Smart City Dashboards: Design, Development, and Evaluation

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***Abstract*—A smart city dashboard is an application that is capable of retrieving historical and real-time data from different sources and visualizing data through different graphical and interactive techniques, and also to act on data storage and IOT devices. To ensure interoperability with various IoT protocols and devices, we have developed Snap4City Dashboard Builder, one-of-a-kind tool that is then used to create multiple smart city dashboards. This paper briefly discusses the tool we developed and presents a thorough evaluation of the tool, followed by description of ten dashboards created using the builder and summary of our extensive assessment of these dashboards. The evaluation indicates that our dashboard builder is powerful and the dashboards are very helpful for city officials.**

***Index Terms*—smart cities, dashboard, evaluation**

I. Introduction

Increasing need of smart and connected communities/cities has inspired lots of research in this area, which further results in a large amount of data coming from various sources such as stationary sensors, mobile devices, online data, social data. This plethora of data comes from "a range of application domains including, but not limited to, the following: agriculture, civil infrastructure, disaster mitigation and response, education and learning, energy, environmental quality, health and wellness including healthcare, human services, resiliency, safety, social services, telecommunications, transportation and mobility, urban and rural planning, and water resources [1]." While understanding, analyzing, processing the data is important, visualizing the data in real-time is also extremely useful for decision makers, city operators, residents, etc. This has highlighted an urgent need to build graphical user interface to display the data in a meaningful way. We call such an interface 'smart city dashboard'.

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Related Work: It is possible that smart city dashboards can be built using business intelligent tools that provide access to data with faceted indexing and search as in SOLR [2] or ElasticSearch [3]. However, those systems are focused on single view of data, filtering and drilling down on data, rather that representing the cities' key performance index and status. Solutions such as SpagoBI [4] and OpenDataSoft [5] provide data virtualization, but they provide limited capabilities on rendering and smart city dashboards must be active all the time. For these reasons, several specific custom solutions have been developed and deployed, examples include London (https://data.london.gov.uk/), Amsterdam (http://citydashboard.waag.org/), Dublin [6], Bandung in Indonesia [7], Torino in Italy [8]etc.

To the best of our knowledge, our system is the most comprehensive and most powerful platform for building smart city dashboards and the evaluation we have conducted for the dashboard builder and the dashboards developed using the builder has also been the most thorough.

II. Smart City Dashboard Builder

In this section, we provide an overview of Smart City Dashboard Builder we have developed and then present a thorough evaluation of this tool.

A. Overview of Smart City Dashboard Builder

We have developed the Snap4City Dashboard Builder Tool, web and mobile application (https://www.snap4city.org/). Our Dashboard Management System manages more than 1.2 million of complex events/data per day [9], reaching 1.8 recently. Dashboards can be created with the Snap4City Dashboard Builder Tool, as well as through the creation of Smart City IoT apps with the help of the integrated IoT App Builder and Node-RED. Node-RED is a programming framework for building IoT applications, based on Javascript Node.JS, which combines a visual composition of nodes/blocks in the

creation of application flows, that are concurrently executed by the Node.JS event-driven engine. Node-RED is a common approach and also directly provided in official releases of several IoT devices, such as those released to the Raspberry Pi family. Dashboards are produced as HTML and Javascript, thus there is no need for registered users to install any software on their clients. Moreover, dashboards widgets can be created and edited in a completely graphical way, without the need for users to know any programming language. On the other hand, the connection between dashboards and Node-RED based on IoT application allow advanced users and programmers to exploit deeper-level actions and customizations, including the creation of new widget types. Dashboards support authenticated user access, based on centralized LDAP and KeyCloack SSO authentication systems; users' personal data are stored and managed through a GDPR compliant framework. Furthermore, dashboards are connected to the data via secure protocols, such as: HTTPS, WSS, TLS. In addition, dashboards can be built from scratch, with the help of the Dashboard Wizard Tool, which can make easier for users to create their dashboards in a few steps, starting from pre-built templates and guided steps to choose the most suitable widgets for representing the chosen data. Users can create a new dashboard also by cloning an existing dashboard of their own, and later editing it. In this way, it is not necessary to create each new dashboard from scratch.

