Investigating the Potential of 3D GIS for Full Lifecycle Road Cadastral Modelling. Requirements and Opportunities

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Acknowledements

There is a saying in Italy that "those who leave the old road for the new one, know the one that they leave, but does not know what they are going to find". Actually, that happened to me when I, as an architect, left my studies dealing with Cultural Heritage to face this research on road infrastructures and the Road Cadastre (even if the topic of 3D information system was the link among these two different fields of research).

If I was able to carry on this new challenge I owe this to a number of people that supported me: first of all to my family, and in particular my husband Francesco and my mother Rita, that always helped me during all my PhD course. I would like to thank my tutor, Professor Orazio Giuffrè, who proposed to me to focus on this new topic and followed me with a paternal care, and my cotutor, Andrea Scianna. I have been fruitfully cooperating with him on Geomatics topic since my Master thesis on 3D road information systems on Cultural Heritage at the Department of Civil, Chemical, Environmental and Materials Engineering at the University of Palermo. I owe to him the suggestion to attend my abroad experience at the University College London that has been very educational and where I met my second cotutor, Claire Ellul. With this regard, I could never have finished this work without the support of her who gave me the opportunity to learn the method of research and have a more international approach to this research work. Hence, I feel really privileged that I was able to work with her. Her enthusiasm stimulated me to do this research: she always encouraged me and followed with great care the stages of this work. Our discussions (also by meetings around the world, from UK to Italy to Greece to the Republic of Malta where we had the opportunity to meet each other and work) were very inspiring for me.

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Chapter 1

Introduction

Mobility and transport represent two key components of economic growth and human welfare of a country. They are increasing worldwide as economies rise (Goldsby et al., 2014; Nistor and Popa, 2014; Sathish et al., 2013; Mathew and Rao, 2006); in turn, as several publications attest, transportation services contribute conspicuously to the growth of global economy (Fig. 1): according to the Bureau of Transportation Statistics (1998), in 1992 they contributed about $313 billion, or 5% of the value generated by the U.S. economy; more recently, in 2011, the annual report on the state of transportation in Canada – i.e. "*Transportation in Canada, 2011*" - described the transportation services sector as representing 4.2% of Canada's GDP (Gross Domestic Product)[1], i.e. $53 billion (Transport Canada, 2011). The same report dating back to 2015[2] noted that approximately 10% of Canada's 2013 GDP - the latest year for which data are available - was produced directly or indirectly from the transportation sector (Transport Canada, 2015)[3].

In particular, road transport has always played an important role in developing countries (Aldagheiri, 2009; UNCTAD, 2003; Banister and Berechman, 2001; U.S. Agency for International Development, 1982) as connecting cities, townships and countries, promoting the viability of urban areas (Padam and Singh, 2004) and rural development (Ale, 2013; Airay, 1984), the transport and selling of agricultural products (Devkota, 2015; Paul et al., 2009), industry and trade (UNCTAD, 2003; Porter, 1995), the expansion of jobs (ILO, 2016; Kane and Puentes, 2015; Heidersback and Strompen, 2013), access to health (Broni et al., 2014; Babinard and Roberts, 2006; Molesworth, 2005), education (Porter, 2007; Jessel, 2002; Levj, 1999), and services (Parami Dewi, 2013; Porter, 2012; Ahmed & Hossain, 1990; World Highways. International Road Federation, 1990), including critical infrastructure (CI) services[4] located within road reserves

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[1] **GDP (Gross Domestic Product)** is one of the most widely used indicators of economic growth and measures the nation's total output of goods and services.

[2] i.e. "*Transportation in Canada, 2015*".

[3] The example of Canada is important as, according the Transportation in Canada 2011, Canada's economic performance was a success compared to that of other industrialised economies.

[4] Critical infrastructure is a term used by governments to define facilities that are essential assets for society and economy: e.g. electricity, gas and oil generation, transmission and distribution, telecommunication, water and heating supply, as well as transportation, financial, public health and security services.

(Withanaarachchi et al., 2012). Therefore, in many countries road infrastructure is the most important of all public assets (Cortè, 2015; ERF, 2014; Burningham and Stankevich, 2005) and, as reported by the European Road Federation (ERF, 2014)[5], in Europe - where road network consists of 5.5 million km (Fig. 2) with an estimated value of € 8.000 billion (ERF, 2013) - it constitutes one of the largest community assets in most of the Member States.

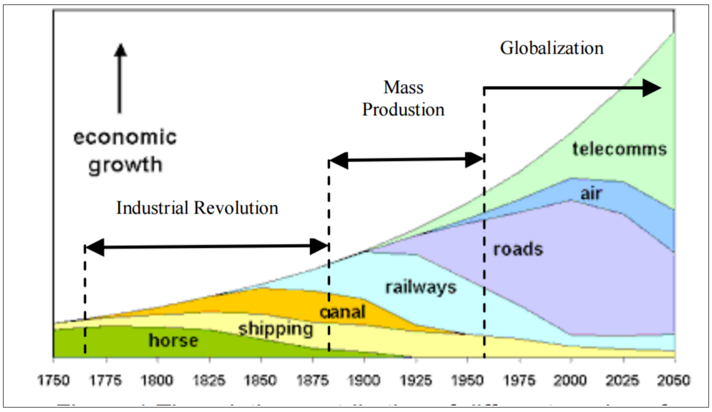

Fig. 1. The relative contribution of different modes of transport to economic growth (source: Nistor and Popa, 2014)

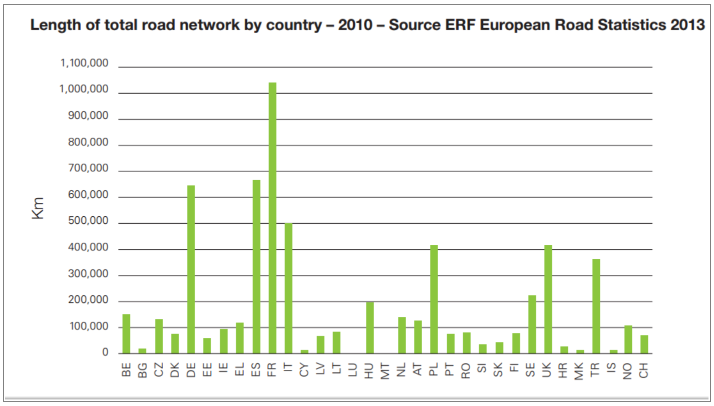

Fig. 2. Lenght of total European road network by country – 2010 (source: European Road Statistics by ERF, 2013)

With regard to developing countries, in Uganda, for example, road transport accounts for 99% of the country's passenger traffic and 95% of freight traffic, and provides the sole form of access to most rural communities (Bird et al., 2010).

The role of roads is equally decisive at the urban scale, as they are a framework for the city structure connecting city parts, ensuring mobility and access to social life, enabling integration, and providing many traffic services (Liu and Zhu, 2004; Sun and Chen, 2000; Sun and Liu, 1997; ERF, 2014). Moreover, they are the core of an integrated transport system - even cycling and walking are highly depending on roads as well as public transport and the access to other transport modes - and their performance is essential for all citizens in terms of quality of

[5] The ERF report is "*Road Asset Management. An ERF Position Paper for Maintaining and Improving a Sustainable and Efficient Road Network*", published in 2014.

life, economic competitiveness and sustainable development (ERF, 2014). Road networks also facilitate provision of other critical infrastructure services, which are located within road reserves: i.e. gas, water, sewerage, electricity, telecommunication and fibre optic cables that are laid above and under ground, and depend heavily on the transportation network to maintain their functionality (Withanaarachchi et al., 2012). Therefore, as the road network is predominately government-owned and managed under local, regional and national responsibilities by road administrations, they must maintain, operate, improve, replace, and preserve this asset (OECD, 2001), so intensively used by people worldwide.

The number of reasons for people to travel between two locations (e.g. for work, leisure, family), in fact, has been increasing over time, with means of transport on wheels mainly used: in 1990 the International Road Federation calculated that roads provided about 80 to 90 percent of the total inland and/or border crossing transport of people and goods (World Highways. International Road Federation, 1990; Queiroz and Gautam, 1992); Boucher et al. (2009) emphasised the distance driven in the UK by private motor vehicles (increased almost linearly from just over 50 billion vehicle kilometres in 1950 to over 500 billion vehicle kilometres in 2008); also, in 2014 the "*Special Eurobarometer 422a - Quality of Transport*" survey (European Union, 2014) highlighted that in the EU people preferred using car for both daily commuting (54%) and journeys over 300 km (66%); in the same year a record of 67 million new passenger cars was registered on the world's roads, as reported by the "*Global Status Report on Road Safety 2015*" (WHO, 2015). Hence, road traffic has become very intense, producing traffic congestion (Department of State Growth, 2016; Robinson, R., 1984) and impacting safety (Theofilatos and Yannis, 2014; Novoa et al., 2011), traffic-related air pollution (Zhang and Batterman, 2013; Armah et al., 2010), road maintenance (Njangu, 2015; Levik, 2001) and many other factors. From many reports it seems that this trend will continue: for example, in England, according to the "*Road Traffic Forecasts 2015*" by the UK Department for Transport, by 2040 road traffic on the Strategic Road Network (i.e. trunk roads' managed by the Highways Agency) is forecast to be up to 60% higher than in 2010 (Road Transport Forecasts, 2015).

In this context, the **management of road networks and traffic** is crucial: as argued by Devkota (2015), the most of the social and economic activities including working, recreation, and freight should use road networks, and the success of these activities highly depends on the performance of road systems. Hence, the existence of a connected road network is essential for economic success of any country (ibidem): worldwide **new roads** are going to be built in order to create new connections among cities and countries and provide access to the more isolated areas (Aneniyi, 2014), whereas **existing road networks**, whose condition is worsened by increasing road traffic, require daily **maintenance** (FHWA, 2014; Levik, 2001) (Fig. 3a).

However, according to the ERF report (2014), investments on roads have been decreasing, as Fig. 3b shows, with the consequence that the lack of road maintenance (e.g. for underfinancing or lack of information or political awareness) are: a huge deterioration of the network, higher risks of accidents, problems of congestions, increased noise, a decline of the quality and service levels, and a reduced service to society (ERF, 2014).

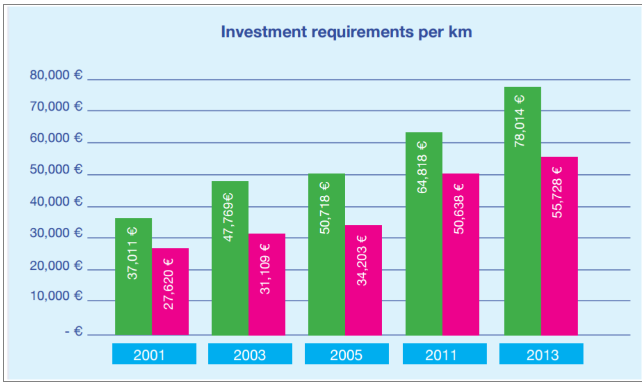

Fig. 3a. Road Investment requirements per km in Spain (source: A.E.C., 2014).

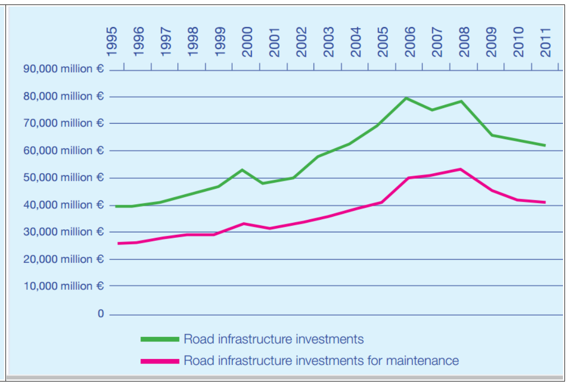

Fig. 3b. Evolution of Road Infrastructure Investments and Road Maintenance Investments in a selection of Western European Countries[6] (source: ERF, 2014).

Figure 4 shows below the consequence of delaying road maintenance with vehicle operating costs increasing exponentially as the condition of the road deteriorates.

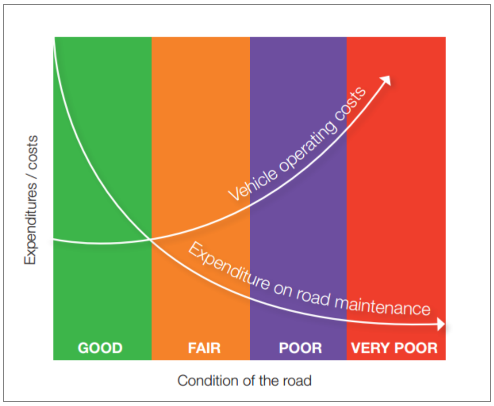

Fig. 4. Consequence of delaying road maintenance (source: SABITA, 2012).

Safety, traffic congestion, and traffic-related air pollution have also to be properly managed and they are often related to the maintenance status of roads.

With regard to **traffic congestion**, Bacon et al. (2011) indicate road works as causes of slowdowns, in addition to accidents and emergency service activities; the ERF report (2014) remarks that congestion may not depend only on a lack of capacity: increasing backlogs in maintenance can generate the necessity of urgent unplanned actions, which can create major

[6] Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxemburg, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Sweden and United Kingdom.

hinders like the closing of bridges to heavy good vehicle traffic for months or years. Bacon et al. (2011) also highlighted the large negative social and economic impact of traffic congestion - especially in urban areas - on both the community and the environment: the above is confirmed by Devereaux et al. (2004) who report the cost of congestion to the UK economy estimated at £12 billion a year in 2004. The "*Urban Mobility Report 2009*" illustrated the trend of costs and travel delay related to urban congestion in the US since 1982 to 2007 (Fig. 5) (Schrank and Lomax, 2009), while the "*2015 Urban Mobility Scorecard*" noted that in 2014 congestion caused urban Americans to travel an extra 6.9 billion hours and purchase an extra 3.1 billion gallons of fuel for a congestion cost of $160 billion (Schrank et al., 2015).

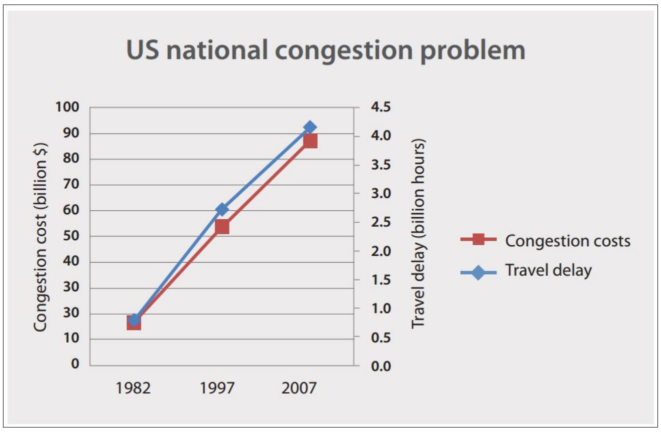

Fig. 5 - Congestion costs and travel delay due to urban congestion in the United States 1982-2007 (source: *Urban Mobility Report 2009* by Texas Transport Institute, in IRF, 2010).

Concerning **safety**, despite the existing safety and road maintenance standards, crashes and collapses on roads and motorways are even more frequent and serious. According to the "*Global Status Report on Road Safety 2015*" by the World Health Organization (WHO)(2015), worldwide the total number of road traffic deaths has plateaued at 1.25 million per year and, despite progress towards improving road safety legislation and in making vehicles safer over the last three years, the pace of change is too slow: road crashes are expected rising to the 7th leading cause of death by 2030 (TSR, 2015; Mohan, 2001). Also the "*White Paper 2015*" by the Together for Safer Roads (TSR)"[7] Global Coalition cites the WHO's report and emphasises such numbers, adding that 50 million people per year are injured, 3,400 people (whose 500 are children) die every day, and 2 people die every minute (TSR, 2015). Road crashes already cost the world USD

[7] In 2015 the Private Sector Global Coalition called "*Together for Safer Road*" (TSR), composed by 11 leading global companies, published a White Paper titled "*Investing in Road Safety – A global imperative for the private sector*", setting the orientations and priorities of the TSR Coalition for advancing road safety in the world. This White Paper was prepared by the TSR's Expert Panel composed by international road safety experts, assessesing progress since the United Nations General Assembly established the United Nations Decade of Action for Road Safety in 2010. It identifies gaps, and discusses the role of the private sector in advancing road safety (source: National Technical University of Athens - NTUA Road Safety Observatory website, 2016).

$518 billion a year (TSR, 2015; WHO, 2013). In its national study titled *"On a Crash Course: The Dangers and Health Costs of Deficient Roadways"* by Miller et al. (2009), the Pacific Institute for Research and Evaluation (PIRE)[8] of Pennsylvania found that more than half of US highway fatalities are related to deficient road conditions, with more than 22,000 of them that can be attributed to poor road conditions, at a cost of $217 billion annually: i.e. more than three times what the country is investing annually in roadway capital improvements. According to the study, in Pennsylvania, the total cost is $10.4 billion annually, while in Canada the provinces and territories spend over $100 million per year for road safety (Transport Canada, 2011). **Road design** and **maintenance** underpinned by a Safe System approach – also linked with actions on vehicle safety and road user behaviour – are required (WHO, 2015).

The Global Status Report (WHO, 2015) mentioned above also highlights the importance to monitor the way the roads are built. In this respect, in fact, in 2014 in Brazil a viaduct under construction in Belo Horizonte (the fifth richest city of the country) suddenly collapsed crushing a bus, a car and two trucks, with 2 dead and 22 wounded (Fig. 6); in October 2016 the central span of a concrete overpass in Lecco (Lombardy, Italy) collapsed onto the roadway below with 1 dead and 5 injured: papers report that the request by ANAS, the maintenance company, to close the bridge before the collapse was denied by the municipality, pending documentation. In June 2016 in Ottawa (Canada) a giant sinkhole opened up next to a major shopping mall collapsing a street and forcing the evacuation of all near business (it was the last of many similar phenomena happened over time in the same place and caused, e.g. in 2013, by a burst underground water pipe) (Fig. 7); other sinkholes appeared in Guatemala City (Guatemala) after the "Agata" tropical storm (2010) in Duluth, (Minnesotha, USA) after a torrential rain (2011), in Toledo (Ohio, USA) (2013), in Kitchener (Canada) and in Florence (2016) for a water main break, and in Kentucki (USA) at the National Corvette Museum in Bowling Green (2014).

Figure 6. Collapse of a viaduct under construction in Belo Horizonte (Brazil) (source:

Figure 7. Sinkhole in Ottawa (Canada) (source: http://www.theglobeandmail.com/news/national/gaping

[8] PIRE is a non-profit public health research organisation that for more than 30 years has been involved in studies related to transportation safety, doing groundbreaking work on issues related to driver behavior, including studies of safety belt use, driver distraction, hazard perception, aggressive driving and fatigue. PIRE has also been an international leader and made seminal contributions in research to understand and prevent impaired driving and reduce harm consequent to it (see Miller et al., 2009)

http://www.telegraph.co.uk/news/worldnews/southamerica/brazil/10945283/Brazil-bridge-collapse-at-least-one-killed-two-miles-from-World-Cup-venue.html) -sinkhole-opens-blocks-from-parliament-hill/article30349445/)

Also in Sicily (Italy), landslides (e.g. in 2015 on both the Palermo-Agrigento main road and the Messina-Catania motorway) and collapses of structures have been retreating several times, preventing regular road traffic between West and East of Sicily with serious social and economical consequences. In particular, the collapses of the Verdura Bridge on the main road linking Agrigento to Palermo (2013) (Fig. 8), the Petrulla viaduct on the "126 main road" connecting Licata and Ravanusa (two southern villages near Agrigento) in 2014, the Himera viaduct on the motorway linking Palermo to Catania (2015) (Fig. 9) and the Scorciavacche viaduct in the Province of Agrigento – opened on Christmas (2014) and collapsed on January 1, 2015 - have highlighted the urgent need to monitor roads, structures, landslides and environmental factors (including their impact on road quality and maintenance procedures), as well as the need to use surveys and sensors to check the status of the road structure on a regular basis.[9]

Figure 8. Viaduct collapse in Sicily (Verdura Bridge) (source: http://www.sicanianews.it/crolla-il-ponte-sul-fiume-verdura-ma-nessun-ferito-strada-statale-115-sciacca-agrigento-spezzata-in-due/)

Figure 9. Himera viaduct collapse in Sicily (source: http://www.grandangoloagrigento.it/frana-a19-anas-demolita-carreggiata-viadotto-himera/)

Again, substantial costs resulted from an uneffective management of roads and motorways. As reported by ERF (2014), in the UK an annual survey of the local road network indicated that the build-up of outstanding road maintenance is valued at several billions of Euros, with deterioration in the network clearly evident and leading to significant claims from users for damages to person and property, whereas in Germany the proportion of motorway bridges requiring urgent interventions has increased from 36 to 46% during the last decade : e.g. from December 2012 to March 2013 one of the most used bridges (A1 Leverkusen) had to be

[9]See in the Appendix 1 the report from newspapers on the road collapses and landslides happened worldwide (and with a main focus on Sicily, Italy) since 2011 to 2016 and their consequences on mobility of countries.

closed to lorries above 3.5 tons, and social costs, caused by losses of time and additional fuel consumption, were estimated to reach 80 million euros. As argued by the National Research Council (2005), in Italy many of the country's bridges and road structures (overpasses and underpasses) were built many years ago, and require ongoing maintenance and often even expensive rehabilitation: in 2000, 29% of the nation's estimated 590,000 bridges were considered structurally deficient or functionally obsolete.

Road conditions are also critical in Developing Countries with regard to rural roads: in the South Africa region it is estimated that some 150 million cubic metres of gravel are consumed annually (O'Neill and Greening 2010), and according to the *World Bank's Country Economic Memorandum* (2009) each year 17 trillion dollars are used for general maintenances.

In the light of above, smart tools, such as real-time sensing of traffic (Zygouras et al, 2015; Tseng et al., 2012) and of the road surface (Astarita et al., 2014; Chugh et al., 2014) and structures (Kõrbe Kaare et al., 2012; Whelan et al., 2009) are required to monitor and analyse road phenomena (e.g. to check the status of the road structure over time, as well as traffic flows that are related to emissions, noises and road degradation). Also, well-organised programs of road management through the whole road life-cycle (from design to maintenance) can ensure a high standard of road performance - including durability, efficiency and safety (Burningham and Stankevich, 2005) - and forecast construction and maintenance costs.

Eadie et al. (2013) define a project life-cycle as an encompassing project inception, feasibility, design, construction, handover, operation, maintenance and eventual demolition. The potential of a life cycle approach for improving road infrastructure planning has been highlighted by Lenferink et al. (2008). In this regard, as noted by ERF (2014), most of the road network are under the responsibilities of authorities in charge of planning, construction, supervision, operation, maintenance and road safety that work with annual budgets generally decided by Parliaments.

All the above highlights just some of the various issues relating to road infrastructures and transport that, as dealing with a number of different fields and data related, reveal their multi-factorial nature (Szymanek, 2015; European Commission, 2008) and require flexible and integrated tools in order to be managed (Velaga et al., 2012; Rebolj, 1995). With this regard, also, according to Sandgren (2004), in the last few years the development of different specialist transport-related topics (e.g. Intelligent Transport Systems (ITS),[10] mobility and traffic management, road planning, construction and maintenance, traffic safety, environmental and society monitoring and planning) has produced a growing need for digital road data

[10] An ITS is defined as "the application of advanced sensor, computer, electronics, and communication technologies and management strategies in an integrated manner to increase the safety and efficiency of the surface transportation system" (sources: Meyer (1997), and Valente et al. (2012)).

infrastructures to integrate and manage the wide range of different data and aspects about roads: such infrastructures would be helpful for analysing phenomena (study), planning (design), and make decisions (policies), also being a basis for a further development (ibidem).

All the above requires inventories/information systems in which roads are properly identified, classified and described, and where geospatial data,[11] administrative and technical-functional road features are collected. In particular, a standardised, seamless, updated and quality assured system to cooperate in data recording and updating among countries is required (Sandgren, 2004). Countries' policies, in fact, as considering national roads as a part of a global road network,[12] have been moving towards the supranational concept of a spatial data infrastructure of roads (as reported in Appendix 2), and have been implementing standards for guaranteeing the interoperability among different systems (as illustrated in Chapter 2). Nevertheless, currently, in the road sector, data recording is still dealing with many issues, such as: different road classifications, a wide variety of road-related information, various types and definitions of road components (including underground structures, pipes and structures on the surface), needs for integrating geospatial information of roads with the natural and manmade environment data by defining mutual spatial relationships, as well as the lack of 3D datasets and models describing roads (that, as a part of the real world - which is three-dimensional (Elwannas, 2011; Abdul-Rahman and Pilouk, 2008) - are to be considered three-dimensional too). Several of them will be addressed in Chapter 5.

Aiming at determining a 3D road inventory system suitable to meet these needs, this thesis will be focused on the Italian road inventory, used as a basic starting point of this research study and widely described in Chapters 3 and 4.

1.1 Road Inventories

Over time, in various countries, administrative and technical-functional classifications of roads as well as registries containing various data sets of road infrastructures have been implemented (or sometimes just legally established while waiting for an effective implementation). So far such inventories - though all oriented to the digitisation of data - have

[11] "Spatial data" has been defined as "any data with a direct or indirect reference to a specific location or geographic area" (EU, 2007). ESRI Inc. (Environmental System Research Institute), one of the world's largest Geographic Information Systems' (GIS) software vendors, also defines it as "any data that can be mapped" (data model) as well as "information about the locations and shapes of geographic features and the relationships between them, usually stored as coordinates and topology" (data structure) (see: http://support.esri.com/other-resources/gis-dictionary/term/spatial%20data 16/08/2016) or - as Benny et al. (2007) also specify - "classified and stored as point, line, area, polygon, grid cell, or object".

[12] An example of this is the European Road Network that ranges from the Trans European Network (TEN), to national (motorway and trunk) roads, to regional roads and, finally, to local roads (source: European Union Road Federation) as well as the Trans-African Highway network.

been based on the use of different technologies (as showed in Chapter 2) and met just national (or regional) policies and requirements (see Chapters 3 and 5). Many European directives and international bodies have been working on interoperability, by implementing common standards in the field of road transport (see Chapter 2). However, at present there remain differences among the systems used in various countries, starting with the name of the registers of roads currently used. As reported by the websites of the Departments of Transports of different countries, in fact, they are named as: "road inventory", "road registry/register", "road book", "road archive", "register of infrastructure", "road registration", "road asset management", "road classification", "road administration", and in Italy "road cadastre/cadaster", "road cadastral registration", and "road cadastral system".

1.1.1 Definition and uses

Several definitions of a "road inventory" can be found in the literature, with all of them describing it as a register of streets within a given area or jurisdiction. In particular, Wathen (1991) defines a road inventory as "a book (or computer disc) containing information to answer legal questions about roads"; according to Mammarella (2014) it is "a compiled data resource that can provide various categories and layers of information based on the structural conditions and status of roads", while the Oregon Department of Transportation (2012) describes it as "a compilation of information about the status and condition of the road system".

The multi-purpose nature of a road inventory is also highlighted by examining varying uses (as also later addressed in Chapter 4): Wathen (1991) highlights its importance in a juridical perspective and for physical maintenance purposes, i.e. to inform citizens on road maintenance - in particular, which roads need what repair - and on legal liability and legal rights related to it. Mammarella (2014) emphasised its role in planning maintenance of safe surface transportation and, particularly, in forecasting costs, and specifies its mandatory nature: "any detailed request for thoroughfare improvement or widening, bridge repair, or highway construction that is submitted to the U.S. Department of Transportation (USDOT), or to similar bodies at the state level, generally requires a road inventory as one of its core documentation features". Higuera de Frutos and Castro (2014) defined road inventories as "a key component in the planning of road networks as they allow for efficient management and a better return on the investment", with a particular focus on those parties interested in designing and building road networks. In Italy the New Road Code ("*Nuovo Codice della Strada*", established by the Act n. 285 of April 30, 1992) emphasised the importance of the road inventory in identifying each road belonging to the national road network in order to evaluate its status and integrate road information with data from other inventories (e.g. relating to buildings and lands) (see Chapter 3).

All the definitions above describe rather differently the road inventory of a country, each focusing on different aspects, but some important key words can be collected from them highlighting their main current uses: i.e. property, management, planning, maintenance, forecasting of maintenance costs, and the possibility of integration with other information (useful for both existing roads and road projects to be still designed).

1.1.2 The Italian Road Cadastre

The link between road property/management and road maintenance responsibilities is central to the definition in law of the Italian road inventory. It is defined by the New Road Code (1992) as a "Road Cadastre", a name that evokes the concept of road property (i.e. aimed at identifying the owners who are required to pay for road maintenance).

According the FIG (International Federation of Surveyors) the word "cadastre" is normally used to define "a parcel based, and up-to-date land information system containing a record of interests in land (e.g. rights, restrictions and responsibilities). It usually includes a geometric description of land parcels linked to other records describing the nature of the interests, the ownership or control of those interests, and often the value of the parcel and its improvements. It may be established for fiscal purposes (e.g. valuation and equitable taxation), legal purposes (conveyancing), to assist in the management of land and land use (e.g. for planning and other administrative purposes), and enables sustainable development and environmental protection" (FIG, 1995).

Italy is the only country using the word "cadastre" for defining its road inventory. As highlighted by Vella (2008), the reasons seem to be etymological and historical.

In Italy the word "cadastre", deriving from the Greek "κατάστιχον" (pr.: katàstichon, from "κατά στίχον" that means "line by line", i.e. registry), is normally used to indicate any systematic detection of homogeneous objects, typically provided of a map and a register, and, in particular, it defines two types of inventory: the Land Cadastre and the Urban Buildings Cadastre (ibidem) (Fig. 10). They both are geometric and divided into particles (ibidem), and show the technical characteristics of the objects and the holders of real estate rights (Maggio, 2014). Moreover, they have no legal evidence, but only a purely fiscal function, as they are used to determine the taxable income on which taxes and property taxes will be calculated (ibidem). In Italy, while the "Land Cadastre" records information such as rights, restrictions and responsibilities related to land parcels through a geometrical description associated with attributes, the "Road Cadastre" includes geometric data and administrative and technical-functional attributes of the roads.

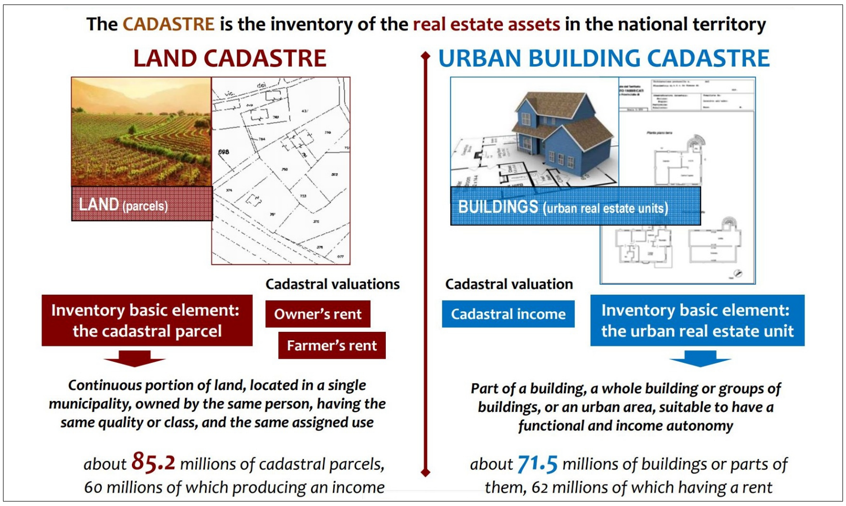

Fig. 10. The Italian cadastral system (source: Maggio, 2014)

In addition to the etymological origin of its name, historically, in Italy the need for a "road cadastre" comes from the Code of Road Traffic and Cars (1929) that defined road properties and introduced rules for preserving them (Vella, 2008). As showed by Fig. 11, in fact, Italy is divided into administrative areas (Regions, Provinces and Municipalities), each managed by an homonymous public institution that is responsible of a part of the road network: in particular, national roads belong to the State, whereas regional, provincial and local roads belong respectively to Regions, Provinces and Municipalities (art. 22 of Code of Road Traffic and Cars). All of them are of public use.

