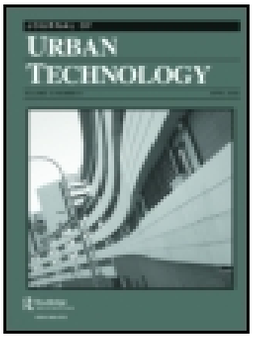

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Smart City L'Aquila: An Application of the "Infostructure" Approach to Public Urban Mobility in a Post-Disaster Context

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ABSTRACT
Ever since the earthquake of April 6, 2009 hit the city of L'Aquila, Italy, the city has been facing major challenges in terms of social, physical, and economic reconstruction. The system of public urban mobility, the bus network, is no exception with its old bus fleet, non-user-friendly information, and poor scheduling. This paper argues that the public transportation system of L'Aquila could be improved towards smart mobility models without large infrastructure investment by leveraging the "infostructure" approach, digital technologies, open data, and open source software. This work presents the digitization and geo-referencing procedure, software architecture, and the web and mobile apps that have been developed to improve the information flow available to citizens and to increase the user-friendliness of the transportation system. Future research will seek to make use of the data and develop applications to perform a public transport accessibility analysis of major points of interest throughout the city.

KEYWORDS
Urban mobility; spatial accessibility analysis; infostructures; open-source software; transit data; smart city; post-disaster

Introduction

The applications of new information and communication technologies (ICTs), computer software, and web applications in the urban domain is constantly increasing. Various are the examples that range from participatory planning GIS (PPGIS), planning support systems (PSS), social media, decision support systems (DSS), trip planners, collaborative mapping tools, web apps, and so on (Klosterman, 1997, 2012; Shim et al., 2002; Dunn, 2007; Ricca and Scattoni, 2008; Evans-Cowley and Hollander, 2010; Casey and Li, 2012; Brown and Kytta, 2014; Pelzer and Geertman, 2014; Schmidt-Thomè et al., 2014; Tomitsch and Haeusler, 2015; Stratigea et al., 2015). The emergence of new expressions such as urban informatics, community informatics, e-planning and urban technology,

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and computing, just to mention some, is a clear indicator of their increased use in cities (Gurstein, 2007; Silva, 2010; Zheng et al., 2014).

The availability of ICT and digital technologies and their application in urban areas and in several sectors (i.e., public transportation, traffic management, governance, energy) have certainly contributed over the last 20 years to the emergence of the smart city concept, even though a shared and single definition of smart cities does not exist (Albino et al., 2015; Caragliu et al., 2011; Hollands, 2008; O'Grady and O'Hare, 2012; Stratigea et al., 2015). Within such a framework and under the wider umbrella of the smart city concept, the present work has sought to apply the concept of *infostructures* – which could be defined as targeted small interventions that rely on digital and information technologies to improve the flow of information and data available to citizens (Tomitsch and Haeusler, 2015) – to the post-earthquake city of L'Aquila, Italy, and its system of urban mobility.

At the moment of writing, eight years after the earthquake, L'Aquila still represents a challenging context. The earthquake destroyed the whole city center and part of its suburbs, disrupting the daily life of citizens (Valenti et al., 2013). Thousands of people were left without a home temporarily. The national government, not without criticisms (Özerdem and Rufini, 2013), responded by building and providing new homes (Progetto CASE and MAP) in different locations spread out within the municipal boundaries (See Figure 1). As a consequence, the bus network, the only means of public transport in L'Aquila, faced greater challenges to serve the population, as described in Castellani (2014) with reference to secondary school students.

The public investment for the reconstruction of the private and public parts of the city has been considerable – 11.9 billion euros have been earmarked, 6.4 of which has already been delivered, for all the municipalities hit by the earthquake, and about 3.5 billion euros for L'Aquila only (CIPE, 2016; USRA, 2016). Given the considerable amount of money that is being spent on the physical reconstruction of private residential buildings of L'Aquila, the infostructure approach proves an implementable paradigm for the improvement of urban services towards a smart city model. This work, inspired by the open data and open source philosophy applied to the field of urban mobility in the challenging context of post-earthquake L'Aquila, contributes to an improvement in the quality, amount, availability, accessibility, and management of public transport-related information and data. With regard to the public transport system, the infostructure approach guided us towards the choice, development, and production of new digital tools, data, and information (GTFS open source editor, web-based trip planner, GTFS data and geo-referencing of public transport information such as bus stops and lines) that were never available before in L'Aquila and that would improve access to the public transport service for citizens. As a consequence, the application of the infostructure approach and digital technologies in the context of L'Aquila aims to contribute to improving the *living* and *mobility* elements of the smart city concept showing that a transition to smartness can be initiated without huge investments.

The main goal of this article is to show a technological strategy (i.e., a process and related data) necessary to improve a public transport service with little investment. The proposed technological strategy can be generalized and applied to other medium-sized cities like L'Aquila which (1) have an important administrative role as regional or provincial capital cities, and (2) struggle at solving the challenge of providing satisfactory ICT services for the mobility of their citizenry.

For these reasons, the target audience of this article is academics, policymakers, and local transport authorities. More specifically, academics can be interested in

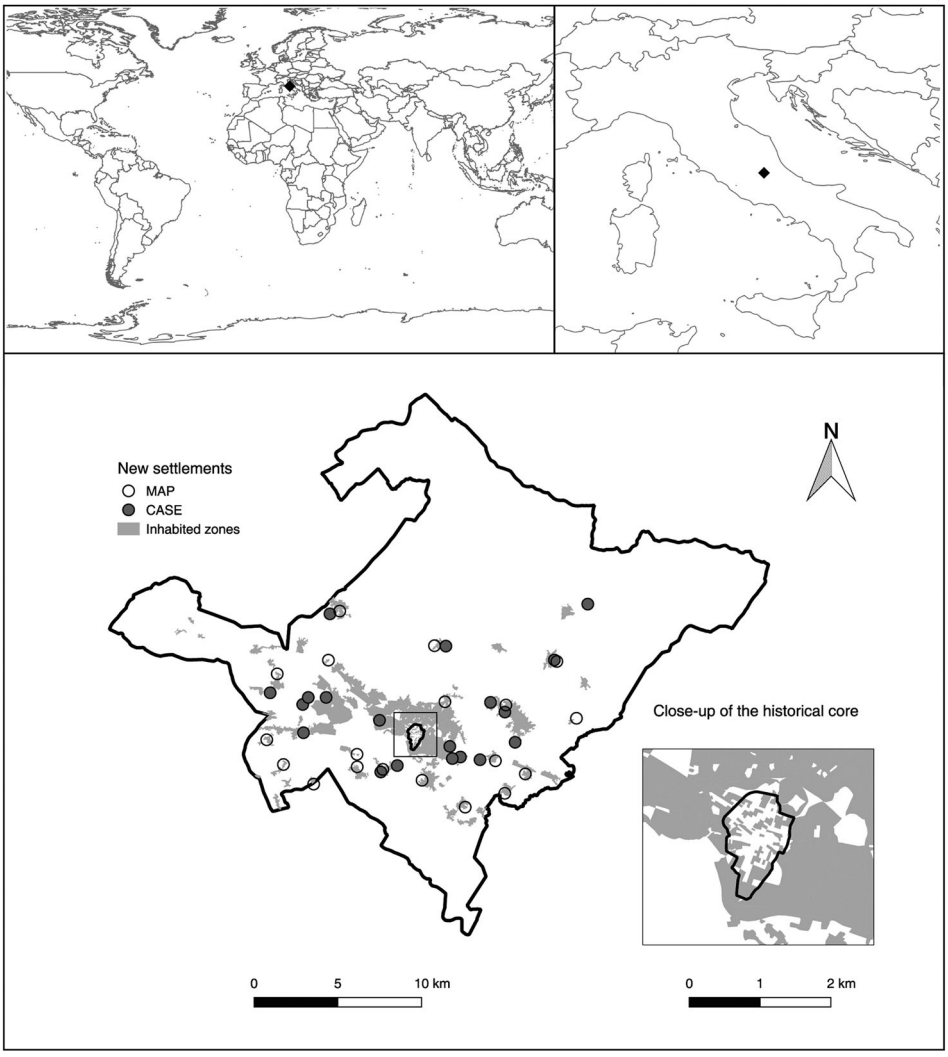


Figure 1. Post-earthquake changes in the spatial structure of L'Aquila: new settlements and the abandoned historical core. Sources: 2011 Census; Protezione Civile, 2016

understanding how a technological strategy based on open-source technologies can be defined and tailored to medium-sized cities with characteristics similar to those of L'Aquila; policymakers and local transport authorities can be interested in understanding, evaluating, and possibly replicating the proposed technological strategy in order to improve the access to the public transport services for their citizens, thus making a positive impact on their quality of life.

