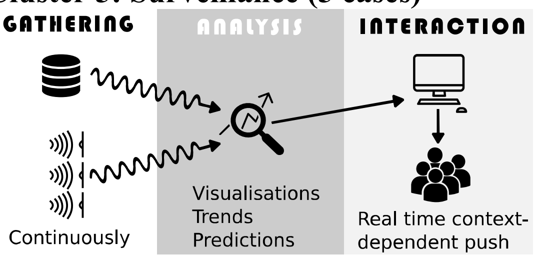
Description: Similar to information dissemination applications, data is also shared from one group of people to another group, who filter it via a mobile device. However, in this case a user can typically be both a creator and consumer of the data. Examples include 'idea sharing' such as rainproof, skills and resource sharing such as dogvacay, yerdle and ride-sharing such as Uber or Lyft.

Cluster 4: Monitoring and Tracking (22 cases)



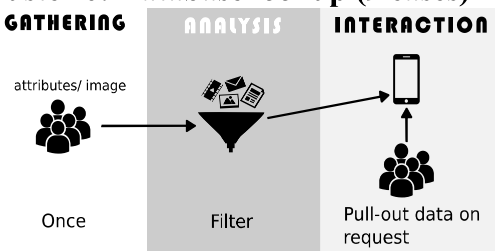
Description: Live sensor data that is gathered continuously is combined with static data sources to provide additional information. Typical data analysis methods include visualisation, analysing and displaying trends in data or prediction which are presented in real-time. Unlike the machine to machine technologies the intelligence is delivered to humans to take action on. Examples include apps that monitor pollution or how resources such as energy or water are used in real-time, or real-time bus-tracking.

Cluster 5: Surveillance (5 cases)



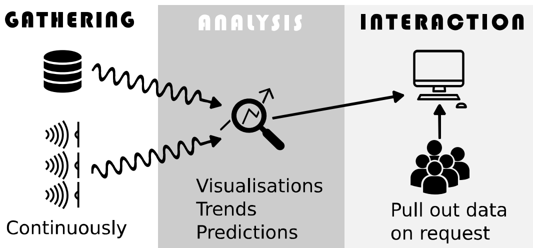
Description: Surveillance applications have a similar infrastructure to monitoring and tracking applications, but where those tend to present information to users on a mobile device the surveillance applications deliver relevant information to a central large display, such as in a control room. They are more likely to produce predictions from data that are pushed to the end user. Examples include crime prediction applications, or applications that monitor and sniff explosives in the environment.

Cluster 6: Database lookup (9 cases)



Description: Much like in an encyclopaedia, professionally authored information is published on a website or app and is then accessed by users on request and filtered according to their search parameters. Data is published once only and comes from a single source. Examples applications are a map of places good for breastfeeding or where it is possible to lookup information on wildlife based on a few attributes.

Cluster 7: Analytics publishing (13 cases)



Description: Similar to the surveillance applications, analytics publishing applications continuously monitor an environment to produce live data. However, in this case the insights derived from the data are not delivered to the user in real-time but instead are available when the user requests them. Similar to cluster 5 but once the analytics create insights, instead of being pushed live to a user they are retrieved on request. Examples include websites that allow exploration of the results of energy monitoring that has taken place over a fixed period, such as New York City's community air survey.

Relating design templates to different contexts of design

As a final step, an analysis has been conducted to identify what percentage of each of the design templates, as derived from the clusters, came from each sample source. The findings are presented in Table 2.

Percentage of design patterns that appears within each source of sample cases.

	Technologies Existing in Real Life Smart Cities			Technologies Proposed in Citizen Ideation Projects		
C	App-stores	Smart city programs	Online Media	App contest	MOOC	Crowd-Sourcing Platform
1	37	14.8	3.7	18.5	14.8	11.1
2	0	42.9	0	0.	42.8	14.2
3	16.7	10	30	16.6	13.3	13.3
4	18.4	0	4.6	4.6	36.3	36.3
5	0	20	40	0	20	20
6	0	0	0	0	88	11
7	0	15.5	0	0	39.4	46.1

The table shows that Information Dissemination (1) type technologies came from all the sources. They were particularly prominent in the app stores sample relative to the other sources and featured the least in the online media sample.