The collection of widgets available in the Dashboard Builder includes:

- Different kinds of charts and graphs , tables, time trends, time trend comparison;
- Multi-data maps for visualizing geo-referenced data, such as Points of Interests (POI), Smart City sensors, personal devices and personal data tracking;
- External Services, allowing to view embedded external web pages and services, such as: Traffic Flow and Public Transportation monitoring;
- Special widgets, such as Weather Forecast, Social Media monitoring, Healthcare status etc.;
- Actuators, represented by interactive widgets, such as knobs, dimers, key pads etc. which are used to interact with IoT devices and applications.

In addition to the creation of a new dashboard, the wizard assists the users also in creating instances of single widgets, showing a pool of data (Smart City related data and users' personal data) from which users can choose data of interest, as well as a set of available widgets that can be used for representing chosen data. Available data is presented in a tabular view; users can choose data of interest by selecting one or multiple rows in the wizard table and, finally, picking a desired widget for visual representation on dashboard. In order to help users in choosing among many different kinds of data available in a Smart City knowledge base, the wizard provides a multi-faceted classification of collected data (acting in the form of multi-faceted filters in the wizard data table), classifying them through several dimensions, such as: High-Level Type (HLT), nature, sub-nature, Value Type. HLT refers to a macro classification of data, describing generally the source of data, e.g., if they are data coming from Sensors, personal devices, or wether they represent POI etc. Nature and sub-nature refer to a semantic classification of data (for instance, data coming from weather sensors can be classified using 'Environment' as nature and 'Weather_Sensors' as subnature). Value-type refers to the format the involved data is represented with (i.e., literal, numerical, boolean); this information is used by the wizard also to automatically filter among available widgets, depending on chosen data, in order to suggest suitable widget choices to users.

An example of a dashboard created with the Snap4City Dashboard Builder is shown in Fig. 1. Different kinds of cross-connected widgets, such as: a selector on the left side, which trigger different kinds of data to be viewed on the map in the central area (e.g.: Smart City sensors, POI, heatmaps). In addition, a single content and a time trend widgets are presented, in order to monitor real-time data trend and last values. Finally, customized buttons linking to external resources are also present. Many of these widgets are connected, allowing the users to view data from different perspectives and dimensions.

B. Evaluation of Our Smart City Dashboard Builder

On July 9, 2019, we offered a three-day course on the Snap4City platform, which included one day on dashboard building. During the training on dashboard, three different exercises have been performed, asking the users to create a dashboard and report the perceived/intended performed action in a form. The form presented the list of widgets composing the dashboard. The purpose was to respond to the question: "how easy it is to use the wizard for dashboard creation, thus matching the intention selecting the icon with respect to the results obtained in creating the dashboard?." The assessment of the activities in three different cases involved: (a) the observation of the form they filled, (b) the verification of what has been really produced by that specific user, (c) the assessment of these results with respect to the correct result that is not unique. The users started the exercise after a general training about the platform, i.e., after the explanation of the mechanisms of the Dashboard Wizards, and of the coding of the icons in modeling the graphic representation, etc.

Users were asked to work on three exercises.

- *Ex1.* Create a Dashboard for the visualization of Sensors values: actual and their trend. In addition, the sensors to be selected should be located in Florence around a point of your interest (home, work, study), report data regarding: environment, traffic, parking, pollution, etc. 20 minutes of time
- *Ex2.* Create a dashboard for the visualization of geolocated services (POI, Sensors, heat map,..) and their selection on Map, with eventual target to see the time trend. The HLT to be selected should be located downtown in Florence, could be of different kid of HLT and nature,