The tools and data discussed in this paper have already been presented to the citizenry, public administration staff, and mayor of L'Aquila in the context of the third "Forum on L'Aquila" organized by the Gran Sasso Science Institute on December 14, 2015 (GSSI YouTube Channel, 2015). At that forum, the mayor of the city expressed interest in a further collaboration on the topic for the implementation of the new tools in the future.

The software infrastructure realizing the proposed technological strategy has been implemented and is (partly) available as open-source project. However, its actual deployment and operationalization has not been carried out yet since more work needs to be undertaken by the municipality itself, especially in terms of GTFS data production and adoption of the new technology. This article therefore aims to create awareness of ICT-related opportunities in the field of urban mobility and to the development of mobility and GTFS data applications with the development of specific software.

This article is structured into four main parts. In the first one, the concepts and approaches of smart cities and infostructures are briefly presented as the conceptual basis upon which the work has been developed. The second part presents the local context of L'Aquila and specifically the local transportation system, describes the process of producing the geospatial data and shows one exemplary application of the data that has been produced. That is followed by sections that describe how the applications and software have been developed. Following that, we discuss the key technical decisions we made when designing the proposed software suite, focusing on how they can contribute to the smart cities agenda and their relation to the infostructure approach. The final section sets out the conclusions. Future research efforts will be aimed at employing the data and tools that have been developed in the context of this research for the analysis of the spatial accessibility via public transport of several points of interests (e.g., city center, university facilities, hospital, CASE public housing projects) in post-earthquake L'Aquila.

L'Aquila: A Smart City

Various definitions of a smart city are present in the academic literature. Albino et al. (2015) provide a thorough account of the available definitions and of the evolution of the concept over the years. Emphasis is on the elements of a smart city that can vary from use of technologies to a strong governance-oriented approach, which emphasizes the role of social capital in urban development, to the importance of higher education and knowledge economy (Winters, 2011). Thus, the concept is not limited to the use of ICT in cities but embraces people, governing bodies, institutions, and community needs (Albino et al., 2015).

The elements that characterize a smart city are various and change in relation to the definition of a smart city that we want to consider. A classification that appears to be particularly interesting in our case, since it is also used by the Osservatorio Nazionale Smart City (ONSC) (Italian National Smart City Observatory), is provided by Giffinger and Gudrun (2010) who identify six smart elements: people, environment, economy, living, mobility, governance. L'Aquila, according to the ONSC, ranks 91st out of 116 provincial capital cities, so it does not seem to be performing well (Ernst and Young, 2016: 15). However, L'Aquila was awarded the SMAU "Smart Communities Milano 2015″ award for the project L'Aquila Smart City: Rete Elettrica Intelligente e Mobilità Verde (Smart Electric Grid and Green Mobility). The details of the project can be found at the website of the SMAU event (SMAU, 2015) and confirm the great investment and amount of financial resources in infrastructure improvements, especially for the smart electric grid that will provide charging stations for electric cars (the latter represents the green mobility action). The project cost is estimated to be around 16 million euros and

is entirely financed by the national government. This reinforces our thesis based on the infostructure approach that aims to improve the city's public transportation service through the development and use of open data and digital technologies. Our focus is on smart mobility and particularly on the "availability of information and communication technologies" as one of the elements that make mobility smart (Giffinger et al., 2007: 12) to improve the service, especially for weaker social categories such as seniors, students, and immigrants (see Castellani, 2014 for work on public mobility and secondary school students). Examples of ICT used to improve the quality of public services and the relationship and communication between citizens and government officials abound in the literature (e.g., Emotional Maps, FixMyStreet, FixVegas, PhillyWatchDog, SeeClickFix, Ushaidi). Reviews and examples of many web and mobile applications are discussed by Anastasiu (2012), Desouza and Bhagwatwar (2014), Ertiö (2015), and Panek and Benediktsson (2017).

Urban mobility is a fertile field for the application of ICT. Examples range from traffic and parking control, app-based bike and car sharing services, on-trip information, and of course travel planning (EC, 2012). The impact of ICT on public transport users is emphasized by Cano Viktorsson (2016) who highlights that such uses of ICT can lead to increased knowledge and changes in attitudes and behaviors. Moreover, as highlighted by some authors (Baron, 2012; Meier, 2012), the application of ICT technologies can also help communities become more resilient to disasters and crises and better adapt to new situations after a shock – e.g., new bus schedules and routes after the earthquake, wireless communication and warnings after Hurricanes Sandy in New York and Katrina in New Orleans (for the evolution of the connotations of the term resilience in different disciplines with regard to the built environment, see Amaratunga and Haigh, 2011). ICT can also contribute to increasing the participation and engagement of citizens in public policies and government decision-making (Linders, 2012; Meijer, 2012; Skoric et al., 2016), which is a fundamental strategy for increased post-disaster resilience as disasters manifest a democratic deficit (Calandra et al., 2014; Castellani, 2014).

The next section will present the context of post-earthquake L'Aquila with an explicit focus on public mobility after a brief general introduction.

Context: Post-Earthquake L'Aquila and Its Public Transportation System

L'Aquila, the capital of the Abruzzo region, despite its high-ranking administrative status, is a town of moderate size. Some symptoms of economic stagnation were perceptible in this mountainous, peripheral region already before the earthquake. In recent decades, L'Aquila has benefitted much less from economic growth than maritime zones like the Pescara-Chieti-Montesilvano agglomeration. Historically, L'Aquila has been considered a part of Italy's southern regions, i.e., of the so-called *Mezzogiorno*.

The city of L'Aquila is characterized by a dispersed settlement structure, because the approximately 70,000 residents are spread over an area of 474 km^2, giving an average population density of less than 150 persons per km^2. Population is split between the relatively small and compact core and a number of smaller settlements (*frazioni*), with a large part of the municipal territory being composed of high mountain areas (the Gran Sasso chain), and therefore not inhabited at all. The dispersed settlement structure offers challenging conditions for the development of an efficient public transportation system.

The automobile appears to be a strongly preferred means of everyday commuting in L'Aquila. In general, driving is more common in Italy than in Western and Northern Europe, and within Italy itself the south is more automobile-dependent than the north (Istat, 2011). Generally, in cities of the *Mezzogiorno* public transportation tends to play a less important role than in the north. In the south, city residents use public transportation almost twice less frequently compared to their northern counterparts. Also, they express more dissatisfaction with the quality of public transportation services (Istat, 2011: 16).

Even accounting for the regional differences, the supremacy of automobile commuting in L'Aquila is remarkable. The city is characterized by an exceptionally high motorization rate, which amounted to 745 automobiles per 1,000 residents as of 2011, compared to the average value of 614 automobiles per 1,000 residents in the largest Italian cities (Istat, 2011: 3–5). Over 90 percent of commutes to work, and nearly 70 percent of commutes for study purposes were effectuated by cars (See Table 1). Interestingly, most commuters traveling to work were drivers not accompanied by any passengers. While automobile commuting had been widespread already before the earthquake, the share of car traffic increased after the quake. It appears that the increase occurred mostly at the expense of pedestrian traffic, since the post-earthquake changes in spatial structure (i.e., the new settlement projects) tended to increase distances between home and workplace. Only in the case of trips to school has the public transportation slightly gained in importance, while in the case of trips to work its role remained marginal.

During the first months following the 2009 earthquake certain measures were undertaken in order to adapt the public transportation system to the emergency situation. For example, the length of the public transportation network has been extended by about 20 percent in order to reach the new settlements, and ticket fees had not been collected until August 1, 2011 (Comune dell'Aquila, 2012: 15). However, it appears that in the longer run public transportation is not perceived as a feasible alternative to the automobile.

The reconstruction after the April 6, 2009 earthquake has profoundly changed the spatial structure of L'Aquila, by shifting functions, creating new development poles, and further decentralizing the already dispersed urban population. The national government decreed the construction of new settlements for households displaced by the earthquake,

Table 1. Modal split of trips to work and study in L'Aquila, before and after the earthquake. Sources: Comune dell'Aquila, 2012; Istat, 2016

	Commutes by purpose			
	Work		Study	
Means of transport	2001	2011	2001	2011
Automobile – total	79.5%	91.9%	56.2%	68.8%
Automobile – driver	–	86.6%	–	13.4%
Automobile – passenger	–	5.3%	–	55.4%
Motorcycle/motor scooter	1.0%	0.5%	3.4%	0.8%
Train	0.0%	0.1%	0.0%	0.0%
Bus	3.5%	3.2%	24.4%	26.3%
Bicycle/pedestrian/not declared	16.0%	–	16.0%	–
Bicycle	–	0.1%	–	0.1%
Pedestrian	–	3.9%	–	4.0%
Other	–	0.2%	–	0.1%

sometimes referred to as "new towns." They include 19 CASE projects (*Complessi Antisismici Sostenibili ed Ecocompatibili*) for a total of approximately 15,000 residents, and 19 MAP projects (*Moduli Abitativi Provvisori*) for about 2,000 residents. According to planning guidelines, these new settlements ought to be constructed in the proximity of existing built-up areas and the places of origin of the displaced persons (Comune dell'Aquila, 2014). However, in reality most settlements have been located in the periphery of the city, and in this way they contributed to strengthening the already dispersed urban tissue of L'Aquila (See Figure 1).