Machine-Machine (2) technologies were well represented within the citizen ideation examples, with the exception of the app design contest. They were similarly absent from the app store examples. This is understandable as there is no need for a human-facing app within these types of technologies. However, it is notable that the media did not report on machine-to-machine technologies, instead focusing reporting around either the sharing economy or else city surveillance.

Sharing economy (3) type technologies came from all the different sources. They were most evenly distributed of all the types, with a range of only 20% between the source where they were least well represented (Smart city program websites sample) and best represented (Online media sample).

Monitoring and Tracking (4) type technologies featured most heavily in the

MOOC sample and crowd sourcing website sample, where they were equally well represented. This suggests that these types of apps were most likely to be ideated but not realised. There were none on the smart city website and a relatively small number on the app store, in the app contest and in the media. The results for this cluster are the first of the seven to show a clear difference between the outputs from the citizen ideation sources as a group (77.2%) and the real world technology sources as a group (22.8%).

Surveillance (5) type technologies also showed a reasonably large split between the citizen ideation sources as group (40%) and real world technology sources as a group (60%). None of the examples of this technology type came from the app stores sample and the app contest sample. This is understandable given that the interface for this technology type is a dashboard control centre and not mobile phones.

The most profound split of all between citizen ideation and real world technologies came from the Database Lookup (6) type of applications. All of them came from citizen ideation samples (88% from the MOOC, 11% from the crowd sourcing website).

The final cluster of technologies – Analytics Publishing (7), were also much more numerous in the citizen ideation group of samples (85.5%) than in the existing technologies group of samples.

Using the design templates and navigating the design space

It is important to reiterate that the proposed templates are by no means exhaustive, there are many others that are also emerging. However, they serve a useful starting point, because they explicate the link between the collected data and the end user, revealing what is happening to the data in between. They can be used either to classify existing technologies or, perhaps more usefully, in the design of new technologies. The following scenarios illustrate further how a template might be used either by manual application or through a tool that guides design decisions.

a) Templates may be used ‘off the shelf’ to help in formulating solutions to design problems quickly and efficiently. By selecting a template and applying the template, this helps the designer to focus on lower level design details by scaffolding many of the higher level decisions for them. For example, if the designer is developing an information dissemination service – e.g. a service for tourists that helps them to visit and locate the key places and attractions in the city – the information dissemination design template would tell them immediately that filtering is the typical analysis method to use. This would free the designer up to focus on planning for other higher level aspects of the application, e.g. what type of data to disseminate. Taking this a step further, an interactive tool could be developed that proposes design possibilities based on current design decisions and which helps to provide relevant examples that the designer can refer to.

b) The design templates can stimulate creativity and innovation by showing designers how they can diverge from the norm and come up with a new design solution. As an example, someone planning to develop a sharing economy dog-sitting app might use a template as a starting point to see that filtering is the typical type of analysis for a sharing economy app, and then draw from the wider design space (and set of attributes and values), to experiment with alternative forms, such as real-time predictions and analysis.

c) Designers may merge templates, or start completely bottom up selecting from among values of attributes within the design space to select different ways of data gathering, analysis and interaction. As they experiment with different combinations, the designer may be shown how close or far they are from the existing templates of design – and hence how original their design is.

We propose the templates would be of most use to citizens who participate within smart city innovation settings facilitated by a designer, where different stakeholders enter into a co-design process which requires a common vocabulary. In these cases, we can assume that participants have a goal in mind and there is some access to a smart city infrastructure, which could be provided by other stakeholders in the process. We propose that the templates would level the playing field and allow citizens to take part in ideating new solutions by providing concrete representations of how data is captured and turned into intelligence.

