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Snap4City Dashboard Manager: a tool for creating and distributing complex and interactive dashboards with no or low coding

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Abstract

Dashboards are fundamental to inspect data in smart city and industrial contexts. Due to the complexity of such interfaces, dashboard design and construction can be a difficult and time-consuming activity, usually requiring coding competences, not always available among users. In this paper the Snap4City Dashboard Manager is proposed. Unlike other available solutions, the Dashboard Manager allows users to create dashboards in a graphical way by composing widgets able to display multiple kinds of data. Additionally, each widget can be extended to both retrieve data from any source and enable event-driven communications among different widgets and users.

Keywords

Dashboards, business intelligence, visual analytics, widget, IoT, digital twin, smart city, business logic

Metadata

Nr	Code metadata description	Please fill in this column
C1	Current code version	v7.7.2
C2	Permanent link to code/repository used for this code version	https://github.com/disit/dashboard-builder https://hub.docker.com/r/disitlab/dashboard-builder/
C3	Permanent link to reproducible capsule	https://www.snap4city.org
C4	Legal code license	GNU AFFERO GENERAL PUBLIC LICENSE, Version 3.
C5	Code versioning system used	git
C6	Software code languages, tools and services used	JAVA, Javascript, PHP, HTML, CSS, SQL
C7	Compilation requirements, operating environments and dependencies	JAVA7 or above, MySQL 5.5 or above, PHP 5.7, Apache HTTP Server, Linux or Windows environment
C8	If available, link to developer documentation/manual	https://www.snap4city.org/drupal/sites/default/files/files/Dashboard%20Manager%20-%20Technical%20%20documentation.pdf https://www.snap4city.org/drupal/sites/default/files/files/Dashboard%20Manager%20Db%20Documentation.pdf training: https://www.snap4city.org/944 https://www.snap4city.org/download/video/course/p2/Snap4City-p2-Dashboards-v12-6.pdf https://www.snap4city.org/download/video/course/p2/
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1. Motivation and significance

The growing attention to smart cities and communities and the increasing production of data of multiple kinds, models, and shapes has led to a great effort in developing systems and platforms able to efficiently handle and present such information. Data ingestion and processing (transformation, transcoding, etc.) are relevant and enable the production of predictions, detection of anomalies, generation of hints, etc. The visualization and interactive navigation of the above-mentioned hints, detected anomalies, predictions and derived data/results are fundamental for both public administration and industrial decision-makers who have to extrapolate some considerations and come to a decision. To this end, much attention has been moved from simple data presentation to actual visual analytic and business intelligence tools for control and planning, including what-if analysis. Visual analytics and insights allow to better understand data and extract knowledge out of them, with the goal of supporting decision-making processes. The increasing popularity of these tools has extended their use in several heterogeneous contexts, involving very different user profiles. In this context, it is essential also to consider final users, with the requirement of managing different complexity levels in the development of dashboards and visual tools.