Research has shown that the residents of the new settlements show more propensity to move to another place of residence (Contreras et al., 2013). However, relocation would not necessarily imply returning to the previous place of residence, as the reconstruction in large parts of the city has not yet been completed. Post-earthquake changes in the settlement structure are more than just short-term displacements, and all these changes have profoundly affected urban mobility in L'Aquila (LAURAq, 2010: 44). However, it is not clear how the system of public transportation should adapt to the new conditions. There have been several studies focusing on various aspects of the reconstruction and recovery after the 2009 earthquake (see e.g., Alexander, 2013; Cofini et al., 2014; Contreras et al., 2013; Özerdem and Rufini, 2013), but the subject of public transportation in post-earthquake L'Aquila has not been addressed so far.

The public transportation system of L'Aquila is in need of substantial investments, both in regard to the fixed infrastructure (especially the bus terminal Collemaggio, but also the minor bus stops), and to the bus fleet. However, in a city still struggling with the reconstruction of the historical core, the improvement of public transportation is actually just one of many objectives, and apparently not one of the most urgent ones.

In 2012 the city of L'Aquila updated its urban mobility plan (piano urbano mobilità; PUM). The previous version of the plan originated in 2008, but after the earthquake many revisions were necessary. According to this document, the future system of public transportation in L'Aquila should be based upon three main elements: (1) suburban railway, (2) bus rapid transit, called "Metrobus," (3) electric buses in the area of the historical core (Comune dell'Aquila, 2012). The suburban railway should connect peripheral districts located to the west and to the east with the core of the city, using the already existing regional railway corridor. Bus rapid transit is intended to complement the railway system, including two lines also running from west to east, but serving districts more distant from the railway corridor. In part it would follow the route of the abandoned monorail project. The urban mobility plan also foresees the construction of a cable car between the historical core and the university campus. Looking at the vision of the future of the urban mobility plan, it is hard to avoid the impression of discrepancy between the present situation and the desired state. Both the suburban railway project and the bus rapid transit system would require substantial infrastructural investments, and, therefore, they are strongly dependent upon the availability of external funding.

In our paper, we argue that improvements in the quality of public transportation could also be made incrementally. Public transportation investments in L'Aquila are necessary due to long-time neglect, and the post-earthquake reconstruction only made the needs more evident. Having this in mind, we suggest looking beyond the logic focused only on physical investments. The climate of the first years after the earthquake and the availability of reconstruction funds fostered thinking in categories of large infrastructural

projects. However, some steps towards sustainable and smart mobility in L'Aquila could be made even without large infrastructural spending. The recent turn towards "infostructures" deserves particular attention here.

In this regard, the use of geospatial data in conjunction with ICT could open many new possibilities. The objective of our project was twofold: first, to create geospatial data for L'Aquila related to the public transportation system, and second, to develop software tools in which these data could be used for both analytical and practical purposes. The next section gives an overview of what has already been achieved in the production of geospatial data for L'Aquila, what obstacles have been faced, and what could be the next steps. Then, the following sections present the process of developing the software tools.

Geospatial Data for L'Aquila

An initial overview has revealed that the availability of geo-referenced data related to the system of public transportation in L'Aquila was fairly limited. The creation of a geo-referenced database, under the framework of the project, has been focused around the following elements: (1) the network of the public transportation system, composed of nodes (bus stops) and connections (bus routes), (2) the general transit feed specification (GTFS).

Data on the location of the bus stops were drawn from the local public transportation company (*Azienda Mobilità Aquilana*; AMA). They were available in the CSV (comma separated values) file form and have been translated into shapefile format. Apart from the latitude and the longitude of each stop, data also included a short description of the location, and in some cases also a link to a pdf file with additional information. This information included a list of all the lines that pass through the stop, and the QR codes that link to the timetables of each line (See Figure 2). In total, the database contains 1,058 bus stops, counting stops in opposite directions separately.

Figure 2. Example of information linked to the bus stops in the database and provided to passengers on selected stops. Source: AMA

The geo-referencing of the bus network was a longer process. On the website of the AMA, only a generalized graph of the network and the maps of selected routes in pdf format were available. For the other routes, the timetables (also drawn from the AMA website) were the main source of information. The timetables show the itineraries of each route as well as stop times for the major stops. For the residual stops, not included in the timetable, it was necessary to interpolate them to a route, using supplementary data when necessary. For example, the routes' information linked to the bus stops through a web link was used for that purpose. The routes' shapefiles were created using the user-contributed Open Street Map database as a basis, in order to assure coherence of the database of geo-referenced routes with the actually existing roads network of L'Aquila. The results of the geo-referencing of the bus stops and lines are given in Figure 3.

The second part of the geo-referencing process was related to the general transit feed specification. The GTFS is a standard of data formatting used in trip planners. From a technical point of view, it is a set of files containing comma-separated values. The creation of a GTFS is a time-consuming process, and in the case of L'Aquila it turned out to be particularly complicated. Beside that the stop times are only given for the major stops of each line, a major difficulty resulted from the organization of bus routes. In L'Aquila, apart from the main bus lines, which are denominated by numbers, there are also a number of sub-lines, additionally indicated by letters. For example, for the main line No. 11, there are also the following sub-lines: 11T, 11L, 11R, 11T, M11T, and 11Y (See an example of timetable in Figure 4). Each of the sub-lines follows a slightly, or even a significantly different route. It is partly a consequence of the dispersed settlement structure of L'Aquila, and of the necessity of providing public transportation services to all the different districts. A practical consequence is that the number of routes that would need to be codified in the GTFS would be very large. Due to this, only a pilot phase of the GTFS creation for L'Aquila, including two lines, has been realized so far. If more staff and possibly also financial resources become available, it would be highly recommendable to proceed with the creation of the full GTFS, which could be used not only for practical purposes (e.g., online trip planning) but also for analytical ones. The initial work with the creation of the GTFS could be used as a starting point in this regard.

The geospatial data for L'Aquila that have been produced during the project have a potentially broad spectrum of applications, ranging from accessibility analyses, online trip planning, to bus network optimization. Here we would like to demonstrate just one exemplary application of the data for a spatial accessibility analysis of post-earthquake settlements for displaced persons (CASE and MAP).

For the purpose of the accessibility analysis, a range of 400 m from the bus stop has been chosen as the accessibility threshold. In the literature, distances ranging from 200 to 800 m have been suggested as a threshold of transit accessibility, but typically authors assume distances ranging from 400 to 500 m (Demetsky and Lin 1982; Zhao et al. 2003). Based on the 400 m threshold, which translates into a real walking distance of approximately 500 meters, a buffer has been created around each stop of a single bus route, for a total of 19 routes. Census tracts and new settlements were assigned a value of 1 or 0 depending on whether or not they were located within the buffer (census tracts were also considered accessible if only partially within). For the census tracts, the accessibility was calculated for the resident population. For the CASE and MAP projects population data was not available, so only the number of projects was considered.