Discussion

When we began this study we used the knowledge we had accumulated while working on a smart city program ourselves to hypothesise that smart city technologies are digital artefacts that gather and analyse data and then disseminate insights generated from this data to people or machines through a network. Through the categorisation and refinement process that we employed in creating our typology of smart city technologies, we were able to gain some validation for this definition and unpack it by formulating 10 defining criteria. The overall sample contained technologies that were conceived in many different places, took a large variety of different physical and aesthetic forms and faced a broad range of design problems in different ways. As outlined above, these factors have led to a nebulous design space. By describing them in terms of their use of data, we have demonstrated a simple and universally applicable categorisation system that could help citizens, smart city designers and planners from different contexts to communicate about smart city technologies. We feel this framing of the technology-types characterises the smart city design space in a way that has more relevance for design and innovation amongst varied stakeholders than previous smart city typology work (Desouza & Bhagwatwar, 2012; Lee and Lee, 2014).

The main focus of our study has been in analysing the interplay between citizens and technology in smart city technology design. Through the following discussion we aim to comment on this complex relationship and signpost where opportunities and threats lie for fostering innovation. The technology samples we analysed were small in size and had different quantities. This means that we are not in a position to directly compare the different sources with a low level of granularity. We can however comment on the broad themes and – also of interest – the outliers in the sample.

The first thing to say, is that the evidence from our study suggests that *citizens – as common problem owners within the smart city – are both well placed and well able to make meaningful contributions to smart city technology innovation.* The cluster percentages table (table 2) shows that the citizen ideation samples produced a diverse spread of ideas, displaying a range of different methods for generating intelligence with data. All of the different clusters are represented in the MOOC sample and the crowd sourcing samples. That three of the four types were not represented in the mobile app contest can be explained by the fact that these types (machine-to-machine, surveillance and analytics publishing) did not include a mobile interface. The absence of the fourth, Database Lookup, is explained by the fact that the person running the app contest explicitly advised that live data - which is not a part of this cluster type, should be a feature of their app. The clustering was generated from a slightly greater sample of citizen ideation ideas than existing real life technologies, which balanced the clustering towards the content of the former by default. All the same, the diversity of the clusters and the distribution of the citizen ideation examples across the clusters comes as somewhat of a surprise. While planning this study, we considered that general citizens would be less attuned to the different ways that a smart city technology can use data than the professionals who have built them. The results simply do not show this.

Citizens can indeed generate the ideas, yet they may lack the methods and tools, the infrastructure and the skills needed to begin structuring their ideas towards a concrete solution.

There is one type (Database Lookup) which is entirely composed of ideas from the citizen ideation samples. This type of technology, which allows users to information authored by website owners about a given topic, is quite conventional and widespread outside the smart city design context. (e.g. about.com, nhs.gov, bbc news). Their absence in the 'expert's' sample may therefore suggest that they have a more nuanced view of what separates smart city technologies from general digital technologies than citizens. Perhaps citizens are basing their understanding of what smartness is on the apps and websites they use and experience in their everyday life, and do not see the value of data-driven, interconnected designs to the extent professional smart city designers do. On the other hand, though, this finding could show that the organisations who produce smart city services have, in some cases, misunderstood what communities really want and need. Perhaps citizens desire slower, simpler services where they can receive vetted, professionally authored information about their city that is not constantly changing and updating in real time. Or they are looking for the security and stability of static, unchanging information that they can trust and do not want the latest opinions and live readings relayed to their device. This second conclusion is given some weight by the fact that all of the other technology clusters were well represented in the citizen ideation pool of sources. Yet, when we consider that 88% (8 of the 9 examples) came from the MOOC, it becomes apparent that there is another layer of complexity here. Through the MOOC sample we were able to see an international perspective.

There were two other sources that represent international views – smart city programs and the media. But the projects found in these samples came from the most mature, most acclaimed smart city projects around the world and they were a narrow representation of different types of socio-economic profile. They do not speak for the views of people living in the less technologically developed cities where smart might mean something different. Perhaps the extremity of the result on Database-Lookup type technologies shows that people from different cultures have different motivations for smart city development. Some cultures may value this type of technology more than others.