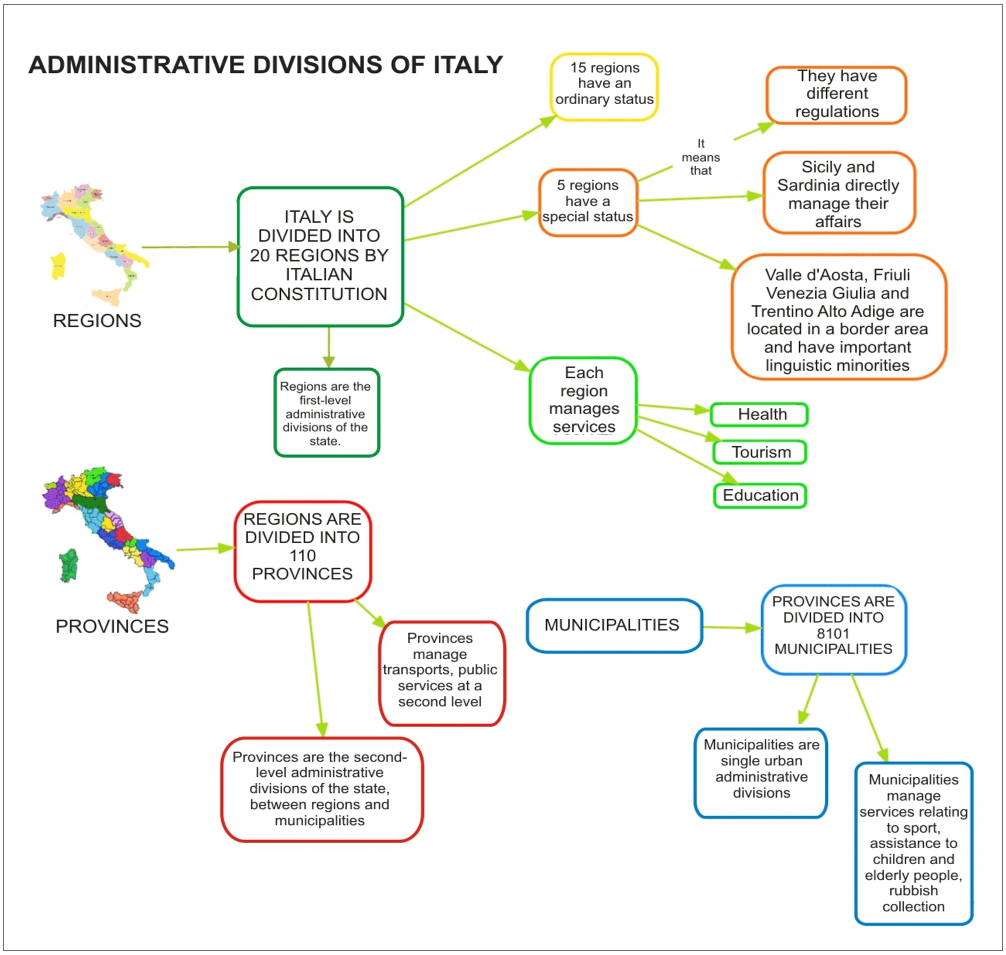

Figure 11. Administrative divisions of Italy (source: Fabio Veronese)

Hence, since the early '90s, the concept of road property – but also of preservation, maintenance and costs to be charged to road owners – has been emphasised by Italian regulations and contributed to name the road register as a "Road Cadastre". In 1992, in fact, the Act so-called "New Road Code"[13] finally established the cadastre of Italian roads, and defined name, purposes and main contents of it as well as the expandability and integrability of the information system with further data, as follows: "the Road Cadastre is the inventory of all the roads for public use on the national territory, with the primary objective of defining the consistency of the national road network within a medium-term perspective and in a compatible and integrated way both with the Land and the Buildings Cadastres" (New Road Code, 1992). Also, importantly, in the '90s it was recognised the need to divide the road network according to the function performed by each road segment in the territory and within the mesh infrastructure: the New Road Code introduced an administrative classification of roads (where road classes are related to the institution responsible for ownership or management) and a technical/functional one (based on constructive, technical and functional features of roads). Both are described in Chapter 3.

13 Legislative Decree N. 285, April 30, 1992.

It also stated the mandatory nature of the Road Cadastre: Paragraph 6 of Article 13 of the New Road Code establishes that all "the institutions that are owners of the roads are obliged to establish and keep up to date the cartography and the cadastre of roads as well as the appurtenances related to them". Therefore, as in Italy the institutions that own or manage public roads are:

a. ANAS[14] (a company in charge for managing the Italian network of highways and national roads) for motorways and roads of national interest,
b. Concessionaires for other motorways of national interest,
c. Regions for regional roads,[15]
d. Provinces for provincial roads,
e. and Municipalities for local roads (both urban and suburban),

each of them is required to implement its own "Road Cadastre", in accordance with a basic road dataset as a common template established by law.

The Italian Road Cadastre collects and provides administrative and technical features - both geometrical and structural - related to roads (as later illustrated in Chapter 3). According to the the New Road Code (1992) and its Implementing Rules (Act of June 1, 2001), the basic road dataset of the Road Cadastre must include:

a) elements relating to the geometric features of roads and related appurtenances,

b) plant and permanent services related to road traffic demands (see the Annex n.2 of the Act), including the location on the road of monitoring devices for detection of movement (see the New Road Code, Art. 227, and the Implementing Regulation, Art. 404).

Currently, just ANAS and several institutions at different level have implemented their own Road Cadastre (as later illustrated). They are based on the dataset established by law (and described in Chapter 3), but enlarged and customised in accordance with specific local requirements.

While containing geometric data sometimes also referred to the three dimensions of space, Road Cadastres are based on 2D GIS (Geographic Information Systems) - addressed in Chapter 2 - where the third dimension is registered as an attribute (Stoter, 2000; Raper and Kelk, 1991) (e.g. the height of some road components): within them entities and attributes should be pretty detailed, as described by the Ministerial Act of June 1, 2001.

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[14] ANAS is a state-owned Italian limited liability company, whose sole shareholder is the Ministry of Economy and Finance. Under the technical and operational supervision of the Ministry of Infrastructure and Transport, it manages the Italian road and motorway network: 25.646,909 kilometres of roads (939,848 km of them are motorways).

[15] The Prime Ministerial Decree of February 20, 2000 transferred the ownership of roads from the State to the Regions; therefore, which are required to set up their own road inventory.

1.2 Needs for a 3D Road Cadastre

In many countries both public and private road inventories have been already implemented using databases and Geographic Information Systems for registering and managing roads. Currently, road data (such as geospatial information describing the road and its environment, attributes describing the semantic aspects of the geometry, engineering drawings and images/photographs) is used by different institutions to store and share information about the status of features of the motorway and urban road systems (King and Kratzchmar, 2010), to plan urban works (Rajkot Municipal Corporation, 2008), to check traffic congestion (He et al., 2016; Bacon et al., 2011; Bovy and Salomon, 1999; ECMT, 1999) and traffic-related pollution (Korek et al., 2015; Batterman et al., 2015; Bellander at al., 2001), and to conduct road safety evaluations (by analysing different data about road geometry, road accidents, traffic, vehicles, road users and others) (Yan et al., 2012; Jiang et al., 2011; Bahar et al, 2004). Chapter 2 includes an overview of several road information systems worldwide already implemented for different purposes, while Chapter 4 focuses on different uses.

Looking at the Italian case, for example, the Road Cadastre of the Province of Crotone (Calabria, a southern region of Italy) is based on a software developed by the Italian company DBCAD Srl that allows implementing a graphic and alphanumerical inventory of roads and road events (i.e. signage, accesses, barriers, landslides, towns, monuments, etc.). Road institution's technicians are enabled to manage (i.e. to record and update), consult and analyse data stored within three basic cartographic databases: the "Road Network" DB (i.e. an alphanumeric list of roads managed by the Province associated with a cartographic archive that, for each road, identifies the corresponding axes and provides all the technical information related), the "Road Cadastre Events" DB, and the "Photogrammetric surveys" DB (georeferenced). They can also handle other graphics and alphanumeric files, such as orthophotos, satellite photos, technical and cadastral maps, place names, and others, that can be integrated with the three basic DBs.

Other several Italian institutions, instead, have taken advantage by the software Road-SIT by SITECO for implementing and managing their own Road Cadastre. In this cases, technicians can use a tool set including: a relational DB with data on each road and related appurtenances, a cartographic DB consisting of a road graph and maps, an application for the Road Cadastre management (in a client-server or web environment), a GIS for the cartographic representation of data, and other applications to make automatic the management of the road network (including signage, permits, ordinances, structures, accidents, and other).

Nevertheless, current DB and GIS-based road inventories (2D) are not able to describe complex road information like 3D spatial features (Sun and Chen, 2000): "3D road situations" (e.g. overlapping and interlocking road networks, structures like bridges, overpasses and tunnels, as well as the description of 3D road parts and components, underground utilities, and 3D environmental and urban contexts) are not described by datasets of current road inventories (D.M. June 1, 2001; Hather and Brenner, 2003).

In this perspective, in the age of smart cities, 3D road inventories may represent innovative solutions to city management complexity: they would improve urban performance by using 3D data and information technologies (IT) to describe physical factors (e.g. obstacles, narrowing of the carriageway and others) influencing safety, traffic congestion and hence traffic-related air pollution, or to monitor each road element of all of urban critical infrastructures, "including roads, bridges, tunnels, rails, subways, airports, seaports, communications, water, power, even major buildings" (Hall, 2000) for maintenance purposes. In particular, 3D GIS-based road models – when implemented – would better describe the complexity of real world to coordinate interventions, plan their preventive maintenance activities (scheduled maintenance), monitor security aspects, and provide more efficient simulations and space analysis.

1.3 3D GIS and Road Cadastre

Geographic Information (GI) is "a composite of spatial data and attribute data describing the location and attributes of things (objects, features, events, physical or legal boundaries, volumes, etc.), including the shapes and representations of such things in suitable two-dimensional, three-dimensional, or four-dimensional (x,y,z, time) reference systems (e.g., a grid reference, coordinate system reference, address, postcode, etc.) in such a way as to permit spatial (place-based) analysis of the relationship between and among the things so described, including their different attributes" (Longhorn and Blakemore, 2007). As all human activity taking place in a geographic context, it is crucial also for the road sector.

Over decades, a wide and significant use of two-dimensional GIS has been made in many branches of road sector, as illustrated in Chapter 2, Section 2.2. Nevertheless, planning, maintaining, upgrading, and managing roads as well as providing them with equipment for safety, noise reduction, and other require the comprehension of real-phenomena that are often lost in the two-dimensional presentation (Zlatanova and Li, 2008; Yuan, 2008; Miller and Shaw, 2001). Also, understanding impacts of planning policy as well as assessing possible interferences of roads with underground utilities, environmental factors, archaeological findings, and others, need both proper visualisation and analysis of specific case that we can call "3D road situations" and that are going to be better explained in Chapter 4. Here multiple "z" coordinates of road elements with the same (x,y) coordinates will require to be considered, moving to 3D while within current 2D or 2.5D GIS features are still visualised and queried as projected on a two-dimensional (x,y) surface with a z coordinate as an attribute (Stoter, 2000; Raper and Kelk, 1991) .[16]

So far, the current GIS-based Road Cadastre has been aimed at collecting and providing data not directly related to visual simulations and checks on new roads to be built (e.g. environmental impact, obstacles, etc.). However, as noted by Panagopoulos (2003), visibility analysis based on view sheds is one of the tools used in GIS analysis. As a visual impact assessment (VIA) is required when harvesting, soil preparation, reforestation, buildings and road construction in scenic areas are planned, the development of a 3D GIS within a Road Cadastre system would help in making better and quicker decisions and to avoid visual and other negative impacts of road projects on the landscape. Moreover, Arens et al. (2004) have highlighted the increasing interest in modelling the world in three dimensions, and the potential of Geo-DBMSs in managing large spatial data sets in data bases accessible by multiple users at the same time. These spatial data sets usually contain 2D data, though more and more applications depend on 3D data: typical examples include 3D cadastres (Stoter, 2000; Stoter et al., 2002), telecommunications (Kofler, 1998) and urban planning (Cambray, 1993). With this regard, 3D models for Road Cadastre management might be a new field of research. Chapter 2 will describe 3D GIS capabilities in the road sector, and particularly in roads' cataloguing and documentation, with a few examples of 3D GIS applications for managing road inventories.

1.4 Research scope

The scope of research on 3D GIS and road inventories is demarcated by three main frameworks determining why, what, and how to register data for a 3D Road Cadastre suitable for large infrastructural projects:

- "Why?" framework: It is the "Aim framework", collecting needs by users in order to register, update and access 3D data on roads (both already existing and planned). It includes the aims of the implementation of the 3D Road Cadastre suitable for large infrastructural projects and its utilities.

- "What?" framework: It is the "Content framework" aimed at defining datasets needed by users to describe and access information on existing roads and new road projects,

[16] Raper and Kelk (1991) argued that geo-data can be represented in two different Euclidean dimensional contexts: i) as 2D, i.e. a spatial object or region which is defined in 2D space by measurements on axes x,y; ii) as 3D, i.e. a spatial object or domain extending through 3D space defined by axes x,y,z. Stoter (2000) remarked that, in the geo-science, "fully 3D" means that every point in space can be identified by a set of (x, y, z) co-ordinate, whereas when the z value is stored as an attribute of a 2 dimensional point, line or polygon, it is called to be 2.5D or 2D+1D (with the limitation that only a single z value can be stored for each x,y location and thus the surface can not be overfolded (Raper and Kelk, 1991).

including their 3D situations and components.

- "How?" framework: It is divided in a "Conceptual framework" and a "Technical framework" respectively addressing how to register and how to provide information of roads in 3D situations from a conceptual and a technical point of view.

1.4.1 Topics within the scope of this thesis

Road inventories are different worldwide, as contents, data structures, legislations and institutions that manage them are different: nevertheless, they all collect juridical/administrative, technical/functional and geospatial information according to criteria generally related to that country and aimed at facilitating roads management, maintenance, planning and construction. The investigation on a specific road inventory (local case) - including its conceptual model, dataset, and specific standards required - better allows verifying its possible development by 3D GIS for road registration. In particular, it aims at developing a method that, using a local case as a case study, compares it with standards and other existing road inventories (also from different countries), as well as the requirements from both literature and stakeholders, reaches results that may be (also partially) extended to general principles, and leads to general conclusions. As main example, this research work focuses on the Italian Road Cadastre.

The study of feasibility for a 3D Road Cadastre will start from the 2D Road Cadastre framework currently used in order to identify the gaps of the current registration and where it needs improvements (extensions) in case of 3D situations (also in relation to the needs for large infrastructural projects) (see Chapter 5). Adjustments will be looked for to improve the current 2D framework.

Standards and existing road inventories, as well, will be considered (in Chapter 2) to examine road datasets and models respectively defined by the working groups of ISO, CEN, and other institutions. The aim is to understand whether and how researchers, directive and international standards, and other countries' authorities or road agencies solved the problem of 3D road registration and to come to more general conclusions (not only valid for the Italian situation). The expandability of the Italian Road Cadastre (case study), as provided by law, also deals with data integration and interoperability: it is a topic of this research as well as the multipurpose nature of the Road Cadastre, relevant for modelling data and designing functionalities meeting the real needs of current and potential users.

As shown in Chapter 3 (and confirmed by surveys results in Chapter 8), existing roads and new road projects deal with different issues in registering 3D road situations: both of them will be addressed as well as the implementation of the 3D Road Cadastre for documenting roads and related elements during its lifetime.

3D Road Cadastres would need to maintain large amounts of (spatial) data of different kind. As a DBMS (DataBase Management System) is suitable for this task, this thesis includes in Chapter 9 the study of a conceptual framework describing how to model 3D geo-objects related to roads in a DBMS, taking into account felxibility (to meet requirements of different users). These data should be easily accessible or provided on demand to different users and stakeholders (institutions, road designers, professionals involved in road construction, road maintenance, companies working on utility systems, GIS/CAD specialists, and others). Therefore another major issue is how the DBMS of the 3D Road Cadastre can be made accessible for users. In addition, in order to allow the access to information and its dissemination via the Internet, road registration should fit in a Geo-Information Infrastructure (GII).

A real implementation of 3D GIS still implies many issues related to geometric construction, data structuring, organisation of 2D and 3D data in one environment, database creation and updating. About that efficient methods have to be developed yet as later addressed in Chapter 2 Subparagraph 2.2.2.5. While developing a method for a 3D GIS applied to roads, this thesis will provide some considerations and proposals about some of these topics.

This research work is mainly aimed to define a conceptual model for 3D road registrations suitable to the full life-cycle description of road infrastructures. In order to implement a 3D Road Cadastre, aims, needs, kind of documents, data (geometry and other information) and basic 3D information for 3D road registration have been gathered from the literature (Chapter 7) and surveys (Chapter 8) and analysed to be turned into technical needs. Indeed, current techniques and software (including Building Information Models addressed in Chapter 2) have been explored to evaluate if they are able to meet such requirements. Levels of detail for describing road infrastructure in accordance with the real needs of users have been addressed.

Importantly, this thesis emphasised also the methodology used for gathering requirements in order to define models and implement applications meeting real needs of people (i.e. not only theoretical, but usable in the daily practice).

1.4.2 Topic outside the scope of this thesis

This thesis also mentions some topics strictly related to the main topic addressed here, but that are not within its specific scope.

It is not the aim of this thesis to provide solutions for 3D registration for any cadastre outside Italy, although cadastres in other countries can use the findings of this thesis that address general issues of cadastral registration in 3D situations.

Data capture issues will not be addressed in this thesis, but merely mentioned to understand the kind of data that the 3D Road Cadastre might include. However, the experiences and findings in this thesis may lead to recommendations for developments and further research on that.

Also data modelling and topology theory, state of research, and issues are not included into this work, and will be part of the further research work.

Consequences on countries' economies and cost/benefit analysis deriving by the use of an integrated 3D Road Cadastre by road administrations and other stakeholders are also out of the scope.

Focusing on the case study of the Italian road inventory (called a "Road Cadastre"), this thesis firstly aims to: a) determine whether, given its potential as a data integrator and as a mechanism to link to multiple, disparate, elements of information, the use of 3D GIS would improve Road Cadastre (for better management of data related to the complete life-cycle of infrastructure projects); b) define a conceptual approach and model for a 3D Road Cadastre for Italy (whose general principles may be extended also to other countries); c) propos a flexible system to be tested by a prototype in accordance with different specific road cadastral uses.

Requirements and opportunities for a 3D Road Cadastre and the potential of 3D GIS for full lifecycle road cadastral modelling are the main topics of this research. Performance testing and benchmarking with respect to 3D cadastral registration or other information systems are therefore not part of this research.

1.5 Previous work and related research

Previous work and related research to this thesis have been widely addressed in Chapter 2, providing a theoretical background for the present work.

A number of road inventories - both experimental and already used - have been already studied and widely discussed in the literature, and relevant examples have been illustrated in Section 2.1: they include many project and research works - reported at Paragraph 2.1.1 - on the implementation worldwide of road inventories systems aimed at different purposes, and respectively focused on data integration (Sub-paragraph 2.1.1.1), the management of road safety (Sub-paragraph 2.1.1.2), road traffic (Sub-paragraph 2.1.1.3), and the road asset including maintenance (Sub-paragraph 2.1.1.4). Studies on automatic data collection information systems have been also carried on and are mentioned in Sub-paragraph 2.1.1.5. The same topics have been explored with regard to existing systems implemented internationally: they are presented in Paragraph 2.1.2.

The spatial nature of road transport has stimulated researchers and developers to study the application of geographic information systems to the road sector: their contribute has been reviewed by many authors who produced definitions, and illustrated GIS technologies (both at general level and applied to road network and transport) for allowing integrated geoinformation and road data management. Some research works also highlighted benefits and limitations of each system. All that involved both 2D GIS technology (a literature review on this is presented in Paragraph 2.2.1) and 3D GIS (see Paragraph 2.2.2), as the increasing interest in the potential of the third dimension for describing reality: the efforts of researchers to implement the transition of 2D GIS to 3D have led to address different issues related (that can be found in Sub-paragraph 2.2.2.5 of the present work). However, authors explored 3D GIS potential in roads' cataloguing and representation (see Sub-paragraph 2.2.2.4), and research works on its application to the road transport field and with regard to the Road Cadastre have been carried out (see respectively Sub-paragraph 2.2.2.2 and 2.2.2.3). The advent of 3D models stimulated new research paths, aimed at also documenting roads' full life cycle: hence, further studies have been conducted on new models and processes like Building Integration Modelling (BIM), able to integrate data and managing constructions during all stages in a cooperative environment (see Paragraph 2.2.3).

In this scenario, interoperability (defined in Chapter 2) also became a precise requirement of integrated geoinformation systems aimed at road data management, and several authors have studied it, also looking for its comprehensive definition (see Paragraph 2.3.1). In order to achieve it, many standards have been implemented at European and international level both in the field of Geographic Information and of Road Transport and Intelligent Transport Systems. As shown in Paragraphs 2.3.2 and 2.3.3, various authors have illustrated them, also discussing their effectiveness and real application by users.

Finally, different applications of the Road Cadastre have been described by many scholars, who offered a great contribute to the present work by their comprehensive review of existing and proposed uses and users of such systems (see Section 2.2.4).

1.6 Research approach

In this section the research approach is discussed through the explanation of the research objectives and the research methods used to achieve them.

1.6.1 Defining the research questions

The main question this work aims at answering is: "Can managing data in a 3D GIS benefit large infrastructural projects over their full life-cycle, from initial design to Road Cadastre?".

To answer to that above, this research work will determine constraints and requirements, needs, and possibilities for a 3D Road Cadastre by answering to the following questions:

- What standards apply to data management for large infrastructure projects and Road Cadastre?
- What are the needs of the users of this data at each stage of the life-cycle (and/or for different purposes/uses)?
- What needs should be modelled in 3D and what should be represented in 2D or by PDF, photo and other?

1.6.2 Research framework

In order to answer to the research questions above, this research work has been carried out according to the following stages:

Analysis of the background: A preliminary overview on experimental and existing road inventories from different countries and grouped for purposes has been carried out, in order to describe the state of art relating to road cataloguing practices. A literature review on GIS applications highlighted capabilities and limitation of the systems already used in order to manage and analyse spatial phenomena especially in the road sector while a focus on 3D GIS pointed out its potential in describing 3D spatial situations road-related. This background helps to explain why a 3D approach to 'indexing' a number of different details might be better than the current approach of creating many files and using file names to indicate what relates to which part of the road structure. Standards on GI and road infrastructures (in particular, regarding transport networks and Intelligent Transport Systems) gives the reader background information to understand how complex the problem of road registering is and to compare the results of this research to standards: they have been defined to guarantee interoperability among users. A particular focus refers to the Italian Road Cadastre (including its aims, datasets, and techniques for recording and accessing data). As road inventories refer to existing roads only, a literature review about data of new road projects has been carried out as well by road design standards. Road cadastral uses have been discussed through a literature review of the multiple uses and users of road inventories.

Gap analysis, research questions and requirements gathering: Road data requirements and 3D functionalities that may improve the Road Cadastre have been gathered from literature review, interviews and questionnaires to different expert users as well as the analysis of existing software for road design and GIS applied to road networks. These needs have been referred both on existing roads and new road projects to be described both during their life-cycle stages. Current issues on data quality and updating, road representation and LoDs, data integration and interoperability, adequacy to users needs (in terms of data, uses and accessibility), compliance with Italian road design and maintenance standards have been highlighted. A focus on 3D road situations and the current Road Cadastre inadequacy to describe them has been carried out.

Implementing an integrated 3D geoinformation system of roads for a 3D Road Cadastre: The first two stages of the research work mentioned above have been followed by a comparison among the results obtained and a definition of a cognitive framework, mainly aimed at:

- defining a list of types of road recording with a possible 3D road component to be compared with the current Road Cadastre,
- identifying which data to be include within the model and what else to be linked to it (e.g. PDF, CAD, text, photos, etc.)

The study continued with the definition of a conceptual model for a 3D Road Cadastre and ended with the implementation of a 3D Road Cadastre proposal based on 3D GIS, fitting to different uses and life-cycle stages and more suitable with users requirements.

1.7 Research outcome

In summary this research work shows that:

- Current road inventories worldwide are based on different technologies, dataset and standards an mainly based on the use of database or 2D GIS and are not adequate to describe roads as three-dimensional objects as they are. This thesis gave an overview on studies and existing road inventories highlighting their characteristics and described in particular the so-called 3D road situations that should benefit from 3D descriptions, representations and analysis. An overview of 3D data model with potential and limitations has been given as well.
- Data integration and interoperability are the most relevant requirements emerged from both the literature and surveys with expert users together with 3D functionalities to display, manage and analyse road data using Road Cadastre.
- The Italian Road Cadastre, chosen as a case study for this thesis, has many purposes

established by law, but made not achievable from its current structure This thesis

- Current standards on Geographic Information and Road Transport are too many or difficult to be translate in reality by local institutions that do not always adopted them. This thesis highlighted the need for including specific design, maintenance, road safety standards, and others related to road full life cycle when designing a model for a Road Cadastre.

This thesis is the first extensive research on 3D Road Cadastres in which issues related have been studied using an approach mainly based on gathering requirements not only from the literature, but from different expert users according to the qualitative research method.

This thesis gives solution-directions for a 3D Road Cadastre by the model proposed and that will need to be translated into several prototype implementations to be validated.

1.7.1 Potential stakeholders and end-users

As the multipurpose nature of the Road Cadastre and the increasing interest of a number of categories of people in three-dimension descriptions, analysis and visualisations to manage reality, it is possible to identify various potential stakeholders and end-users of this research:

1. road owners and road management institutions,
2. road designers and builders,
3. road maintainers,
4. institutional and technical subjects involved in topics strictly related to road construction,
5. those who study road infrastructures and transport issues,
6. road users and citizens,
7. researchers and software producers interested in 3D GIS and 3D data.

1.8 Organisation of the thesis

A number of stages composed this research: they are described in Figure 12 below, which illustrates each research stage with the related content and its corresponding Chapter in the document, in order to give an overview of the whole work to the reader.

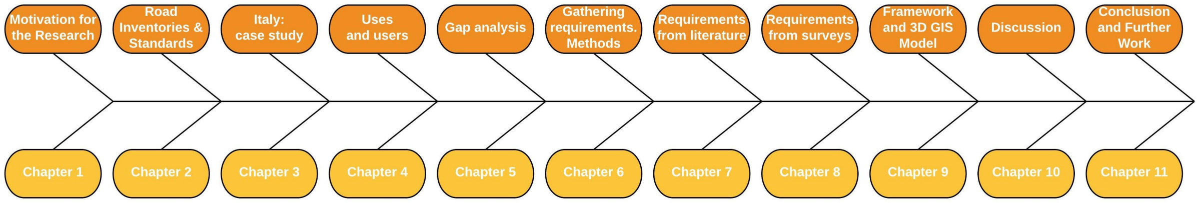

Figure 12. Overview of Document Structure

The present Chapter 1 illustrates the Motivation for the Research and introduces the topic and the research questions. A literature review from Chapter 2 to Chapter 4 composes the analysis of the background. In particular, Chapter 2 describes in the first Section the road cataloguing framework worldwide, giving an overview on the information systems studied and used in the road sector. Both road inventories' studies and projects and road information systems already existing have been grouped by purpose: i.e. respectively aimed at data integration, road safety management, road traffic management, road maintenance and asset management. In the second Section, Chapter 2 also addresses technologies mainly used in road inventories: 2D GIS, particularly applied to the road sector, and including GIS-T applications, and 3D GIS and Building Integration Modelling as systems looking for meeting the three dimensional nature of man-made constructions (road infrastructures included). Chapter 2 also highlights capabilities and limitations and research issues of such systems by a wide literature review. In its third Section it also gives an overview on standards used both in sectors like Geographic Information, Transport Network and Intelligent Transport Systems.

Chapter 3 focuses on the Italian Road Cadastre as a case study. It gives an overview of Italian standards relating to road classifications, design and construction, and maintenance, and then focuses on the Act of June 1, 2001 providing specifications on dataset, structure, and levels of detail of the legal Road Cadastre in Italy. One of its most relevant functionality is addressed: i.e. expandability. National and regional standards for Road Cadastre have been also illustrated with a focus on some road cadastral applications as examples at different level.

Chapter 4 widely documents a number of existing and proposed uses of the Road Cadastre: they represent a relevant basis for identifying expert users to gather requirements from and implement a model meeting their needs with regard to the whole lifetime of roads.

Gap analysis and research questions are addressed in Chapter 5. Road cadastral issues are described, with a particular focus on a set of different 3D road situations: they show limitations of the current Road Cadastre in terms of a three-dimensional description of road infrastructures and their surrounding and underground context.

The methodology used for this research work is explained in Chapter 6: after an overview on research methods, it focuses on the qualitative method of research and the use of both questionnaires and interviews with different road expert users.

Chapter 7 contains the requirements for a 3D Road Cadastre gathered from the literature, while Chapter 8 illustrates the results from surveys (questionnaires and interviews with road designers, managers, underground utilities managers and archaeologists).

Starting from summaries and comparisons of results, a framework for the implementation of a 3D geoinformation system of roads is addressed in Chapter 9. It includes the definition of the cognitive framework on the basis o the results gathered and descries the three stages of implementation (i.e. conceptual, logical and physical model).

The most relevant aspects emerged in this research work are discussed in Chapters 10, while Chapter 11 concludes the thesis with a review of the work undertaken and results obtained. The research questions defined in this Chapter are reconsidered, and further work suggested.

Figure 12 is repeated through the document to give each Chapter context in terms of the overall research process.

Chapter 2

Road inventories: a review on current systems and standards used or related

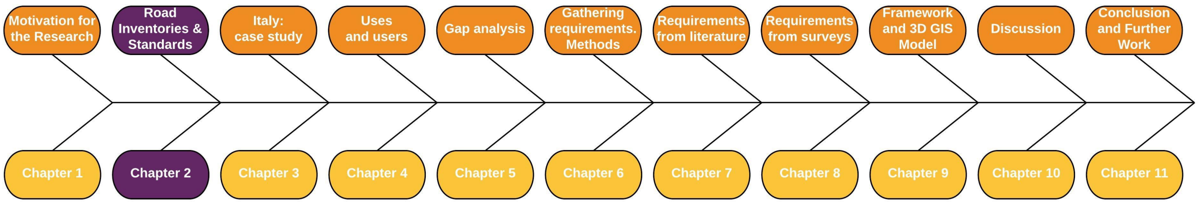

Figure 13. Overview of Document Structure showing context of this Chapter

As cited in Chapter 1, worldwide new roads are planned, existing road networks require daily maintenance and management, and safety, traffic congestion, and traffic-related air pollution have also to be properly managed together with the large amount of data related. So far, in many countries both public and private road inventories have been implemented in order to identify and classify roads, and collect different road information: geospatial, administrative, technical/functional, and related to specific domains (depending on the particular aims and uses of each inventory). Such systems have been mainly based on databases and Geographic Information Systems (GIS) used for registering and managing roads. Moreover, over time further studies have been carrying on, also taking into account the advent of three-dimensional systems to describe the real world in many fields (infrastructures included), and the recent development of different specialist transport-related topics (e.g. ITS), in addition to the need for digital road data infrastructures, able to integrate and manage road-related information (Sandgren, 2004).

In this chapter a detailed literature review was conducted to identify the theoretical background and relevant studies on the implementation of road inventories through journals, books, references, Internet and articles. A first review (in Section 2.1) illustrated studies, projects and existing systems, including main characteristics, purposes and domains. Geographic Information Systems (both 2D and 3D) have been discussed in Section 2.2, as they are widely used for implementing Road Cadastres; benefits and limitations highlighted in the literature have been cited. Other three-dimensional information systems like BIM have been also reviewed, pointing out their capability of describing the full life cycle of constructions. Moreover, then followed by a focus on the international and European standards used for implementing road inventories (and mainly aimed at achieving interoperability, data integration and a unique and shared definition of data structures). Therefore, the literature review is presented here under four general headings:

1. Digital road inventories (studies and existing systems)
2. Systems for integrated geoinformation on roads (2D GIS, 3D GIS and others)
3. Interoperability and standards for Road Cadastres.