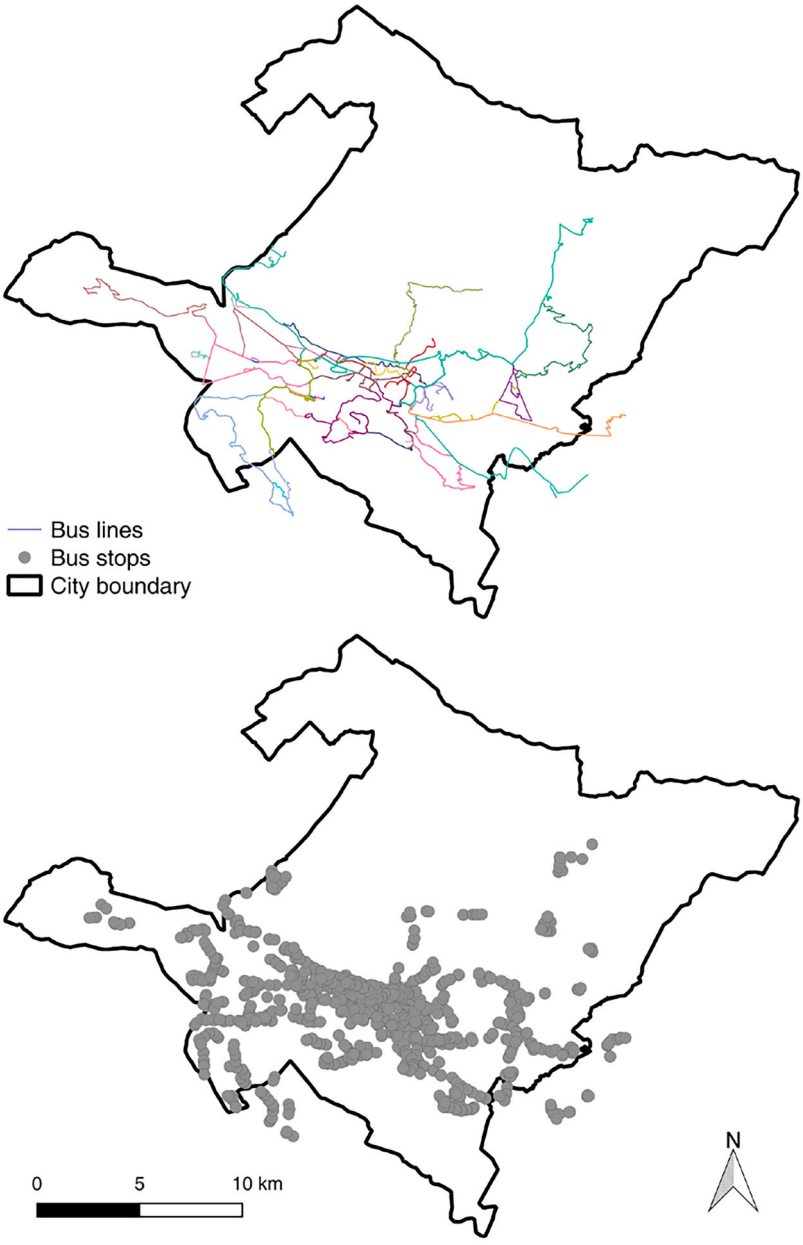
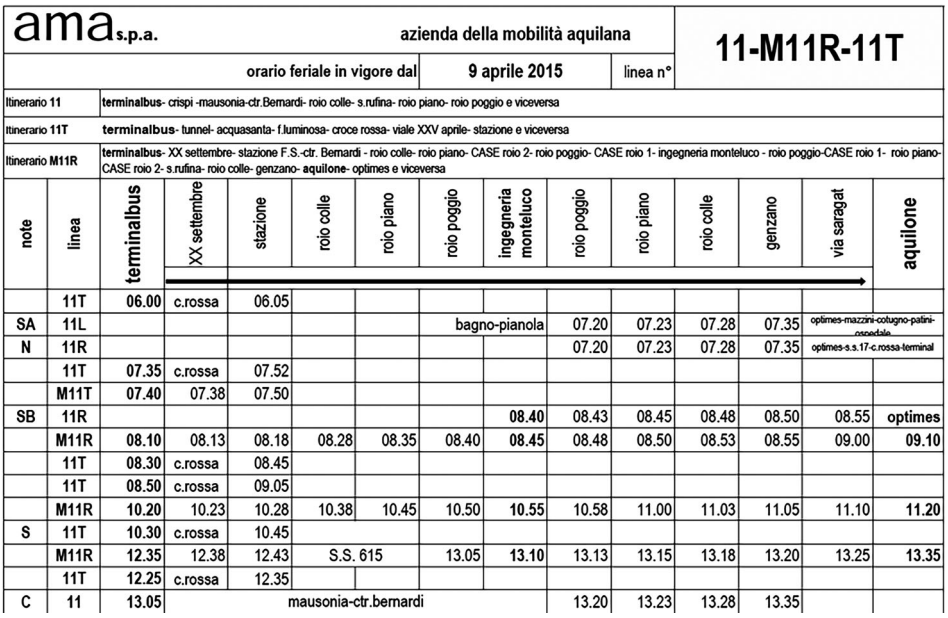


Figure 3. The geo-referenced bus stops and bus lines of L'Aquila. Source: authors' elaboration

Results show a significant difference in accessibility of the bus network between the residents of the new settlements and the rest of L'Aquila population (See Table 2; Figure 5). The population of L'Aquila could be roughly divided into two groups, with about one third residing in areas where the spatial accessibility of the bus network was at least satisfactory or good (five or more routes available). However, for the residual two-thirds, the accessibility of public transportation was limited, and every fifth resident only had access to a single route or no routes at all. In contrast to this, all the residents of



ama s.p.a. azienda della mobilità aquilana **11-M11R-11T**

orario feriale in vigore dal 9 aprile 2015 linea n°

Itinerario 11 **terminalbus**- crispi -mausonia-ctr.Bernardi- roio colle- s.rufina- roio piano- roio poggio e viceversa

Itinerario 11T **terminalbus**- tunnel- acquasanta- f.luminosa- croce rossa- viale XXV aprile- stazione e viceversa

Itinerario M11R **terminalbus**- XX settembre- stazione F.S.-ctr. Bernardi - roio colle- roio piano- CASE roio 2- roio poggio- CASE roio 1- ingegneria monteluco - roio poggio-CASE roio 1- roio piano-CASE roio 2- s.rufina- roio colle- genzano- **aquilone**- optimes e viceversa

note	linea	terminalbus	XX settembre	stazione	roio colle	roio piano	roio poggio	ingegneria monteluco	roio poggio	roio piano	roio colle	genzano	via saragat	aquilone
	11T	06.00	c.rossa	06.05										
SA	11L						bagno-pianola		07.20	07.23	07.28	07.35	optimes-mazzini-cotugno-patini-ospedale	
N	11R								07.20	07.23	07.28	07.35	optimes-s.s.17-c.rossa-terminal	
	11T	07.35	c.rossa	07.52										
	M11T	07.40	07.38	07.50										
SB	11R							08.40	08.43	08.45	08.48	08.50	08.55	optimes
	M11R	08.10	08.13	08.18	08.28	08.35	08.40	08.45	08.48	08.50	08.53	08.55	09.00	09.10
	11T	08.30	c.rossa	08.45										
	11T	08.50	c.rossa	09.05										
	M11R	10.20	10.23	10.28	10.38	10.45	10.50	10.55	10.58	11.00	11.03	11.05	11.10	11.20
S	11T	10.30	c.rossa	10.45										
	M11R	12.35	12.38	12.43	S.S. 615		13.05	13.10	13.13	13.15	13.18	13.20	13.25	13.35
	11T	12.25	c.rossa	12.35										
C	11	13.05	mausonia-ctr.bernardi						13.20	13.23	13.28	13.35		

Figure 4. Example of timetable for a line with a number of sub-lines. Source: AMA

the new settlements had limited access to the city's bus network. Half the settlements were only accessible by a single route, and none of them had access to more than three routes. In practical terms, it meant that the residents of the new settlements had few incentives not to use automobiles in their daily commutes. The limited accessibility of public transportation could negatively affect those without a private means of transportation, including adolescents and seniors.

In the future, it will be possible to use the data produced during the project for other purposes. Here, only the spatial aspects of accessibility were taken into consideration, but the temporal aspects surely also deserve attention. The GTFS editor, which is described in the following part of the paper, would allow some insights into the temporal aspects of mobility. In conjunction with GTFS data, it would facilitate the creation of an online trip planner for L'Aquila, which in turn could be a starting point for a data-informed optimization of the bus network.

Table 2. Number of bus lines accessible from census tracts and new settlements. Source: authors' elaboration

No. of Accessible Bus Routes	Population in Census Tracts	Percentage of Population	CASE and MAP Projects	Percentage of Projects
null	329	0	–	0
one	11598	17	19	50
two	14223	21	14	37
three	16090	24	5	13
four	2474	4	–	0
five	786	1	–	0
six	3265	5	–	0
seven	1192	2	–	0
eight or more	17007	25	–	0

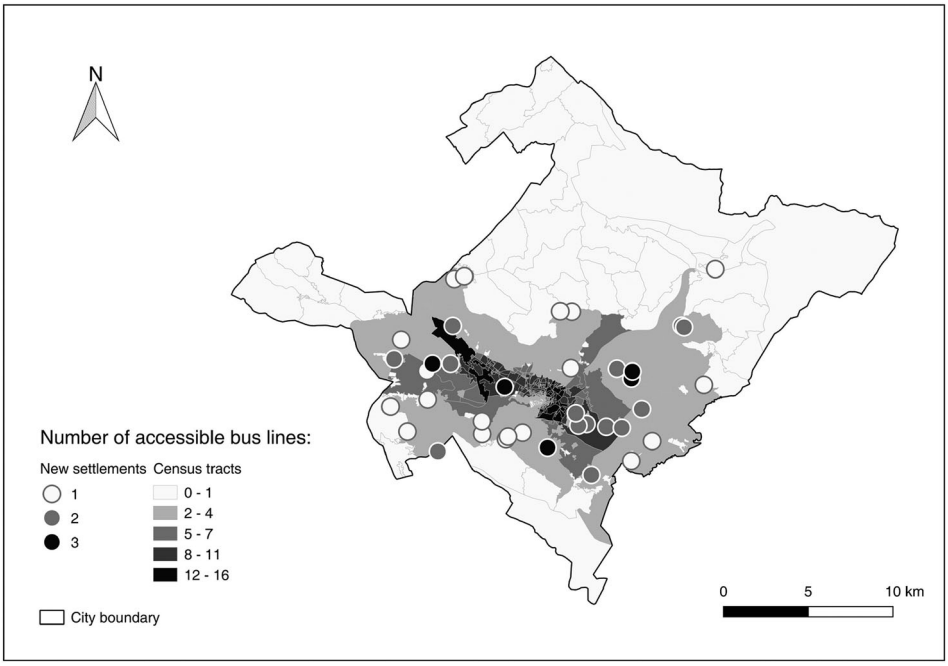


Figure 5. Spatial accessibility of the bus network in L'Aquila. Source: own elaboration