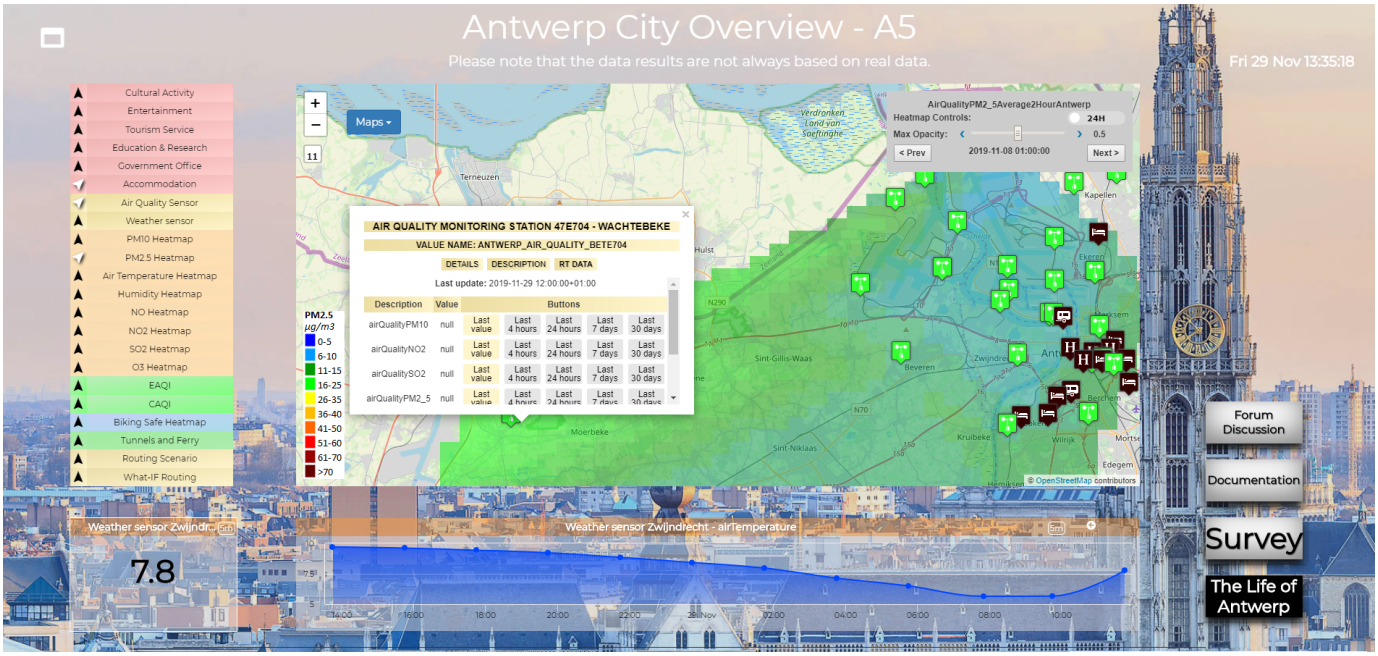

Fig. 1. A Dashboard Example

at least 5 of them; data regarding environment, traffic, parking, pollution, etc. 20 minutes of time

- *Ex3.* Create a dashboard for the visualization of MyKPI regarding my trajectories and eventually those of other users. We suggest to open wizard and search for trajectories of your mobile. 15 minutes of time.

The assessment has been carefully performed since each exercise can be solved with multiple solution. For example, exercise 1 can be solved realizing a dashboard with a number of Time Trend widgets and some mechanism to show real time data. The latter can be realized with: single content, gauge, speedometer, bars, etc. Their combination also selecting a template called Multi data trend, etc. For this reason, the assessment has assigned a vote that depend on percentage of matched widget proposed with respect to one of the possible solutions (100% all taken). Moreover, we added a bonus of 10 points over 100 when the user added an additional widget that could add value to the view. For example, it could be a widget Clock, or Meteo, etc. And, a -10 Points when they have added a wrong widget, let say out of context.

Results from these three exercises are reported below.

- Results of Ex1.
  1) 22 users have performed the exercise on paper
     a) Obtaining the 80% of average score on paper
     b) The 63.63% of them selected the correct widgets at the 90% or over.
  2) 18 users have performed the exercise on the Snap4City Dashboard Builder. Some of those presented the result on paper, have not been interested in performing the exercise on the real tool.
     a) Obtaining the 86.11% of average score on the real result
     b) The 72.22% of them developed the Dashboard correctly
  3) A number of those solved the exercise in the dashboard editor have actually performed better in the tool rather than reporting it on paper.
- Results of EX2
  1) 19 users have performed the exercise on paper
     a) Obtaining the 60.52% of average score on paper
     b) The 47.36% of them selected the correct widgets at the 90% or over.
     c) It should be noted that a number of wrong answers on paper have been due to the similarity of the Icons and thus they have marked the wrong one. On the other hand, on tool there is a text that appear when the mouse pass over the icon that provide a help to confirm their selection.
     d) Those icons have to be changed
  2) 15 users have performed the exercise on the Snap4City Dashboard Builder. Some of those presented the result on paper, have not been interested in performing the exercise on the real tool.
     a) Obtaining the 100% of average score on the real result
     b) The 100% of them developed the Dashboard correctly
  3) A number of those solved the exercise in the dashboard editor have actually performed better in the tool rather than reporting it on paper.