In most cases, dashboards for decision makers can be created by exploiting business intelligence tools with classic faceted indexing and search to access data, as for example SOLR [1] or Kibana/Grafana [2]. Such solutions focus on single views of data, filtering, and drilling down, rather than representing key performance indicators (KPIs) and status and are limited on the data type they can manage, and on the widget types they can offer and build in the user interface. Solutions such as SpagoBI [3] and OpenDataSoft [4] have limited rendering capabilities, insufficient to build smart city dashboards. Indeed, the necessity of tailoring dashboards on specific user requirements is a relevant topic, as highlighted by recent literature surveys [5]. For these reasons, custom solutions have been developed for specific cases, as for example for London [6], Amsterdam and Duisburg [7], Dublin [8], Milan [9]. Such solutions being developed for specific scenarios do not provide general dashboard building tools and therefore require long development times and high costs. Similarly, research projects have investigated on smart city dashboards [10] without providing specific tools for building them. More interesting are approaches like Cities-Boards [11], where authors have proposed a dashboard building framework; however, the process is based on a graphical programming language that is successively transformed into a web interface, therefore requiring programming competences to start with. Similarly, in [12], dashboards are generated by serializing information expressed in knowledge graphs. In [13], a tool based on the definition of meta-models to build dashboards using a code-generator has been proposed. Such solution does not require deep programming competences and users have to learn a modelling tool in order to select data, define widgets (with their properties), and manually connect each variable to the right widget input. The capability of automatically associating any data kind to the right visualization modality is a relevant topic in dashboard building as stated in [14]. For example, in [15], data kind-widget association has been provided by exploiting a semantic reasoner that selects the best visualization modality, given a data input. In [16], authors have proposed the PTAH meta-model to design dashboards and address the selection of a correct widget using feature models to describe all the available widgets and relate them to the PTAH concepts. More recently, some smart-city framework solutions have been proposed for the development of dashboards, for example as paid solutions like Wisetown [17], others as open source are still not accessible to be downloaded and used [18]. Briefly, there is not any open source easy-to-use dashboard building and management system, which is general enough to be deployed in different smart-city or industry scenarios, so as to be used without any programming competence for creating simple solutions; there is no dashboard building and management system which may need only small coding, when it comes to creating complex visual analytic and business intelligence tools. Moreover, in the current state-of-the-art most solutions do not offer the possibility of showing 3D data.

73 Therefore, there is the need to create meaningful graphic and custom interactive
74 representations (beyond the classic GUIs and dashboards), with visual intelligence and business
75 intelligence tools, providing capabilities for displaying 2D maps, KPIs, time series, and other kinds
76 of plots and diagrams, with high level of interactivity and customization of the business logic, to
77 implement what-if analysis tools, and to enable 3D visualization of advanced interfaces, with local
78 and global digital twins interactive representation [18], [19]. The Snap4City Dashboard Manager,
79 as presented in this paper, covers multiple domains addressing use cases as for example the
80 observation of current status and the execution of prediction or reconstruction exploiting what-if
81 analysis, in industrial and smart-city contexts. The produced Dashboards provide visual tools
82 representing data as: multi data maps, time series, vectors, tables, heatmaps, etc., and complex
83 data for specific domains, such as: mobility and transport (traffic flow density network and
84 animations, origin destination maps and animations, trajectories); energy (simulation of energy
85 production with PV panels); environmental (the widespread presence of pollutant in a 3D shape
86 of the city, and its related animation); 3D representation with what-if analysis to observe the impact
87 of possible changes, etc. Moreover, a Dashboard Builder has been realized in order to facilitate
88 and speed up any visual tool construction. It consists of a set of web tools to build connected and
89 intelligent dashboards/visual tools through the composition of several kinds of widget in a
90 completely graphical way, thus requiring programming only when custom business logic is
91 needed, thus becoming more accessible to a wide range of users. The Dashboard Builder allows
92 to create simple or advanced dashboards according to the target audience and the specific
93 application scenario and it offers a wizard which can shorten any dashboard production by
94 reducing the time to associate data with graphic representations, thanks to the data semantic
95 modelling exploitation, as reported in [20].

96 The Dashboard Manager and Builder are modules of the Snap4City open-source platform
97 (www.snap4city.org) [21]. Dashboard Manager is able to manage multiple organizations as
98 tenants and billions of data with its key focus on interoperability. At present, it is in operational
99 use in several Smart Cities, industries, and areas within Italy (Firenze, Pisa, Livorno, Prato,
100 Lonato del Garda, Modena, Merano, Cuneo, etc.) and Europe, too, (Antwerp, Santiago De
101 Compostela, Valencia, PontDuGard-Occitanie, Dubrovnik, Mostar, and West Greece, etc.). The
102 largest installation of the platform is a multi-tenant with 19 organizations and more than 8000
103 operators / developers, more than 1700 Dashboards, among which about 280 are public. The
104 solution has been installed in almost all continents and the Dashboard tool has been downloaded
105 from GitHub and included in Snap4City tools thousands of times.