2.1 Digital road inventories

The advent of the digital era has revolutionised the management of road data (Khattak et al., 2000): paper inventories have given way to even more advanced road information systems such as digital inventories where different data may be integrated and more easily accessed and updated. The use of databases and road inventories based on GIS permits storing a wider range of different type of data (including text, vector, and raster) required for managing road infrastructure (e.g. geometrical and physical elements, administrative and technical road classifications, and specific attributes), and meeting the spatial nature of road data analysis (Kiema and Mwangi, 2009). As noted by Tao (1998), technologies as photogrammetry, remote sensing, GISs and spatial positioning have been becoming fully integrated and characterised by "the capabilities of multi-discipline combination, multi-platform compensation, multi-sensor integration and multi-data fusion" (ibidem). Relevant literature can be found in Zhou et al. (2015), who illustrated a survey study on data collection methods currently used for public road inventories in the United States. Further methods for collecting and recording data within road inventories have been discussed also by Jalayer et al. (2015), Zhou et al. (2013), and Hou (2009) – the latter mainly focusing on road sign recognition and inventory systems. A technical review can be found in Guan et al. (2016), who addressed the use of mobile LiDAR in road information inventory.

In the light of above, this section includes a review of studies and projects on the implementation of road inventories worldwide, as well as existing systems already used, properly grouped depending on their main purpose:

1. data integration,
2. road safety management,
3. road traffic management,
4. road maintenance and asset management.

As the literature review shows, they have been implemented in USA and Europe mainly.

2.1.1 Review of studies and projects

Various different studies have been carried out on road inventories, focusing on both data integration and specific topics and purposes like road safety, traffic management, services for drivers and ITS, road maintenance as well as automatic process of collecting data for road inventories.

2.1.1.1 Research on road inventory systems for data integration

Data integration in the road sector has been addressed by Huang (2003) for urban transport planning purposes, Kimoto et al. (2015) for planning road reconstruction, and Woldesenbet (2014) relating to motorway infrastructures. Candappa et al. (2014) discussed it as a requirement of road inventories aimed at: 1) categorising roads according to multiple criteria (e.g. **design**, impacts on **traffic flow**, **environmental impacts** and available operational **facilities**), 2) providing road stakeholders and civil engineers with more comprehensive and uniform data on road infrastructure, 3) enabling evaluations not only of road safety measures but also of traffic related improvements within the road network, 4) and monitoring environmental impacts depending on various factors.

A brief report by TEC (2016) - a traffic and civil engineering and surveying firm based in Ohio and Kentucky (USA) - illustrates an example of data integration research relating to the CEAO Countywide Inventory and Safety Study Program: data collected from several different inventory studies on about 384 miles of Clermont County roads in Ohio[17] was incorporated into a database and integrated into the County's GIS system.

With regard to Europe, Candappa et al. (2014) describe a protocol for a road database with a common structure for road networks and infrastructure objects, produced in 1992 in Germany by the ASB German Road Information Bank. It was a theoretical description of data structures with each road trunk subdivided into identifiable sections, and different data collected[18] referenced to this system. Thomas (1997), ANAS (1998), Hawker and Queree (1999), and Soor (2002) discussed the European project called RADEF (Road Administration Data Exchange Format), aimed at avoiding the imposition of standards to countries by providing all European public road administrations with a prototype of a road data model (ANAS 1998):[19] a data exchange system with the further adoption of GIS (Hawker and Queree, 1999; ANAS, 1998)

[17] They were respectively carried on roadside hazard, guardrail location, signs, ball bank (curve safe speed), pavement marking, and no passing zone.

[18] Data includes: information on traffic, road geometry details – e.g. lanes, road widths, shoulders and intersection configurations - vertical and horizontal alignments, and road and roadside furniture and hazards.

[19] ANAS (1998) described RADEF as a result of a decision by the WERD (Western European Road Directors, i.e. the European association of the managers of national road networks) that did not want to push for the adoption of a standard for the Road Cadastre, as in some developed countries database were already consolidated and difficult to change.

including data dictionaries and a translation software of road database information from one structure to another in fifteen or more different formats (i.e. one for each Member Country at that time) (ibidem). Thomas (1997) emphasised the process of cooperation among different parties to implement the RADEF data model and dictionary. Hawker and Queree (1999) described the project as a response to the growing needs of Intelligent Transport Systems (ITS) across regional and national boundaries, and remarked the successful integration of its requirements for a motorway data exchange standardisation into the ISO Geographical Data Files (GDF) international standard (later described in Chapter 2). Soor (2002) focused on the RADEF Road Data Model and its domains,[20] while ANAS (1998) provided evaluations on the model from the point of view of road managers: importantly, it defined RADEF as "unnecessarily complex" and looking for a meaningless common denominator among many different classifications and mismatching coding (as many as the number of countries).[21]

2.1.1.2 Research on road inventory systems mainly aimed at road safety management

Many researchers explored models to improve road inventories for safety purposes, focusing on both data integration and the definition of road features categorised by collaborative evaluations (i.e. stakeholders participation in evaluation) and then collected into an inventory. Lefler et al. (2010) (2013), Pollack (2011), Mallela et al. (2012), Altobello et al. (2013), and Fiedler et al. (2013) described MIRE (Model Inventory of Roadway Elements), a listing of more than 200 roadway features and traffic volume elements important to safety management, created and improved over time in USA by the Federal Highway Administration (FHWA) Office of Safety: a primary standard to provide States and local transportation agencies with a structure for roadway inventory data elements and traffic data variables, using common consistent definitions and attributes.[22]

Lefler et al. (2013) widely illustrated MIRE Version 1.0 with roadway and traffic data elements grouped into three broad categories (roadway segments, roadway alignments and roadway junctions). Mallela et al. (2012) highlighted MIRE element collection mechanisms and related issues in current practical implementation, while Fiedler et al. (2013) described the effort

[20] i.e. Road Network, Restriction, Traffic, Structure, Equipment, Accident, Condition, Road Geometry, Route, and Network Enquiry.

[21] In particular, ANAS (1998) defined not productive that those countries that did not yet have an established Road Cadastre (including Italy) will have been allowed the multiple repetition of the structure and coding and different specifications (as many as the countries), and considered useful to align also partially the structure of information: at least among the countries starting the implementation of their own national road inventory (ibidem).

[22] It also provided all the data required by analysis tools such as Safety Analyst and the Interactive Highway Safety Design Model (IHSDM), and other procedures by the new Highway Safety Manual (Lefler et al., 2013; Lefler et al., 2010). Safety Analyst software requires typical data including: crash data (e.g. crash severity, crash location, day and time of crash), road condition, weather conditions, and vehicle types involved; road inventory data such as road length, horizontal and vertical alignment, number of lanes, speed, traffic volumes, heavy vehicle proportions; intersection details, such as, layout characteristics, area type (rural/urban), traffic control type, traffic volumes through the intersections; interchange ramp data; cost data) (Candappa et al., 2014).

of FHWA in studying how to collect, store, and integrate MIRE data into a Management Information System (MIS). Also, Lefler et al. (2010) focused on data integration issues: as MIRE did not contain all inventory data elements needed for all safety decisions, additional databases linked to the MIRE DB and including further elements[23] were required (ibidem). Importantly, Lefler et al. (2013) focused on the cooperative method of gathering data by volunteer agencies, linking information with crashes and other relevant data for safety analyses, and finally incorporating it into the agencies' safety programs.

2.1.1.3 Research on road inventory systems mainly aimed at road traffic management

Traffic road management also requires smart applications for urban road inventories where data are associated with volume demand traffic maps. Nevertheless, currently, up-to-date road inventories are not available in some countries as the lack of funds, making 24-hour traffic counts difficult. To solve this problem, Uddin et al. (2013) have carried out a research study on the use of satellite imagery to create road network planimetric maps for road inventory as well as traffic flow attributes and traffic volume demand maps.

Semantic road network models to simulate traffic have been also implemented, such as the AVeSi[24] Project, based on the generation of 3D scenarios from data describing real city roads. The resulting 3D model has been described by Haubrich et al. (2013): a 3D mesh consisting of road geometry and material properties for visualisation and physics simulation, with a road description file to generate a semantic road network model. Both provide all data required for traffic simulation[25] while the road description file (an OpenDRIVE file format)[26] contains data influencing the driving process.[27] Roads are described by single reference lines, whereas junctions by a list of links connecting incoming roads to paths.

2.1.1.4 Research on road inventory systems mainly aimed at road maintenance and asset management

Road inventories for management and maintenance have been also investigated: a study by Higuera de Frutos and Castro (2014) presented a method based on the use of smartphones to

[23] e.g. roadside fixed object, signs, speed data, automated enforcement devices, railroad grade-crossing and bridge descriptors, land use elements related to safety, and safety improvements.
[24] i.e. 'Agentenbasierte Verkehrssimulation mit psychologischen Persönlichkeitsprofilen' – engl. 'Agent-based traffic simulation with psychological personality profile.
[25] e.g. road geometry, priorities, speed limits.
[26] OpenDRIVE® is an open standard for the description of track-based road networks. The standard provides the option to describe the geometry of roads as well as features along the roads which can influence the driving process (Dupuis et al., 2010). "A road description consists of a number of information such as planar geometry, elevation, lane sections, lane features and objects surrounding the road. The general course of a road is described by a single reference line. Junctions are described by a list of links which connect incoming roads to paths (1:n). Each path leads to exactly one outgoing road (1:1). Paths are described as roads leading through a junction" (Haubrich et al., 2013).
[27] i.e. the geometry of roads (e.g. planar geometry, elevation, lane sections), lane features and objects surrounding the road.

create inventories of all types of road networks not accessible to cars, manage the small road networks' routine maintenance, and as a basis for future research projects on road design and outline. Larson and Skrypczuk (2004) documented the result of the Inventory and Condition Assessment System (ICAS) pilot project conducted from 1996 to 2002 by the Virginia Department of Transportation (VDOT): it was designed to allow storing, accessing, and using condition and location information for a comprehensive set of assets in day-to-day asset management decision making.

2.1.1.5 Research on automatic data collection for road inventory systems

Methods to obtain automatic road inventories from MMS camera's images (Laflamme et al., 2006) and LiDAR data (Landa and Prochazka, 2014) have been studied in order to record information (such as position, condition or type) of traffic signs, road markings, guardrails, general pole-shaped objects (e.g. city lights or trees), and other: a result achievable by algorithms detecting traffic signs in LiDAR measurement and transforming the results to a common format used in GISs may be used. The development of Mobile Mapping System for 3D Road Asset Inventory using extraction techniques along with a sample GIS database structure has been discussed by Sairam et al. (2016).

2.1.2 Review of existing systems

As noted by Thlakma et al. (2015), GIS based road information management system applications are currently used broadly by transportation analysts and decision makers in different areas of transportation planning and engineering, from infrastructure planning, design and management, traffic safety analysis, transportation impact analysis, public transit planning and operations to intelligent transportation systems (ITS) such as Advanced Traveller Information Systems (ATIS) and Commercial Vehicle Operations (CVO) (Vonderohe et al, 1993).

2.1.2.1 Existing road inventory systems for data integration

An example of a road inventory for data integration can be found in Oregon (USA): the Public Road Inventory, illustrated by King and Kratzchmar (2010), is used by the Transportation Data Section of the Oregon Department of Transportation (ODOT) to collect and maintain information on status and condition of the state road system[28] as well as data required to classify and monitor country's roads. Its "TransInfo" database includes different data inputs (divided into paper, file and automated sources), databases, interfaces, extracts, and reports, and allows users to

[28] i.e. about 13,000 km of state roads owned and maintained by ODOT.

have access to mileage statistics and traffic counts. The system also integrates: a) "Straightline Charts" (representing features along state roads as lines), downloadable in .PDF format from a link in the Department website, and used as a quick reference to locate an attribute along a state road, connection, or frontage road,[29] b) interchange diagrams for each connection and frontage road along the motorway, with their features noted by milepoint, c) and digital images, taken from the driver's perspective at every hundredth of a mile in both directions and collected in the State Highway Digital Video Log (Fig. 14).

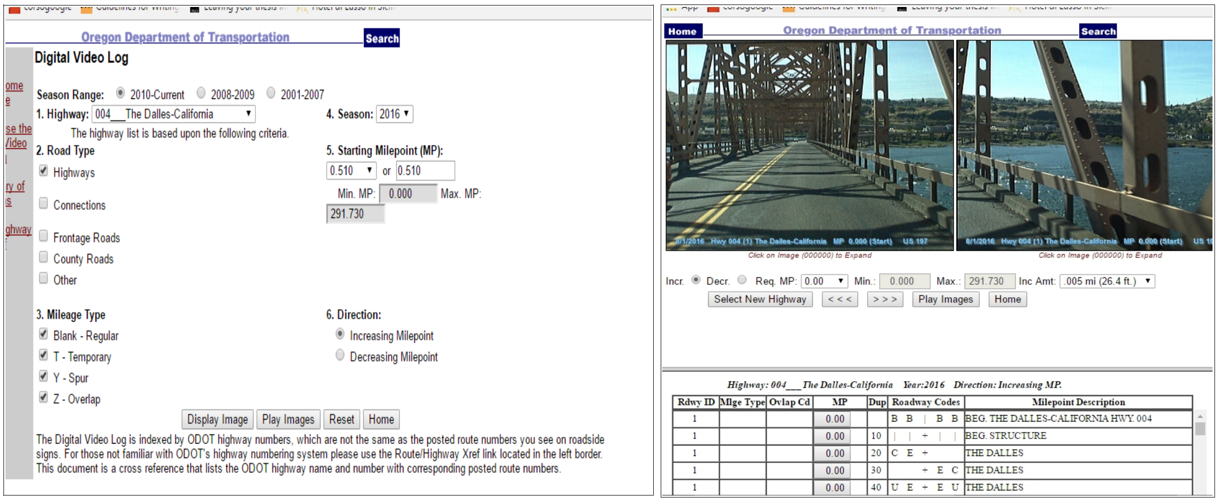

Figure 14. Digital Video Log representing the Dallas-California highway – Form for selecting roads of interest and images and data related.

Copies of current or historic videos can be obtained by filling out the on line form provided on the ODOT website, or by calling the office. Subscription service for updated videos is also available to both public and private agencies. All the information above is collected by different tools made available on the Oregon Department of Transportation website.

2.1.2.2 Existing road inventory systems mainly aimed at road safety management

Other inventories mainly aimed at road safety are reviewed by Candappa et al. (2014) in the final report within the European project "*Road Infrastructure Safety Management Evaluation Tools*" (RISMET). Different databases allowing easy access to information and road safety assessments within each country are described alongside the kind of data required. Tukhral et al. (2013), Harwood et al. (2010) and Richard et al. (2007) studied the SafetyAnalyst software package: a set of software tools with a database[30] adopted by both several state and local road agencies for road

[29] i.e. intersecting roadways, culverts, rivers, bridges, city limits, state parks, viewpoints, etc.

[30] It includes: data on roadway characteristics, traffic volume, and crash data traffic crashes, road cross section and infrastructure details, road network configuration, intersection and interchange ramps locations as well as costs for an agency's road network.

safety management (mainly in USA and Canada)[31] and universities worldwide. By analysing data collected into the inventory, the software enables road agencies to identify, assess and prioritise sites requiring road safety improvements (by the Network Screening Tool), diagnose the nature of safety problems at specific sites (by the Diagnosis Tool), assist users in selecting countermeasures to reduce crash frequency and severity at specific sites (using the Countermeasure Selection Tool), perform an economic appraisal of a specific countermeasure (or several alternative) for a specific site (through the Economic Appraisal Tool), and provide a priority ranking of sites (via the Priority Ranking Tool). It also allows road agencies to propose improvement projects, based on the benefit and cost estimates determined by the economic appraisal tool and the capability to conduct before-and-after evaluations of implemented safety improvements (using the Countermeasure Evaluation Tool). A data management tool also helps users to import and manage data (Tukhral et al., 2013; Harwood et al., 2010; Richard et al., 2007).

Gorell and Tootill (2001) described the MOLASSES (Monitoring of Local Authority Safety Schemes) database, implemented by the County Surveyors' Society (CSS), UK, in 1991, (and then replaced by the UK Morse database): it encourages safety schemes monitoring by providing road authorities with data for road safety evaluations.[32]

Candappa et al. (2014) also reviewed the Highway Safety Information System (HSIS): a DB US-based with data on crashes, roadways, and traffic variables for various states from the US, used to analyse a large number of safety problems (e.g. predictive modelling of future accident frequencies from roadway characteristics and traffic factors), also identifying its severity and extent.[33]Also Li and Madanu (2008) conducted a literature review on the existing roadway safety hardware management practices in the US.

2.1.2.3 Existing road inventory systems mainly aimed at road maintenance and asset management

Many road inventories have been implemented in USA with road maintenance and management purposes: Traffic Structure Inventories Inspection and Maintenance Systems in Maryland, Pavement Marking in Missouri, Guardrail and Crush Cushion Management Systems,

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[31] Such data derives from 2014 licenses reported in the Safety Analyst website.

[32] The database contained information within categories such as intersection details, horizontal and vertical geometry, pedestrian and cyclist facilities, road network and area wide details as well as percentage change in accidents per annum, average annual accidents saved, expenditure per accidents saved per annum, and first year of return.

[33] Typical data imported into the database are in particular: crash data (e.g. crash type, vehicle types, occupant details, crash severity, and weather conditions), road characteristics (including data on road cross-section and geometry: number and width of lanes, presence and type of shoulders and median, vertical and horizontal alignments, rural/urban designation, and functional classification), and also intersection details (e.g. intersection type, control type, and intersection layout), traffic data (including annual average daily traffic (AADT)), vehicle Identification Number (VIN) (with model of the vehicle, body style, body type, curb weight, and wheelbase), motorway interchange/ramp (interchange type and ramp characteristics), and barrier data (e.g. barrier type, post type, rail height, and terminal type).

Maintenance Management Systems in California[34] and Roadway Characteristics inventories in Florida.[35] In New Mexico all the asset data of Road Feature inventories is imported to an Oracle database with the video of each lane (recorded at 50-ft intervals and a video image width of 120-ft) to create an extensive DB of the whole New Mexico roadway system, easing maintenance and limit legal liability by documenting safety assets (FHWA, 2005). Flintsch and Bryant (2009) described the road inventory system implemented in Virginia by VDOT: a complete inventory of highway-maintainable assets in three counties, including statewide centerlines for the entire road network, a data dictionary, functionalities for measuring asset conditions, managing and accessing asset information, supporting the use of multiple location-reference systems. Authors also discussed PST (i.e. Project Selection Tool), a software package developed by Maryland State Highway Administration (MDSHA), whose data are integrated with the MDSHA pavement management DB. In order to create the PST roadway section, data are merged from three sources: the Roadway inventory database (with information on the roadway geometry, designation, and traffic), the Pavement performance database (including ride quality, rutting, cracking, and friction condition data), and the Construction history database (recording every layer of the pavement structure with construction, material type, and thickness data). From data aggregated, summary information can be retrieved at fixed intervals defined in the construction history database.

Moreover, Li and Madanu (2008) discussed Sign Inventory Management Systems in Wisconsin and Virginia, with a database of list of signs to be replaced or reviewed, and Traffic Signal System Information Systems and Inventories (in Oregon and Virginia), containing a wide range of different data.[36]

2.2 Systems for integrated geoinformation and road data management

Spatial data is involved in a wide range of application domains, ranging from decision support through planning and design to medicine and robotics, and their manipulation is progressively more important in today's information-driven world (Belussi et al., 2007; Ellul, 2008). In particular, the road sector deals with that, as the very nature of transport and mobility is spatial (Loidl et al., 2016), and the use of GIS, able to manage road and transport spatial data,

[34]It contains detailed information about each motorway asset, where it is located on the roadway, and work being performed on the asset, all electric power system, including luminaries, signals, ramp metres, flashers, cameras, message signs, all lighting, tunnel lighting, and loop detectors.

[35]They contain physical and administrative data related to the roadway networks, roadway signs, traffic signals, pavement markings and treatments, guardrails, and barriers, roadway lighting, structural supports, and detectors.

[36] e.g. motorway location and name, street name, direction of traffic flow, intersecting street name, nearest city, name of county, name of district, region number, name of company supplying power, metre number for location, mile point, date of activation, recent date of repair, months of inspection and maintenance, comments, and signal priority.

has become essential in the transport sector leading to the birth of a new subject called GIS-T (i.e. Geographic Information Systems for Transportation) (Yuan, 2008).

As the previous section illustrated, many of the road information systems described above are based on GIS. However, as increasingly spatial data has been considering three-dimensional - and hence requiring 3D representations and analyses - even the road sector has to address the challenge of managing road data in 3D.

This section presents an overview of 2D and 3D GIS, focusing on their applications to the road transport sector, and discusses purposes, possible benefits and obstacles in using 3D GIS to manage the Road Cadastre. An overview of 3D models like BIMs applied to infrastructures is also included to be later compared with 3D GIS in the Discussion Section (Chapter 10).

2.2.1 2D GIS

There are several definitions of a Geographical Information System (GIS) (Campbell and Shin, 2012). Heiwood et al. (2006), Chrisman (2000) and Maguire (1991) provided some review of them. According to a "component definition" (Murayama and Estoque, 2010; Woodhouse, 2004; Guler et al., 2004; Rhind, 1996), GIS consists of: 1) a **software**, able at handling and presenting geographic data and information as maps. It consists of a **database management system** (DBMS), capable of storing, editing, processing, and integrating **spatial data** (such as streets, buildings, lakes, countries, and their respective locations) with **attribute data** (i.e. descriptive data, such as name, address, type, depth, quality, and other) linked to map features; 2) a **hardware**, including a computer, memory, storage devices, scanners, printers, global positioning system (GPS)[37] units, and other physical components; 3) **geographic data**; 4) **procedures/methods**; 5) and **people** (i.e. personnel managing all stages of geographic data capture, storage, analysis, query, display, and output).

A "functional definition" is given by many authors who describe GIS as a computer-based system for **collecting, storing, editing, validating, integrating, manipulating, querying, analysing, visualising and presenting spatially-referenced data** (i.e. related to positions on Earth's surface) (Burrough, 1986; Department of the Environment, 1987; Maguire and Dangermond, 1991; Raper and Maguire, 1992; Zlatanova et al., 2002; Worboys and Duckham, 2004; Abdul-Rahman and Pilouk, 2008; Murayama and Estoque, 2010; Rodrigue et al., 2016), and including both the locational element and associated attributes (Ergun et al., 2010; Gattrell and Elliot, 2009).

[37] The Global Positioning System (GPS) is a global navigation satellite system (GNSS) that provides geolocation and time information to a GPS receiver in all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites.

Within a GIS, data can be represented spatially by raster datasets (coming from grids, like images and aerial photos) or vector datasets (e.g. points, lines, polygons or a mixture of these, whose 2D coordinates (x, y) represent the position of each feature) (Dale and McLaughlin, 1988; Peuquet, 1990; Heiwood et al., 2006). Moreover, data are modelled through themed map layers - each containing one object theme and representing physical features (like buildings, parks, rivers, lakes, and roads) or other concepts (such as administrative boundaries) - and can be stored in an object-relational DB and integrated with non-spatial data (Ellul, 2008).

2.2.1.1 Current state

Currently, there are many systems both free&open source[38] (FOSS) - e.g. Quantum GIS and GRASS - and proprietary - e.g. ArcGIS by ESRI - that implement GIS functionality. Caitlin Dempsey has described both FOSS (2016b) and commercial (2016a) GIS applications, highlighting their main functionalitites. A review and comparison of FOSS GIS software packages, projects, and literature related can be found in Bradt (2008), Sanz-Salinas and Montesinos-Lajara (2009), Ballatore et al. (2011), and Steiniger and Hunter (2012), while Donnelly (2010) compared several free desktop GIS with the proprietary ArcGIS software. A further GIS classification can be found in Zatelli (2009) who divided GIS into: generic (allowing all or most of GIS functions, with additional modules for specific operations); specialised (to be used in specific fields); viewers (mainly used by occasional users to view data and create maps); and instrumental (performing service functions like conversion of formats or datum).

GIS functionalities and benefits have been discussed by many authors. Guler et al. (2004) and Ergun et al. (2010) found the main advantage by using GIS in: 1) its **multiple functionality** (that includes **geo-visualisation capability, analytical capability,** and **database management features**, able to capture spatial and topological pre-defined relationships between geo-referenced entities), and 2) the **integration of disparate and specialised data and technologies** available to users within one environment (ibidem). Monroe County (2008) emphasised GIS role as a computer based mapping tool for **mapping visualisation** and **geographic analysis**: that "integrates common database operations such as **query and statistical analysis** with the **unique visualisation** and **geographic analysis** benefits offered by maps" (ibidem); while Murayama and Estoque (2010) highlighted its function of allowing maintaining, analysing, and **sharing** a wealth of data and geographical information.

Because of its powerful functionalities, GIS is recognised as a decision support system involving the integration of spatially referenced data in a problem-solving environment (Estoque,

[38] i.e. software whose source code is freely accessible and modifiable and typically worked on by a community of volunteer programmers.

2012; Wu et al., 2001; Cowen, 1988), and has been used in fields as diverse as utilities management and health (Garner et al., 1993; Patel and Waters, 2012; Fradelos et al., 2014), agriculture (Wilson, 1999; Pierre and Clay, 2007; Bill et al., 2012; Yousefi and Razdari, 2016), archaeology (Ebert, 2004; Scianna and Villa, 2011; Scianna and Gristina, 2016), transportation (Souleyrette et al., 1996; Alterkawi, 2001; Loidl et al., 2016), and any field in which spatial data makes sense.

2.2.1.2 2D GIS applied to the road sector

As noted by Loidl et al. (2016), the movement and transport of people and goods is spatial by its very nature. Hence, transportation issues have met an effective tool in GIS technology due its capabilities in capturing, management, analysis and visualisation of spatial road data (Rodrigue et al., 2006; Chen et al., 2008; Shaw, 2010; Loidl et al., 2016). Moreover, different aspects of transportation require the capability to cope with the large volume of data with geographic spatial characteristics that GIS allows (Chen et al., 2006). Therefore, over time, transportation has been taking on particular relevance among the wide range of potential applications fields GIS can be used for (Rodrigue et al., 2016; Miller and Shaw, 2001; Fletcher, 2000; Wiggins et al., 2000; Miller, 1999; Kwan, 1997).

As shown in the literature, GIS technology has opened up new horizons in transportation planning and especially in travel demand modelling (Alterkawi, 2001; Thill, 2000; Bhat and Koppleman, 1999), as the system allows analysis previously considered impossible due to the very large amounts of data involved (Veerabathini et al., 2015; Alterkawi, 2001), an integration of various data sources (Gupta et al., 2009) into a scalable, dynamic and adaptable geospatial framework, as well as visualisation and spatial simulation (Loidl et al., 2016). Many researchers have turned to GIS technology for accessibility analysis (Miller and Wu, 2000; O'Sullivan et al., 2000; Juliao, 1999; van Eck and de Jong, 1999; Gutiérrez et al., 1998; Kwan, 1998; Shen, 1998; Geertman and van Eck, 1995; Arentze et al., 1994; Miller, 1991), and studies illustrate that various uses of GIS in modelling activities for long and short range planning can also be applied to the roadway network and network maintenance and updating (Alterkawi, 2001). In addition to the above, Alterkawi (2001) and Antenucci et al. (1991) noted that some of the specific transportation applications of GIS include road design, road mapping, and analysis of accident data and traffic volumes.

Due to both the increasing relevance of GIS and road sector's requirements, Geographic Information Systems for Transportation - commonly labelled as GIS-T - has been developed as a specific branch of GIS applied to this field (Shaw, 2010; Chen et al., 2008; Dueker and Peng, 2008; Yuan, 2008; Curtin et al, 2003; Miller and Shaw, 2001), and, as noted by Goodchild (2000) and Waters (1999), it has become subject of annual conferences (such as the GIS-T Symposium held in the USA), an expanding literature, and numerous specialised software applications (Liu and Zhu, 2003; Greaves and Stopher, 1998).

In comparison with a generic GIS, a GIS-T includes transportation layers and various transportation networks (e.g. roads, rail corridors, waterways, bicycle trails, and other, with all of the other point, line, and polygon data) (Moyer, 1994). It is used to support integrated operations of government-owned road systems, including planning, visualisation and construction of new infrastructures and facilities (with environmental evaluation), as well as management, monitoring, maintenance and updating of the existing ones (Alterkawi, 2001). Asset management systems tipically include geospatial location data for infrastructure features, and employ GIS-T mapping to locate, visualise, and analyse those features, also determining funding levels for transportation maintenance and improvements based on objective needs for building and maintaining facilities, and allocation of resources (Alterkawi, 2001). GIS-T also provides buffer, deficiency and air quality analysis (relating to traffic air-pollution) (ibidem). As highlighted by Kiel, GIS-T algorithms and mapping are also often incorporated within Intelligent Transportation Systems (ITS) to locate a vehicle along a roadway and display characteristics like traffic speeds, manage vehicle routing and permitting, or to identify the shortest path along a road network (Ford et al., 2015; De Smith et al., 2015; Alterkawi, 2001) for solving route guidance in a navigation system or spatial allocation problems (Zeng and Church, 2009), travel time allocation, and future areas of congestion by travel demand analyses (Ford et al., 2015). Also, GIS-T road-related uses include: computer-assisted design (CAD) integration, integration with digital ortophotography, transportation planning and travel demand modelling, safety planning and monitoring, planning of multimodal facilities, and integration property management (Alterkawi, 2001). In the road sector, GIS has also been extensively used for: pavement and bridge maintenance management (Xiao et al., 2012), modelling disaster response plans (Cheng et al., 2014) as well as analysing impacts of transportation infrastructure construction (Cai et al., 2012), routing of overweight and oversized vehicles (Steere, 2012), identifying high-crash-risk road segments (Mohaymany et al., 2013), high safety and truck traffic analysis (Schultz et al., 2012), the management of rural roads network (Manyazewal et al., 2014), and others. It is also a useful tool to support decisions on the construction of new roads, as it facilitates analysis of the effects of new infrastructure on an area's accessibility, optimising the route, and minimising the possible environmental and visual impact of new roads (Seguì Pons and Ruiz Pèrez, 2003).

2.2.1.3 Advantages from using GIS in roads' inventories and roads' life-cycle

Benefits from using GIS for roadway inventories have been highlighted by many authors. Kiema and Mwangi (2009) remarked that GIS based road inventories permit meeting the spatial nature of road data analysis: each data record is tied to a unique location defined in a given referencing framework (global, national or local datum) (Guler et al., 2004), and by the spatial referencing of objects topology of the data can be defined and enables a host of spatial query operations of objects and set of objects (ibidem). Goodchild and Longley (1999) and the European Commission (2015) emphasised different kind of geospatial analysis allowed by GIS, such as: buffer analysis (e.g. how many road structures to be maintained are within an area x? What should be the minimum distance of buildings from a major road – with ≥10,000 vehicles per day - to avoid road noise?), overlay analysis (e.g. which wet areas are within the proposed road project area?), find 'n' nearest (e.g. find the three closest road facilities to the point x), line of sight (e.g. which road signs can be seen from a car from a point of the road?), way finding (e.g. what is the shortest route from place x to place y?), and travel time (e.g. how many drivers will have to travel more than half an hour to get to their office location?) (Sinha and Labi, 2007).