- Results of EX3
  1) 13 users have performed the exercise on paper
     a) Obtaining the 98.46% of average score on paper
     b) The 100% of them selected the correct widget at the 90% or over.
  2) 10 users have performed the exercise on the Snap4City Dashboard Builder. Some of those presented the result on paper, have not been interested in performing the exercise on the real tool.
     a) Obtaining the 100% of average score on the real result
     b) The 100% of them developed the Dashboard correctly
  3) A number of those solved the exercise in the dashboard editor have actually performed better in the tool rather than reporting it on paper.

Out of the 30 participants in the dashboard building training, 22 responded to our questionnaires. These people's expertise is shown in Figure 2. We aggregated the results for the whole set of exercises and observed that 90% of the users completed in time the development of the Dashboards that satisfy the requirements; the speedup of using Snap4City with respect to any other platform is 7 times on building dashboards. Only 9 people reported the specific tool they used to build dashboards: 44% use Penthao (which is the tool for ETL) and it is not an actual Dashboard Builder, and 33% use Power BI of Microsoft, that is business intelligence tool far from the Smart City world and features. A variety of other tools were reported by a single person include Arcgis, OnlineClarity, Geoserver, Grafana, Hortonworks, Mapseruer, Prometheus, Qlick, Redssh, Superset, Talend Data Integration, Traffic Supervisor.

56.70% were very satisfied and 37.11% were somewhat satisfied with the training day. 90% were happy with the dashboards, among them 49.38% were very satisfied. 93% stated that the dashboard builder would be useful for their work, 51.72% thought it would be very useful in their daily work. 72.63% were more than somewhat satisfied with the easiness for the dashboard production, 96.51% were more than somewhat satisfied with the completeness of the dashboard, and more than the 40% were very satisfied.

We surveyed the most appreciated aspects of the Dashboard Builder. Everyone appreciated the builder and wizard, 70% liked widget collection, 45% liked external services, 45% liked data inspector, and 35% liked micro applications. Suggestions to improve the tool include adding data on the same widget, better contextual guidance, dashboard customization, clearer user interface.

III. Smart City Dashboards

We first discuss the main requirements for smart city dashboards. We will then present the evaluation methodology and results of ten smart city dashboards.

A. Overview of Smart City Dashboards

As reported in [9], a Smart City dashboard should be capable of retrieving historical and real-time data from different sources (from big data to traditional data sources, as well as users' personal data), and showing data and metrics through many different graphical and interactive paradigms. With the increasing and massive diffusion of IoT devices, Smart City Dashboards should be also able to interact with a large variety of IoT protocols, providers and formats. In addition, geospatial inference and reasoning should be provided, in order to properly visualize geolocated data. Dashboards created by Smart City operators, as a control room to monitor what is happening in the city, have to be actively shown on web or mobile browsers 24/7, and should provide notification tools to allow early monitoring and decision making. Furthermore, the security aspect is of pivotal importance, hence the Dashboard management system should provide secure authenticated access and handle personal users' data according to the last GDPR directives.

The main general features and functionalities of a dashboard are listed as follows.

- A dashboard is composed of a set of graphical widgets, (data viewers and actuators), which can be customized through a dedicated edit grid view modality;
- Dashboard widgets can act as autonomous data viewers and actuators, or they can be interconnected to other widgets;
- A new dashboard can be created from scratch through the Dashboard Wizard Tool, or an existing dashboard can be cloned to derive a new dashboard, allowing to perform versioning and additional customization;
- A dashboard can show, through its widgets, historical and real-time data coming from data lake, virtual store and many different data sources: SQL database, database via ODBC, noSQL database (e.g., MongoDB or Hbase), HDFS directly or via Phoenix, RDF stores via SPARQL, Smart City knowledge bases from Smart City API calls, as well as from streaming data and IoT devices;
- A user who has created a dashboard (referred as the dashboard owner in the following) can manage its visibility, by choosing whether to share its view as a public dashboard, or whether to keep it private, or delegate the view to specific users or groups;
- A dashboard can be connected with IoT applications, thus integrating and viewing data coming from one or multiple IoT applications;
- Dashboard widgets can be connected to a notification system which can send custom alerts based on data thresholds set by the user.