106 The paper is organized as follows: in Section 2 the architecture and the main functionalities
107 of the Dashboard Manager and Builder are presented. In Section 3, some examples on the usage
108 of the Dashboard Builder are provided, while in Section 4 impacts of such proposed software are
109 discussed. Finally, in Section 5 conclusions are drawn.

110 2. Software description

112 In this section, both architecture and functionalities of the Dashboard Builder are presented.
113 The Dashboard Builder is the core part of the Snap4City Dashboard Manager, which collects and
114 distributes dashboards on demand. Dashboards are organized in Organizations which are tenants
115 and can be shared, cloned, and delegated in access among users. The Dashboard Builder
116 provides a set of tools for creating dashboards which can provide information and interaction tools
117 to users and receive and send data from/to the platform and from/to third parties solutions.

118 2.1. Software architecture

119 The architecture of the Dashboard Builder is represented in **Figure 1**. The Dashboard Builder
120 is composed by three main blocks: the **Widget Collection**, the **Dashboard Wizard**, and the
121 **Dashboard Editor**. The **Dashboard Editor** is used to create/modify dashboards (including their
122 logic, visual analytics, what-if tools, etc.), by collecting and configuring Widgets and their
123

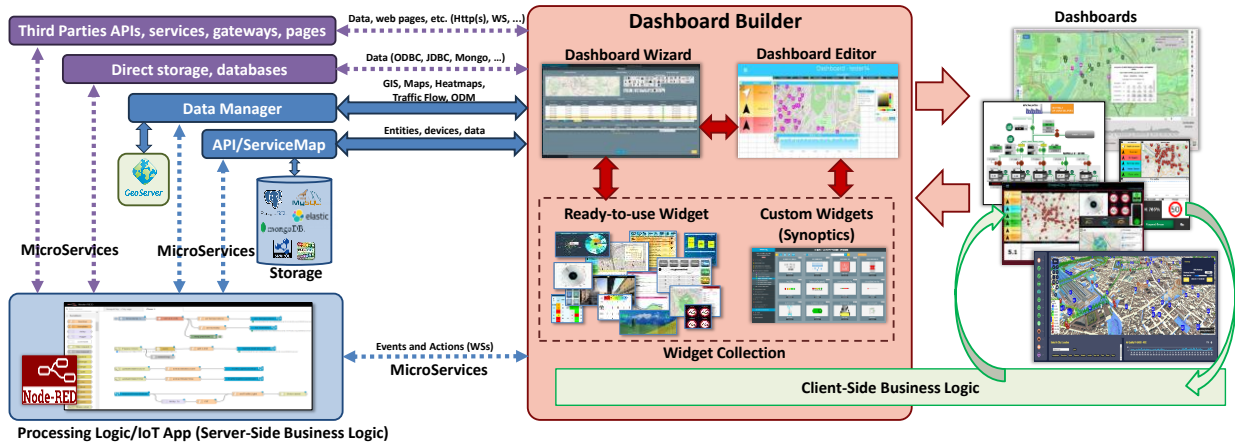


Figure 1. Block diagram illustrating the Dashboard Builder architecture and its integration with the Snap4City platform (blue blocks and arrows) and with external resources (purple blocks and arrows).

124 relationships, sizing and placing them into dashboard canvas [20], [22]. Each widget has a
 125 number of capabilities in presenting data, collecting data and interacting with users and protocols.

126 The **Widget Collection** includes several ready-to-use widgets and custom widgets (that can
 127 be created for implementing new interactive graphic representations and Synoptics by using any
 128 SVG graphic editor). Each **Widget** is realized as an independent module which can: (i) present
 129 information to the user, (ii) get actions/interactions from the user, and (iii) interact back and
 130 forward with different channels. Channels are implemented as protocols and formats and allow to
 131 exploit storage systems (e.g., knowledge bases, relational DB, ODBC, JDBC, NoSQL api), any
 132 heterogeneous data sources, connection protocols such as HTTP/HTTPs, API REST,
 133 WebSocket, IoT Brokers API, etc. Therefore, widgets can work/react in an event driven way by
 134 Web sockets, and also access the historical data (time series) of sensors, maps, heatmaps, traffic
 135 flows, origin-destination matrices (ODMs), as well as query GIS servers (e.g., a GeoServer via
 136 WMS, WFS protocols).