The emergence of ITSs and smart cities suggests that existing systems will need to be extended to incorporate newly available information (Urmson et al., 2009), and to integrate data on all phases of road design, construction and maintenance and from multiple sources (Gristina et al., 2016; ESRI India, 2014, ESRI, 2011). In this regard, Hall (2004) noted that GIS allows all that, due to its relevant capabilities to integrate data from disparate databases and display information in new and unique ways for decision-making. Also ERSI (2008) and Gristina et al. (2016) remarked that GIS enables storing a wider range of different type of data (including text, vector, and raster) required for managing road infrastructure (e.g. geometrical and physical elements, administrative and technical road classifications, and specific attributes) - no matter their source or original format. It allows a qualitative and quantitative selection of information associated with different layers (Hornsby, 2001) to produce a wide variety of individual maps, depending on which data layers are included; also, it is able to combine the information from different sources (e.g. maps) (ESRI, 2008) to process and display all by using one common scale and projection and showing on one map many different kinds of data (e.g. people, vegetation, soils, buildings, storm drains, roads, electric power lines):[39] all that enables people to more easily see, analyse, and understand different things in different locations to discover how they relate to

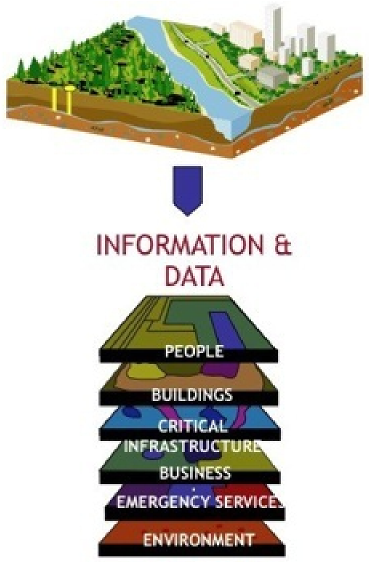
[39] "ArcGIS can handle data in different coordinate systems as long as the projection/coordinate system of each data set is defined in a way that the software can understand. Typically this means a shape file has a .prj file in addition to all the other files that make up the data set (e.g., parks.prj). When you pull up data in different coordinate systems, ArcGIS tries to use the information in the various .prj files to project all the layers into one projection so that they all correctly overlay each other" (Tufts GIS Tip Sheet, 17 April 2007, Trouble Shooting Map Projections in ArcMap. Available at: http://ocw.tufts.edu/data/54/626825.pdf)

each other. Finally, GIS allows researchers to look at change of road phenomena over time, and selected users to access to information (ESRI, 2008a): often GIS contains a large variety of data that do not appear in an onscreen or printed map.

The GIS capability of **displaying the road network** on a computer monitor, while linking features to attribute tables, has become a valuable tool for observing the relationship between the spatial and physical attributes of roadway facilities (Alterkawi, 2001; Ng'ang'a, 2009), maintaining and updating roadway network files (Abdullahi and Rabiu, 2014; Alterkawi, 2001; Ng'ang'a, 2009), and easily identifying errors in link connections, channelling, consistency of functional classification along a facility, number of lanes, and other attributes essential for successful travel demand analysis and trips loading from traffic analysis zones (Abdullahi and Rabiu, 2014; Alterkawi, 2001). It also allows the correction of roadway alignment and the updating of node coordinates used in identifying link end points, and provides by coloured maps a visual dimension for travel demand analysis and the perception of the different planning scenarios impact possible for non-planners (Alterkawi, 2001). Moreover, as noted by Alterkawi (2001), statistical summaries enabled by GIS are used as a support of planning decisions in the analysis of networks (e.g. to identify the number of links by facility type, number of lanes monitoring changes in network, and travel characteristics overtime).

2.2.1.4 Limitations of 2D GIS in roads' cataloguing and representation

Traditionally GIS is two-dimensional (Ellul, 2007): objects are represented using its projections on 2D plane (Sloot et al., 2003), map layers are stacked (overlaid) in order to build up a representation of the real (3D) world (Fig. 15) (Laurini and Thompson, 1992; Heiwood et al., 2006) and the third dimension is usually recorded as an attribute. In the road sector, as noted by Yuan (2008), over decades road networks have been commonly modelled as 2D centrelines, simplifying the complicated transportation system to a network of single lines and treating flyovers as points.



6.

Figure 15. The layer-based approach (ESRI, 2008; Geoscience Australia, 2008)

With regard to road inventories, currently 2D GIS-based systems are not able to describe complex road information like 3D spatial features (e.g. overlapping and interlocking road networks, bridges, overpasses and tunnels, as well as the description of 3D road components, underground utilities, and 3D environmental and urban contexts), and this aspect has been highlighted by Hatger and Brenner (2003). Also Yuan (2008) reports that 2D systems do not enable the comprehensive description of road networks in their full three spatial dimensions and moving from street-based level descriptions to 3D lane-based ones is compelling. Limitations of 2D GIS related to data dimensionality have been discussed in the literature by Raper and Kelk (1991) and Bonham-Carter (1996) noting that 2D and 2.5D GIS are inadequate for data with multiple-z values; so far, attempts to solve this issue have focused on regular objects such as buildings and houses (De Cambray, 1993; Bric, 1994; Abdul-Rahman and Pilouk, 2008). In addition, the situation on the ground is complex and very difficult to represent in 2D (as required e.g. by Italian design standards, as mentioned in Chapter 3): again, as Abdul-Rahman and Pilouk noted, GIS packages handling both 2D data and DTM (Digital Terrain Model) are not enough to describe 3D real world, as DTM is not real 3D spatial data[40]. Moreover, Yuan (2008) observed that 3D objects presented in 2D in GIS may lose properties such as texture, graphic, height, and their spatial relationships to other objects. However, Abdul-Rahman and Pilouk (2008) noted that true representation and spatial information can not successfully achieved with 2D systems, and inappropriate spatial data structure of 2D GIS to describe three-dimensional entities have been reported by Jones (1989), Houlding (1994), Rongxing (1994), and Wei Guo (1996).

[40] "The third dimension of the DTM data only provides (often after interpolation) a surface attribute to features whose coordinates cosnist only of planimetric data or x,y coordinates" (Abdul-Rahman and Pilouk, 2008).

2.2.2 3D GIS

As noted by Zlatanova et al. (2002), the need of 3D information has been rapidly increasing over the last decade and an extension of 2D GIS to the third dimension has been required for managing 3D spatial data in many application areas (Pilouk, 1996; Köninger and Bartel, 1998; Zlatanova, 2000; Abdul-Rahman, 2000; Scianna, 2013), such as environmental monitoring, landscape planning, hydrographical, geological and mining activities, urban planning, civil engineering, utility management, telecommunications, and transportation monitoring (Raper and Kelk, 1991; Rongxing, 1994, Förstner, 1995; Bonham-Carter, 1996; Zlatanova, 2002; Abdul-Rahman and Pilouk, 2008).

The ability of GIS to overlay and display spatial datasets (e.g. infrastructure locations, street widths, building footprints and tree locations) allowing users to visualise and understand mutual relationships between data (Al-Rawabdeh et al., 2014), and its capability to analyse spatial data for physical planning (e.g. land use, infrastructure and transportation planning) met the increasing use by GIS specialists of 3D maps and many interactive computer graphics applications for presenting spatial data to non-experts, and enabling the exploration and manipulation (ibidem). All above lead GIS researchers to explore the possibilities of extending the existing systems to at least a third dimension (Abdul-Rahman and Pilouk, 2008).

A definition of 3D GIS can be found in Worboys (1995) and Xue et al. (2003), both describing it as a software system able to input, store, edit, model, represent, manage, manipulate, analyse, visualise and support decisions based on information (like 2D GIS), but associated with three-dimensional phenomena. Hence, as noted by Abdul-Rahman et al. (2001), 3D GIS should be able to perform the same tasks as 2D GIS, and also according to Pigot (1998) 3D GIS should be capable to perform metric (distance, length, area, volume, etc.), logic (intersection, union, difference), generalisation, buffering, network (shortest way), and merging operations like 2D GIS.

Differences between 3D GIS and 2D GIS can be found in the literature. They relate to the integration of height information into 2D GIS (Raper and Kelk, 1991; Fritsch, 1996), the amount of data to be processed and the user interface (Kofler, 1998), and the inclusion of terrain visualisation, cityscape modelling or virtual reality and analysis of complex spatial data (Raper and Kelk, 1991). Moreover, Raper and Kelk (1991) emphasised 3D data capture, 3D visualisation and 3D modelling and management as the main components of 3D GIS, while Pfund (2001) pointed out that most applications and data structures for 3D GIS are optimised for visualisation. However, though the novelty of 3D display functionalities within a GIS has been often over emphasised by some software producers, the potential of 3D GIS lies on the multiple GIS functionalities allowed by it in 3D. Such importance has been highlighted by an interesting 3D GIS definition given by Costamagna (2014): "3D Geographic Information Systems (3D GIS) are systems for structuring and managing 3D spatial data and are capable of handling 3D geometry structures and performing onto them basic spatial analysis functionalities of a GIS. This means assigning the same importance to the <x,y,z> coordinates both in data visualization operations and data retrieving or editing ones".

2.2.2.1 Current state

Zlatanova et al. (2002) and Abdul-Rahman et al. (2008) summarised the status of 3D GIS development by an overview on a few popular systems[41] attempting to provide some 3D data processing functions (structuring, manipulation and analysis), and including 3D Analyst of Arc View (by ESRI Inc.), Imagine VirtualGIS (by ERDAS Inc.), GeoMedia Terrain (by Intergraph Inc.), and PAMAP GIS Topographer (by PCIGEOMATICS). As noted by Zlatanova et al. (2002), such systems can handle efficiently only 3D data display with extended tools for 3D navigation, animation and exploration (i.e. presentation function), whereas they are still lacking full 3D geometry for 3D representation.

Boyes et al. (2015) overviewed 3D GIS applications in the built environment that include energy performance simulation (Bazjanac, 2008), indoor navigation (Worboys, 2011), urban planning (Stoter et al., 2011), cadastral registration (Stoter et al., 2011), noise propagation (Gröger et al., 2012) and renewable energy modelling (Resch et al., 2014). Held et al. (2015) discussed web 3D GIS for urban environments, and presented a review of current web 3D systems.

2.2.2.2 3D GIS applied to the road sector

The potential of 3D GIS applications to the road sector has been addressed by several authors from different points of view for different purposes and with various results. Researchers have been focused on the use of 3D models to better understand road surface texture (Woodward et al., 2014), to assess pothole growth (McQuaid et al., 2015), and to virtually reproduce vehicle, road sections, and barriers, and to evaluate their deformations during crashes (Bonin et al., 2004). Yu (2005) and Yu et al. (2007) addressed digitising and 3D modelling of road surface using an integrated multisensory approach, while Wang et al. (2014) studied a method to produce automatically 3D high-fidelity road network models from 2D real road GIS data only containing 2D road centreline information: e.g. basic road elements such as road segments, road intersections and traffic interchanges. A similar approach can be found in Nguyen et al. (2014) in

[41] The systems were: 3D Analyst of Arc View (by ESRI Inc.), Imagine VirtualGIS (by ERDAS Inc.), GeoMedia Terrain (by Intergraph Inc.) and PAMAP GIS Topographer (by PCIGEOMATICS).

order to obtain realistic road path reconstructions from GIS data by using algorithms applied to sample points organised in 3D polylines. However, these are pure 3D reconstructions from 2D GIS data, whereas - as noted by Billen and Zlatanova (2003) - the challenge of 3D GIS is to support analysis between all kind of real 3D objects (not only to visualise them). Zhu et al. (2006) presented a method for integrating 3D GIS and road CAD and promoting the application of 3D GIS to road planning, design, construction and management: despite the integration of a 3D route surface model with the 3D construction solid model within a 3D road GIS database, the research work was mainly aimed at the real-time and dynamic visualisation technology of 3D road GIS with large database and for the geometrical route design and the facility management. Pamanikabud and Tansatcha (2009) used 2D and 3D GIS to visualise road traffic noise impacts in the form of 3D noise contour on the building and ground surface along the roadway: the combination of traffic noise model with geoinformatic technique aimed again at a visual display of impact levels from roadway noise within an area investigable at different angles. Peng et al. (2009) proposed a geo-localisation method for intelligent vehicle navigation in urban areas based on the use of 3D-GIS, GPS and laser scanner (with a 3D city model managed in real-time by a 3D GIS): sets of distances (laser scan data) were matched with depth information (virtual laser scan data), provided by 3D GIS, using iterative closest point algorithm. Kim et al. (2016) described an underground monitoring system using 3D GIS, consisting of wireless sensor networks (providing sensing values on the state of underground facilities), middleware (providing an abstraction layer for various sensing devices and communication protocols), and a 3D visualiser (to show shapes, locations, states, and the indexes associated with facilities by adding the depth to 2D GIS data). The 3D GIS used in the visualiser is described as a powerful tool facilitating the underground environment monitoring for public safety with different data are uploaded into the database via the Internet. It creates a detailed model describing the objects both from above and below the city ground, and including maps, imagery, and subsurface features such as water pipes, water supply manholes, sewage pipes, sewage manholes, subway lines, and subway stations. However, again GIS technology is mainly used for its 3D display function.

2.2.2.3 3D GIS applied to the Road Cadastre

There is still not a literature addressing the topic of 3D GIS applications to the Road Cadastre. Choy et al. (2005) presented a 3D Web-based GIS project for road simulation. They studied how using virtual reality technology through the three-dimensional road design in order to: search problems in real-time on the Web during design and construction work stages by the user-based Virtual GIS, find problems during decision-making and design/construction work stages, and provide an effective decision-making method between petitioner and user. Jalayer et al. (2014) addressed road inventory data collection methods, but focusing on technical problems relating to data capture: e.g. they noted that a vehicle-mounted LiDAR,[42] though capable of collecting a large amount of detailed 3D road data, requires expensive equipment and data reduction efforts to extract the desired road inventory data. Amoureus et al. (2007) discussed the integration of LiDAR and terrestrial Mobile Mapping technology for the creation of a comprehensive Road Cadastre, but 3D data are actually aimed at implementing a 2D GIS. Sairam et al. (2016) examined the use of low cost road data collecting systems - from sensors to MMS - aimed at obtaining geo-referenced data and store it into a 3D asset inventory based on a GIS database: event though the MMS provides a 3D model of the entire scene, authors do not describe a real 3D GIS of roads, as they just focus on a direct method to accurately determine 3D coordinates of road assets in the corridor. Cheruty (2015) illustrated Sivan Design's 3D-GIS, a cloud system providing GIS experts, professional users, and public users with 3D views and 3D analysis tools, enabling them to use spatial information in 3D and specific solutions for underground infrastructures, roads and cadastre. Finally, Stoter (2000; 2003; 2004), together with Salzmann, Van Oosterom, and Van der Molen (2002) Billen and Zlatanova (2003), and Ploeger has been among the first researchers addressing the topic of 3D GIS applied to Cadastre in general, and since 2011 the International FIG Workshop on 3D Cadastres has been receiving a number of scientific contributes on 3D recording, 3D modelling, construction of 3D primitives and simulations, topology and visualisation (Ying et al., 2012): issues that can be also related to the specific topic of the 3D Road Cadastre. However, the application of 3D GIS to road inventories has to be explored yet.

2.2.2.4 Capabilities of 3D GIS in roads' cataloguing and representation

According to Burchi et al., (2009) 3D GIS Road Cadastre has the potential to improve the management of roads (both for construction and maintenance). While discussing city planning management - whose principles can be extended also to infrastructure - Al-Rawabdeh et al. (2014) highlighted that using 3D GIS modelling offers a flexible interactive system and provides one of the best visual interpretation of data which supports planning and decision processes. As Bokyo and Funkhouser (2012) explain, semantic tagging and 3D modelling of roads "is crucial to understanding the complete structure of a city, since roads provide a continuous surface spanning an entire city, segment the city into blocks, and provide contextual cues for recognizing smaller objects (e.g., fire hydrants are usually a fixed distance from a roadside)". As mentioned in paragraph 2.2.2.3, the visualisation functionality of 3D GIS is greatly considered by researchers.

[42] It is a type of mobile mapping system.

However, in the literature we can find a number of further motivations for using 3D GIS in roads' cataloguing and representation. Luliang and Quingquan (2004), Yuan (2008) and Fredericque et al. (2011) note that 3D GIS can additionally: simulate the landscape of a road and visualise 3D structures such as overpasses and on-ramps, simplifying the communication of complex situations; improve the planning, construction and maintenance of roads and bridges; allow complicated road designs to be modelled and tested in a virtual environment before construction; demonstrate in 3D any features requested by stakeholders; integrate geospatial data with heterogeneous documents like legal documents, urban plans, technical reports, images and existing scanned plans, allowing the 3D model to serve as an index to other data; permit 3D operations such as distance measurement; relate to 3D geometric information to each lane. Advantages in using 3D GIS in infrastructure planning have also been pointed out by Sivan Design (2015): they include the possibility to visualise underground features and their relation to the 3D space, realistically model subsurface features of underground networks and facilities optimise facility placement or resource location, approximate a more realistic feature space needs, identify processes and spatial patterns when looking for problems solutions, create and maintain building, infrastructure, and utility networks, and examine and calculate volumes of subsurface structures and networks. All that is able to reduce road management costs pointed out in Chapter 1, by preventing repetitions, avoiding resources and time waste, minimising pedestrians and vehicles traffic interruptions, and maintaining uninterruptable daily life during works.

2.2.2.5 Limitations and research issues

Most of the 3D GIS applications tend to focus on visualisation such as walk-through animations or scenic simulations (Al-Rawabdeh et al., 2014). However, Al-Rawabdeh et al. (2014) note that while 3D GIS display functionality is currently advanced, relatively little has been accomplished in the implementation of a practical 3D GIS, and impute such delay to the needed transition to 3D of an even greater diversity of object types and spatial relationships that can now be represented alongside very large volumes of data (ibidem). Abdul-Raman and Pilouk (2008) find the reason in the lack of proper spatial data models and data structures, and the absence of a comprehensive theory of object relationships and data basing for the 3D environment: that requires investigating on a different concept of GIS modelling, representations and data structuring (ibidem). As noted by Billen and Zlatanova (2003), GIS researchers and producers have been focusing on technical aspects relating to the way of capturing, modelling, handling, querying and analysing 3D data. With regard to data collection, despite the progress in automatic object detection and 3D reconstruction, modelling in 3D - also combining data from various sources - is expensive, as they acquire only geometry and images for texturing, and manual work is still predominant (Abdul-Rahman et al., 2001). Moreover, algorithms for the automatic building of 3D topology and ensuring consistency of data are required and have been widely discussed in the literature (ibidem). Yuan (2008) overviewed the use of 3D data capture methods[43] stimulating research on models and systems like 3D GIS and Virtual Geographic Environments (VGE) for the enhancement of 3D data management, 3D representation and 3D-analysis. Held et al. (2015) argued that the implementation of true 3D primitive (e.g. polyhedron) - also with curved surfaces and curved edges to be able to maintain urban objects created in CAD (e.g. complex buildings and bridges) - is the first urgent development. Held et al. (2015) and Zlatanova et al. (2002), while focusing on topological issues (e.g. to perform in 3D traditional GIS spatial analysis and operations like inclusion, adjacency, equality, direction, intersection, connectivity), noted that the third dimension is still in the hands of the researchers.

Research works by Pilouk, Zlatanova and Abdul-Rahman also addressed the development of a database from the spatial data (Abdul-Rahman et al., 2001). Several data structures are available for the 2.5D and 3D data and an overview of Three-Dimensional GIS Data Models can be found in Tuan (2013), Haidacher (2011), Abdul-Rahman and Pilouk (2008), and Zlatanova (2000):[44] for each of them strong and weak points in representing spatial objects have been pointed out by Abdul-Rahman et al. (2001). Difficulties in 3D data structuring, particularly topological, has been addressed by Raper (1992) and Li (1994).

Though visualisation is one of the most advanced 3D GIS functionalities, appropriate tools have been studying to visualise the result of 3D spatial analyses, effortlessly explore and navigate through large models in real time, and texture the geometry (Abdul-Rahman et al., 2001). Also, an efficient organisation of Levels of Detail (LODs) and images for textures should speed up visualisation and navigation of 3D data (Held et al., 2015). Zlatanova (2000) discussed data structuring and 3D visualisation also with respect to data query over the Web (Zlatanova et al., 2002). Specifying 3D queries and analysis (Held et al., 2015), with algorithms for 3D buffering, 3D shortest route, and 3D intervisibilities has to be fully achieved as well as the integration of object-oriented approaches with the 3D GIS (Zlatanova et al., 2002; Guo et al., 2013). Stoter and Zlatanova (2003) highlighted difficulties of some systems in covering the integration into a web environment (Stoter and Zlatanova, 2003). Held et al. (2015) noted that software products are difficult to use, and, above all, not very suitable for non-expert users:

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43 Yuan (2008) mentions Terrestrial Laser Scanning (TLS) and DGPS (Differential GPS).

44 Many proposal of models have been made by Carlson (1987) (with the simplicial complex- so-called “simplexes” - made by spatial objects of node, line, surface, and volume); Molenaar (1992) (with the 3DFDS - 3D Formal Vector Data Structure - belonging to the group of Boundary representations (B-reps); CAD models for 3D objects combined with DTM (a combination of Constructive Solid Geometry (CSG) and B-rep) have been proposed by Cambray in 1993; a 3D topological model based on 0,1,2,3, cell by Pigot in 1995; a combination of TIN data structure and 3D FDS by Pilouk in 1996 and the Tethraedron Network (TEN) data structure; object-oriented models by De la Losa (1998) and Pfund (2001) and Abdul-Rahman (2000).

moreover, 3D editing requires a GUI (Graphic User Interface) extended with tools for pointing and selecting objects, parts of objects and constructive elements (vertices, edges, polygons) and a corresponding interface for editing (ibidem). Authors stated that the most challenging 3D topic remains the maintenance of data. Importantly, with regard to standards, though many of them are already available, the third dimension is not still in their focus (ibidem), and further research on 3D standards (especially on the Web) should be carried out (Held et al., 2015). All above shows the increasing interest of researchers in applying 3D GIS to real world, but, despite of the effort, Zlatanova et al. (2002) commented a fully integrated 3D GIS solution has not still provided.

2.2.3 3D models documenting roads' full life cycle

In the age before the advent of 3D models, two-dimensional (2D) drawings were the traditional media of communication for various phases of a building's life cycle. Then, CAD software facilitated using 3D graphical models during all architectural design stages (Megahed, 2015). However it is widely recognised by researchers that two dimensions are not effective to describe real world (see Chapter 1), and cannot meet requirements relating to the whole life cycle of buildings and infrastructures: hence, advanced 3D models have been developed with these purposes. Among the 3D information systems experimented (e.g. City models and others), a focus on Building Information Modelling (BIM) follows here, as its applications to road networks meet some issues addressed by this thesis and related in particular to: subdivision of the road network in entities to make analysis (Kolbe et al., 2015), data integration and road life cycle description (Autodesk, 2012). Also, over time new digital information systems like BIM have been creating the base for the so-called "nD models" (Megahed, 2015): the utility of 4D models (i.e. 3D model linked to the time schedule) have been discussed by Koo and Fischer (2000) for virtual construction and space-conflict identification, and Heesom and Mahdjoubi (2004) to save resources prior to construction and avoid re-work during the project; Bryde et al. (2013), Goedert and Meadati, (2008), and Tanyer and Aouad (2005) addressed 5D models (that integrate a 3D drawing with time and cost estimates), while 6D models link building's life cycle to sustainable systems also supporting the maintenance process, which represents the 7D model (Bryde et al., 2013; Mohandes et al., 2014; Oreni et al., 2013). Importantly, BIM relevance has been stated by 2014/24/EU on public procurement that introduced the mandatory use it for documenting, presenting, and delivering to institutions any project - hence, also relating to infrastructure - in order to be authorised.

2.2.3.1 BIM

As noted by Strafaci (2008), road and highway projects can benefit from design using Building Information Modelling (BIM), a revolutionary technology and process - as defined by Hardin (2009) - which changed the way buildings are designed, analysed, constructed and managed, gaining over time a significant acceptance in construction industry (Suermann and Issa, 2009). Many researchers highlighted that BIM is not a product or proprietary software program, but a multidimensional (Lee and Wu, 2005) extensive (Mattson and Rodny, 2014) and "integrated process built on coordinated, reliable information about a project from design through construction and into operations" (Strafaci, 2008), which, by a comprehensive digital and data-rich representation of buildings containing both the detailed 3D geometry and alphanumeric information (e.g. material types, building types or costs), enhances team collaboration and Facilities Management (FM), and facilitates reduced construction time and costs (Amann and Borrmann, 2015; Utiome et al., 2014). Also Mattson and Rodny (2014) described BIM as based on the development and use of a computer-generated model to simulate digitally the phases of a construction project - including planning, design, construction and operation of buildings and structures (Azhar et al, 2008) - and yield considerable advantages in many areas of planning and execution (Borrmann et al. 2015). This aspect was highlighted also by Eastman et al. (2008) while defining BIM as "the continuous use of high-quality digital data over the entire life cycle of a building - from the initial design and building construction to its operation and servicing and finally its demolition". A good definition of BIM which summarises what above can be found in Succar (2009) and Succar and Kassem (2015) who emphasise BIM as a set of **interacting policies, processes, and technologies** that generate a **methodology** to **manage** the essential building information in **digital format** throughout the building's **life cycle**. However, as noted by Strafaci, while BIM has its roots in architecture, its principles "apply to everything that is built, including roads and highways, and the *benefits* of BIM are being experienced by civil engineers in the same way they are enjoyed by architects".

Autodesk (2012) remarked that BIM models are not just 3D geometry (although that is part of it), but data-rich objects which are intelligent, knowledge-based, scalable, and visual, from which data can be extracted and processed for generating information helpful to facilitate decision-making (Azhar, et al., 2008), predicting the performance of projects before they are built, responding to design changes faster, optimising designs with analysis, simulation and visualisation, and delivering higher quality construction documentation (Strafaci, 2008). Models are visualisable, navigable, measurable, queryable and analysable through semi-automatic selection processes and specific queries based on ontological schemes (Scianna et al., 2014; Lee et al., 2008).

2.2.3.2 Current state

BIM increasing relevance is witnessed by the studies of many authors, such as Succar (2009; 2010), Gu and London (2010), Jung and Joo (2011), Porwal and Hewage (2013), and Kassem et al. (2015) who discussed BIM processes, concepts and policies. A review of that can be found also in Neto (2016). However, as noted by Scianna et al. (2014), so far just a few software (e.g. Graphisoft Archicad, Autodesk Revit Architecture, Nemetschek Allplan and Bentley Microstation) support BIM models. Recently, BIM applications to infrastructure (e.g. Infrastructure Design Suite by Autodesk, and Professional Design Suite (PDS) by Causeway) and civil engineering (e.g. Autocad Civil 3D by Autodesk) have been developed (Autodesk, 2012). A comparative analysis on the adoption and use of BIM in road infrastructure projects can be found in Chong et al. (2016).

2.2.3.3 Advantages and functionalities of BIM

Sandberg (2015) conducted a literature review on the potential benefits resulting from BIM implementation. With regard to the topic of this thesis, several main aspects of particular interest can be defined. They respectively refer to: 1) visualisation and control of the project allowed by 3D models; 2) logistics (time and exchange of data), facilitating the delivery of projects; 3) teamwork effectiveness and enhancement and improvement of cooperation among stakeholders; 4) integration of data and multidimensional analysis; 5) management of projects' full life cycle. They are interrelated each other.

With regard to point 1 (visualisation and control), Goldberg (2004) stated that: "One of the greatest benefits of using a BIM application at the design stage is the ability for the designer to understand the relationships of the building and its systems instantaneously in regard to aesthetic, performance, and program issues." By the 3D model capacity of photorealistic visualisation, flythrough and animations, Bryde et al. (2013) emphasised the positive impact of BIM on the definition of the project scope and its role in decision making (as 3D model offers a better communication of the design to the client and reduce significantly the risk of misunderstanding).

Regarding point 2 (logistics and data quality), Bryde et al. (2013) and Eastman et al. (2011) emphasised the BIM process capability of making the transition between design and construction phases more efficient among stakeholders by exchanging the 3D model, instead of traditional 2D documentation. Eastman et al. (2011) notes that BIM allows changing the building very easily at each stage, while Amann and Borrman (2015) highlight that views and sections, as generated from the 3D model itself, are consistent with one another. The consequences in terms of reduction of time for delivering the construction documentation and of costs have been highlighted respectively by Bryde et al. (2013) and Sandberg (2015).

BIM benefits on teamwork effectiveness and cooperation among stakeholders (point 3) have been addressed by Strafaci (2008), Bryde et al. (2013) and Sandberg (2015), as BIM "has a potential use for construction project managers in improving collaboration between stakeholders, reducing the time needed for documentation of the project and, hence, producing beneficial project outcomes" (Bryde et al., 2013). BIM potential in leading to new methods of collaboration based on Integrated Databases (Bryde, 2013) or Integrated Project Delivery (IPD)[45] methods (with all the actors involved able to see the progress or lack of progress by each other) (Jung & Joo, 2011; Eastman, et al., 2011) has also been highlighted in the literature.

With regard to the integration of multiple data with the 3D model (point 4), Scianna et al. (2014) pointed out that BIM technology provides 3D models in which geometry is associated with semantic data, while Mattson and Rodny (2014) described BIM building components as represented by digital objects containing data regarding graphics, attributes and parametric rules[46] that allow them to interact in an intelligent way. Chen et al. (2013) noted that BIM models include project data with a consequent reduction of information lost by printing - common in the 2D drafting - and a potential increasing of quality (and financial savings) throughout the entire process. Impact of BIM on quality improvements are also mentioned by Bryde et al. (2013). Jung and Joo (2011) emphasised that 3D models are used as a base for engineering analysis like quantities take off, scheduling and maintenance, estimating, energy analysis, project management, construction planning, structural analysis, LEED/green analysis, storm water analysis and facility management: hence, extracting valuable different data from the model facilitates earlier decision making and more economic project delivery (Strafaci, 2008). Moreover, as mentioned above, the multidimensional potential of BIM is referred by some researchers as a "nD" modelling (Aouad et al., 2006).

About point 5 (full life cycle management), in addition to the authors mentioned in paragraph 2.2.3.1, also Grilo and Jardim-Goncalves (2010) and Bazjanac (2006) identified one of BIM points of strength in its usability through the entire life-cycle of the building, including feasibility (Azhar and Brown, 2009; Cheung et al., 2012; Ham et al., 2008), design (Ham et al.,

[45] Cohen (2010) defines IPD as "a project delivery method distinguished by a contractual agreement between a minimum of the owner, design professional, and builder where risk and reward are shared and stakeholder success is dependent on project success". As noted by Parrott & Bomba (2010), in the IPD contractor, client and designers are involved in all phases; the parties involved work together in an integrated team; the relationship is based on equity, trust, openness and that all actors share potential rewards as well as risks.

[46] As described by Scianna et al. (2014), BIM is mainly composed of "families" that are predefined entities, which are also parametrically modifiable and linked to data tables that can be expanded. Families are included into "Categories" (general groups by constructive element) and, in turn, include "Types" (further specific groups inside a family). Families contain both direct data related to the object to be described and indirect information (e.g. eventual topological relationships among the object and other components). The concept of parametric representation within the definition of BIM has been also addressed by Shim et al. (2012).

2008; Azhar and Brown, 2009; Azhar et al., 2012), pre-construction (detail design and tender) (Giel et al., 2010; Hardin, 2009; Azhar and Brown, 2009; Azhar et al., 2012; Cheung et al., 2012), construction (Ibrahim et al., 2004; Azhar et al., 2008; Yan, and Damian, 2008; Grilo and Jardim-Goncalves, 2010; Azhar et al., 2012), handover, operation and management (Ibrahim et al., 2004; Azhar et al., 2008).

2.2.3.4 Limitations of BIM and current research topic

Sandberg (2015) emphasised three main categories of BIM issues, affecting: 1) costs, 2) time needed, 3) and collaboration on the project, while Pakhmor et al. (2016) identified the main BIM limitation in costs relating to: 1) hardware (as BIM results in much larger file sizes than traditional CAD systems, and requires higher performing computer hardware to operate it effectively), 2) software (as current trends show that the cost of BIM software packages on the market tends to be more expensive than CAD tools), 3) and training (due to the extra time to construct the 3D model and the conversion of drawings and standards from CAD to BIM required by users (Bryde, et al., 2013)). However, no issues related to the quality decrease were found in the literature.

Azhar (2009) divided BIM risks into two broad categories: legal (or contractual) and technical (due to the the lack of determination both of ownership of the BIM data - and the need to protect it through copyright laws and other legal channels – and of supervisors of the entry of data into the model as responsible for any inaccuracies, also with difficulties in proving faults). Bernstein and Pittman (2005) mentioned BIM interoperability issues that are not limited to different software platforms (inter-product compatibility): due to the rapid development of the BIM software industry newer versions of programs within the same platform can have interoperability issues[47].