B. Evaluation of Smart City Dashboards

We assess the dashboards that were created using the Snap4City Dashboard Builder Tool. Snap4City Smart City Dashboards are interactive visual tools, based on a large collection of graphic widgets, which are useful for viewing and monitoring data from many different sources (e.g., users' private and public personal data, referral data from storage, Smart City knowledge base accessed through Smart City APIs, real time data from stream and IoT devices, external web and

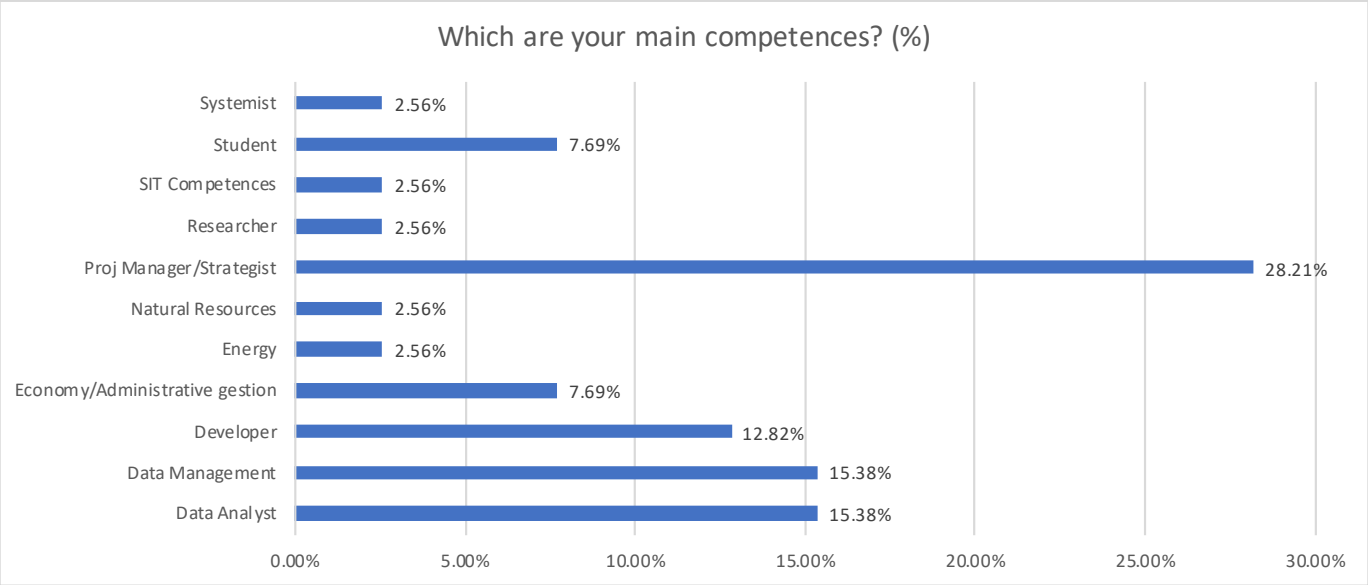

Fig. 2. Distribution of evaluator's expertise

database sources). Dashboards allow users to view data on customizable maps, to perform multi-faceted drilling-down on data, data analytics, as well as to interact with Smart City and personal IoT devices through actuators such as buttons, keypad, and knobs, in order to create interactive environments also for navigating different dashboards. Dashboards are suitable for decision makers, city operators, administrators and citizens as final users, and they can be created, edited and viewed on a wide range of devices, including mobiles.

We have conducted assessment of Snap4City dashboards by city officials and ICT officials from Antwerp (August 21st, 2019) and Helsinki (June 11th, 2019). We evaluated the following dashboards.

1) Antwerp City Overview (A5a): This dashboard has been created to provide an instrument to City Officers and Experts about environmental and weather aspects of the city. The users can pass from the overview to see the values and trends of specific data type and piking values in specific GPS points of the map.
2) The Life of Antwerp (A5b): This dashboard has been designed to provide an overview to the city officials about the main trends of the city in terms of people flow and usage. These specific views are taken from the data coming from the Mobile App "Antwerp in a Snap", and potentially from PAX counters installed in the SmartZone.
3) Antwerp vs Helsinki Comparison (A6): This dashboard has been designed to provide a tool for comparing two cities on the basis of nearly common parameters to the city officials of Antwerp and Helsinki. This dashboard allows to control at the same time data from the same kind of sensors in the cities of Antwerp and Helsinki to have a complete view on other environmental parameters in the cities.
4) Antwerp vs Florence Comparison (A6): This dashboard is similar to the Antwerp vs Helsinki Comparison dashboard, but compares Antwerp and Florence.
5) Helsinki City Overview (H5a): This dashboard has been created to provide an instrument to City Officers and Experts about environmental and weather aspects of the city. The users can pass from the overview to see specific data and piking values in specific points of the map.
6) The Life of Helsinki (H5b): This dashboard has been designed to provide an overview to the city officials about the main trends of the city in terms of people flow and usage. These specific views are taken from the data coming from the Mobile App "Helsinki in a Snap".
7) Enfuser vs RealTime Comparison (H4) daily/weekly: This Dashboard is dedicated to Environmental professionals. The idea is to show the values of main environmental data in real time with respect to the predicted data provided by Enfuser service. This dashboard shows the daily/weekly trends. The comparison of Enfuser vs Real Time values is referring to specific sensors located in the Jätkäsaari island.
8) Helsinki vs Antwerp Comparison (H6): this dashboard is equivalent, in terms of functionalities and visualized features, to the one described at point 3), with the only difference that the comparative view is focused on the first city in the title (Antwerp in this case, Helsinki in the former dashboard); thus, widgets related to the first city are shown first in the comparative view.
9) Helsinki vs Florence Comparison (H6): This dashboard is similar to the Antwerp vs Florence Comparison dashboard, but compares Helsinki and Florence.