137 Such dashboard editing/creation is simplified by the **Dashboard Wizard**, by means of which
 138 users can create/connect dashboards in a few steps, exploiting pre-build templates. Moreover,
 139 the related wizard guides users in the selection of the most appropriate widgets for displaying the
 140 data of interest, or stating from the preferred widget to identify the data which can be used for
 141 populating it, or stating from the map to identify the data which are present in the area and the
 142 widgets for their rendering, etc. The Wizard assists users by reducing complexity, providing
 143 suggestions on finding combinations between data types (time series, vectors, array, maps,
 144 trajectories, heatmaps, origin destination, point of interest, typical trends, histograms, etc.), and
 145 graphic representations (trends, multi-trends, pie, donut, maps, chords, hierarchies, solar,
 146 dendrograms, single content, Italian flag, traffic flow, 3D building, etc.). Once the editing operation
 147 has been completed, users can save the related dashboard (with the possibility to delegate it or
 148 grant access to different users) and it is made available in the dashboard collection.

149 Moreover, with the aim of enabling developers in using the Dashboard Builder to create
 150 custom visual analytics, business intelligence, and what-if analysis tools, a flexible approach for
 151 modelling any business logic is provided with two different manners: Server-Side Business Logic
 152 (SSBL) and Client-Side Business Logic (CSBL) [23], [24]. According to the SSBL approach, some
 153 graphic Widgets of dashboards have a counter part in the Node-RED nodes [25] and thus are
 154 regarded as MicroServices which the Node-RED can send data and controls to, and which the
 155 Node-RED can receive events/actions from, as provided by users [26]. This approach allows the
 156 dashboard designer to create SSBL by using the visual programming in Node-RED. This



Figure 2. Dashboard Editor of the proposed Dashboard Builder.

157 approach also implies that once a new widget node is deployed on a Node-RED flow, the related
 158 widget is automatically created into the selected dashboard and a WebSocket secure connection
 159 is established. The integration of Dashboards with Node-RED is also used to activate Data
 160 Analytics (data processing with machine learning and artificial intelligence algorithms) based on
 161 user actions on dashboards and/or scheduling in Node-RED [27], [28].

162 The CSBL approach is realized by coding segments of JavaScript directly into the graphic
 163 interface configuration of widgets (green block in Figure 1). The CSBL code can call: (i) any
 164 external APIs (purple blocks and arrows in Figure 1), (ii) any API and data base services of the
 165 Snap4City platform (blue blocks and arrows in Figure 1), and (iii) specific functions to
 166 send/receive commands and data to other widgets (green block in Figure 1). This approach
 167 allows users who can interact with some widget graphic element (a line, a legend, a bar, a pin on
 168 map, etc.) to activate a rendering, a computing, or a visualization on one or more widgets in the
 169 dashboard, and even open another dashboard with some parameters. With a minimal JavaScript
 170 programming capability to code the logic in these dashboards, a user can add intelligence
 171 functionalities to any widget to retrieve data directly from internal and external sources and
 172 generate and catch messages from other widgets in an event-driven way.

173 174 2.2. Software functionalities

175 The Dashboard Builder allows users to create interactive dashboards by composing widgets
 176 starting from a white canvas by means of the Dashboard Editor (see Figure 2). As above
 177 described, widgets are specialized in handling different data kinds, without requiring any
 178 programming competence. In addition, widgets can exploit business logic as CSBL and SSBL
 179 which can be defined on server side with Node-RED and client side in small JavaScript coding.
 180 The widget selection and generation within dashboard can be accelerated by using the
 181 Dashboard Wizard (see Figure 3), that matches data to widgets taking into account data types,
 182 locations, organization, and any multiclass faceted search. In any case, widgets put on dashboard
 183 can be edited for setting their configuration and relationships among them by using graphical
 184 panels and contextual menus on graphics elements. Such setting includes map position and