As mentioned in the methodology, a small number of outliers were discovered in the clustering stage. At this point it is interesting to revisit them. The likely reason for these outliers is that they were not well represented within the set of examples used to derive the typology and design templates. One particular variant was to be found within the sharing economy clustering group, where in two cases the primary data was combined with other data sources and information was then used to push context- dependent information to the user. In addition, a small number of cases presented outputs via a public display. One of these, *Smartquesina* represented a smart bus stop that appeared in the cluster of city surveillance technologies. This technology pushes predictions on bus arrival times to each stop. The other was a proposal for a tube-style map of a city cycle-way. This appeared in the cluster of database look-up technologies. Whilst it is easy to see the common features that have caused these technologies to be assigned to those clusters, it is worth considering that these do in fact represent new archetypes, in that they represent a different type of interaction between humans and data. This is supported by considering the ongoing research into public displays and urban screens in smart cities. On explanation for why there may have been a lack of public displays in the sample could be due to a sampling error, or it could reflect that they are not yet in the public consciousness. In either case, it demonstrates that in a fast moving area such as the smart city, it is necessary to regularly update knowledge.

We therefore conclude that the seven design templates are not exhaustive of the possibilities, nor should they be. Not least because new technologies will extend the affordances of the design space. Indeed, they are intended as an entry point from which new design ideas can take root – through the extending and merging of existing ideas – rather than an ending point. A good place to start for innovation would be to assess what the design templates do not do and then consider how data can be used in a novel way to solve a design problem. The outliers in our analysis may be just this: the buds of new smart city technology design types. In future work we intend to test how the typology might be used as an innovation stimulus.

While we were compiling our samples for analysis we also identified evidence of the institutional dimension (Chourabi et al., 2011). Yet, we had to discount proposed project ideas and existing smart city services that might be described as institutional infrastructure – social groups that handle civic issues - as they were not our focus. We can do no more than to simply reaffirm that there does seem to exist a clear motivation from professionals working in smart city development and from smart city-focused citizen ideation channels for the creation of institutions as well as technologies that can confront civic issues. But if we also take into consideration that (in a general sense) the technologies we have analysed on-the-ground do not currently appear to fulfil the technology-centric smart city visions articulated by Hall et al. (2000), then this causes us to consider the overall importance of technology in the citizens perceptions of a smart city. If the smart city is becoming citizen focused, then perhaps the existing 'smart' infrastructures are not the correct ones and what is needed are not just technical, but social and other governmental infrastructures to support citizens to build the city they want and need. This could this explain the lack of civic, grass-roots approaches noted by Cowley et al. (2018). To this end, our work lends further support to initiatives such as the 'City Commons' of

Balestrini et al. (2017) that seek to infrastructure the city to support citizen innovation. It is seen in the framing of new approaches to usability that are inclusive to notions of citizen empowerment above mere engagement, a term referred to as 'citizen-ability' (Foth et al., 2015; Foth, 2018).

Concluding remarks

The contribution of this paper is a proposal for the development of a typology, which formally models the different ways that humans interact with data within smart services. It is based on the analysis of a range of smart city apps and services. A typology, like other classification tools, such as taxonomies, are primarily sense making tools that defines concepts and their relationships (Jennings, 2007). It suggests a shared vocabulary and facilitates the reasoning about them, including design decisions. Indeed, typologies have been investigated (Feinberg, 2011) as tools that lay the foundations for creativity. Through developing the typology we have identified seven distinct design templates for the design of smart technologies and services. They represent the most common data flows and combinations of interactions between humans, sensors, data and interfaces within smart city technology. These templates can be used as an ideation tool during the design process; a means to assess how a range of past and potential technology designs might support the needs of the city and citizens livings in the city.