The Proposed Software

In order to achieve the goals and results presented in the previous sections, we designed and developed a set of software applications and tools. The proposed software suite is based on BusOnAir (http://github.com/lorenzosfarra/busonair), an open-source project developed in collaboration with the University of L'Aquila, the Gran Sasso Science Institute, and the Vrije Universiteit Amsterdam. BusOnAir is a generic information system with three main drivers: (1) to efficiently manage static and real-time information about public transportation systems, (2) to make such information available to the user by means of a dedicated responsive web app, and (3) to make such information available to third-party developers as open data. The software architecture of BusOnAir has been extensively studied, analyzed, and validated from a software engineering perspective (Hilliard et al, 2012; Malavolta, 2012) and it is represented in Figure 6.

From a high-level point of view, the BusOnAir system is composed of three main subsystems, each of them deployed in a dedicated physical server:

1. The **front-end** subsystem hosts a web app dedicated to citizens and can perform the following tasks: (1) consult the static timetable of all the bus routes of the managed network, (2) find the more convenient bus stop in order to reach the destination, and (3) provide the timetable of a given bus stop. The web app has been developed following the responsive web design approach, aimed at building websites that provide an optimized view and user interaction among a wide variety of devices (e.g., desktop computer and mobile phones). The next section details the front-end server subsystem.

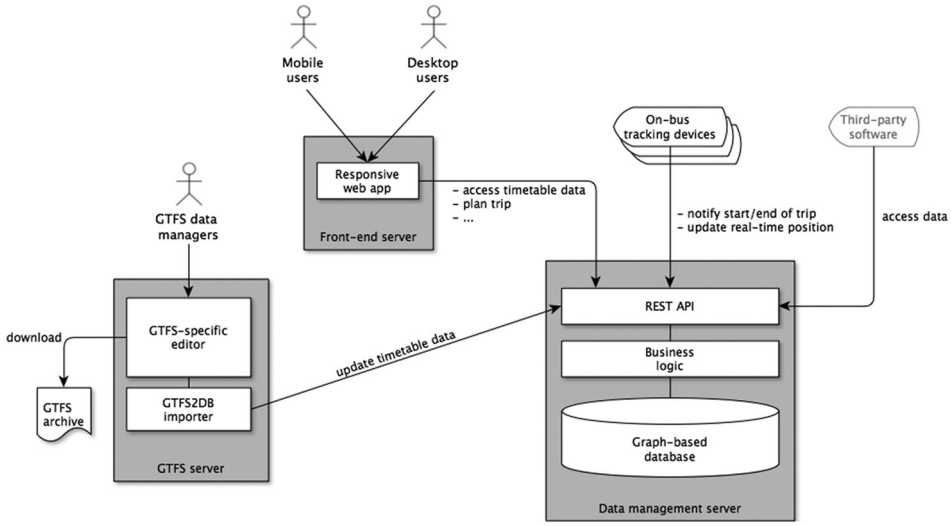


Figure 6. Architecture of the proposed software

2. The **data management** subsystem is responsible for storing and preserving data, mainly related to travel agencies and their services including bus routes and timetables, and distributing them to the clients. This subsystem is structured around the two following components. The first one is a graph-based database that provides optimized performances while processing the typical data types involved (e.g., timetables, routes, stations, stops). The second component is a REpresentational State Transfer (REST) API that provides read, write, and update access to data. This API has optimized methods for bulk operations (e.g., periodic timetable updating), as well as for more time-constrained operations such as updates related to an actual bus position. Moreover, a specialized set of API methods is dedicated to trip planning. The communication between the REST API and the graph-based database is mediated by a software layer dedicated to: (1) validating data consistency, (2) granting API access only to authorized users, (3) maintaining a log of all users operations for security purposes, (4) calculating statistics about transport services and securely storing results at predefined intervals.
3. The **GTFS** subsystem hosts a web-based dedicated editor for creating and managing public transportation transit data, schedules, and associated geographic information. Here the main goal is to allow non-technical stakeholders (e.g., a transit service manager of a public transit agency) to create, edit, and maintain public transit data. We decided to design this editor relying on the well-known and accepted General Transit Feed Specification (GTFS) format, proposed by Google and acting as a de facto standard for specifying and exchanging public transit data across the world.[1] Our platform allows GTFS data managers either to directly send the data to the data management server to update current transit data in the graph-based database, or to download it as a stand-alone archive for further analysis with third-party tools.

BusOnAir is designed to be extremely flexible and to easily accommodate needs that may arise in different contexts, involving other cities or different agencies. This adaptability is a

key aspect of the whole project. BusOnAir's REST API publicly exposes transit data by following the principles of the open data movement (Kitchin, 2014).

Responsive Web Front-End

In this section we provide details about the BusOnAir web application, a useful tool to obtain information about lines, bus routes, and the position of bus stops. BusOnAir Web offers several services as part of the larger web application, as follows:

- a route planner which shows the directions for users of the public transportation service travelling from one specific location to another
- timetables at various stops
- a list of all bus lines by public providers.

Figure 7 shows a screenshot of the web application. This tool is able to automatically geolocate the user in order to immediately provide the user with his/her location within the city. The web application provides an interactive map of the city and, on the left panel, the two main services offered by the web platform:

- Trip planner
- Routes

As shown in Figure 7, selecting one of the routes, e.g., M11, the app shows the user the associated path on the map. The user is thus able to check the departure and terminus points (markers A and B) and the numbered markers in between indicating the main locations travelled by the route.

As shown in Figure 8, the trip planner also allows the user to specify departure and arrival locations (either as text or via interactive markers on the map) and shows multimodal information, combining buses with walking, to reach the destination.

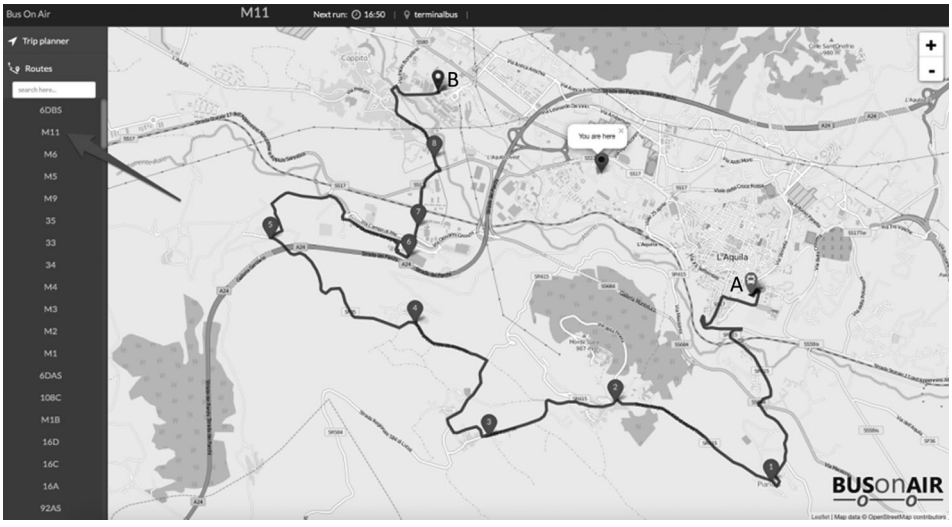


Figure 7. Routes menu

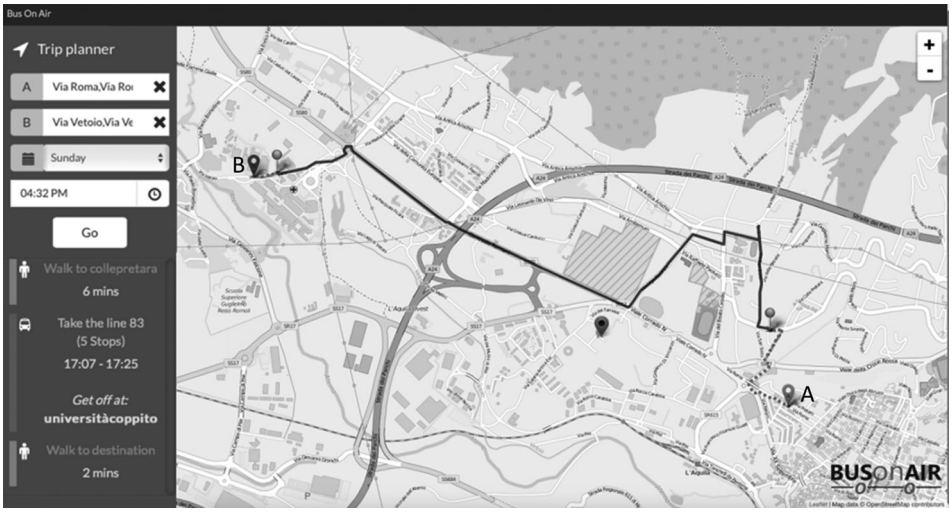


Figure 8. Trip planner form, route visualization on map, and textual representation of itinerary