Recently, research studies have been carried on in order to integrate BIM and GIS using Industry Foundation Class (IFC)[48] space objects and boundaries (Boyes et al., 2015) or for indoor geovisual analytics (Wu and Zhang, 2016), as well as urban GIS, CAD, and BIM data by service-based virtual 3D City models (Döllner and Hagedorn, 2008).

2.2.3.5 BIM for infrastructure

Although most literature on BIM focuses on house design, there are many analysis and

[47] One alternative to the current product-specific models is a vendor-independent, neutral-file format. One such file format is the Industry Foundation Classes (IFC) format which captures both geometry and properties of intelligent building objects (objects with associated usable metadata) and their relationships within Building Information Models, thus facilitating the sharing of information across otherwise incompatible applications.

[48] IFCs (IAI, 2000) provide the AECOO community with an interoperable format for exchanging BIM data between different software platforms (Laakso & Kiviniemi, 2012). More specifically, IFC is suitable for exporting BIM data to GIS and energy simulation software (Boyes et al., 2015).

simulations that apply to infrastructure projects (Mattson and Rodny, 2014). As noted by Bennet (2012), BIM simulation can predict the impact of seismic events on bridges, roads and tunnels, helping designers to produce durable design solutions. Also, road safety simulation can ensure that the road design meets the requirements for sight distances, taking into account both road geometry as well as external obstructions (Strafaci, 2008). Strafaci (2008) noted that traffic capacity, noise, lighting, drainage, and signage analysis could all be done earlier in a project as part of the design process, well before significant effort is invested in construction documentation. Couto Cerqueiro (2014) and Eastman et al. (2011) included also quantity take off and cost estimation among BIM applications, as well as schedule simulation: BIM allow linking scheduling and planning to the 3D model with work tasks linked to physical objects and visualised sequentially (Eastman, et al., 2011). 3D models allow visualising infrastructures highlighting the relationships with the surrounding environment (Strafaci, 2008) and enable engineers quickly to cycle through iterations and get instant feedback on project performance. Moreover, Strafaci (2008) emphasised that, though the use of 3-D modelling, visualisation, and analysis is nothing new for road and highway design professionals, the novelty of BIM approach in this field consists in traditional drafting-centric approaches, design, analysis, and documentation - that are disconnected processes - allowing to make evaluation of what-if scenarios inefficient and cost prohibitive.

2.2.4 Levels of Detail

GIS and 3D city modelling also faced the problem of describing the complexity of the representation of a geographic object in terms of amount of detail (both geometry and attributes) consistent with a specific scale of a map or the virtual distance of sight between the user and the object represented and visualised on the screen: as noted by Biljecki et al. (2014), as 3D models are an abstraction of the real world, certain elements need to be simplified or omitted in a similar way to traditional maps. It depends on the adopted Level of detail (LoD), a concept pioneered by Clark (1976), and borrowed from computer graphics (Luebke et al., 2003), with the aim of reducing the geometrical complexity of an object for visualisation performance.

Today the LoD's concept is not officially standardised (Biljecki and Stoter, 2013; Fan and Meng, 2012; Meng and Forberg, 2007) and it depends on the usage (Biljecki, 2014). Luebke et al. (2003) define it as "the real-time 3D computer graphics technique in which a complex object is represented at various resolutions and the most appropriate representation chosen in real time in order to create a trade-off between image fidelity and frame rate": they emphasise its usage **in computer graphics** to improve the performance and quality of 3D visualisation. Biljecki et al.

(2014) focus on its usage **in 3D modelling** as a specification-related instruction for the acquisition, modelling, generalisation and exchange of spatial data: it serves to define a series of different representations of real world objects and suggest how thoroughly they have been acquired and modelled (in contrast with computer graphics where models are simplified to their coarser counterparts in a dynamic process). Fan and Meng (2012) and Meng and Forberg (2007) state that LoD is uniformly considered as a number of milestones along the scale space of 3D buildings when taking it as a linear continuum, whereas Löwner et al. (2013) define LoD a characteristic quality of CityGML[49] and proposed a new Level of Detail (LoD) concept for CityGML buildings composed of a Geometrical Level of Detail (GLoD) and a Semantical Level of Detail (SloD). Erikson et al. (2001) define LoDs as error bounded simplified versions of a model that can be displayed more quickly. The technical and cognitive challenge of how to represent an object without the user noticing its degraded geometric quality has been discussed by Coltekin and Reichenbacher (2011).

2.3 International roads standards for road inventories

Road inventories implementation is related to standards. Some of them relate to GI in order to guarantee the interoperability while managing geographic information. Others have been focused on road transport and the new field of Intelligent Transport System (ITS). Some organisations have addressed specific standards for thematic road inventories. In order to define whether managing data in a 3D GIS can benefit large infrastructural projects over their full life cycle - from initial design to Road Cadastre - (main research question), and aiming at investigating the current standards and limitations and proposing a 3D Road Cadastre for Italy whose general principles may be extended also to other countries, this research work aims at answering to the following intermediate research subquestion: "What standards apply to data management for large infrastructure projects and Road Cadastre?"

Within this second chapter devoted to the analysis of the background, this section provides an introduction to standards with a focus on their benefits, especially in enabling interoperability. An overview on the International and European standards on Geographical Information will be included to better understand the main requirements relating to georeferencing, interoperability, access to information and also language and format used. In this thesis, we will refer to ISO and CEN standards in particular, as they both provide solutions and achieve benefits for many sectors of activity including accessibility, construction and transport that is of our main interest, but also the INSPIRE European Directive and initiatives by Open

[49] CityGML is an open data model and XML-based format for the storage and exchange of virtual 3D city models.

Geospatial Consortium (OGC). All above will be followed by a focus on ITS and Road Transport standards at international and European level, also including the INSPIRE European directive. That will help to highlight the role of standards in designing spatial data infrastructure for roads and transport as well as the main requirements emerged from the literature (and later analysed in Chapter 7).

The diagram below represents the three different groups of standards that will be addressed in this Chapter.

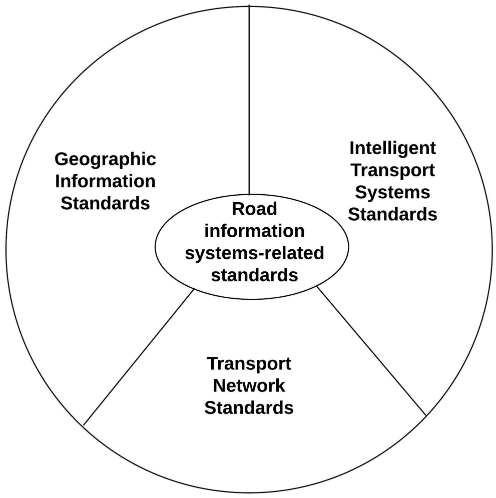


Figure 16. Standards related to road information systems addressed in this Sections

2.3.1 Standards and interoperability

Standards (or 'norms') are a vital component of everyday life that involves all areas of the world we live in (European Commission, 2012b). They include both written criteria developed by standardisation organisations (*de jure*) and implicit and informal accepted bases and reference rules commonly agreed for measuring in different human activities and helping to bring order to the world (*de facto*) (Salgè, 1999; Ping, 2011; European Commission, 2012b). A brief history of standards and standardisation organisations can be found in Ping (2008; 2011).

ISO (2008) explained the growing need for standardisation as an effect of globalisation and improvements in economic and physical infrastructure, information technology, manufacturing techniques, automation, transportation, and other aspects dealing with industry and trade and leading to a consistently increasing of the trade volume within and between countries. All above required the interoperation of systems, whose issues have been highlighted in the literature. Soares and Matos Martins (2012) noted that the separate legislation of the EU Member States (MS), as well as the use of different sets of databases (based on different internal structures), vocabularies and languages in Europe have been an obstacle to the integration and sharing of information: so far information is fragmented, duplicated and unavailable (also due to multiple and repetitive practices), and it is difficult to identify, access, and use them (ibidem). Also Visser et al. (1997) and Nogueras et al. (2005) argued that the interoperation of systems has been made difficult by the heterogeneity of data and services used to manage it. Richen and Steinhorst (2005) pointed out that quality and harmonised information has been even more frequently required, also by preventing or deleting differences in the technical content of standards with the same scope; in particular, as highlighted by Salgè (1999), in the public sector, International organisations - such as the European Commission, the United Nations, and the Organisation for Economic Cooperation and Development (OECD) - require transnational harmonised datasets and efficient updates from data at national or local levels to simulate, determine, and manage their various policies in agriculture, transport, and other sectors. On the other hand, Sondheim et al. (1999) noted that local governments and utilities require interoperability mainly between the heterogeneous information systems owned by local actors, while harmonisation of datasets is not required in a wider context than local areas. Nevertheless, the EU encourages local governments in transposing the contents of European directives on standardisation within their local standards (ibidem).

On the basis of this premise and as also explained later, **interoperability** is one of the main key words and requirements related to standards and has been discussed by many authors. Bates (2012) and Sliwinski (2007) define it as the ability of two or more systems or components to exchange information and to use the exchanged information without special effort on either system, while the Open Geospatial Consortium (2003) describes it as the ability of **digital** systems to **freely** exchange **all kinds of spatial** information and **cooperatively** run software capable of manipulating such information over networks. INSPIRE Directive (2007/2/EC) mentions it as the possibility to: 1) combine spatial data and services from different sources across the EC "in a consistent way without involving specific efforts of human and machines", 2) and provide access to spatial data sets through network services, typically via Internet, after changing (harmonising) and storing existing data sets in the INSPIRE infrastructure later described.

Kubicek et al. (2011), Sliwinski (2007) and Nogueras et al. (2005) distinguish between:

1. **syntactic interoperability**, concerned with the technical level (i.e. intercommunication at communication level protocol, hardware, software, and data compatibility layers). It refers to the ability for a system or components of a system to provide information portability and interapplication as well as cooperative process control (IEEE, 1990; ETSI, 2006);
2. **semantic interoperability,** dealing with the domain knowledge necessary for informatics

services to "understand" each other's intentions and capabilities" (European Communities, 2004). This latter has been studied by Harvey et al. (1999) and Lutz et al. (2003).

As noted by Megahed (2015), the issue of interoperability has been widely and largely addressed by many researchers, and international organisations have developed various practical details (Jung and Joo, 2011; Taylor and Bernstein, 2009; Evans, 2003; Sondheim et al., 1999; Vckovski, et al., 1999; Vckovski, 1998). Sondheim et al. (1999) have addressed in particular GIS interoperability, while Bertolotto (2000) emphasised its link with the requirement of a fast data exchange. Hetherington et al. (2011) and Neuhold (2014) described interoperability in the AEC (Architecture/Engineering/Construction) sector: i.e. as traditionally relied on file-based exchange formats and characterised by the seamless sending and receiving of building data into multiple applications. With regard to the road sector, interoperability has been discussed by Westerheim (2014) (among Public Roads Administrations and external stakeholders), Ahsan et al. (2016) (among heterogeneous devices), and Terziyan et al. (2010) (amongst the smart road devices and services).

In order to implement interoperability and data harmonisation, standards are required. The European Commission (2012a) has officially defined standards as "formal technical documents that set out and define criteria, methods, processes and practices" with regard to actual or potential problems and provision and "define technical or quality requirements with which current or future products, production processes, services or methods may comply" (European Commission, 2013). They derive from the voluntary and participated process of developing technical specifications carried out by recognised standards bodies acting at national, European and international level (Bartha and Kocsis, 2011) - as described in Appendix 4 - and are based on consensus among all interested parties (e.g. industry, SMEs, consumers, trade unions, environmental Non-Governmental Organisations (NGO), public authorities) (ISO, 2012).[50] Such characteristics are also highlighted by the International Standardization Organization (ISO), officially defining standards as documents "established by consensus and approved by a recognised body that provide for common and repeated use, the rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context" (ISO/IEC Guide 2:1996; ISO/IEC Guide 2:2004; Russell, 2004; Sakakura, 2004; UNIDO, 2006). They cover all industry sectors.

Standards are important in our increasingly connected and networked world, as they provide nodes and rules for interconnections: since the mid-1980s the European Union has made

[50] (source: http://ec.europa.eu/enterprise/policies/european-standards/index_en.htm).

an increasing use of them[51] as a policy instrument to achieve technical harmonisation and free trade within Europe;[52] similarly, at international levels, standards aim at diminishing trade barriers, allowing interoperability of products, systems and services, promoting safety and common technical understanding safe.[53]In the literature the role of standards has been highlighted by many authors: Clarke (2013) emphasised the importance of standards to ensure that products and services meet minimum thresholds in terms of functionality, performance, structure, and others, and cover areas such as quality, performance, design, safety, and environmental impact. The European Commission highlighted the relevance of standards in the economy and how their use is crucial to support growth, competitiveness and innovation: by the codification and dissemination of new knowledge and innovations, helping to improve products and services, and ensuring interoperability and enabling trade, they facilitate business interaction and access to markets (EU, 2012b). Again, many authors noted that standards enable interoperability of systems and services, promoting mutual understanding, ensuring compatibility and interface coordination, helping to prevent duplications of efforts and coordinating diversity, clarifying appropriate product quality and sharing good management and conformity assessment practices; they encourage innovation and greater competition, aiding the transfer of research, fostering enterprise, eliminating barriers to trade and opening up new markets for suppliers. In addition, they promote ecological safety and sustainability, enhance the safety of products, and create trust and confidence in products and services. Finally, they help manufacturers to comply with European legislation, facilitate technological cooperation, allow economies of scale, and bring down costs increasing competition (Swann Peter, 2000; DIN, 2000; Russell, 2004; Sakakura, 2004; UNIDO, 2006; Stoelhorst, 2010; Gerundino and Weissinger, 2011; Gerundino and Weissinger, 2012; European Commission, 2012). Thus aiming at establishing uniformity, Ping (2011) noted that, as standards derive from the economic and social fields, they are influenced by culture, civilization and values that are different from country to country (2011). However, the European Commission (2016), recently defining standard as "a voluntary technical document helping economic operators in a value chain to interoperate easier", confirmed interoperability as one of the main goal of standardisation.

2.3.2 Standards for Geographical Information

Bartha and Kocsis (2011) described spatial information in Europe, for long characterised by fragmentations of datasets and sources, duplication of information collection, gaps in

[51] (source DG ENTR website/ Source: commissione EUROPEA).
[52] (source: http://ec.europa.eu/enterprise/standards_policy/index_en.htm).
[53] (source: CEN website; + http://www.iso.org/iso/home/standards/benefitsofstandards.htm).

availability, absence of a coherent wide framework on which standards should be used, as well as clear general feature models[54] to follow, and common data sharing policies, lack of interoperability or harmonisation between datasets with different geographical scales and languages. With regard to the road sector, Bottai et al. (2009) emphasised a gap between the usual creation of data and its subsequent processing methods within GISs, such as visualisation and integration with other information sources: despite the increasing development of IT has been producing applications and services (e.g. info-mobility, webGIS-services, navigation systems)for the dissemination and use of GI, so far numeric data of technical maps occur in the format linked to the software used by the authorities, often with characteristics of non-interoperability (ibidem).

Salgè (1999) and Kresse an Fadaie (2004) discussed standardisation initiatives to guarantee interoperability started in the last decades in the field of GI (Xu et al., 2014), in order to overcome the issue of exchanging data between partners in Europe. The importance of GI standards has been also highlighted by Aalders and Hunter (2003). A detailed overview on GI standards can be found in Salgè (1999), Kresse and Fadaie (2004), and Dietz (2010) – the latter regarding Geospatial Web Service.

In this paragraph several relevant initiatives are presented, highlighting how they are related to road inventories and, hence, to this research work. They include:

1. the so-called "official standards"[55] implemented by:
   - the ISO/TC 211 initiative,
   - and the CEN/TC 287 initiative,
2. the INSPIRE European Directive,
3. and the "industry standards" developed by:
   - the Open Geospatial Consortium (OGC).

2.3.2.1 ISO TC/211

The **Technical Committee 211 (ISO/TC 211) "Geographic information – Geomatics"** was created in 1994 by the International Standardization Organization (ISO)[56] (described in Appendix 4) in order to define standardisation in the field of **digital geographic information**. It aimed at establishing a set of standards for structuring information about objects or phenomena that are directly or indirectly associated with a location on the Earth

[54] i.e. for example attribute names, common spatial reference models, etc.

[55] i.e. the ones developed by the "Standards Developing Organizations" (SDOs).

[56] ISO is a worldwide nongovernmental federation of national standards bodies, coordinating the development and promulgation of formal International standards in almost **all industry sectors**, except for electrotechnical and telecommunications standards.

(ISO/TC 211, 2012). Kresse and Danko (2012) and Hanson and Heron (2008) described in detail the so-called ISO 19100 standards produced by this initiative, which specified methods, tools and services for georeferencing, acquiring, processing, analysing, accessing, presenting and exchanging GI data in digital form, between users of various countries also using different system. Salgè (1999), Vries and Zlatanova (2004), and Soares and Matos Martins (2012) highlighted that ISO/TC211 standards ensured the definition, description and management of geographic information, in order to simplify the development of GIS and applications. Sarafidis et al. (2007) explained the design of an ISO compliant profile for documenting spatial datasets and series of the Hellenic cadastre. With regard to the Road Cadastre, Caroti and Piemonte (2010) and ANAS (1998) cite standards by ISO TC/211 as a basic reference for the implementation of georeferenced road inventories in Italy. A summary of the 19100 standards mainly relating to the implementation of Road Cadastres is illustrated in Appendix 4 – Table...

Actually, the 20 basic standards of the ISO 19100 family had been already defined by the CEN/TC 287, and were also adopted as the technical base of INSPIRE (as explained in the following subparagraphs).

2.3.2.2 CEN/TC 287

With regard to Europe, a specific Technical Commission (TC) called as **CEN/TC 287** was officially created in 1991 within the **European Committee for Standardization (CEN)** to produce a structured set of **standards in the field of digital Geographic Information (GI) for Europe** aimed at defining, describing and transferring **geographic data and services.** As explained by Aalders (2004), it worked **in cooperation with ISO/TC 211,** which adopted CEN/TC 287 standards: it avoided a duplication of data by the European "profiling" of the ISO standards, making European standards compatible with international usage, and facilitating interoperability. Soares and Matos Martins (2013) and Longhron (2006) highlighted that the Working Group 5 (WG5) of CEN/TC 287 is currently involved in the INSPIRE standardisation activities on the "Spatial Data Infrastructure (SDI)": a framework of technologies, policies, and institutional arrangements aimed at facilitating the creation, exchange, and use of geospatial data across an information-sharing community of one or more organisations for use at a national, regional, or global level (ESRI, 2010).[57] As noted by OGC (2016), SDIs play an important role -

[57] In the literature, Steiniger and Hunter (2012) distinguish five components of an SDI: (i) Spatial Data (or spatial information), (ii) Technologies, i.e. hardware and software, (iii) Laws and Policies, (iv) People, i.e.: data providers, service providers, users, and (v) Standards for data acquisition, representation and transfer, while ESRI (2010) distinguishes SDI from GIS. Kuhn (2005) defines an SDI as "a coordinated series of agreements on technology standards, institutional arrangements, and policies that enable the discovery and use of geospatial information by users and for purposes other than those it was created for." ESRI (2010) specifies that an SDI will provide an institutionally sanctioned, automated means for posting, discovering, evaluating, and exchanging geospatial information by participating information producers and users.

also with regard to the road sector - as location information is important in managing everything that governments manage.[58]

2.3.2.3 INSPIRE

In order to solve most of the problems related to GI in Europe (e.g. lack of availability, quality, organisation, accessibility, and sharing of spatial information), the European Commission (EC) carried on the so-called **INSPIRE Initiative (INfrastructure for SPatial InfoRmation in Europe)**: a project aimed at making available harmonised geographical information to facilitate monitoring and coordinated planning of European policies on the **environment** and activities impacting on it (Architecture and Standards Working Group, 2002), and turned into a European Directive (Directive 2007/2/CE of the European Parliament and of the Council or INSPIRE Directive) entered into force in 2007. By consistently combining spatial data and services from different sources across the EC, it aimed to provide users with integrated spatial information services, and to allow them to identify and access - locally and globally - spatial or geographical information from a wide range of sources, in an interoperable way and for a variety of uses through network services (typically via Internet) from a single common point of access to data. INSPIRE Data - covering 34 themes relating to the sustainable environmental development and arranged in three Annexes, as follows - also includes the "transport network" topic in Annex 1:

INSPIRE Annex	Topics
Annex I	Coordinate systems, geographical grid systems, geographical names, administrative units, addresses, cadastral parcels, **transport networks**, hydrography, protected sites
Annex II	Elevation, land cover, ortho images, geology
Annex III	Statistical units, buildings, soil, land use, human health and safety, utilities and administrative services, environmental monitoring facilities, manufacturing and industrial plants, agricultural and aquaculture, distribution of the population-demography, area management/restriction/regulation zones and reporting units to communicate passenger data, natural risk zones, atmospheric conditions, meteorological geographical features, oceanographic geographical features, sea regions, bio-geographical regions, habitats and biotopes, species distribution, energy resources, mineral resources

Table 1. Topics of INSPIRE Annexes

INSPIRE documents illustrate the purpose of this European infrastructure for spatial information - also called ESDI (European Spatial Data Infrastructure), i.e. having a common structure based on National Spatial Data Infrastructures made interoperable through common standards:

- a common framework for the unique identification of spatial objects (also defining the way in which they are geo-referenced);
- the relationship between spatial objects;

[58] (http://www.opengeospatial.org/domain/gov_and_sdi) 11.09.2016.

- the key attributes and the corresponding multilingual thesauri;
- information on the temporal dimension;
- updates.

Hence, INSPIRE aimed at: 1) making spatial information of the various Member States compatible and usable in a cross-border context, in order to overcome problems as spatial data availability, quality, organisation, accessibility and sharing, 2) facilitating the search for spatial data over the web, via network services providing data in several ways (e.g. from the display, the downloading, and other). The three level of interoperability allowed by the Directive can be found in Appendix 4.

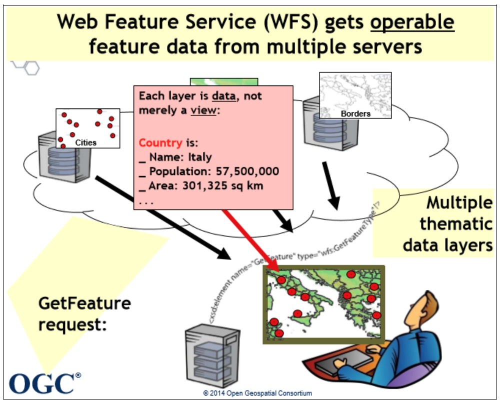
As illustrated by Caroti and Piemonte (2010), INSPIRE Directive (2007), and JRC (2005), on the basis of common Implementing Rules, Member States should ensure that spatial data (and related metadata) are stored, made available and maintained at the most appropriate level, in order to avoid duplications: therefore, data from different sources within the Community can be coherently combined and shared between several users and applications, as well as between public administrations. However, currently, though the Directive provides for harmonisation of geographic data sets from various States, in each of them different criteria for their definition have been followed so far (Caroti and Piemonte, 2010). In this regard, Implementing Rules aim at ensuring the consistency between items of data referred to the same location, or to the same object represented at different scales, and guaranteeing that information from different spatial datasets is comparable. Importantly, every INSPIRE data specification conforms to ISO 19000 family standard.

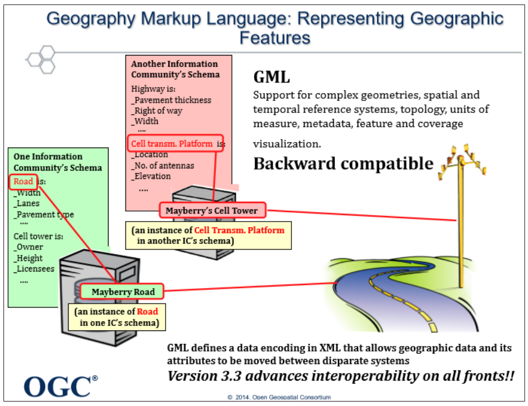
Ombuen et al. (2013) discussed data harmonisation aimed at urban planning in accordance with INSPIRE, while Caroti and Piemonte (2010) addressed an overview of the main specifications of the European Directive to be used for the creation of a topographic database of transport networks.

The INSPIRE approach on interoperability described above has been fundamental in developing a 3D data model supporting the inventories of road infrastructure studied in this thesis.

2.3.2.4 OpenGeospatial Consortium

The Open Geospatial Consortium (OGC), founded in 1994, is an international industry consortium of over 534 companies, government agencies and universities, promoting together the development and free sharing of specifications related to GI for a global use. Its mission is advancing the development and use of international standards and enabling interoperability of geoservices (i.e. geo-information and geo-processes together)[59]. Hence, it develops publicly available interface standards (the OGC® Standards) that enable the Geospatial Web (i.e. the complete integration and use of location at all levels of the internet and the web). OGC standards support services promoting geospatial interoperability (i.e. interoperable solutions that "geo-enable" the Web, wireless and location-based services and mainstream IT), making complex spatial information and services accessible and useful with all kinds of applications. They also allow the interchange of "open and extensible" geographical data.





Figures 17 and 18: Geography Markup Language: Representing Geographic Features (Reed, 2012).

In order to highlight the practical usefulness of OGC specifications to enable interoperability, Reed (2014) cites a use case for emergency response (i.e. creating a seamless digital map of the transportation network between two counties in two adjacent states) that deals with different road classifications, different street names, edge match issues, and scale differences. He illustrates how OGC standards (such as Web Map Service (WMS), Web Feature Service (WFS), Geography Markup Language (GML), Web Processing Service (WPS), Web Coverage Processing Service, and GeoSPARQL) are relevant to conflation (Figg. 17, 18, and 19). The latter is defined as the process of "unifying two or more separate datasets, which share certain characteristics, into one integrated all-encompassing result" (OGC) (Covazzi, 2016) as well as combining map data from separate sources to create data better than either source on its own. Longley et al. (2001) also define it as "the process of combining geographic information from overlapping sources so as to retain accurate data, minimize redundancy, and reconcile data conflicts".

[59] A service is a collection of operations, accessible to a user through an interface (OpenGIS Consortium, 2003. OpenGIS Reference Model. Technical report, Wayland, Mass., VS). Geoservices are web services making accessible the geodata according a structured shape and allow the interconnession between geodata.

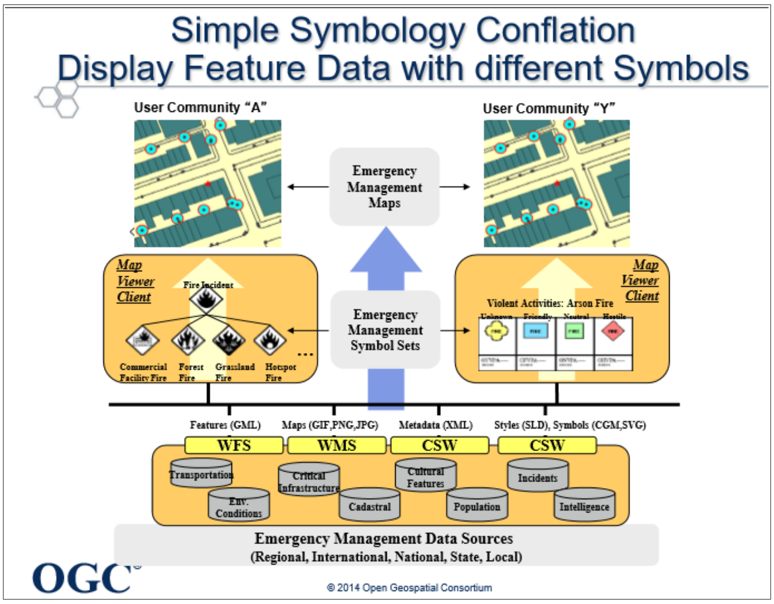


Figure 19. Simple simbology conflation display feature data with different symbols (Reed, 2012)

2.3.3 Standards for Intelligent Transport Systems

As highlighted by the International Road Federation (IRF)[60], road standards and specifications are very critical for the safe and efficient transportation of people and goods. Uniform standards ensure an efficient and safe road infrastructure: e.g, specifications for asphalt and concrete material ensure roads are smooth and durable, helping to make lower the cost of maintenance; also, the use of uniform Traffic Control Devices (e.g. messages, location, size, shapes and colours) helps reducing crashes and congestion and improves the efficiency of the surface transportation system (ibidem). In the road sector, specific standards have been implemented relating to Intelligent Transport Systems (ITS).

ITS are officially defined as "advanced applications which without embodying intelligence as such aim to provide innovative services relating to different modes of transport and traffic management and enable various users to be better informed and make safer, more coordinated and 'smarter' use of transport networks" (Directive 2010/40/EC); and also as: "the application of advanced sensor, computer, electronics, and communication technologies and management strategies - in an integrated manner - to improve the safety and efficiency of the surface transportation system" (United States Department of Transportation Federal Highway Administration, 2016). They include: vehicle, airplane & ship operations, crash prevention and safety, electronic payment and pricing, emergency management, freeway management, incident management, information management, intermodal freight, road weather management, roadway operations and maintenance, transit management, and traveller information (Novacki, 2012), and

60 The IRF works with national road associations, public road agencies, and the private sector to ensure best practices are followed when developing road standards.

benefit of technologies such as Global Positioning System (GPS), Dedicated-Short Range Communications (DSRC), Wireless Networks, Mobile Telephony, Radiowave or Infrared Beacons, Roadside Camera Recognition, and Probe Vehicles or Devices.

Before the advent of the ITS industry, spatial data interchange standards were developed mostly at a regional level and not for road transport-related applications. By the late 1980, as the lack of a common data interchange standard limited the commercial growth of industries using digital road map data, as noted by Russell (2004), ITS standards were required to promote the interoperability of services, ecological safety and sustainability, the environmental safeguard, the transfer of research, and common understanding (Russell, 2004). They were developed at international level by:

- ISO/TC204 – Intelligent Transport Systems,
- ISO/TC22 – Road vehicle,

and at European level by:

- CEN/TC278 for ITS,
- CEN/TC226 Machine Readable cards,
- CENELEC/TC226 Road equipment,
- ETSI – telecommunications, new: ETSI TC ITS.

An overview of existing and developing standards supporting ITS services and their interoperability, standards developing organizations (SDOs) at national and international levels, and references to other generic standards to be used to ITS service provision can be found in Williams (2008).

2.3.3.1 ISO/TC 204

The **ISO/TC 204** for **Transport Information and Control Systems** was established in 1993 for developing international Intelligent Transportation Systems (ITS) standards. It produced **ISO 14825:2011** standards ("*Intelligent Transport Systems – Geographic Data File (GDF) – GDF 5.0*" that replaced the first version of 2004), focusing on ITS applications and services (e.g. in-vehicle or portable navigation systems, traffic management centres, or services linked with road management systems, including the public transport systems) and emphasising road and road-related information. They defined the **conceptual and logical data model** and **physical encoding formats** for **geographic databases** for **ITS** applications and services and included specifications on: a) potential contents of ITS databases (with data dictionaries for Features, Attributes and Relationships), b) how these contents shall be represented, and c) how relevant information about the database itself shall be specified (metadata).[61] In particular, since 1994 WG3 (the Working Group 3 responsible for developing standards promoting map data interchangeability and interoperability of systems using map databases) has reviewed the available regional standards documents, also including standards from the Japan Digital Road Map Association (JDRMA) and Spatial Data Transfer Standard (SDTS) in the US. It produced the GDF3.0 (Geographic Data Files) standard - or ENV14825:1996 - initially drawn up by CEN in cooperation with digital map providers, automotive and electronic equipment manufacturers to model, describe and transfer road networks and other geographic data. Its specifications provided a base for both capturing and exchanging of geographic content: in order to provide interoperability for exchanging digital map data between map manufacturers and navigation system integrators, in 1990s it addressed the requirements for rich databases of navigable maps, promoting the European market of in-vehicle navigation. GDF has then evolved in terms of boosted data modelling capabilities, broadened international applicability, expanded geographic domains, and diversified exchange formats, leading to the publication of GDF4.0 in 2004 (formally referred to ISO14825:2004) and of GDF5.0 in 2011 (i.e. ISO14825:2011) developed between 2001 and 2008. The latter include support for 3D content and time coordinates.