Moreover, the study provides an insight into how different types of stakeholders conceptualise smart city design. The clustering of the sample of technologies has provided an indication that citizens, when taken as a group, have a mental model of what constitutes smartness in smart city technology design, which may be comparative in scope to that of smart city designers. Hence citizens appear to have the capacity to contribute, although they may not have the digital skills to actually build technologies themselves. This is a strong argument for finding new ways to involve citizens in co-design of smart cities and in providing better tools and support for citizens to gain the new skills that they need to innovate in this space, such as improving access to maker spaces and better training and tools for working with and interacting with data.

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Smart city application	URL	ID	dataset	type	primary_source	update	end_user	curse	analysis	combined	dynamic	interface	theme	cluster	
Grocery genie - keep track of what people buy (2)		41	A	T	H	P	H	N	T	Y	OR	M	B	1	
Walking wardrobe - show trending clothing items in the local area (1)		43	A	T	H	P	H	N	T	Y	OR	M	C	1	
Enjoy the night sky		86	M	S	H	P	H	N	T	N	OR	PC	C	1	
News aggregator		91	M	IA	H	P	H	N	F	N	OR	M	C	1	
Community support app - city info		99	M	S	H	P	H	N	F	N	OR	M	C	1	
Where we like to go		69	O	S	H	P	H	N	F	Y	OR	M	C	1	
Urban air - the smart city app	[illegible]	110	RA	S	H	P	H	Y	F	Y	C	M	CI	1	
P-indicator - smart city guide	[illegible]	112	RA	S	H	P	H	N	F	Y	OR	M	CI	1	
Craiova city app by aventys (and various other cities)	[illegible]	113	RA	S	H	P	H	N	F	Y	C	M	CI	1	
Community energy data map (mksmart project)		55	O	A	H	P	H	N	T	Y	OR	PC	E	1	
Sustainable barcelona map	[illegible]	2	RS	SI	H	P	H	Y	V	Y	OR	M	E	1	
Zocity -	[illegible]	8	RS	S	H	P	H	N	V	Y	OR	PC	ED	1	
Ripe near me mobile app		60	O	SA	H	P	H	N	v	Y	OR	M	F	1	
Lucknow smart city	[illegible]	29	RA	S	H	P	H	N	N	Y	OR	M	I	1	
Smart city - active	[illegible]	30	RA	A	H	P	H	N	F	Y	OR	M	I	1	
Nhs. For making doctor's appointment		34	A	A	H	P	H	N	F	Y	OR	M	R	1	
Railway problem reporting app		65	O	SI	H	C	H	N	F	V	RT	M	R	1	
Smart city apartment	[illegible]	22	RA	S	H	P	H	Y	F	Y	OR	M	R	1	
Smart city unitone ict	[illegible]	27	RA	SI	H	C	H	N	V	Y	OR	M	R	1	
Cramat smart city app	[illegible]	28	RA	SI	H	C	H	N	V	Y	OR	M	R	1	
Yango	[illegible]	32	RA	A	H	P	H	N	S	Y	OR	M	R	1	
Fixmystreet	[illegible]	13	RN	SI	H	P	H	N	FV	N	C	PC	R	1	
Gozo island app	[illegible]	31	RA	A	H	C	H	N	F	Y	OR	M	RI	1	
Y2k youth - find events for teenagers (2)		37	A	S	H	P	H	Y	F	Y	OR	M	S	1	
leisure time - meet like-minded people in your area within hours (2)		38	A	S	H	P	H	Y	F	Y	OR	M	S	1	