Graph-Based Data Management

In this section we describe our data management subsystem, discussing the design decision of storing transit service data in a graph-based database; indeed this is one of the novelties of our fast and efficient software infrastructure. We have implemented the data layer using Neo4J (The Neo4J Team, 2016). A graph-database (graph-db) uses graph theory (West, 2001) to map, store, and query relationships between entities. In a graph-database each node corresponds to an entity of the domain (e.g., a bus stop, a route, etc.). Nodes can contain attributes representing their own main characteristics (e.g., name of a bus stop, unique identifier of a route). As of today the majority of implementations of graph databases have a strong focus on performance and scalability, making them good candidates for being used in production-ready software systems.

Graph-based databases are well-suited for analyzing interconnections and working with data in business domains that involve complex relationships such as the travel and transport industry. One of the main benefits of graph-databases is that developers can reuse built-in and well-known algorithms for solving common problems, such as computing the "shortest path" between two geographical locations. Moreover, in some domains (like the transportation one) the use of graph-based databases improves the quality of the design of the application since software architects and developers are able to map the domain model to the data model, reducing the gap between the business and IT. Graph database implementation increases performance, since it can traverse millions of relations in a fraction of the time, which is unthinkable for relational databases. Queries are faster than in relational databases, so the performance of the entire application is optimized. With their flexible data models, graph databases can be easily adapted to business changes and software evolution (this is important for an evolving field such as that of public transportation technology).

For what concerns the database model, we extended the Simplified Time Expanded model (Pyrga et al., 2007) and the concepts for the domain we modeled can be summarized as follows:

- Station: contains an index (time based) of every the stop associated to itself
- Route: is a graph path represented with a set of stations
- Stop: represents a node with the attributes *Time* and *Static Time* to manage delays
- Run: is an instance of Route with the specific timetable and all the expected checkpoints
- Departure: is the starting node for a route
- Arrival: is the destination node for a route.

Our data management subsystem communicates with the rest of the proposed architecture via the REpresentational State Transfer (REST) architectural style. REST has been defined by Roy Thomas Fielding in 2000 and since then it has received increasing attention both from academia and research (Fielding, 2000). Indeed, most of the current web applications (e.g., YouTube, Google Maps, Twitter, Digg, etc.) provide their services by means of a REST interface. A RESTful web service is also called a RESTful web API, and it realizes a simple web service implemented through HTTP and the principles of REST. Our data management subsystem follows this technological trend and provides the data collected from the database using the REST API layer in combination with the plugins accessing the database layer. The REST API layer provides data in response to HTTP requests that may be performed by any kind of client (e.g., a mobile app, an Internet-of-Things device, a third-party server, etc.).

Managing GTFS Data

Our goal is to support analyses of the transit system in L'Aquila and enable a modern use of this system by riders. The tools supporting these objectives consume structured information representing the actual model of the transit system. At the time of writing, two are the main open standards for representing transit models:

- The European Transmodel (formally CEN TC278, Reference Data Model For Public Transport, EN12896)
- General Transit Feed Specification (GTFS) (an open standard produced initially by a collaboration of Google with the Trimet Transit Agency).

Among the relevant factors to take into account when choosing a model, we considered the availability of data in an already usable structured format and the support tools already in use by the main stakeholder, namely the municipal public transport agency AMA. The main source of information came in a flat CSV file form, containing partial stops details and other unstructured information from the AMA's website. Lack of information regarding adopted tools within AMA and the need for important supplementary information gathering was immediately evident. In this scenario the production of open data available for analysis and public utility was not limited to the selection and conversion of structured data to be shared with the public: a phase of real construction of the dataset itself was needed.

Within such a context and bearing in mind our initial goals related to public benefits, such as an improved passenger experience, transport analysis and planning, we chose the simplest open model: GTFS. This standard guarantees a lightweight software

implementation that requires developers with no specific background in the topic. It also allows the main efforts to be focused on the collection, reconstruction, and analysis of transit data. Leaving out the complexity of a full-featured model, we still have all the necessary information for the citizens on available services, and a number of tools, like Open Trip Planner Analyst, for performing analyses.

Until now many GTFS-based datasets, especially from the general public or small agencies, have been produced using directly text editors or spreadsheets, as for example the US Rural Transit Assistance Program (http://www.nationalrtap.org/Web-Apps/GTFS-Builder). This process is error prone and makes it difficult to update and manipulate data with the well-known usual frequency. In light of this, we propose a new open-source software application to manage, manipulate, produce, and export GTFS data in a collaborative manner. Our software application has been developed using the latest, state of the art open source web technologies such as HTML5, CSS3, JavaScript, and AngularJS. This tool provides a simple and straightforward way to specify all the needed transit information without being an expert. Visual help, like maps (See screenshot in Figure 9), makes it possible to directly place bus stops, and auto-completion functions help to solve simple doubts on stop names, location, or other similar issues.

The current version of our GTFS editor promotes collaboration among users and transit agencies that can upload data in large CSV files produced by their own software, or even directly in GTFS format. Thanks to the web nature of our GTFS editor, volunteers are able to collaborate from any point at any time with a very small initial learning step. It is possible, at any moment, to get updated GTFS files from the web application.

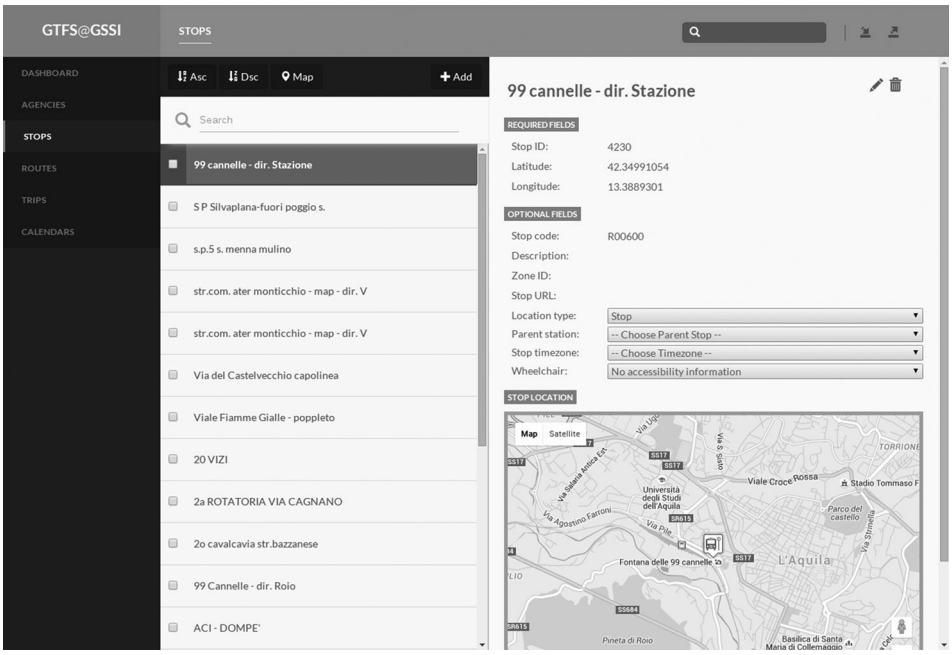


Figure 9. A screenshot of our GTFS editor

Discussion

In this section we discuss the key technical decisions we made when designing the proposed software suite, the ways those decisions can contribute to the smart cities agenda, and the relation of those decisions to the infostructure approach. Indeed, the infostructure approach presented in the previous sections guided and mandated the whole architecture of the proposed software and influenced all our technological choices. For example, the introduction of a trip planner meant that GTFS data were needed in conjunction with the geo-referenced location of all bus stops.

Moreover, the REST API of BusOnAir is meant for making publicly available the transit data by following the principles of the open data movement. This allows third-parties to exploit our data while developing new applications in the city of L'Aquila. We hope this will encourage the growth of an ecosystem of creative developers and designers to create new and useful services for the citizenry in a sustainable and virtuous manner (this is one of the points of the smart cities agenda as well).