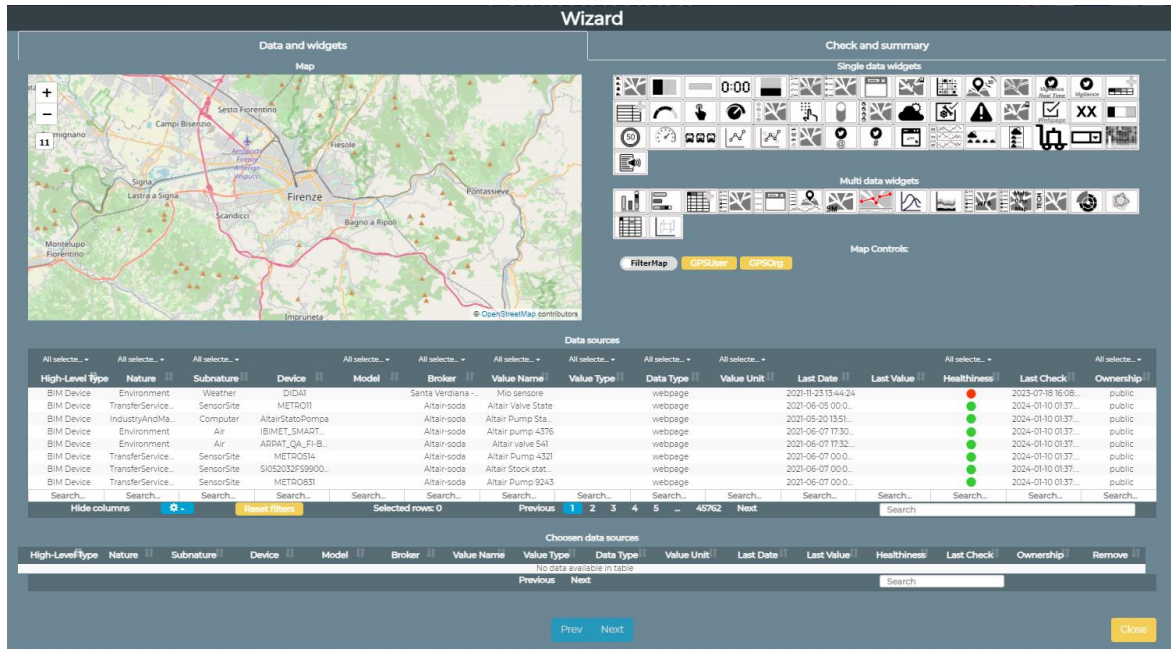


Figure 3. Dashboard Wizard for data kinds and widget association.

185 zoom, colors, time series (single/multi, stacked, shaded, comparative, double axes, etc.), kinds
 186 of bar/pie plots (staked, horiz./vert., etc.), all the selector parameters and data to be recalled on
 187 map with icons, color, heatmaps, tracks, ODM, shapes, scenarios, etc. Moreover, any widget can
 188 be sized, titled and placed in any position within the dashboard, in a way the user prefers.
 189 Examples of the basic available widgets in the Widget Collection are presented in Figure 4, while
 190 a very large set is accessible from the training course in PDF, Interactive and videos [29].