GDF is of main interest for the purpose of this thesis as the computer specifications of the structure of the database of the current Italian Road Cadastre are partially based on the pre-standard CEN/TC 278, Geographic Data Files (GDF), version 3.0 of October 12, 1995. In GDF real world objects (e.g. roads and buildings) or activities at a certain location (e.g. services) are represented by “Features” defined in the Feature Catalogue (as shown in the Fig. 20 below). The overall conceptual model describes database representations of Features in GDF (grouped semantically in eleven topics - i.e. “Feature Themes” (represented in the diagram below) - and logically and physically in “Sections” by area or “Layers” by contents), their characteristics (Attributes), and the topological and non-topological interrelations between them.

[61](source: ISO 14825:2011(en) Intelligent transport systems — Geographic Data Files (GDF) — GDF5.0).

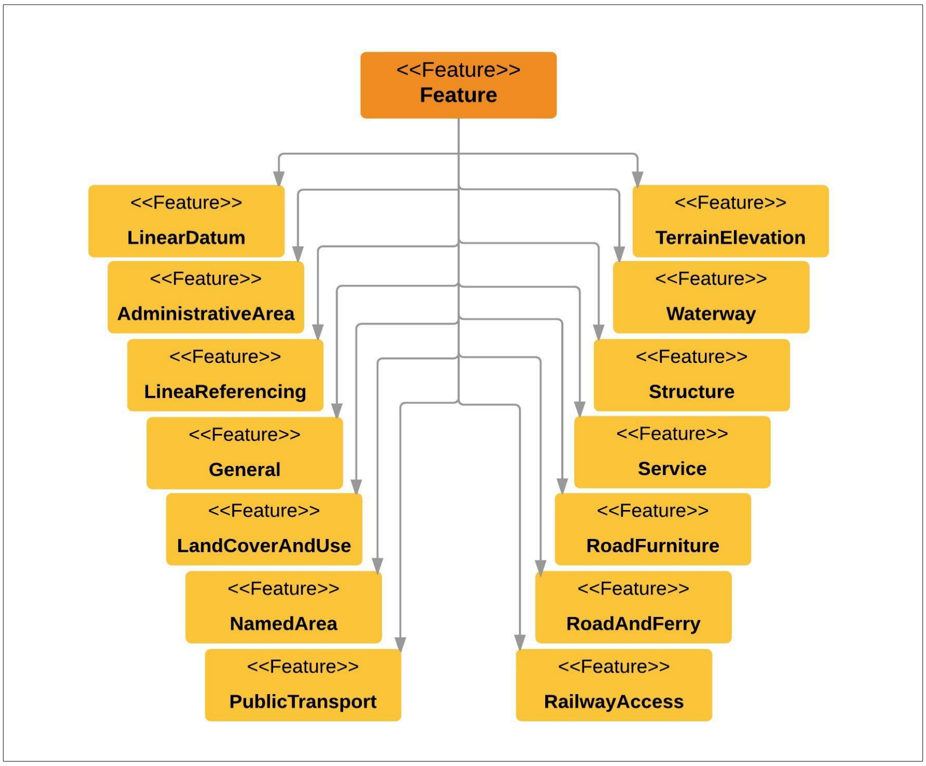


Figure 20. The Conceptual Data Model of the Feature Catalogue (ISO 14825:2001)

As shown above, Features such as "Roads" and "Ferries" are grouped together into the "Feature Themes" group as "Roads and Ferries", whose conceptual data model is illustrated below:

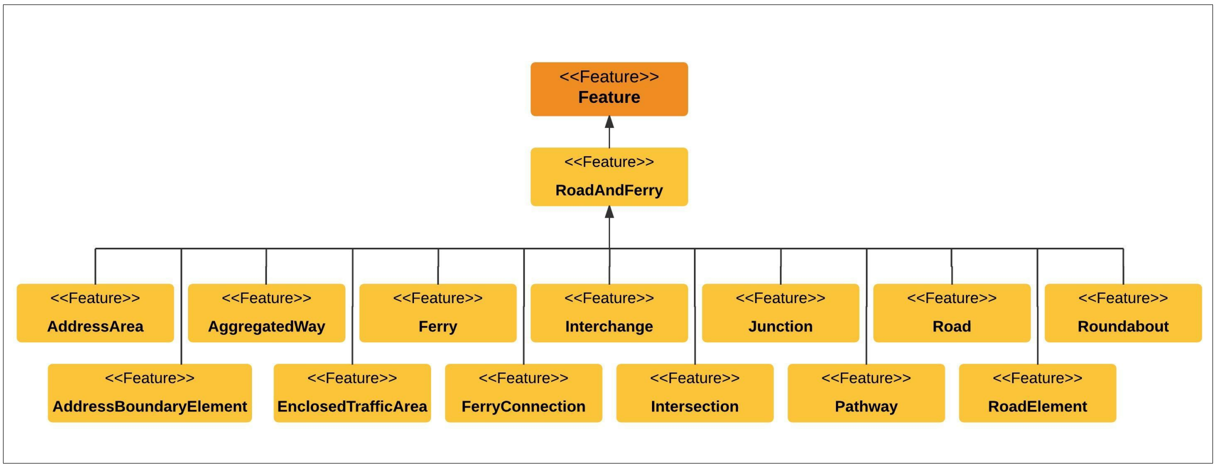


Figure 21. The Conceptual Data Model for Roads and Ferries (ISO 14825:2001)

Importantly to be later addressed for the purpose of this thesis, GDF makes a distinction between Simple Features (i.e. not composed of other Features) and Complex Features (i.e. composed of Simple Features and/or other Complex Features: e.g. an Intersection is a Complex Feature made up of a set of Features such as Road Elements and Junctions). It also introduces a representation of the road network at two different levels: Level 1 describes the Simple Features such as Road Element, Junction, Ferry Connection, Enclosed Traffic Area, Address area Boundary Element and Address Area, whereas Level 2 describes the Complex Features such as Road, Intersection, Ferry and Aggregated Way.

The wide set of different features related to road transport provided by ISO standards are partially included in the Italian Road Cadastre dataset, as illustrated in Chapter 3. All above confirms the shared approach by different standard bodies in considering the multifactorial nature of the road network. Importantly, with regard to comparison with the Italian Road Cadastre.

2.3.3.2 CEN/TC 278

At European level, in order to solve problems of ITS standardisation, CEN promoted **CEN/TC 278 Intelligent Transport System**: a Technical Committee of CEN/ISO members bodies, established in 1992 to produce **road transport and traffic telematics** standards for Europe. It identified several work areas including interfaces, protocols, digital road maps, data elements, and databases. In particular, CEN/TC 278 Road Transport and Traffic Telematics, by different WG in close cooperation with ISO/TC 204 Intelligent Transport System, addresses standards on Public transport (WG3), Traffic and Traveller Information (WG4), Traffic Control (WG5), and Parking Management (WG6). Particularly relevant for this study is Geographic Road Data (WG7), dealing with Geographical Road Database for only Road Transport and Traffic Telematics. It produced over 80 European ITS standards on road and vehicle safety, network efficiency including fee collection, traffic and traveller information, interoperable public transport and digital traffic information RDS/TMC (which provides standardised information in almost every European country in the home language of the traveller). Other standards of interest are also: CEN Transmodel v5.1 (2006), the Reference Data Model for Public Transport, and IFOPT (Identification of Fixed Objects in Public Transport), a Technical Specification providing a Reference Data Model to describe the main fixed objects (e.g. airports, stations, bus stops, ports, entrances, platforms, and other stop places and points of interest) required for public access to Public transport (2009). Several standards for road design are defined into the documents produced by CENELEC/TC226 Road equipment. Importantly, CEN/TC 278 also adopted Geographic Data File (GDF) as an ENV (ENV 14825).

2.3.4 Standards for Transport Network

Over the last decades, in Europe the asset management policies in the road sector have been considering each national road network as a part of a European road system (Peaslee, 1974; OECD, 2001; Regmi, 2011; Adamatzky and Kayem, 2013; COUNCIL DECISION of 29

October 1993 on the creation of a trans-European road network (93/629/EEC), Official Journal of the European Communities, 10.12.93, No. L. 305/11),[62] requiring the interconnection and interoperability of national road networks: a key element - as noted by Bergman (2009) and the European Union Road Federation (2014) - of the reinforcement of economic and social cohesion in Europe. Nevertheless, currently, in the road sector there are many international rules and standards, as well as several systems, of road classification (Bergman, 2009). As Sandgren (2004) writes, "there is a clear need for an updated and quality assured digital road data infrastructure for Europe as a basis for further development within the areas of intelligent transport systems, mobility management, traffic management, road maintenance, traffic safety, environmental and society planning and many other areas". All above requires standards to implement asset management systems shareable by all the UE Member Countries.

2.3.4.1 INSPIRE Directive and Road Sector

Although the INSPIRE Directive has been developed in an environmental perspective, its applicability to the transport networks - and particularly to the road network that is one of the INSPIRE spatial theme as relates to activities impacting on environment - is clear: it aims to develop an integrated transport network, where spatial objects establish relationships with each other without barriers, allowing its use at Pan-European level. As underlined by Soares and Matos Martins (2012), the creation of an infrastructure for spatial road information is fundamental for the development and management of road infrastructures in each EU countries and the global EU context (TEN-T), but its extension to local road networks is also essential. For example, it is fundamental linking transport network through "intermodal nodes especially at a local level, in order to meet the requirements of an intelligent transport system" (European Commission, 2007). Therefore, the INSPIRE Directive foresees the existence of an interoperable geographic dataset and services also with regards to the road infrastructure information (Transport Networks is a component described in the Annex I of the Directive). This service would be commonly used to provide supporting data for decision-making in planning, building and maintenance of roads; it would also be used for services (also including the ITS systems at the operational level) aimed at enhancing the usage of roads considering safety and accessibility, and reducing negative environmental effects of traffic (Soares and Matos Martins, 2012).

As mentioned above, the INSPIRE Directive addresses 34 spatial themes, grouped in three annexes. The present work deals essentially with the one on Transport Networks, defined as

[62] An example of this approach in europe is the Trans-European road networkproject that started in 1993 and laid out by Article 9 of Decision 661/2010/EU. See Appendix 2. Reagrding the extra-European context Appendix 2 also addresses some examples of supranational road network projects such as the Pan-American Highways network, the Pan-Philippine Highways, the Asian Highway project, and the trans-African Highway project.

"road, rail, air and water transport networks and related infrastructure". It includes links between different network as well as the Trans-European transport network (as defined in Decision 1692/96/EC of the European Parliament and Council) and future revisions (Directive 2007/2/EC). The transport component should comprise an integrated transport network - and related features - that are seamless not only within each national border, but also at European level (i.e. connected at national borders), in accordance with article 10.2 of the Directive. Importantly, the INSPIRE data specification for Transport Networks has been prepared by the INSPIRE TWG-TN (Thematic Working Group Transport Networks), a team of experts in the field from different EU Member States. They elaborated different materials such as: references submitted by the Spatial Data Interest Communities (SDICs) and Legally Mandated Organisation (LMOs) of INSPIRE, responses to the User Requirements Survey, a set of agreed use cases (e.g. on environmental impact assessment, noise mapping, speed limits and journey planning), material from road mapping agencies and road authorities, documents on the Trans-European networks, and additional research.

Transportation data includes topographic features related to transport by road, rail, water and air (INSPIRE Feature Concept Dictionary) (Fig. 22).

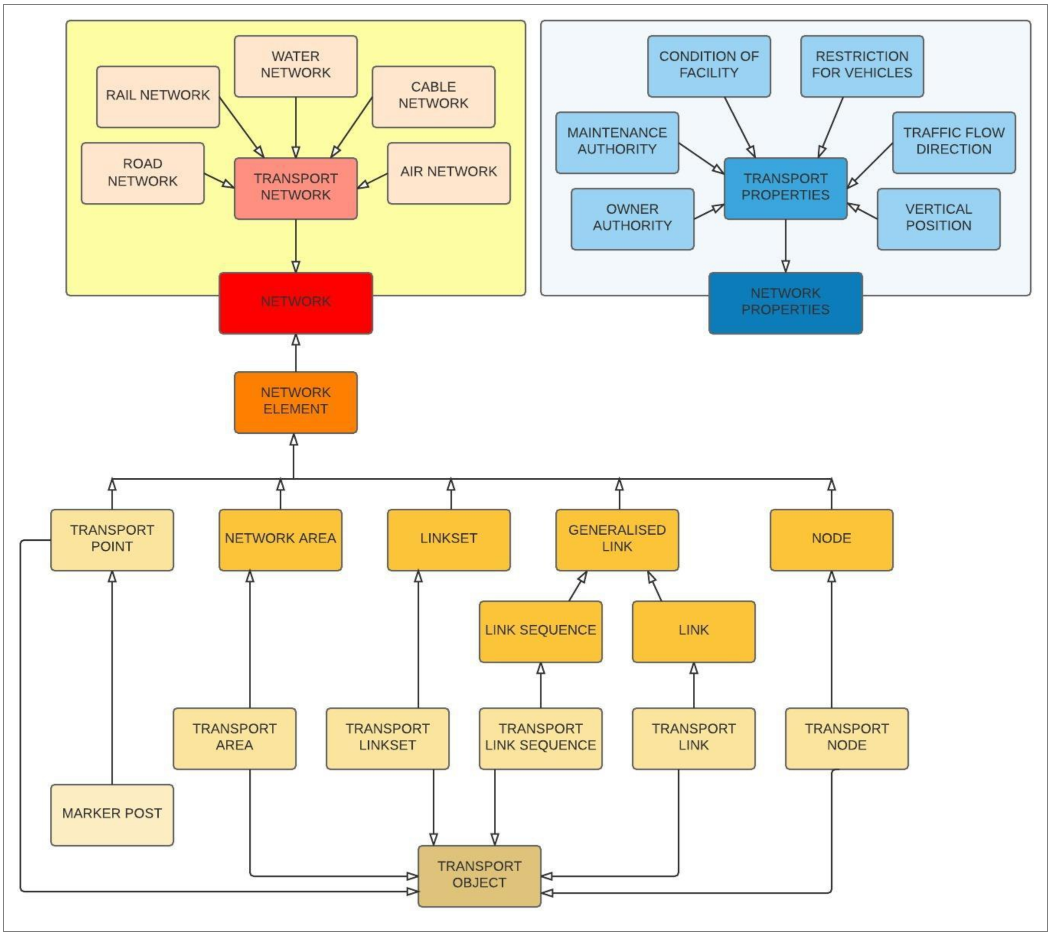


Figure 22. Overview of the main Transport Networks Feature Types

“The transport network should also support the referencing of transport flow to enable our navigation services” (INSPIRE Thematic Working Group Transport Networks, 2010). The data specification defined by TWG-TN covers fiveTransport network elements modelled are: the spatial, temporal and thematic aspects, the geometric representation of various elements that are parts of a network with links, nodes and areas characterised by various types of attributes, and the validity of elements. distinct transport sub-themes (Road, Rail, Water, Air transport and Cableways), including multi-modal nodes and other links between such major network transport types. It is a basic framework to reuse and share data about a network, taking into account both the variety of responsibilities in collecting, managing and using data, and different approaches in the data base management practice, (and also the diverse applications and users needs it should fit into). The main mechanisms used to describe the transport network are defined in the Generic Network Model (INSPIRE Thematic Working Group Transport Networks, 2010). It contains an application schema for the networks that it includes the elements in the network (nodes, links, aggregated links, areas, and points) and their relationships (Fig. 23).

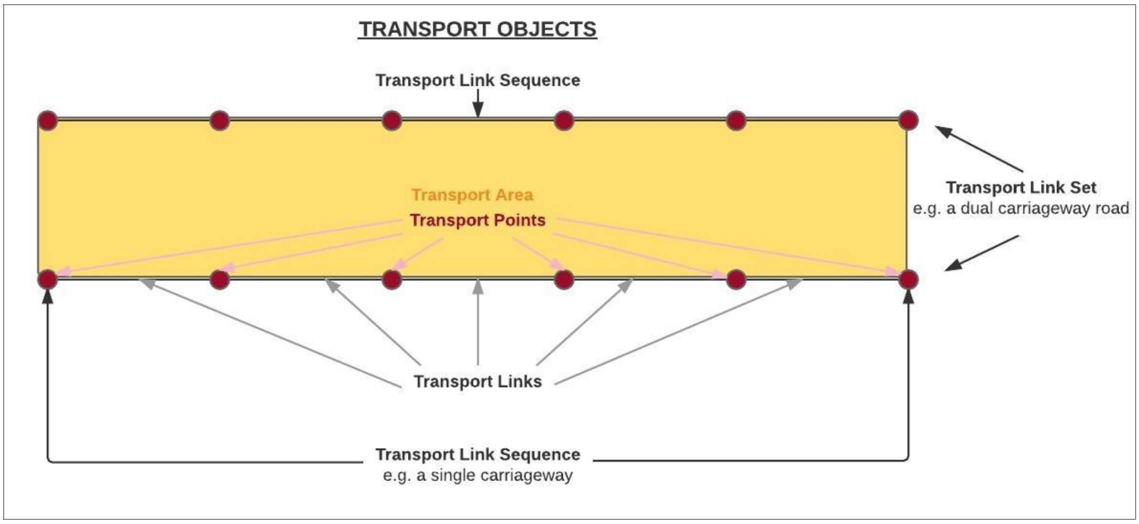


Figure 23. Overview of the main Transport Networks Spatial object types.

The GNM provides their basic structure as well as basic mechanism for:

- object referencing (to support the reuse of information, e.g. avoiding the duplication of the geometry and linking complementary feature types from different organisations);
- linear referencing (based on ISO 19148) to position phenomena along a linear object using a distance from the beginning of it (to support and link the different transport properties to the transport elements and, hence, adding properties to a network and internetwork connections);
- cross referencing (to establish cross-border connections between the transport networks),

- adding properties to a network (including the use of linear referencing) and adding internetwork connections;
- combining the network elements into high-level semantic meanings.

The Road Transport Networks application schema is a structure of links and nodes interconnected: it includes nodes, links, aggregated links, areas and points (Fig. 24).[63]

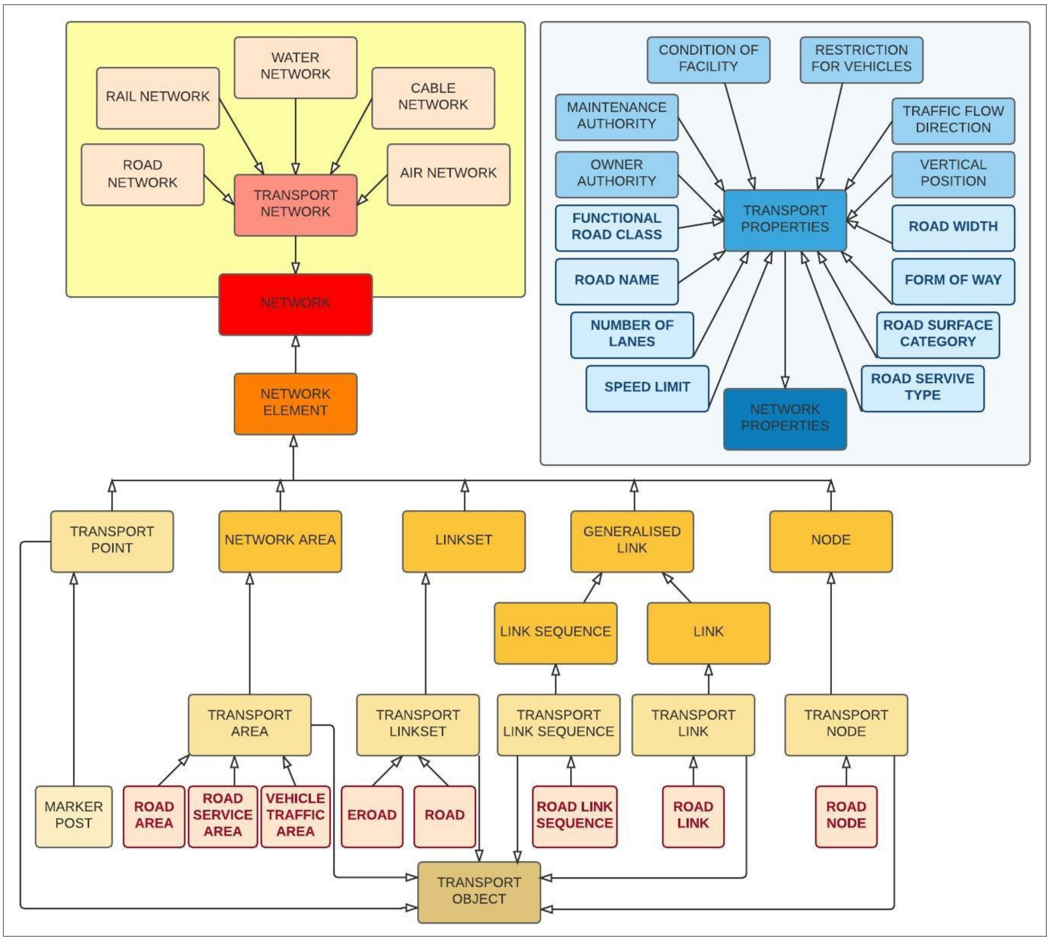
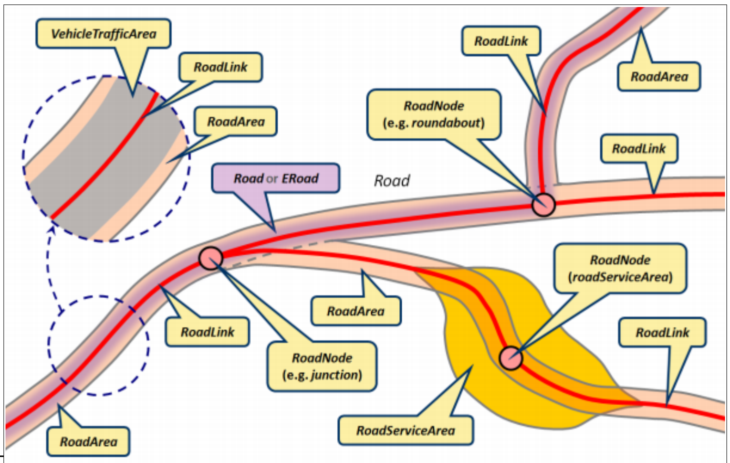


Figure 24. Overview of the main Road Transport Networks objects (source: D.2.8.I.7 Data Specification on Transport Networks – Technical Guidelines)



[63] The geometric basis of a transport network consists of a number of connected linear elements (Transport Links) with optional point elements (Transport Nodes) at the ends of the lines (at junctions, terminals, etc.)

Figure 25. Example of use of elements forming the Road Transport Network (source: D.2.8.I.7 Data Specification on Transport Networks – Technical Guidelines)

Its main purpose is the representation of a road system used for the transportation of vehicles in the form of a linear network (INSPIRE Thematic Working Group Transport Networks, 2010) (Fig. 25). The applications schema inherits road class diagrams of common transport application schema and also contains their own classes, with the specific objective of describing the properties of road transport network, as well as the attributes applied to sections of the network elements or subsections represented by linear referencing.

Data specifications includes three types of geometry: area objects, centreline objects and point objects. In order to promote the smooth functioning of the ESDI, INSPIRE data specification for road transport networks requires the consistency of spatial datasets and services at three levels: i.e. 1) of spatial datasets and services belonging to the same topic, regardless of the level of detail; 2) between the different objects existing within the same geographic area; and finally, 3) of spatial objects across borders or boundaries of the Member States.

With regard to interoperability, according to the INSPIRE Generic Conceptual Model, all spatial objects in the Transport Networks themes have a persistent unique identifier in the infrastructure; moreover, INSPIRE promotes the reuse of information (e.g. a transport link is used by several other objects, which may be collected by different organisations – e.g. survey conditions survey, speed limit/restrictions, etc.). Such objects would normally inherit geometry from underlying referenced objects.

Importantly for the present research work are the following notes specified in the Directive:

1. The Directive does not require collection of new spatial data and do not attempt to incorporate every spatial object that might be used by any application.
2. The model is flexible and permits a cross organisational approach where different users may collect and use different kind of information about a network. Users can extend the schema and add their own spatial objects to support an application.
3. While INSPIRE is primarily an environmental directive, Transport Networks data can be referred to a wide range of applications and use cases (e.g. asset management, capacity planning, construction, design & planning, disaster management, emergency response, environmental impact assessment - including noise, estate management, flow modelling, in car information systems, incident management, journey planning, maintenance, navigation, network operation, rerouting & diversions, routing, traffic control, traffic management, and other).

4. Specifications have Local, Regional, National and European relevance, as they are used extensively at the local level and extend to the other levels mentioned above.

5. Specifications support alternative forms of representation of a real world entity (centreline, and others) that can be cross referenced, to support easy data exchange between them.

6. Though lower resolution representations may be preferred as a starting point from which zooming to higher levels, ideally the lower resolution datasets would be derived from the local/high resolution data, and referenced (no geographic) data could then be aggregated and disaggregated as desired.

7. Several levels of details can be usually be stored to represented the network at different operational levels, (but currently there is a little correspondence between each level). An integration of the levels of detail is required, as specification applies to all of them.

8. It is expected that most applications will use the network data within a topological environment.

In addition, for the purpose of this thesis, it has been particularly important the INSPIRE approach of providing a framework for users to configure and associate their own information - from surface condition surveys, to journey planning, to trans-European transport policy making, etc. - using existing transport networks information in each MS. Also the approach to define datasets that are used extensively at the local level and extended to regional, national and European levels has highlighted the requirement of an expandable system, while the implementation of a Generic Network Model (GNM) within the Conceptual one meets the need of sharing any network spatial data theme (e.g. Hydrography) to ensure a consistent approach across all network themes.

2.4 Summary

This Chapter, in its first Section, has highlighted a number of road information studies as well as systems already implemented and currently used worldwide. They show different purposes - like road safety management, road traffic management, and road maintenance and asset management - and are all focused on the identification, classification and description of the existing asset. Some road inventories have been mainly aimed at data integration for a better and full management of different road-related aspects. The main purpose of each system has oriented the selection of different and specific datasets, technologies and functionalities used for their implementation, and resulting in heterogeneous systems. Nevertheless, they often contain similar data (i.e. general data or information that are usable for multiple aims: e.g. both road maintenance and road safety): however, they frequently are differently named or grouped, making difficult interoperability and data integration. Currently they all are based on 2D.

The second Section of the Chapter has illustrated transportation as one of the most important and growing applications of GIS (Miller and Shaw, 2001; Fletcher, 2000; Wiggins et al., 2000). 2D GIS technology has been widely used in the road management field due to its capability to link both geospatial and descriptive ('attribute' or 'semantic') information to represent and analyse spatial phenomena, understand the spatial relationships of data (viewable on maps), and perform spatial and network analysis through queries (Gristina et al., 2016). In particular, GIS-T also attains prominence and significance in government transportation agencies as it supports the reporting of the condition of transportation infrastructure. The clear perception of the three-dimensional nature of real world stimulated developers to produce new 3D information systems and researchers to investigate potentials, benefits and limitations (both conceptual and technical) of each. Particularly, with regard to the road sector, the most urgent requests refer to the need of management and integration of heterogeneous data (today even including point clouds, data from sensors, and others), 3D analysis, road full life cycle management, and interoperability: with this regard, 3D information systems like BIM and first experimental applications of 3D GIS shows different approaches and characteristics. All above will be properly addressed in Chapter 5 (gap analysis) and will be compared in Chapters 8 with results from literature and questionnaires and interviews.

The relevance of interoperability has been highlighted in the third Section of the Chapter: in that standards for Geographic Information, Intelligent Transport Systems and Transport Network have been illustrated as different components of standards relating to the road information systems implementation. They represent an important background information to understand the complexity of the topic, and all the aspects (e.g. datasets, levels of detail, relationships among road features and the environment) that have been addressed over time by standardisation bodies to enable interoperability both in Europe and internationally (and that will be later compared to the results of this research). Nevertheless, as mentioned in the Chapter and later addressed in Chapter 5, differences in traditions are more difficult to be solved (Kresse and Fadaie, 2004), while, on the other hand, International Standards do not mean that national or regional distinction are overridden (ibidem).

If GI standards are fundamental to establish a common way of handle spatial information among States and exchange it, standardisation is also relevant in the road transport sector. Road standards and specifications are very critical for the safe and efficient transportation of people and goods: uniform standards mean efficient and safe road infrastructures: the International Road Federation (2016) points out that the use of uniform Traffic Control Devices (messages, location, size, shapes and colours) helps to reduce crashes and congestion and improves the efficiency of the surface transportation system; uniformity also helps lower the cost of TCDs (i.e. time/cost-distance) through standardisation, while specifications for asphalt and concrete material ensure our roads are smooth and durable. With regard to the road asset management, standardisation is one way of dealing with large amount of data, as described by Nastasie and Koronios (2011). All of these once again highlight the range of applications making use of road data.

In addition, road and transport standards allow exchanging public transport information among countries so that people travelling is enabled to make efficient travel choices (Soares and Matos Martins, 2012). At global level, International Standards can contribute to the quality of life in general by ensuring that the transport, machinery and tools we use are safe (source: ISO website; Gupta, 2006). Moreover, the implementation of GDF standard has provided a standardised way of representing the road graph by edges and nodes, and with different levels of details, with semantic information assigned to each road entity defined. At European level, existing standards for the road sector are developed by the CEN: they relate to Intelligent Transport Systems (CEN TC/278) and provide reference data models for public transport (CEN Transmodel v5.1, 2006; IFOPT (Identification of Fixed Objects in Public Transport), 2009) and road design specifications (e.g. the ones provided by CEN/TC226 Road equipment). In particular, standardisation for transport networks and interoperability in Europe has found a fundamental contribute in the INSPIRE Directive, aimed at an infrastructure for spatial information in Europe.

This background, also used at national level for the Italian Road Cadastre as shown in Chapter 3, has been later compared with real needs and uses of expert road users. Nevertheless, as we will see with regard to the Italian case in Chapter 3 and 5, the effort to introduce global standards in the implementation of road inventories have also met difficulties.

Chapter 3

The Italian Road Cadastre: a case study

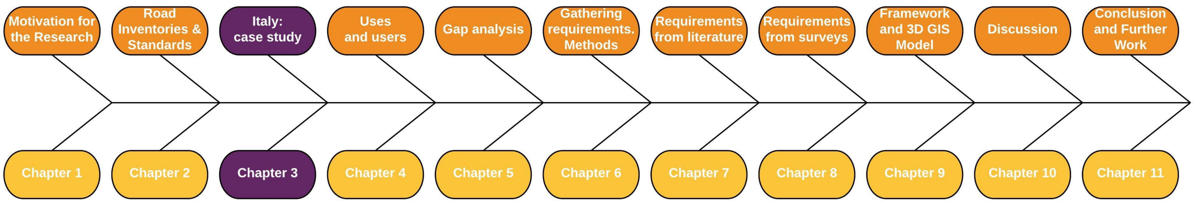


Figure 26. Overview of Document Structure showing context of this Chapter

The international review of road inventories, including information systems technologies and standards used for implementing them (addressed in Chapter 2), highlighted a variety of existing systems and research works on roads cataloguing and road data management with different purposes, structures and datasets (then further analysed in Chapters 4 and 7). As seen in Chapter 2 – Section 2.3, standards aim at providing different systems with common conceptual and technical features, allowing interoperability. Nevertheless, due to the multiplicity of data, data sources, tools, uses and standards road-related, a focus on a single road inventory (referred to a single country) as a case study can help to easily gather, process, and analyse road information and requirements, answer to the research question, and then extend the general principles defined to a larger context including further countries. The case study selected in this thesis is the Italian Road Cadastre.