The production of transit data in an open exchange format like GTFS can be seen as the very first step in enabling the growth of an entire ecosystem where every transport agency could share its data with the wider community and benefit from the improvements that are brought about by other users. Transit agencies would ideally benefit from downloading updates from the web, having the opportunity to check if what they have in their official database is consistent with user perceptions. Also, end users can easily use these data within already existing third-party trip planning tools such as Transit on Google Maps; researchers can make use of these data for their research purposes and analyses. This last point is specifically important for pushing forward the scientific knowledge and understanding of various phenomena related to smart cities and the infostructure approach. For example, empirical experiments on how public transport services evolve over time in a post-disaster context are now possible and surely worth being investigated from both a scientific and a decision-making perspective.

Conclusions and Future Research

This paper has looked at the application of ICT in the urban domain in relation to the emerging infostructure approach in a post-disaster context. This approach leverages information and communication technologies to bring about important changes which require little investment while improving the flow of information, data, and ultimately services available to citizens. In this article, we have shown how the concept of infostructures can be applied to the public transportation system of a post-earthquake context, the city of L'Aquila in Italy, for the benefit of citizens, users, and the public transport agency. In a post-disaster city where billions of euros are being invested in its physical reconstruction, the application of ICT and the concept of infostructures can bring substantial benefits for the city of L'Aquila, increasing the quality of its public transportation system and providing a valuable, immediate, and easily implementable alternative.

By adopting the infostructure approach and leveraging small targeted changes through the application of ICT, the usability of public transport can be improved considerably with real-time information, trip planner options, transit data digitization, and the availability of web applications. Important steps towards a smart mobility model can be taken by

policymakers and local transport authorities and the proposed technological strategy can be replicated in other medium-sized cities where large investment resources are not available. In fact, benefits for transit agencies are also at stake since updates, changes, and improvements to transit and spatial data can come from the wider community by means of easy-to-use, open-source applications.

Such an application of the infostructure concept would contribute towards a smart mobility model for the public transport system of L'Aquila as one of the main pillars of the smart city concept. In addition to this, scholars (Baron, 2012; Meier, 2012) emphasize that the application of ICT in a post-disaster context can bring about advantages in terms of increased community resilience, an essential element for a post-disaster context.

The application of the infostructure approach to the public transport system of the city L'Aquila has consisted of two main phases: the creation of new geospatial and transit data; and software development able to generate, elaborate, and make data available to end users.

In the first phase, starting with very little geospatial data, a geospatial dataset of bus stops, lines, and connections has been created for the public transportation system that can be used in the future (See Figure 3). Transit data have also been produced with reference to a sample of bus lines. In the second phase, with regard to software development, the presented software infrastructure has been based on the open-source project BusOnAir. The main features covered by the proposed architecture can be summarized as meeting three main requirements: efficiently managing static and real-time information about public transportation systems; making public information available to the users by means of a responsive web app; providing such information to third-party developers as open data in order to encourage the development of new applications. We have presented the proposed architecture, highlighting the most important components, e.g., data importer, data layer, back-end and front-end of the system, and providing details about the main features implemented by the BusOnAir framework.

However, for the full implementation of the infostructure approach, it is not enough to have the web tools and applications ready. A pro-active and central role of the local administration is indeed required. Specifically, the local public transport agency (i.e., AMA in the case of L'Aquila) should keep working on the creation and continuous update of a full transit feed specification (GTFS) and encourage the use of the tools by the population by promoting and publicizing their availability when fully operational. Sharing the full GTFS on open repositories (see note) is also essential for involving the community of developers and improving transit data.

For future research, we are planning to extend the experiment to include private and public transportation agencies in our system and perform a public transportation accessibility analysis of major points of interests in the city of L'Aquila (e.g., new CASE and MAP settlements and public services such as the city hospital, university buildings, and schools).

Note

1. A list of public transit agencies providing public GTFS data is available at the following link: https://code.google.com/archive/p/googletransitdatafeed/wikis/PublicFeeds.wiki

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Bibliography

V. Albino, U. Berardi, and R.M. Dangelico, "Smart Cities: Definitions, Dimensions, Performance, and Initiatives," *Journal of Urban Technology* 22: 1 (2015) 3–21. doi: 10.1080/10630732.2014.942092.

D. Alexander, "An Evaluation of Medium-Term Recovery Processes After the 6 April 2009 Earthquake in L'Aquila, Central Italy," *Environmental Hazards* 12: 1 (2013) 60–73. doi: 10.1080/17477891.2012.689250.

D. Amaratunga and R. Haigh, *Post-Disaster Reconstruction of the Built Environment: Rebuilding for Resilience* (London: Wiley-Blackwell, 2011).

I. Anastasiu, "FixVegas: Facilitating Multi-Directional Communication between Government Officials and Citizens to Support Urban Planning in the City of Brisbane" (PhD thesis, Ludwig-Maximilians-Universität München, 2012).

M. Baron, "Do We Need Smart Cities for Resilience?" *Journal of Economics and Management* 10 (2012) 32–46.

G. Brown and M. Kytta, "Key Issues and Research Priorities for Public Participation GIS (PPGIS): A Synthesis Based On Empirical Research," *Applied Geography* 46 (2014) 122–136. doi:10.1016/j.apgeog.2013.11.004.

L.M. Calandra, G. Forino, and A. Porru, "Introduction. Why Hold a Session on Hazards and Disasters in the EUGEO Congress 2013?" in L.M. Calandra, G. Forino, and A. Porru, eds, *Multiple Geographical Perspectives on Hazards and Disasters* (Rome: Valmar, 2014) 5–10.

A. Caragliu, C. Del Bo, and P. Nijkamp "Smart Cities in Europe," *Journal of Urban Technology* 18: 2 (2011) 65–82. doi: 10.1080/10630732.2011.601117.

C. Casey and J. Li, "Web 2.0 Technologies and Authentic Public Participation: Engaging Citizens in Decision Making Processes," K. Kloby and M.J. D'Agostino, eds, *Citizens 2.0: Public and*

Governmental Interaction through Web 2.0 Technologies (Hershey, PA: Information Science References, 2012 767–793).

S. Castellani, "Participation as a Possible Strategy of Post-Disaster Resilience: Young People and Mobility in L'Aquila (Italy)," in Calandra, Forino, and Porru, *Multiple Geographical Perspectives on Hazards and Disasters* (2014) 105–117.

CIPE, "Ricostruire l'Abruzzo, Comitato Interministeriale per la Programmazione Economica" (2016) <http://www.cipecomitato.it/it/in_primo_piano/ricostruire_abruzzo.html> Accessed April 20, 2106.

V. Cofini, A. Carbonelli, M.R. Cecilia, and F. di Orio, "Quality of Life, Psychological Wellbeing and Resilience: A Survey on the Italian Population Living in a New Lodging After the Earthquake of April 2009," *Annali di Igiene* 26 (2014) 46–51. doi: 10.7416/ai.2014.1957.

Comune dell'Aquila, "Aggiornamento del piano urbano della mobilità" (2012) <http://www.comune.laquila.gov.it/pagina1169_il-piano-urbano-della-mobilita.html> Accessed April 20, 2016.

Comune dell'Aquila, "Assessorato alla ricostruzione, Settore ricostruzione pubblica, Settore ricostruzione privata" (2014). http://www.comune.laquila.gov.it/pagina82_normativa-e-documenti.html, Accessed April 30, 2016.

D. Contreras, T. Blaschke, S. Kienberger, and P. Zeil, "Spatial Connectivity as a Recovery Process Indicator: The L'Aquila Earthquake," *Technological Forecasting & Social Change* 80 (2013) 1782–1803. doi: 10.1016/j.techfore.2012.12.001.

M.J. Demetsky, M. Asce, and B. Lin, "Bus Stop Location and Design," *Transportation Engineering Journal* 108 (1982) 313–327.

K.C. Desouza and A. Bhagwatwar, "Technology-Enabled Participatory Platforms for Civic Engagement: The Case of US Cities," *Journal of Urban Technology* 21: 4 (2014) 25–50. doi: 10.1080/10630732.2014.954898.

C.E. Dunn, "Participatory GIS: A People's GIS?," *Progress in Human Geography* 31: 5 (2007) 616–637. doi: 10.1177/0309132507081493.

EC (European Commission), *ICT Concepts for Optimization of Mobility in Smart Cities*, DG Communications Networks, Content & Technology (Brussels: European Commission, 2012).

Ernst and Young, *Italia Smart: Rapporto Smart City Index*. Ernst & Young Global Limited (2016). <http://www.ey.com/IT/it/Services/Advisory/Smart-City-Index> Accessed September 14, 2017.

T. Ertiö, "Participatory Apps for Urban Planning-Space for Improvement," *Planning Practice & Research* 30: 3 (2015) 301–320. doi: 10.1080/02697459.2015.1052942.