191 The Dashboard Builder includes the following functionalities:

- 192 • create, import, export, delete dashboards and/or widgets;
- 193 • dashboards and/or data can be made private or public; when private the access can be
 194 controlled;
- 195 • manage widgets for data: single contents (text or numbers), time trends (even accepting
 196 multiple time series, staked and not staked, single and double axes, etc.) with drill-down and
 197 comparison capabilities, speedometer, gauge, single bars; Kiviart charts, spider net, donuts
 198 and pies, bar series and histograms, chords, etc.; tables with dynamic row indexing according
 199 to the selected column, search, column selection, server side paging, etc.;
- 200 • manage widgets External Services, to embed external web pages and services, BIM viewer,
 201 TV cameras (using WebRTC), etc.;
- 202 • manage special widgets, such as Weather Forecast, Social Media monitoring, Healthcare
 203 status, synoptics as SVG augmented with anchors, to display static and dynamic data [30];
- 204 • manage 2D multi-data maps for visualizing geo-referenced data, such as Points of Interests
 205 (POI), Smart City sensors, personal devices and personal data tracking, as well as
 206 trajectories, paths, heatmaps, etc., and allowing user interactions and any triggering of
 207 CSBL/SSBL;
- 208 • manage widgets which are nodes in Nore-RED and allow bidirectional web-sockets secure
 209 communication for SSBL;