In Helsinki, we had eight participants from Select4Cities consortium and nine participants from the City of Helsinki, mainly City Official of several kinds. In Antwerp, we had

15 participants. A total of more than 4.6 million of minutes have been spent on Dashboards with a total of more than 41,000 accesses to Dashboards. In most cases, the dashboards have been maintained on browser for several minutes. Most of the activities performed on dashboards have been accessing detailed data from sensors of different kinds. Detailed results are shown in Figure 3. The #Accesses is the number of

Dashboard name	ID	#Accesses	#Minutes	#Days	Status
Antwerp City Overview (A5a)	1407	11.988	855.665	90	Public
The Life of Antwerp (A5b)	1706	4.238	416.517	61	Private
Antwerp vs Helsinki Comparison (A6)	1756	448	42.642	29	Private
Antwerp vs Florence Comparison (A6)	1757	255	19.892	18	Private
Helsinki City Overview (H5a)	1406	14.629	2.057.898	92	Public
The Life of Helsinki (H5b)	1752	6.124	640.136	66	Public
Enfuser vs RealTime Comparison (H4) daily	1732	895	117.159	43	Public
Enfuser vs RealTime Comparison (H4) weekly	1735	407	35.395	31	Private
Helsinki vs Antwerp Comparison (H6)	1740	1.349	331.698	42	Public
Helsinki vs Florence Comparison (H6)	1741	1.001	114.332	42	Private
total		41.334	4.631.334		
Total for Antwerp		16.929	1.334.716	198	
Total for Helsinki		24.405	3.296.618	316	

Fig. 3. Total dashboard usage

accesses performed to see the dashboard, call to the URL of the dashboard performed on the Dashboard system from some client; The measure of #Days is the number of days in which we have measured some activity on that dashboard; the measure #Minutes is the number of minutes the dashboard has been active. There is a process on the dashboard client that for every minute in which the dashboard is on browser send a call to the Dashboard system.

From these statistics, we have derived a number of metrics that show the interest provoked with those dashboards, as reported in Figure 4. Overall, our dashboards were well-

Dashboard name	AVG Min/day	AVG Acc/Day	AVG Min/Acc	Status
Antwerp City Overview (A5a)	9507,4	133,2	71,4	Public
The Life of Antwerp (A5b)	6828,1	69,5	98,3	Private
Antwerp vs Helsinki Comparison (A6)	1470,4	15,4	95,2	Private
Antwerp vs Florence Comparison (A6)	1105,1	14,2	78,0	Private
Helsinki City Overview (H5a)	22368,5	159,0	140,7	Public
The Life of Helsinki (H5b)	9699,0	92,8	104,5	Public
Enfuser vs RealTime Comparison (H4) daily	2724,6	20,8	130,9	Public
Enfuser vs RealTime Comparison (H4) weekly	1141,8	13,1	87,0	Private
Helsinki vs Antwerp Comparison (H6)	7897,6	32,1	245,9	Public
Helsinki vs Florence Comparison (H6)	2722,2	23,8	114,2	Private
Total for Antwerp	18.911	232	343	
Total for Helsinki	46.554	342	823	

Fig. 4. Average dashboard usage

received by city officials and considered very helpful.

IV. Conclusion

In this paper, we present a high level overview of the Snap4City Dashboard Builder and evaluation of its usefulness by 30 participants. We also introduce ten smart city dashboards created using the builder and present a summary of the assessment results of these dashboards. Feedback we received was very positive and we will implement the suggested changes in our system in the future.

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