In order to understand its framework (both legal and technical), and highlight which standard may be considered helpful to draw a proposal for a full road life cycle information system, Section 3.1 firstly illustrates the New Road Code of 1992 and the Italian road classifications introduced by it, as a base of the current Road Cadastre in Italy. A review of Italian standards on road design and maintenance has been conducted in Sections 3.2 and 3.3. The Italian law on Public Works, stating different project stages and instructions for delivering projects to public offices, is also cited. Finally, laws and acts assigning road management tasks (including the implementation of Road Cadastres) to institutions at different level are also mentioned in Section 3.4.

In the second part of this chapter, Section 3.5 addresses technical aspects of the Italian Road Cadastre defined by the Implementing Rules of the New Road Code (Ministerial Act of June 1, 2001): i.e. the structure (graph and database), the basic dataset with references of the system to ISO and CEN standards, and its expandability with further data to create local Road Information Systems. Different kinds of data, data sources, and methods of survey used are also mentioned. Few examples of implemented Road Cadastres in Italy (at regional, provincial, local level) have been illustrated in Section 3.6 as well as the ANAS Road Cadastre, in order to compare them with the basic legal Road Cadastre and to highlight possible gaps and requirements, especially in 3D descriptions of road situations, to plan further improvements.

3.1 The New Road Code (1992) and road classifications in Italy

The New Road Code - introduced in Italy by the Act of April 30, 1992 and entered in force on January 1st, 1993 - replaced the "Consolidated Law on Road Traffic" ("Testo Unico sulla circolazione stradale") of 1959 (Chianca, 2013).[64] As already described in Chapter 1, it introduced some important definitions, established the Italian Road Cadastre as a mandatory commitment for each road owner institution, also defining its basic common structure by law (Act of June 1, 2001), and introduced the current road classifications for Italy (also stating rules and road users' behaviour).

The importance of road classifications has been emphasised in the literature: Sharma (1983) defined them as "crucial" for administrations dealing with planning, designing, managing, and maintaining roads and facilities, but also "numerous", with class definitions varying depending on the purpose of classification (ibidem). Talvitie (1996) noted, however, that worldwide countries manage their road systems essentially by administrative and functional classifications: the former assigns road ownership, while the latter presides over technical requirements and maintenance practices, and influences the administrative classification and financing (ibidem). This is the case of Italy where the New Road Code (1992) established two separate - but closely interlinked (D'Apollo, 2015) - road classifications, based respectively on: a) the technical and functional design of the various road sections **(technical/functional classification)**, and b) road ownership **(administrative classification)** (ibidem). Importantly, the New Road Code (1992) defined the road as "the area for public use intended for traffic of pedestrians, vehicles and animals" (article 2, paragraph 1). It also highlighted **roads interrelationships with the surrounding environment**, by defining the inhabited centre (centro abitato): i.e. a continuous - although interspersed with streets, squares, gardens or similar -

[64] The first national legislation concerning cars in Italy is the Royal Decree nº 416 of July 28, 1901, i.e."Rules for the movement of vehicles on ordinary roads".

grouping of no less than twenty-five buildings and public use areas with vehicular and pedestrian access on the road, delimited along the access roads by appropriate signals of start and end. As also stated by the subsequent Implementing Rules (DPR n. 495 of December 16, 1992), inhabited centre boundaries identify the geographical area where **road users** are required to drive with a particular caution; also D'Apollo (2015) in its juridical review of the Code pointed out the link between the **location of roads from the inhabited centre** and the **behaviour of different road users**.

In the literature both Italian road classifications have been discussed by several authors. Most of them addressed legal aspects (e.g. relating to damages by road injury and civil liability): D'Apollo (2015) explained in detail the administrative road classification, linking it in particular to the identification of the owner/manager for legal purposes, while Magni (2005) and Giuffrè (2011) illustrated both road classifications within the framework of the Italian Road Cadastre.

3.1.1 Technical Classification

Talvitie (1996) defines the functional classification as "the process by which the roads are grouped into classes by the service they are intended to provide". In Italy the New Road Code of 1992 established a precise hierarchical classification of all roads based on their role within the territorial framework and the overall road infrastructures system, as also illustrated by Magni (2005). Giuffrè (2011) discussed the Italian technical classification of roads in the light of the Ministerial Act of November 5, 2001, and cited the "rank" of the infrastructure network (i.e. primary, main, secondary, and local) (see Fig. 28), depending on road territorial functions, geometric features and functionality (Table 7). Cataldo and Villani (2016) highlighted difficulties in its implementation.

The Italian technical-functional classification of roads (defined by article 2 of the New Road Code) is based on constructive, technical and functional features of roads. It provides 6 road types (each identified by a Latin capital letter) that, in turn, as noted by D'Apollo (2015), are grouped into two "macro-categories": 1) **urban roads** (within inhabited centres), and 2) **extra-urban roads** (outside inhabited centres). They are defined as follows:

Class	Type of road	Definition by the New Road Code (1992)
A	**Motorway**	"[...] a suburban or urban road provided of carriageways that are independent or separated from an impassable median, each with two lanes at least, any paved shoulder on the left and an emergency lane or a paved shoulder on the right, without intersections and private accesses, with fence and user-assistance systems along the entire path, reserved for traffic of some specific categories of motor vehicles and marked with appropriate signs of beginning and end; it must be equipped with special service areas and parking areas, both provided of accesses with deceleration and acceleration lanes " (article 2, paragraph 3, letter A). A motorway can have even a service road (article 2, paragraph 4) for grouping the side entrances to the main road, and allowing the movement and the maneuvering of vehicles (not allowed on the main road itself).
B	**Suburban main road**	"a road provided of carriageways that are independent or separated from an impassable median, each with two lanes at least, any paved shoulder on the right, without intersections, with coordinated accesses to the side properties characterised by specific signals of beginning and end, reserved for traffic of some specific categories of motor vehicles; adequate facilities for any other categories of users must be provided. It must be equipped with special service areas including areas for the stop, provided of accesses with deceleration and acceleration lanes"(article 2, paragraph 3, letter B). A suburban main road can have even a service road for parking, grouping accesses from the side properties to the main road and vice versa, and allowing the movement and the maneuvering of vehicles (not allowed on the main road itself).
C	**Suburban secondary road**	"[...] a single carriageway road provided of one lane in each direction at least, and shoulders" (article 2, paragraph 3, letter C).
D	**Urban expressway** (it: "strada di scorrimento veloce")	"[...] a road provided of carriageways that are independent or separated from an impassable median, each with two lanes at least and a possible lane reserved for public transport, a paved shoulder on the right and pavements, with any signalized intersections; there are separate areas or side bands for parking that are unrelated to the roadway and provided of concentrated access and exit roads"(article 2, paragraph 3, letter D). A urban expressway can have a service road for parking, grouping accesses to the main road from the side property and vice versa, and allowing the movement and maneuvering of vehicles (not allowed on the main road itself).
E	**Urban neighbourhood road**	"[...] a single carriageway road provided of two lanes at least, paved shoulders and pavements and areas equipped with an appropriate driveway, outside the roadway, for parking" (article 2, paragraph 3, letter E).
F	**Local road**	"[...] urban or suburban road [...] for public use, intended for traffic of pedestrians, vehicles and animals" (article 2, paragraph 1), "not belonging to any other types of roads" (article 2, paragraph 3, letter F). Local roads are roads that do not have one or more features to be classified into any other categories (e.g. suburban secondary roads missing of shoulders on the sides or urban roads without sidewalks).

Table 2. Road classes' definition from the technical classification (source: New Road Code, 1992).

A further class - "**Fbis**" - identifies cycle and pedestrian routes.

Different road characteristics and components deriving from the technical classification by Italian law have been summarised in the Table below:

Road Type	Independent carriageways (or any impassable median) (min)	Number of lanes for each carriage (min)	Paved shoulder on the left	Emergency lane or paved shoulder on the right	Intersections	Private accesses	Fence and user-assistance systems (reserved and marked)	Special service/ Parking areas	Deceleration/ Acceleration lanes	Service road (optional=opt.)	Sidewalk
A	2	2+2	✓	✓	X	X	✓	✓	✓	Opt.	X
B	2	2+2	✓	---	X	✓	---	✓	✓	Opt.	X
C	1	1+1	✓	---	--	---	---	---	---	---	X
D	2	2+2	---	✓	✓	✓	---	✓	---	Opt.	X
E	1	1+1 or 2 in the same direction	---	---	---	---	---	✓	---		✓
F	1	1+1 or 1	---	---	--	---	---	---	---	---	✓

Table 3. Summary table of road characteristics from the Italian technical road classification (Source: New Road Code, 1992).

Importantly, Talvitie (1996) noted that the functional classification is a permanent but evolving representation of the road network: due to economic growth, relocation of population, trade routes and expansion of urban areas, it must be updated periodically to record transport demands' and road network's variations, and fulfill its role as a management tool. With this regard, over fifteen modifications of the Italian Road Code have taken place since 1993 (the year following its approval): e.g., a new version of the Road Code approved in July 2003 by the Italian Parliament stated that the right lane on three-lane motorways should not be reserved anymore to slow vehicles alone (Richiardi, 2004), while the law n. 120 of July 29, 2010, replaced, inserted, deleted, and modified well-seventy-eight articles, most of which related to relevant aspects of the road traffic discipline (Bellagamba and Cariti, 2010). Also, road functional classes may vary due to road performances' modifications (e.g. in terms of level of services,[65] whose minimum value for each functional road class has been established by the National Research Council) (Giuffrè, 2011). Any modification of road classes and related features determines modifications of the corresponding road cadastral data as well.

3.1.2 Administrative classification

The administrative classification of roads (New Road Code, Article 2, paragraphs 5-9) includes 5 road classes, depending on the owner institution, the territorial area (and number of inhabitants), and the type of road connection; each administrative class may include different

[65]The level of service is a measure of the quality of the road traffic in correspondence of a vehicular flow assigned (a precise road section). The quality of road traffic depends on the geometrical flow characteristics of the track, the number and type of intersections, the descriptive parameters of the vehicle flow (flow, density, speed), the composition of the traffic (light vehicles, heavy, pedestrians, etc.), the type of users (habitual or not), weather-climate conditions and lighting conditions (day, night, artficial lighting, etc.) (Giuffrè, 2011).

technical road classes. Such features are summarised in the following Table[66]:

Road type and identification code	Owner	Responsible	Territorial area	Technical class included	Town inhabitants	Connections (A is linked to B)	
						What connected (A)	To what (B)
State road **SS**= Strada Statale	State	State	Extra-urban	Main roads Secondary roads Local roads	≤ 10,000	The main road network of the State	Road networks of neighbouring States
			Urban	Expressways Local roads		Regional capitals (or provincial capitals in different regions)	Each other
						Seaports, airports and shopping centres relevant for industry, tourism and climate	The state roads' network
						State roads	Each other
Regional road **SR**= Strada Regionale	Region	Region	Extra-urban	Main roads Secondary roads Local roads	≤ 10,000	A provincial capital	The capital of the region
			Urban	Expressways Local roads		Provincial capitals	Each other
						Provincial capitals or municipalities	The network of state roads, if relevant
Provincial road **SP**= Strada Provinciale	Province	Province	Extra-urban	Main roads Secondary roads Local roads	≤ 10,000	Chief towns of a province	The corresponding provincial capital
			Urban	Expressways Local roads		Chief towns of a province	Each other
						Chief towns of a province	The network of state roads or regional roads, if relevant connections
Municipal road **SC**= Strada Comunale	Municipality	Municipality	Extra-urban	Main roads Secondary roads Local roads	≤ 10,000	Villages of a municipality	The capital of the corresponding municipality
			Urban	Expressways Neighbourhood roads Local roads		Villages of a municipality	Each other
						The capital of a municipality	A place of interest for the community
						Local roads that are private roads for public use, out of settlements	Each other
	Different owners	Municipality	State urban, regional and provincial	Expressways Local roads	> 10,000		

[66]In the table "relevant" means relevant for industry, commerce, agriculture, tourism and climate, while places of interest for the community are: railway stations, tram stations, car stations, airports, seaports, lake ports, river ports, freight=interporti, intermodal interchanges.

			roads				
Military road **SM**= Strada Militare	Command of the Territorial Military Region[67]	Command of the Territorial Military Region	Roads intended exclusively for military traffic (article 2, paragraph 5).				

Table 4. Summary table of road characteristics from the Italian administrative road classification (Source: New Road Code, 1992).

By the New Road Code (1992) road classification (or declassification) is responsibility of the Ministry of Infrastructure and Transport – in agreement with the Superior Council of Infrastructure and Transport and the ANAS Board (for national roads), and Regions and local authorities concerned (for the remaining roads). According to the administrative classification, roads are identified – both in the Road Cadastre and physically by signs on the carriageway - by initials, corresponding to the road owner institution (see the Table above), and a growing number, depending on the date of the road establishment. Classified roads are then entered in the Road National Archives, which distinguishes between network of national interest (Act of October 29, 1999, n. 461) or regional interest (Act of February 21, 2000).

The administrative classification is mainly important to establish who is responsible of the road network management. However, as later described in Chapter 5, over time the responsibility on roads has been changing (with some duties transferred by law from the State to regional and local administrations): as a consequence, also road administrative classes and nomenclature have to be updated within both Road Cadastres and the National Road Archive.

3.2 Italian standards for road design and construction

In Italy, over time a huge number of road-related standards have been produced (see Appendix), providing various rules, instructions, and specifications that differently characterised road features design and construction in the various ages. Cocetta (2011) and Monutti (2013) described Italian road design standards as based on the functional road classification by the New Road Code, while Giannattasio (2005) gave a detailed overview of Italian standards related to road construction, and grouped them into three main categories that highlight how large and complex this topic is (see Table below and Appendix):

[67]Commands of Territorial Military Region are branches of the Italian Army, carrying out the command and control functions with both operational and territorial tasks on territories grouping several regions. They also have representative functions in the jurisdiction, and are involved in the State-owned assets management.

Standards on Design, Maintenance and Classification	Specific standards on Road Safety	Standards on construction aspects: Materials and facility
Topics: General rules, Road Cadastre and classification, Geometry, Road Surfaces, Signage, Underground utilities, Safety barriers, Lighting systems, Traffic, Air pollution, Noise pollution, and Technical specifications	**Topics:** Security Plans	**Topics:** various items, such as lands and aggregates, surface treatments, different materials and characteristics of road surfaces and joints sealing, road safety barriers, lighting columns, road signs, anti-glare schemes for roads, and devices for parking, checking traffic, and reducing the noise
Enacted by: the Ministry of Public Works, with the agreement of the National Council of Research (CNR) and the Superior Council of Public Works	**Enacted by:** the Ministry of Public Works	**Drawn by:** CNR, CEN and UNI (the Italian Standardisation Body)
Aims: standardising road characteristics fitting to social, economic and environmental aspects	**Aims:** safety	**Aims:** setting characteristics and a minimum quality level for each product category, also defining quality test

Table 5. Summary table of topics related to the three groups of standards according to Giannattasio (2005)

The table above refers to a very large number of standards that, however, are not always mandatory: standards from the first category have a binding nature; the third group even includes 354 standards (ibidem).

According to Cafiso et al. (2010), over time in Italy various road design standards influenced differently the existing road network in terms of network layout and architectural and landscape constrains. With this approach, Monutti (2013) grouped Italian road design standards according to chronological phases (corresponding to specific road design and construction standards and practices in use at that time). Actually, roads dating back before the Act of June 1, 2001 (Implementing Rules of the New Road Code) were built in accordance with standards required by the great road network development of the early '60s.[68]They mainly aimed at defining and standardising the geometric characteristics of the track and the profile of the cross section, as the following section shows.

Year	Standard	What introduced/provided (main topics)	Current use
1963	**C.N.R.-UNI 10005 and 10015**	- a road classification (different from the current one) - different values of design speed for each road class - minimum geometric parametres of track and profile for each class	---
1973	**Standards on the Geometric Features of Roads (CNR B.U. n. 31, March 28, 1973)**	- a comprehensive framework for designing roads and suburban road intersections - a classification of road platforms - the concept of design speed range - fully defined criteria for designing road profiles	Some standards (e.g. related to curve geometry eyelash, visibility triangles, and others) are still a

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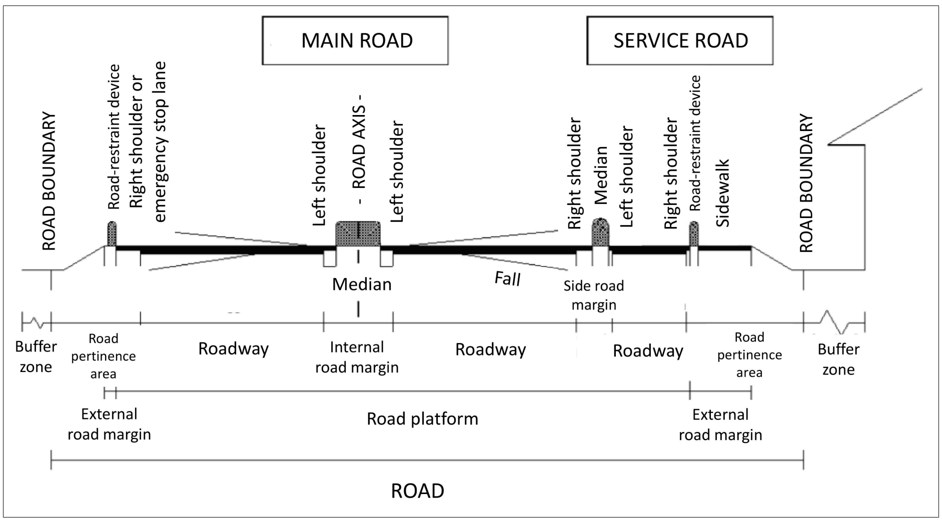
		and tracks	reference for designing intersections in suburban areas
1978	**Standards on the Geometric and Traffic Features of Urban Roads (CNR B.U. n. 60, April 26, 1978)**	- a new functional and geometric classification of urban roads, - the identification of traffic components (e.g. heavy vehicles, public transport vehicles, private cars, parking for private and public vehicles) - the definition of type sections suitable to accommodate all traffic components (e.g. roadways, shoulders, sidewalks, parking areas) - the concept of the pertaining areas (i.e. shoulders equipped with auxiliary side spaces for sidewalks, public transport stations, embankments, and others)	---
1980	**Standards on the Geometric Features of Interurban Roads (CNR B.U. n. 78, 28 July 1980)** only affecting rural roads and no intersections	- a review of the platform types classification, the design speed range, and the track and profile design criteria	Until 2001 they have been the reference for the design of rural roads in Italy
1983	**Standards on the Geometric and Traffic Features for Urban Road Intersections" (CNR B.U. n. 90, 1983)**	- updating standards on road intersections	---

Table 6. Summary table of road design standards (used before the Act of 2001) according to Monutti (2013)

Roads built after the '90s, instead, were based on new standards whose review can be found in Monutti (2013): the **New Highway Code (1992)** required new road design standards to substitute the road design guidelines until then in force. It introduced new road classifications (replacing the ones by CNR) and the concepts of buffer zones and signage. Its **Implementing Rules (2001)** did the same with the speed chart, different methods for calculation of the design speed, the sight distance, the geometrical parametres, and more stringent checks on the alignment geometry. Importantly, on the basis of Road Code's definitions, they represented road components (included into the legal Road Cadastre) (Fig. 27).

Figure 27. Cross section representing road components (source: Act of June 1, 2001)



Finally, by the **Act of November 5, 2001,** the Italian Ministry of Infrastructures and Transport established **"Functional and geometrical standards for road design"**. It includes each technical road class into four network levels (depending on four functional main road factors) (as Table 7 and Fig. 8 show), and reports design dimensions and traffic categories admitted for each road class (Tables 8 and 9), standardising the correspondence between each road class and its design features.

Figure 28. Four road network levels (a: primary, b: main, c: secondary, d: local) (source: Act of November 5, 2001).

ROAD TYPE	ROAD NETWORK LEVELS	KIND OF TRAVEL MOVEMENTS	AVERAGE DISTANCE TRAVELLED BY VEHICLES	ROAD NETWORK FUNCTION	TRAFFIC COMPOSITION AND RELATED CATEGORIES (light vehicles, heavy vehicles, pedestrians)
A	PRIMARY (a)	Main movement (Transito, scorrimento)	Long	National and inter-regional Urban area-related	Limited
B	MAIN (b)	Distribution (Distribuzione)	Medium	Inter-regional and regional Inter-neighbourhood areas	Limited
C	SECONDARY (c)	Collection (Penetrazione)	Reduced	Provincial and inter-local Neighbourhood area-related	All
D					
E	LOCAL (d)	Terminal access (Accesso)	Short	Inter-local and local Within the neighbourhood area	All
F					

Table 7. Correspondence between 4 road network levels and 4 functional factors (source: Act of November 5, 2001).

	Territorial area	**Denomination** (Main road=M; Service Road=	**Number of lanes in each direction**	**Lane width (m)**	**Min median width (m)**	**Min left shoulder width (m)**	**Min right shoulder width (m)**	**Min inner margin width (m)**	**Min side width (m)**	**Min radius (m)**	**Design speed range (km/h)**	**Speed limit (km/h)**	**Max slope (%)**	**Transverse coefficient of adhesion**	**Level of service and**	**Service capacity per lane (vehicles/h)**

											min	max					
A	Extra-urban	M	2 min	3.75	2.0	0.7	2.50	4.0	6.1	339	90	140	130	7	0.118	B 2min	1100
		S	1 min	3.50	--	0.5	1.25		5.3	45	40	100	90	7	0.210	C 1	650
																C 2min	1350
	Urban	M	2 min	3.75	1.8	0.7	2.50	3.2	4.25	252	80	140	130	7	0.130	C 2min	1550
		S	1 min	3.00	--	0.5	0.50			51	40	60	50	3.5	0.210	D 1	1150
																D 2min	1650
B	Extra-urban	M	2 min	3.75	2.5	0.5	1.75	3.5		178	70	120	110	7	0.147	B 2min	1000
		S	1 min	3.50	2.0	0.5	1.25			45	40	100	90	7	0.210	C 1	650
																C 2min	1200
C	Extra-urban	C1	1	3.75	--	---	1.50			118	60	100	90	7	0.170	C 1	600
		C2	1	3.50	--	---	1.25			118	60	100	90	7	0.170	C 1	600
D	Urban	M	2 min	3.25	1.8	0.5	1	2.8	3.3	77	50	80	70	5	0.205		950
		S	1 min	2.75	--	0.5	0.50			19	25	60	50	3.5	0.220		950
E	Urban		1 min	3.00	--	---	0.50	0.5		51	40	60	50	3.5	0.210		800
F	Extra-urban	F1	1	3.50	--	---	1.00			45	40	100	90	7	0.210		800
		F2	1	3.25	--	---	1.00			45	40	100	90	7	0.210		800
	Urban		1 min	2.75	--	---	0.50			19	25	60	50	3.5	0.220		800

Table 8. Summary table of road design characteristics linked to the Italian road classification (Source: Act of November 5, 2001).

	Territorial area	**Denomination**	**Traffic categories admitted** O non admitted in the platform * partially within the carriageway □ outside the carriageway (within the platform) ♦ within the carriageway

			Pedestrians	Animals	Arms and animal-drawn vehicles	Cycles	Mopeds	Cars	Buses	Trucks	Lorries/ Articulated trucks	Operating machines	Rail vehicles	Emergency stop	Stop	Direct private accesses
A	Extra-urban	Main	O	O	O	O	O	♦	♦	♦	♦	O	O	□	O	no
		Service	□	□	♦	♦	♦	♦	♦	♦	♦	♦	O	□	□	yes
	Urban	Main	O	O	O	O	O	♦	♦	♦	♦	♦	O	□	O	no
		Service	O	□	♦	♦	♦	♦	♦	♦	♦	♦	♦	□	□	yes
B	Extra-urban	Main	O	O	O	O	O	♦	♦	♦	♦	O	O	*	O	no
		Service	□	□	♦	♦	♦	♦	♦	♦	♦	♦	O	*	□	yes
C	Extra-urban	C1	□	□	♦	♦	♦	♦	♦	♦	♦	♦	O	*	□	yes
		C2	□	□	♦	♦□	♦	♦	♦	♦	♦	♦	O	*	□	yes
D	Urban	Main	O	O	O	□	♦	♦	♦	♦	♦	♦	O	*	O	no
		Service	O	*	♦	♦	♦	♦	♦	♦	♦	♦	♦	*	□	yes
E	Urban		O	♦	♦	♦□	♦	♦	♦	♦	♦	♦	♦	♦ *	□	yes
F	Extra-urban	F1	□	♦	♦	♦□	♦	♦	♦	♦	♦	♦	♦	□	□	yes
		F2	□	♦	♦	♦□	♦	♦	♦	♦	♦	♦	O	□	□	yes
	Urban		O	♦	♦	♦	♦	♦	♦	♦	O	♦	□ ♦	□	□	yes

Table 9. Road users depending on the Italian administrative road classification (Source: Act of November 5, 2001).

Design standards also related to intersections and interchanges by the **Ministerial Act in 2006: "Guidelines for the functional and geometric Design of Road Junction".** A discussion on them can be found in Barzizza et al. (2015).

An important set of standards refers to the way of preparing and presenting to the Public Administration road projects to be approved: in 1980 CNR also published the first **"Instructions for drafting road projects" (CNR B.U. n. 77 of May 5, 1980)** as guidelines; more recently, the Law 109/1994 on the Public Works (the so-called **"Merloni Law"**) and its **Implementing Regulation Act** (D.P.R. n. 554 of December 21, 1999) defined a list and characteristics of documents and data required for all construction projects (including both building and infrastructures) during three different subsequent stages (preliminary, final and executive).

As shown above, Italian road design involves a number of aspects and components: they refer to **geometric design,** but also to **traffic management, traffic-related air and noise pollution, road equipment and underground utilities planning and construction**, and **safety** (both general rules and specific standards on barriers, street lighting, signs, and road surface condition). Most of them can be found in Appendix.

3.3 Italian standards for roads maintenance

A discussion on Italian road maintenance standards can be found in Campolongo (2015), who widely described **"Guidance on planning for road maintenance"** ("Istruzioni sulla pianificazione della manutenzione stradale") (Boll. Uff. CNR, n° 125 of April 20, 1988): the first relevant Italian standard for road maintenance by CNR (1988). Importantly, it defines in detail each stage of road surfaces survey, analysis and intervention providing basic concepts to proper design road maintenance by **sequential maintenance phases**:

1. Initial design (aimed at construction);
2. Data survey (methodology, introducing the use of paper form for compiling data);
3. Analysis of possible maintenance interventions (special techniques);
4. Interventions planning;
5. Execution of road maintenance interventions (and check on the execution).

Such methodological approach will be then applied to the "programmed maintenance of road surfaces" and can be found also in Giarratana (2010) and ANAS (1999) with regard to SOAWE: an ANAS management application for road structures and plant maintenance linked to the ANAS Road Cadastre and recording both defects and monitoring data.

Importantly, CNR road maintenance standards introduced important documents, such as the **Catalogue of deteriorations** to identify and quantify road degradation and possible interventions techniques. Comparisons with the Swiss VSS (Suisse Standards Catalogue des degradation), the French SETRA (Entretien preventif du reseau routier national, 1979), the American RDDHD (Catalogue of road defects, 1992) and SHRP (Distress identification manual for the long-term pavement performance project, 1993) can be found in D'Amico (2009).

Canestrari (2016) cited the **Act 554/99** and the **Act n. 163 of April 12, 2006** that, in accordance with the **UNI 10874:2000 standard ("Drafting criteria for manuals of usage and maintenance" of real estate – including roads)**,[69] introduced: 1. a set of checks and interventions to be run at fixed time intervals over the whole real estate life cycle, 2. and the maintenance plan, as one of the mandatory documents to be included into the"executive project" (i.e. the final and most detailed stage of the project in Italy).[70]

[69] In 2000 UNI 10874 standard provided a well-illustrated list of all documents needed for the maintenance plan of real estate (including roads). It includes: a) the manual of usage (aimed at users in order to avoid/limit improper usage of real estate, to learn properly about maintenance operations not requiring specialised technical skills, to encourage proper management to avoid an early decay, to early recognise abnormal deterioration phenomena and report them to technical managers; b) the maintenance manual (aimed at providing technicians with instructions for a proper maintenance of real estate); c) the maintenance plan (indicating a set of checks and interventions to be run at fixed time intervals over the whole real estate life-cycle).

[70]As noted by Coni et al. (2000), CNR **"Guidance for Editing Road Projects"** (Official Bulletin of CNR N°77, 1967) had already included the maintenance plan among the 30 documents required for each executive road project. Nevertheless, very few road projects were provided with it (probably due to the lack of reliable tools predicting the value of different road condition parametres over time) (Coni et al., 2000).

Regional standards and documents,[71] such as **"Road surfaces maintenance standards and criteria"** and the **"Catalogue of road surface deterioration"** (2006) for the northern Italian Region of Lombardy, have been described by Crispino et al. (2008), the Regional Act of January 25, 2006, and the General Direction of Infrastructure and Mobility of Lombardy (2005a). The latter (2005) reported difficulties in implementing local standards on road maintenance.

The document **"Functional Standards for Smart Roads"** by the Italian Ministry of Transport and Infrastructure (2016) highlighted the lack of specific standards on road surfaces monitoring in Italy, with measurements and checks on single road elements have been defined only by national (e.g. UNI EN and CNR) and international standards (e.g. ASTM and ISO) that are just guidelines; however, a work-group within UNI is currently working on national standards helpful to road managers to implement monitoring plans (ibidem). Nevertheles, in 2014 the European Union Road Federation (ERF) published **"Road Asset Management - An ERF position paper for maintaining and improving a sustainable and efficient road network",** providing guidelines for all European countries (Italy inlcuded) to create a data structure for road maintenance and to implement a road inventory to be updated regularly.

3.4 National and regional road cadastral standards in Italy

As mentioned in Chapter 1, in Italy the New Road Code (1992) imposed to roads owner authorities the mandatory implementation and updating of cartography, cadastres of roads and related appurtenances, including facilities and permanent services related to traffic requirements. The Code (Art. 227) and its Implementing Rules (Art. 404) stated the use of road traffic monitoring devices to be installed on the roads, requiring road owners authorities to indicate promptly their location within the own Road Cadastre and to the General Inspectorate for Traffic and Road Safety of the Ministry of Public Works. The Code (Art. 225) also established the institution at the General Inspector of a National Road Archive, whose implementing specifications and contents are defined by Article 226 and the Implementation Regulations (Art. 401): the Archive, which must include all data related to technical and legal status of the roads, with indications on vehicular traffic, accidents, practicability and noise and air pollution, must be digitalised, and related data have to be provided by local road owner authorities from their road systems and other sources (Regione Piemonte, 2012).

Importantly, in Italy the Act DPCM of February 20, 2000 transferred the road ownership from the State to the Regions that, therefore - as all road management agencies - are required by

[71] Due to the transferring of responsibilities for planning, managing and maintaining regional and provincial roads to Regions and Provinces by the Italian Law no. 59/97 and the Act no. 112/98.

law to set up their own digital Road Cadastre, collecting information about the road network under the own jurisdiction and related appurtenances (SITECO, 2016). As remarked by Provincia de La Spezia (2016), the Implementing Rules of the Road Cadastre only provides its "minimum contents"; then local authorities must collect further data (maps, traffic data, number of accidents, state of conservation of structures, road surface and complementary works, environmental monitoring, signage, and other) to be referred and added to the legal Road Cadastre's "basic" information, in order to implement their own Road Information System.