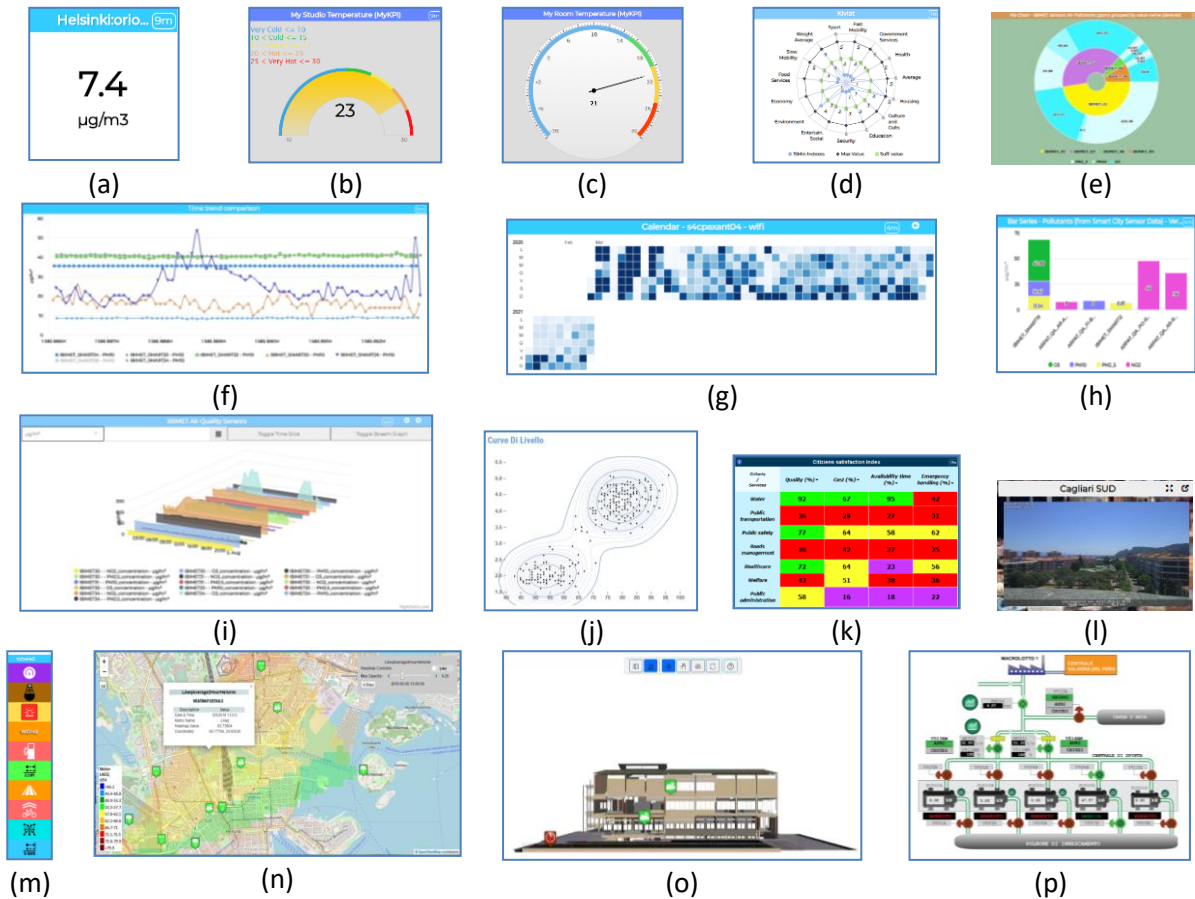


Figure 4. Some of the main widgets included in the Snap4City Widget Collection: (a) single content text, number, HTML; (b) gauge; (c) speedometer; (d) Kiviati/spider net; (e) donut; (f) multi time series; (g) calendar heatmap; (h) bar chart; (i) data cube; (j) contour/level lines; (k) table; (l) TV-Cam; (m) selector menu (icon version); (n) 2D multi data map; (o) BIM viewer/inspector; (p) custom widget (synoptic).

- 210 • allow to code CSBL into widgets to enable the creation of visual analytics, business
 211 intelligence and what-if analysis tools;
- 212 • manage widgets for providing tools of selection, menus, connected to 2D and 3D map
 213 widgets, to show and hide information dynamically on user request;
- 214 • manage interaction and interactive widgets, such as buttons, knobs, dimers, keypads, etc.
 215 which are used to interact with IoT devices and applications, and also any interaction of
 216 graphic elements of widget, so as to provoke actions via standard relationships as drill down,
 217 zoom/pan on maps, etc., as well as riggers on CSBL and messages to SSBL;
- 218 • manage 3D multi-data maps to build smart city digital twin interfaces where 3D
 219 reconstructions of city entities are augmented with static and real-time information coming
 220 from sensors, analytic services, open data, etc.;
- 221 • extensively support CSBL and SSBL solutions to enable the creation of visual analytics and
 222 business intelligence tools and related applications [24];



Figure 5. 3D multi-data map widget used to represent the smart city digital twin of Florence, Italy.

- provide secure end-to-end connections from users to data, also supporting authentication and authorization mechanisms with standards such as LDAP, OpenID connect, etc., and in the respect of data privacy according to GDPR [31], [32].

Each and every widget includes CSBL [24] to enable a dynamic exchange of information among one another, but also with internal and external services. With a minimal coding effort, users can implement abstract functions to let the widget requests data from services and storages and throw messages from/to other widgets in order to update/change visualization. For example, after a drill-down operation on a time-series to select a specific time range, a widget sends a message to one or more widgets to control their rendering, or what they have loaded from the storage.

3. Illustrative examples

To illustrate the Dashboard Builder, in **Figure 2** an example of the graphical interface used to compose a dashboard is reported. Using buttons in the top bar, users can set the dashboard metadata (e.g., title, subtitle), change theme, add different widgets, import/export, save and request a preview of the dashboard. Widgets appear in the main panel and can be sized and placed using drag-and-drop. Due to its particularity and complexity, in **Figure 5** an example of the 3D multi-data map is presented. The 3D multi-data map can handle different 3D representations for the terrain, the buildings, and other urban elements. It can visualize sensors and services as pins, different maps and static and animated heatmaps by texturing the terrain, interactive elements, so as to show the road graph, cycling paths and public transport routes and stops. Moreover, specific 3D representations are used to show real-time traffic conditions (as animated 3D arrows and crest) and measurements from city sensors (presented as 3D pillars with a height proportional to the observed value). A freely accessible demo showing these capabilities of a 3D multi-data map can be found at <https://digitaltwin.snap4city.org/>. A video on this tool can be accessed from: <https://www.youtube.com/channel/UC3tAO09EbNba8f2-u4vandq>

4. Impact

Dashboards are extremely diffused GUIs, from industrial to smart-city contexts, and their development could be difficult and time consuming due to specific user requirements, in particular if interactive functionalities must be granted and direct access to data and business logic

254 processes is requested. The proposed Dashboard Builder offers an easy-to-use solution to those
255 problems, allowing even non expert users to build effective dashboard with minimal efforts and a
256 high level of tailoring possibilities, while providing automatic association among widget and data
257 types. Moreover, the proposed solution is extendable, thanks to its modular architecture, and able
258 to accommodate more complex visualizations and interactions, granting additional customization
259 possibilities to more expert users. For example, in External Content D3 graphic libraries can be
260 used. Therefore, the Dashboard Builder offers multiple level of complexity, meeting the needs of
261 different users.