J. Evans-Cowley and J. Hollander, "The New Generation of Public Participation: Internet-based Participation Tools," *Planning Practice & Research* 25: 3 (2010) 397–408. doi: 10.1080/02697459.2010.503432.

R. Fielding, "Architectural Styles and the Design of Network-Based Software Architectures (PhD thesis, University of California, Irvine, 2000).

R. Giffinger and H. Gudrun, "Smart Cities Ranking: An Effective Instrument for the Positioning of Cities?," *ACE Architecture, City and Environment* 4: 12 (2010) 7–25.

R. Giffinger, *C. Fertner, H. Kramar, R. Kalasek, N. Pichler-Milanović, and E. Meijers, Smart Cities: Ranking of European Medium-sized Cities* (Vienna: Centre of Regional Science, 2007).

GSSI Youtube Channel, Forum 3 L'Aquila del future, 14 December 2015. Accessed May 30, 2016.

M. Gurstein, *What is Community Informatics (and Why Does it Matter)?* (Milano: Polimetrica, 2007).

R. Hilliard, I. Malavolta, H. Muccini, and P. Pelliccione, "On the Composition and Reuse of Viewpoints across Architecture Frameworks," paper presented at the 10th Working IEEE/IFIP Conference on Software Architecture (WICSA) & 6th European Conference on Software Architecture (ECSA) – WICSA/ECSA, (Helsinki, August 20, 2012). pp. 131–140.

R. G. Hollands, "Will the Real Smart City Please Stand Up?," *City: Analysis of Urban Trends, Culture, Theory, Policy, Action* 12: 3 (2008) 303–320. doi: 10.1080/13604810802479126.

Istat, Statistiche focus – mobilità urbana (2011) <http://www.istat.it/it/files/2013/06/Focus_Mobilita_Urbana.pdf?title=Mobilit%C3%A0+urbana+-+14%2Fgiu%2F2013+-+Testo+integrale.pdf> Accessed March 15, 2016.

R. Kitchin, *The Data Revolution: Big Data, Open Data, Data Infrastructures and their Consequences* ((London: Sage, 2014).

R.E. Klosterman, "Planning Support Systems: A New Perspective on Computer-Aided Planning," *Journal of Planning Education and Research* 17: 1 (1997) 45–54. doi: 10.1177/0739456X9701700105.

R.E. Klosterman, "E-Planning: Retrospect and Prospect," *International Journal of E-Planning Research* 1: 1 (2012) 1–4. doi:10.4018/ijepr.2012010101

LAURAq, "Dio salvi L'Aquila. Una ricostruzione difficile," *Urbanistica Dossier* 123/124 (2010) 1–70.

D. Linders, "From E-Government to We-Government: Defining a Typology for Citizen Coproduction in the Age of Social Media," *Government Information Quarterly* 29: 4 (2012) 446–454.

I. Malavolta, "Software Architecture Modeling by Reuse, Composition and Customization" (PhD thesis, University of L'Aquila, Computer Science Department, 2012) <http://www.ivanomalavolta.com/files/papers/IvanoMalavoltaPhDThesisLight.pdf> Accessed June 7, 2016.

P. Meier, "Crisis Mapping in Action: How Open Source Software and Global Volunteer Networks Are Changing the World, One Map at a Time," *Journal of Map and Geography Libraries* 8: 2 (2012) 89–100.

A. Meijer, "Co-Production in an Information Age: Individual and Community Engagement Supported by New Media," *VOLUNTAS: International Journal of Voluntary and Nonprofit Organizations* 23: 4 (2012) 1156–1172.

M. O'Grady and G. O'Hare, "How Smart Is Your City?" *Science* 335: 3 (2012) 1581–1582.

A. Özerdem and G. Rufini, "L'Aquila's Reconstruction Challenges: Has Italy Learned From Its Previous Earthquake Disasters?," *Disasters* 37: 1 (2013) 119–143. doi:10.1111/j.1467-7717.2012.01296.x.

J. Panek and K. Benediktsson, "Emotional Mapping and Its Participatory Potential: Opinions about Cycling Conditions in Reykjavík, Iceland," *Cities* 61 (2017) 65–73. doi: http://doi.org/10.1016/j.cities.2016.11.005.

P. Pelzer and S. Geertman, "Planning Support Systems and Interdisciplinary Learning," *Planning Theory & Practice* 15: 4 (2014) 527–542. doi: 10.1080/14649357.2014.963653.

Protezione Civile, "Case–Complessi Antisismici Sostenibili ed Ecocompatibili" (2016). <http://www.protezionecivile.gov.it/jcms/it/view_dossier.wp?contentId=DOS274> Accessed June 6, 2016.

E. Pyrga, F. Schulz, D. Wagner, and C.D. Zaroliagis, "Efficient Models for Timetable Information in Public Transportation Systems", *ACM Journal of Experimental Algorithmics* 12 (2007).

F. Ricca and P. Scattoni, "Pianificazione nell'Approccio della Scelta Strategica," in G. Felici and A. Sciomachen, eds, *Scienza delle decisioni in Italia: applicazioni della Ricerca Operativa ai problemi aziendali* (Genova: ECIG, 2008) 1–39.

K. Schmidt-Thomé, S. Wallin, T. Laatikainen, J. Kangasoja, and M. Kyttä, "Exploring the Use of PPGIS in Self-Organizing Urban Development: The Case of softGIS in Pacific Beach (California)," *The Journal of Community Informatics* 10: 3 (2014) 131–144. <http://www.ci-journal.net/index.php/ciej/article/view/1080>. Accessed June 1, 2016.

J.P. Shim, M. Warkentin, J.F. Courtney, D.J. Power, R. Sharda, and C. Carlsson, "Past, Present, and Future of Decision Support Technology," *Decision Support Systems* 33: 2 (2002) 111–126. doi: 10.1016/S0167-9236(01)00139-7.

C.N. Silva, "The E-Planning Paradigm––Theory, Methods and Tools: An Overview," in C.N. Silva, ed., *Handbook of Research on E-Planning: ICTs for Urban Development and Monitoring* (Hershey, PA: Information Science Reference, 2010) doi:10.4018/978-1-61520-929-3.ch00.

M.M. Skoric, Q. Zhu, D. Goh, and N. Pang, "Social Media and Citizen Engagement: A Meta-Analytic Review," *New Media and Society* 18: 9 (2016) 1817–1839.

SMAU, "L'Aquila Smart City: rete elettrica intelligente e mobilità verde" (2015) <http://media.smau.it/x-exhibition/upload/multimedia/pdf/2015/09/28/SMAU_2015_SMART_Aquila_1.pdf> Accessed April 15, 2016.

A. Stratigea, C. Papadopoulou, and M. Panagiotopoulou "Tools and Technologies for Planning the Development of Smart Cities," *Journal of Urban Technology* 22: 2 (2015) 43–62. doi: 10.1080/10630732.2015.1018725.

The Neo4j Team, *The Neo4j Manual* (2016) <http://neo4j.com/docs/stable/> Accessed June 6, 2016.

M. Tomitsch and M.H. Haeusler, "Infostructures: Towards a Complementary Approach for Solving Urban Challenges through Digital Technologies," *Journal of Urban Technology* 22: 3 (2015) 37–53. doi: 10.1080/10630732.2015.1040296.

USRA, "Ufficio speciale per la ricostruzione dell'Aquila" <http://www.usra.it/> Accessed April 19, 2016.

M. Valenti, F. Masedu, M. Mazza, S. Tiberti, C. Di Giovanni, A. Calvarese, R. Pirro, and V. Sconci, "A Longitudinal Study of Quality of Life of Earthquake Survivors in L'Aquila, Italy," *BMC Public Health* 13: 1143 (2013) 1–7. doi: 10.1186/1471-2458-13-1143.

C. Viktorsson, "From Maps to Apps: Tracing the Organizational Responsiveness of an Early Multi-Modal Travel Planning Service," *Journal of Urban Technology* 22: 4 (2016) 87–101.

D.B. West, *Introduction to Graph Theory*, Vol. 2 (Upper Saddle River: Prentice Hall, 2001).

J.V. Winters, "Why are Smart Cities Growing? Who Moves and Who Stays," *Journal of Regional Science* 51: 2 (2011) 253–270. doi: 10.1111/j.1467-9787.2010.00693.x.

F. Zhao, L. Chow, M. Li, I. Ubaka, and A. Gan, "Forecasting Transit Walk Accessibility: Regression Model Alternative to Buffer," *Transportation Research Record: Journal of the Transportation Research Board*, 1835 (2003) 34–41.

Y. Zheng, L. Capra, O. Wolfson, and H. Yang, "Urban Computing: Concepts, Methodologies, and Applications," *ACM Transactions on Intelligent Systems and Technology* 5: 3 (2014) 38–54.