Barcelona electric vehicle charge points	[illegible]	105	RS	S	H	P	H	N	N	N	OR	PC	T	1	
Death data	[illegible]	107	RS	A	H	P	H	N	V	Y	OR	PC	T	1	
Smart light	[illegible]	5	RS	M	SS	C	M	Y	T	Y	RT	N	E	2	27
Smart lighting -	[illegible]	7	RS	M	MS	C	M	N	N	N	RT	N	E	2	
Live webcam views of milton keynes at key sites - linked to from one promoting website		77	O	I	E	C	H	N	N	N	RT	M	I	2	
Light pollution and energy efficiency - activity tracking		85	M	M	MS	C	M	N	P	N	RT	N	R	2	
Light the railways with solar power		50	O	M	SS	C	M	Y	N	N	RT	N	R	2	
Motion sensored solar-powered led lighting		51	O	M	SS	C	M	Y	N	N	RT	N	R	2	
Orthogonal bus routes -	[illegible]	1	RS	M	MS	C	M	N	N	N	RT	N	T	2	
Essential savings pop-up shop for families and individuals on low incomes		74	O	S	H	P	H	Y	F	N	OR	M	B	3	7
Vayable	[illegible]	102	RN	S	H	C	H	Y	F	Y	OR	M	C	3	
Smartcitybir	[illegible]	109	RA	S	H	C	H	N	F	N	OR	M	CI	3	
Rainproof	[illegible]	10	RS	S	H	P	H	Y	F	N	OR	PC	E	3	
Ripe near me app		56	O	S	H	P	H	Y	V	N	OR	M	F	3	
Guide me - find safe route for people based on declared disability (2)		40	A	S	H	C	H	Y	T	Y	OR	M	I	3	
Smart city slate technomedia	[illegible]	23	RA	S	H	P	H	Y	F	N	OR	M	I	3	
Toadways	[illegible]	24	RA	S	H	C	H	Y	F	Y	OR	M	I	3	
Taxis on demand - match people to a nearby taxi with appropriate number of seats (2)		39	A	M	H	C	H	Y	S	Y	OR	M	R	3	
Barcode scanner - scan your recycling and earn points (1)		44	A	T	H	P	H	Y	V	N	OR	M	R	3	
Baby steps - timely advice for mothers on when to tend to their baby (1)		45	A	A	H	P	H	Y	F	N	RT	M	R	3	
Community app - sharing/ borrowing		97	M	S	H	C	H	Y	F	N	OR	M	R	3	
Volt - social ridesharing	[illegible]	21	RA	S	H	C	H	Y	VT	Y	C	M	R	3	
- seeclickfix -	[illegible]	12	RN	S	H	C	H	N	F	N	OR	PC	R	3	
Sidecar	[illegible]	15	RN	S	H	C	H	Y	V	Y	OR	M	R	3	
Yerdle	[illegible]	16	RN	S	H	C	H	Y	F	N	OR	M	R	3	
Dogvacay	[illegible]	17	RN	S	H	P	H	Y	F	N	OR	M	R	3	
Homedine	[illegible]	18	RN	S	H	C	H	Y	F	N	C	M	R	3	
Getaround	[illegible]	19	RN	S	H	P	H	Y	F	N	OR	M	R	3	
Postmates	[illegible]	20	RN	S	H	P	H	Y	F	N	OR	M	R	3	
Zaarly	[illegible]	103	RN	S	H	C	H	Y	F	Y	OR	M	R	3	
Citizen's position	[illegible]	4	RS	S	H	C	H	N	F	N	OR	PC	R	3	
Oldies - social media app for older people to connect with each other (2)		35	A	S	H	C	H	Y	F	Y	OR	M	S	3	
Local colony -social network/ noticeboard		83	M	S	H	P	H	Y	F	N	OR	M	S	3	
Klup	[illegible]	6	RS	S	H	C	H	Y	T	N	OR	M	S	3	
Jakarta car pooling		84	M	S	H	C	H	Y	T	Y	OR	M	T	3	
Transit scheduling fairfax - citizens report and track transport		92	M	S	H	C	H	N	F	N	OR	M	T	3	
Public transport issue app		49	O	S	H	C	H	N	F	N	OR	M	T	3	
Sourcing potential bus users		64	O	S	H	C	H	N	T	N	OR	PC	T	3	
Uber	[illegible]	111	RA	S	H	C	H	Y	V	Y	OR	M	T	3	
Bcn smart city tour	[illegible]	108	RA	M	SS	C	H	N	V	Y	OR	M	C	4	30