262 The use of the Dashboard Builder eases any realization of interfaces when used to display
263 results of research and planning activities. For example, city councils can exploit map widgets to
264 observe traffic density reconstruction [33] and heatmaps of pollutant dispersion [28], as well as to
265 view predictions of landslide events [27], and to visualize 3D digital twins of the whole city [34].
266 On the other hand, charts, time trends, tables, etc., can be used to visualize results of pedestrian
267 detection in video surveillance [35] for security and commercial scenarios, as well as to show data
268 and measurements of industrial plants [30], [36], [37]. Several scenarios have been developed
269 with the Dashboard Builder in a large number of domains (mobility and transport, environment,
270 energy, security, tourism, etc.), as reported in <https://www.snap4city.org/4>.

271 An evaluation of the impact of the Dashboard Builder in improving and simplifying the process
272 of creating dashboards and visual data analytics has been reported in [20]: during a training
273 course of the Snap4City platform, users with different levels of technical expertise were provided
274 with exercises and questionnaires on the Dashboard Builder, in order to assess if the tool is
275 effective in matching the user's intention and needs with respect to the results obtained by
276 creating the dashboard. Some of the most significant results emerging from this survey are the
277 following: 93% of participants stated that the Dashboard Builder would be useful for their work;
278 72.63% were more than somehow satisfied with the easiness concerning the dashboard
279 production with respect to the other products in their usage; 96.51% were more than somehow
280 satisfied with the completeness of the dashboard.

281 The Dashboard Builder, integrated into the Snap4City platform, has been deployed in several
282 industrial and smart-city contexts by DISIT lab and several private companies and public
283 administrations for their installations as listed in <https://www.snap4city.org/661>. Many other
284 private installations are not listed. The largest installation includes 19 organizations and more
285 than 8000 operators and developers. More than 1700 dashboards have been created (among
286 which, more than 500 are connected with SSBL based on Node-RED), including more than 11700
287 active widgets managing an average of about 2.2 million of complex data messages per day, from
288 more than 260 thousand distinct data sources. Moreover, the Dashboard Builder was used to
289 realize the dashboards in use to monitor the ISPRA Joint Research Centre (JRC) of the European
290 Commission. A training course is accessible at <https://www.snap4city.org/944>.

291 The Dashboard Builder is also one of the main tools used and installed by Snap4 [38], a spin-
292 off of the University of Florence that develops data ingestion and monitoring solutions exploiting
293 the Dashboard Builder to customize dashboards for several industrial realities.

294 A list of publications regarding these activities is reported in <https://www.snap4city.org/426>.

295

296 5. Conclusions

297 In this paper the Dashboard Builder (freely available from our GitHub [https://github.com/disit/
298 dashboard-builder](https://github.com/disit/dashboard-builder) and as Docker container <https://hub.docker.com/r/disitlab/dashboard-builder/>)
299 was presented. The Dashboard Builder is a modular software used to create interactive
300 dashboards with minimal efforts carried out even by non-expert users, thanks to its graphical
301 interface. By exploiting different widgets available in the Dashboard Builder collection, and with
302 the help of the Dashboard Wizard, a dashboard can be composed to visualize data in charts, time
303 trends, tables, maps, and even full urban digital twin. Additionally, widgets can interact with
304 multiple storage systems and with analytic processes and allow the possibility to specify client-

305 side and server-side business logic functionalities to exchange information and update their
306 visualizations in an event driven manner, thus developing visual analytics, business intelligence
307 and what-if analysis tools. The Dashboard Builder, integrated into the Snap4City platform, is
308 widely used both in academic and industrial fields, since it provides an easy and quick solution
309 for presenting research results and visualize historic and real-time data.

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316

317 **Compelling Interest**

318 No compelling interest is involved among authors.

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320

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