SITECO (2016) provided and overview of standards adopted by several Italian regions (such as Lombardy, Liguria and Emilia-Romagna) to implement their own Road Cadastres. It includes: the Road Cadastral Implementing specifications by the Ministerial Act of June 1, 2001, the RADEF (Road Administrator Data Exchange Format) Project launched in 1995 in Europe by WERD (the European association of road networks administrators, aimed at defining standards for the exchange of data between different national authorities); Regional regulations and guidelines of Lombardy, Liguria and Emilia-Romagna, IVCA (Supervisory Inspectorate of ANAS Motorway Concessionaires) Specifications for the delivery of GDF data; and CONSIP - Ministry of Finance Technical specifications for the CONSIP Road Cadastre call of tenders. With regard to the Road Cadastre of the Emilia Romagna (Italian northern region), Dondi et al. (2003) also included the Regional Law 12/01 (**"Amendments to the Regional Law of April 21, 1999, No. 3 on the environment, roads and transport, and changes to the Regional Law of January 14, 1989, No. 1"),** confirming the effort to create regional Road Cadastres fitting to local requirements, but lacking of homogeneity and uniformity of dataset and systems. In Lombardy, the Regional Law No. 9 of May 4, 2001 (**"Planning and development of the road network of regional interest"**) assigned the Regional Council to define detailed technical aspects of the Regional Road Cadastre, homogeneous parametres of storage information and unified protocols for data exchange between various Bodies. Caroti and Piemonte (2010) studied the Regional Road Cadastre in Tuscany (northern region of Italy) and compared it to the Road Cadastre of the Municipality of Pisa (one of the main cities in Tuscany) in order to highlight the relationships of both with regional, national and international standards as well as European Directives.[72]

3.5 The Italian Road Cadastre structure by the Act of June 1, 2001

While the New Road Code of 1992 is the law establishing the Italian Road Cadastre, standards for registering and updating road cadastral data were provided by the subsequent Act

[72] Specific comparisons with the Regional Law (D.G.R. 44/2006), the Italian Road Cadastral Implementing Rules (2001), Intesa-GIS specifications, and the INSPIRE Directive are addressed.

of the Ministry of Public Works of June 1, 2001:[73]an implementing act, enacted nine years later the New Road Code after consulting the Board of Public Works and the National Research Council (CNR) for technical aspects, and addressed to all the institutions owning public roads. It describes characteristics and the basic structure of the Italian Road Cadastre, whose database, as mentioned above, should be then expanded by each local administration to implement its own Road Information System (or SIS, Sistema Informativo Stradale): i.e. a database where each road institution should organise all data of all roads owned, and log further information (e.g. accident data) not included in the legal Road Cadastre (but in accordance with it).

The Italian Road Cadastre has been designed as an archive management with a hardware and software architecture allowing road asset management and maintenance operations (Provincia di Brescia, 2010). Its physical model should consist of a network-based, multi-user, client-server system, based around a relational database (whose structure is also defined by the Act of 2001) and a GIS. The latter allows the representation of the map of the area and the graph of the road network at varying levels of detail, the selection of each road element, and the display of the attributes stored in the database. The Road Cadastre structure has been widely discussed by Magni (2004) and Cera (2009).

3.5.1 Road Cadastre's entities and levels of detail

As mentioned in Chapter 2, the computer specifications of the DB structure of the Road Cadastre are partially based on the pre-standard CEN/TC 278, Geographic Data Files (GDF), version 3.0 of October 12, 1995: an international standard, used to model, describe and transfer road networks and other geographic data. As shown by the Figure below, each **GDF file** is composed of: **album** and **volume** (identifying data relating to the data distribution system) as well as **dataset, section** and **layer** (i.e. three different levels for grouping data). The Italian legal Road Cadastre only includes dataset, section, and layer.

[73] The Act is titled as "Procedures for the Road Cadastre's setting up and updating in accordance with art. 13, paragraph 6, of Legislative Decree April 30, 1992, n. 285, as amended" (see Delvino et al., 2016).

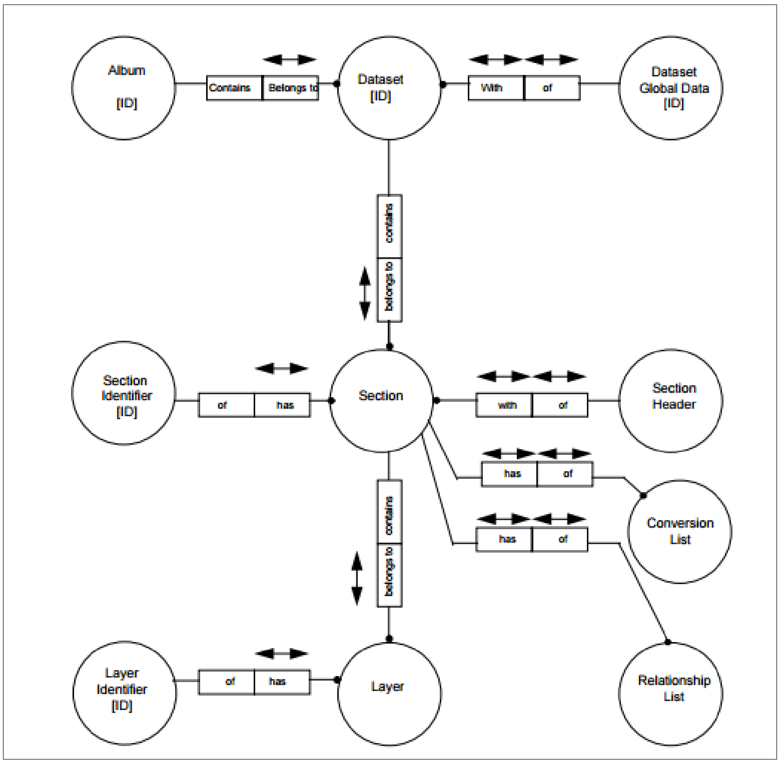


Figure 29. Data model representing the relationships among Album, Dataset, Section and Layer within a GDF file. (source: Italian Ministerial Act of June 1, 2001, Appendix 1)

The **dataset** is the main one and identifies the institution managing the database; the road network is subdivided into **sections** (based on geographical criteria) in order to represent different geographical areas, while each section is subdivided into one or more **layers** (i.e. the set of all nodes, edges, and polygons forming a single planar graph (Level 0) relating to one or more themes). The Italian Road Cadastre uses themes n. 41 (Roads and Ferry) and n. 75 (Bridges and Tunnels) by CEN standards (illustrated in Chapter 2). As well as in the GDF model, within it the road network is described by **"Entities"** (or **Features**), **"Attributes"** (entities' properties), and **"Relationships"** (between entities), according to three different levels of analysis (or LoD, i.e. Levels of Detail), depending on what has to be described (Fig. 30):

- the geometric/cartographic road features (Level 0),
- the road modelling through junctions, road elements and enclosed traffic areas (Level 1),
- the transit routes (Level 2).

They ave been widely illustrated by Magni (2004).

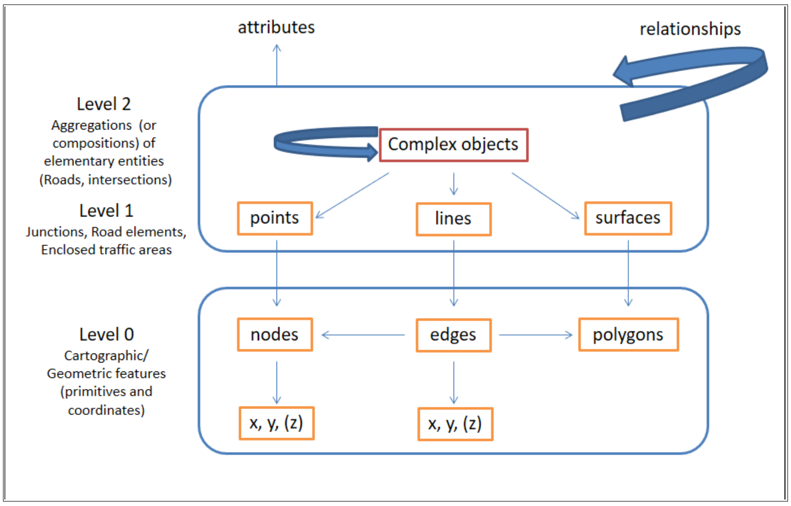


Figure 30. Comparisons among Road Cadastre's Levels and their primitives

Level 2 operates at the smallest scale and is suitable to represent some elements of the SIS and of the Roads National Archive (Act of June 1, 2001; Magni, 2005). At this level the road network is represented by two basic and complex entities: **roads** and **intersections.** An Intersection identifies the convergence/divergence of two or more traffic routes; it is defined as well as the ISO Level 2 representation of a crossing bounding Roads and Ferries, and joining them to other ones (ISO 14825:2001), and includes: roundabouts, exit roads (i.e. exit roads themselves or exchange roads), and intersections (where roads provided of two or more single carriageways or single carriageway roads join each other).

Level 1, indeed, operates at a bigger scale then Level 2. It is based on three elements:

- the **road element**, i.e. the axis of a single carriageway road trunk (simple line feature), delimited by two junctions and identified by an ordered set of points;
- the **junction** (simple point feature), i.e. the end of a road element, also used to describe: the point of intersection of more road elements, the interconnection between a road element and a traffic area, the interchange points between the road system and another transmission system, and the break points of global attributes of a road element (Act of June 1, 2001; Magni, 2004);
- and the **enclosed traffic area** (simple area feature), i.e. an area intended for vehicles movements, but where traffic flows are not defined (e.g. squares, widenings, parking places).

ISO 14825:2001 explained similarities and differences between Intersections (Level 2) and Junctions (Level 1). As seen above, in Level 1 each road is represented by one or more road elements with a junction at each end; similarly, in Level 2 each road is included between two intersections: hence, the Feature Intersection at Level 2 plays a similar role as the Feature

Junction does at Level 1. Nevertheless, as ISO 14825:2001 argued, the difference between an Intersection (Level 2) and a Junction (Level 1) lies in the degree of generalisation, as an Intersection (Level 2) is a Complex Feature, made up of a set of Level 1 Features (i.e. Junctions, Road Elements and Enclosed Traffic Areas), e.g. more road elements and more junctions. The diagram in the Figure below shows such relationships:

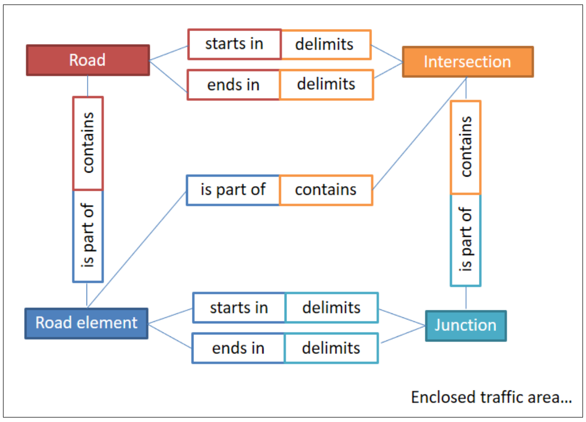
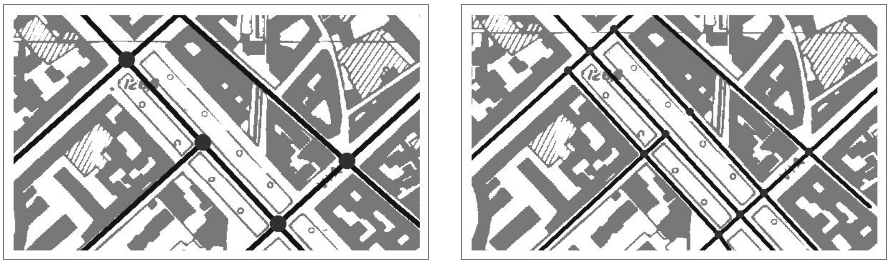
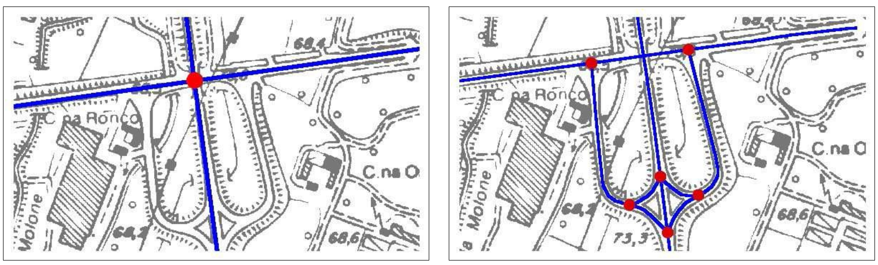


Figure 31. Model about relationships among entities at Level 2 and Level 1 (basis of the Italian Road Cadastre)

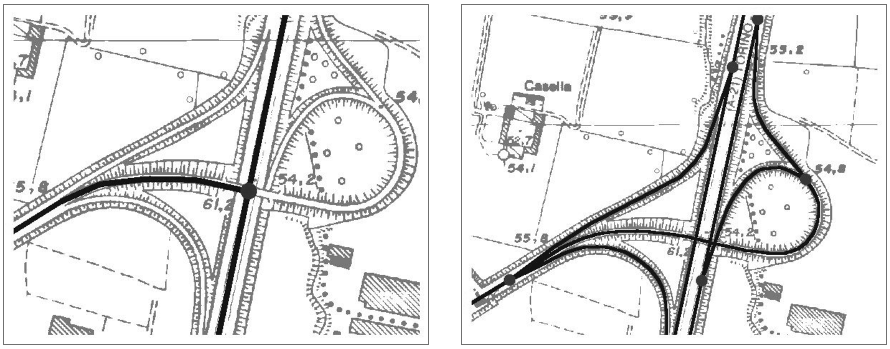
Hence, a multi-element crossing described at Level 1 by many Road Elements and Junctions may be represented at Level 2 by one single Intersection (ISO 14825:2001); moreover, both carriageways of a dual carriageway road (Level 1) are represented as a single road at Level 2, as shown by Figures below.



Figures 32 e 33. Urban roads at Level 2 (left) and Level 1 (right)



Figures 34 e 35. Extra-urban roads with road junction without roundabout at Level 2 (left) and Level 1 (right)



Figures 36 and 37. Motorway with junction at Level 2 (left) and Level 1 (right)

Finally, at **Level 0** (the most detailed), the road network is described by two geometric primitives (points and segments). Fig. 38 shows how the different entities are represented at Level 0 by the geographic features "node", "arc" and "surface" (i.e. geometric primitives, consisting of one or more points represented by a triple of coordinates). At this level curves are represented by an ordered sequence of intermediate points, while each pair of consecutive nodes identifies a segment (Act of June 1, 2001).

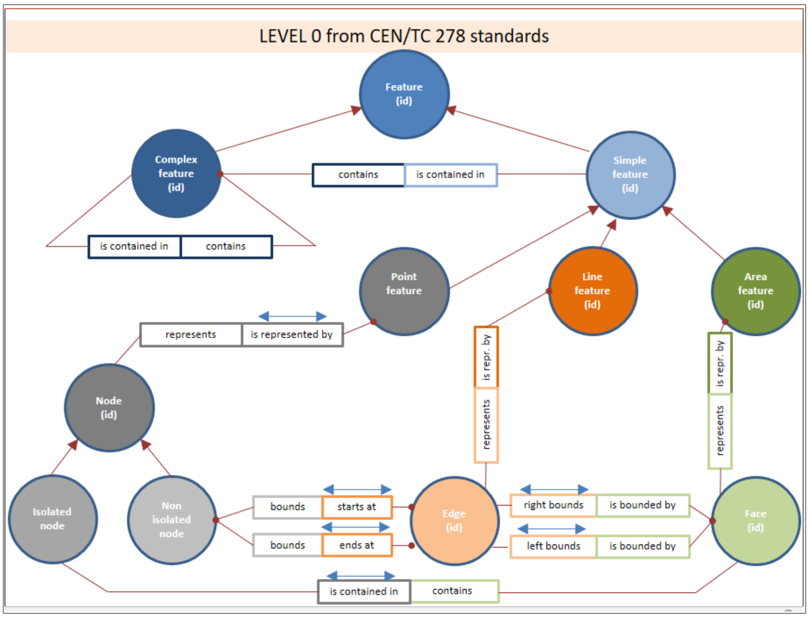


Figure 38. Database structure for the layer 0 from CEN/TC 278 standards. Entities are represented by nodes, arcs and surfaces.

This section focuses mainly on Level 1, as it is the basis for the Italian Road Cadastre structure by law. It describes the Road Cadastre on a large scale (Magni, 2005).

3.5.2 The Road Cadastre dataset

By law, the Road Cadastre database collects different information describing the road network in structural, functional and administrative terms (Provincia di Brescia, 2010). As illustrated in Chapter 1, the basic road dataset of the Road Cadastre must include:

1. elements relating to the geometric features of roads and related appurtenances,
2. plant and permanent services related to road traffic demands, including the location on the road of monitoring devices for detecting traffic flows.

As noted by Burchi et al. (2009), the legal Road Cadastre would provide data on:

1. the road network's status by a digital graph including all edges and intersections, georeferenced;
2. all the geometric characteristics of the road: the length, the width of the roadway, bending radii, shoulders, sidewalks, road gutters, embankments, type of road surface, and other;
3. the geo-referenced location of milestones, as well as the signage and road signs, accesses and other road components;
4. a smooth upgrade of road data, both directly (during road maintenance or updating campaigns) and indirectly (by requesting the update files to anyone making changes or additions).

In order to properly record data within the Road Cadastre database, the Act of June 1, 2001 also provides instructions on data survey and capture and establishes the elements to be surveyed: i.e. road axes, longitudinal profiles, transverse profiles, road width and existing milestones. According to the Act, such elements can be surveyed directly (by theodolites, wave or laser rangefinders, GPS, and photogrammetric methods) or from existing maps, whether suitable.[74] Coordinates used are the ellipsoid WGS84 coordinates (deriving from GPS) or Gauss Boaga (obtained by projecting the ROMA 40 geographic ellipsoidal coordinates on the International (Hayford) ellipsoid with Monte Mario orientation) or UTM (obtained by projecting the ED1950 geographic coordinates on the international ellipsoid (Hayford) with average European orientation). The lattest are both deriving from triangulation, trilateration, and stagger starting from ROMA 40 vertexes.

Data recorded should be collected into the Road Cadastre database, whose basic structure by law includes several tables in accordance with CEN/TC 278, Version 3.0 of 1995. Most of them are represented in Fig. 39:

[74]i.e. framed in the national network – IGM95 or ROMA40 network - through at least 3 fiducial points well materialised to use GPS or theodolite-rangefinder for further detailed relief operations (Act of June 1, 2001).

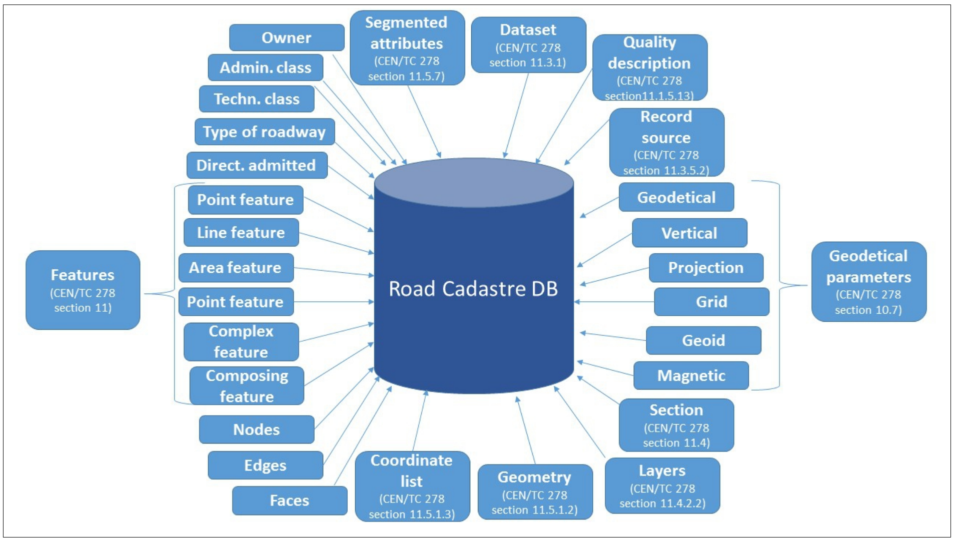
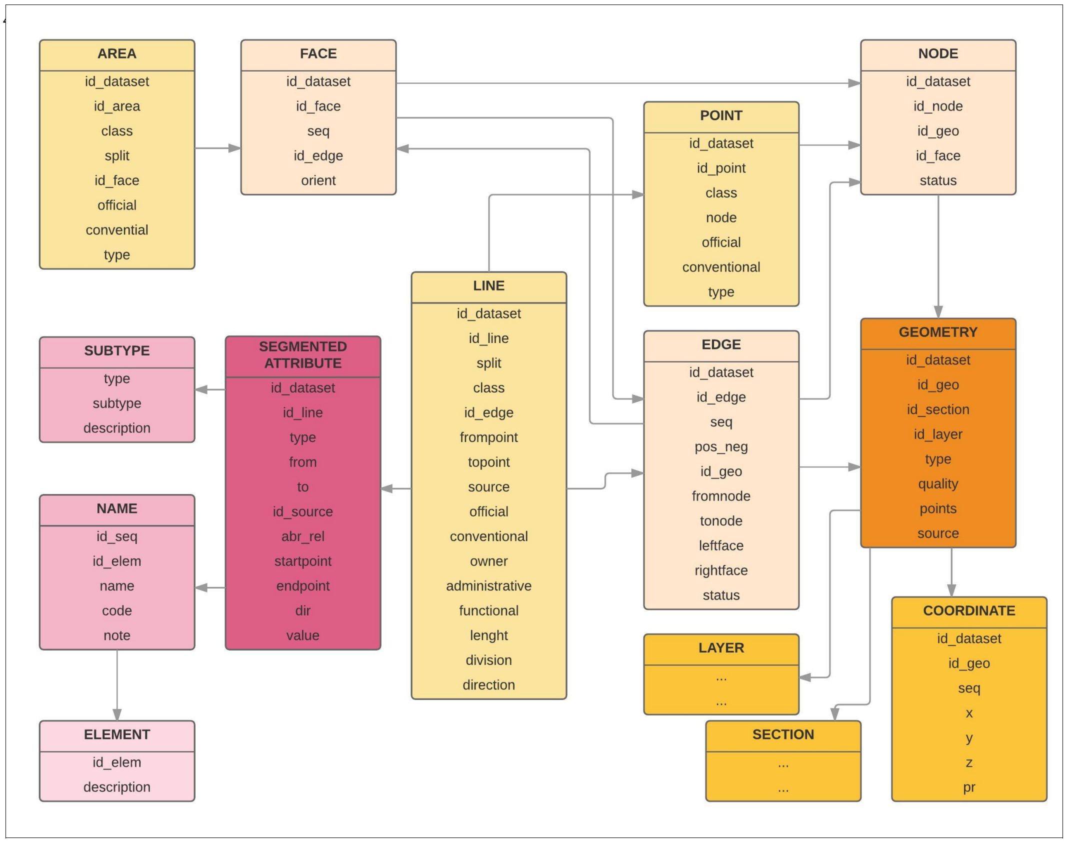


Figure 39. Road Cadastre's database tables in accordance with CEN/TC 278 standards.

The **dataset** includes the identification number code (id_dataset) assigned by the National Archive management to each DB owner, date of creation, geographic area represented, title and owner of the dataset; **quality description** refers to the accuracy and percentage of completeness of elements and attributes; **record source** includes data on completeness, map scale, author, edition, publisher, and others; data on **geodetical parameters** derive from national mapping agencies; **section** includes section borders and fiducial points. The following diagram shows a part of the Road Cadastre DB structure with some attributes and relationships:

Figure



At various levels entities have properties (i.e. **attributes**) that may be **global** (i.e. they are constant throughout the entity they refer to), or **segmented** (i.e. they vary throughout the entity they refer to). At Level 1 all the three entities are defined by global attributes (as shown by the diagram in Fig. 41), whereas only road elements have also segmented attributes in accordance with the GDF standard (e.g. the number of carriageways, the length of each element, the longitudinal and transverse gradient).

Fig. 41 illustrates Level 1 Road cadastral Entities with their global attributes, while Fig 42 shows global attributes' code lists related.[75]

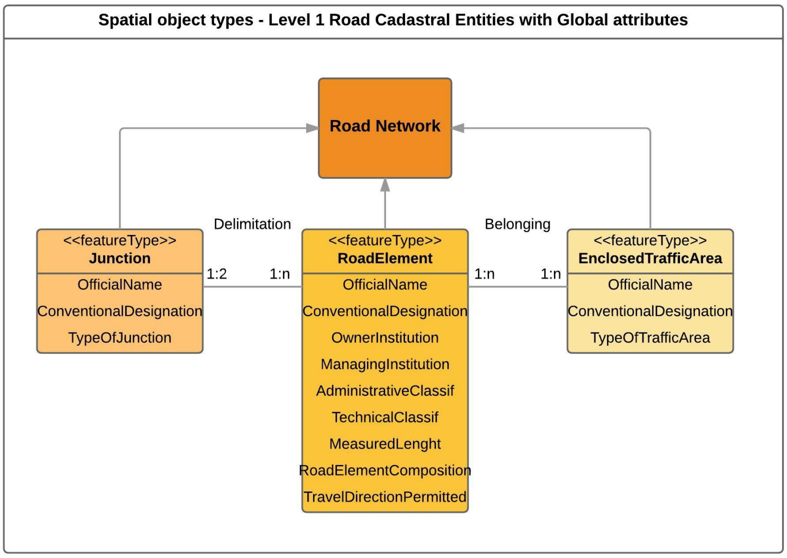


Figure 41. Level 1 Road Cadastral entities with Global attributes

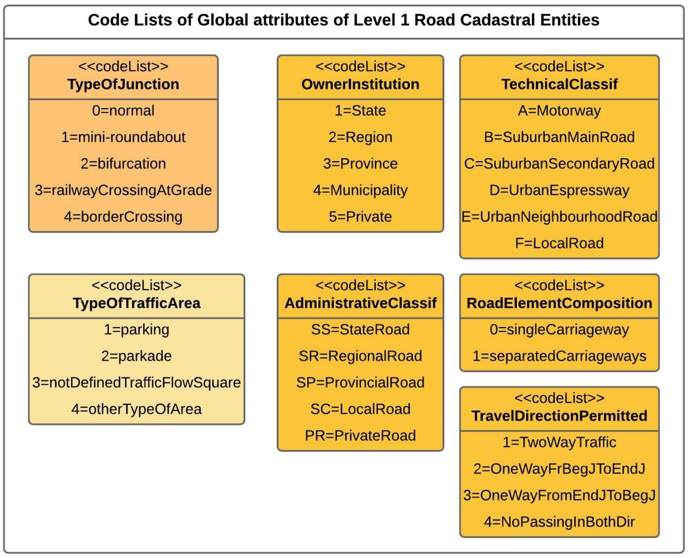


Figure 42. Code Lists of Level 1 Road Cadastral Entities' Global attributes

75 Code lists include different values for each entity's attribute: for example, the attribute "Type of Juction" is defined by numbers, each associated with a different type of junction (e.g. a mini-roundabout, i.e a roundabout designed primarily to reduce the speed of the vehicle and requiring a small deviation of the trajectory of the vehicles that are not operating activities; or a bifurcation, i.e. a subdivision of a road in two).

In addition, as mentioned, at Level 1 road elements are described by segmented attributes grouped according road sub-entities (i.e. road components, such as road surface, gutter, and others) (see Fig. 43), and recorded into a table that users cannot modify.

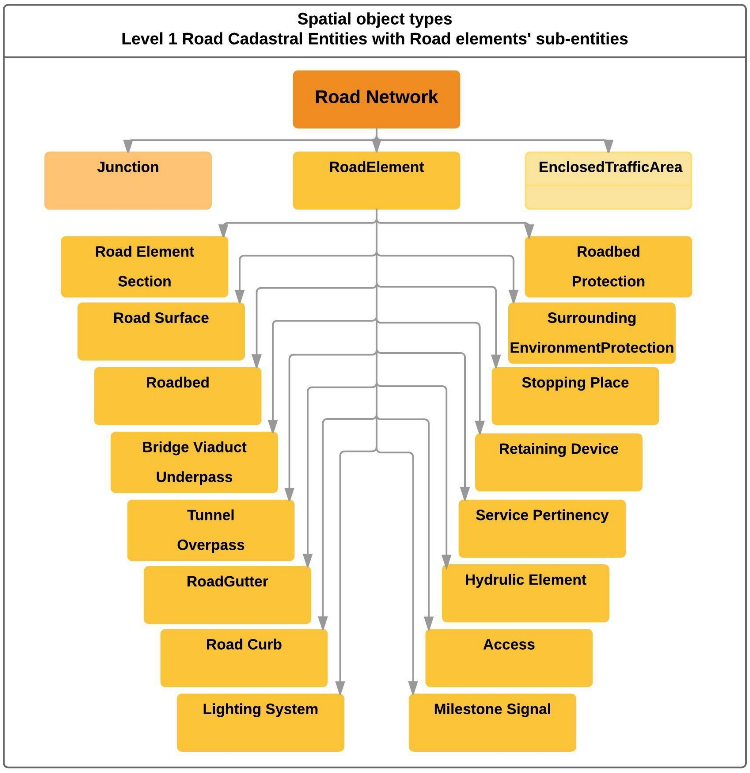


Figure 43. Entities and Road element's sub-entities from Level 1

Segmented attributes refer to a single road element and are described by some essential data, i.e.:

- Code of the type of attribute (the ID number of the attribute);
- Curvilinear abscissa (m) of the beginning of the presence of the attribute;[76]
- Curvilinear abscissa (m) of the end of the presence of the attribute;[77]
- Reference type of coordinates;[78]
- Location;[79]

and by further segmented attributes grouped according to road sub-entities, as represented in the following diagram:

[76]The curvilinear abscissa, introduced by The Act of June 1, 2001 for the positioning of the segmented attributes of road elements and measured along the centreline of the road according to the road planoaltimetric profile, is an example of a relative reference, since it is reinitialized in at the junction of each initial road element.

[77] In the case of punctual attributes the curvilinear abscissa of the end coincides with the initial one.

[78] Within the Road Cadastre only relative reference are used (the origin of coordinates coincides with the road start point).

[79]It specifies whether the attribute is present on the right side only (+), the left side only(-), or both sides (NULL) of an observer along the road element axis in ascending curvilinear abscissas. The encoding NULL referring to segmented attributes is used when specifying location is not necessary.

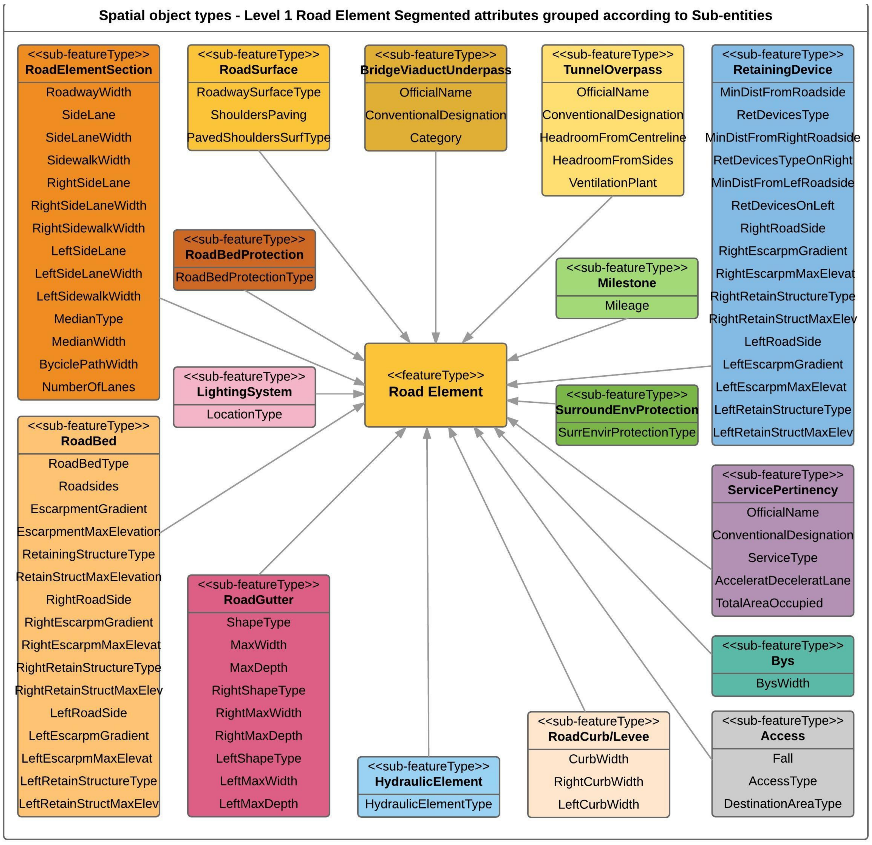


Figure 44. Level 1 Road element's Segmented attributes grouped according to Sub-entities

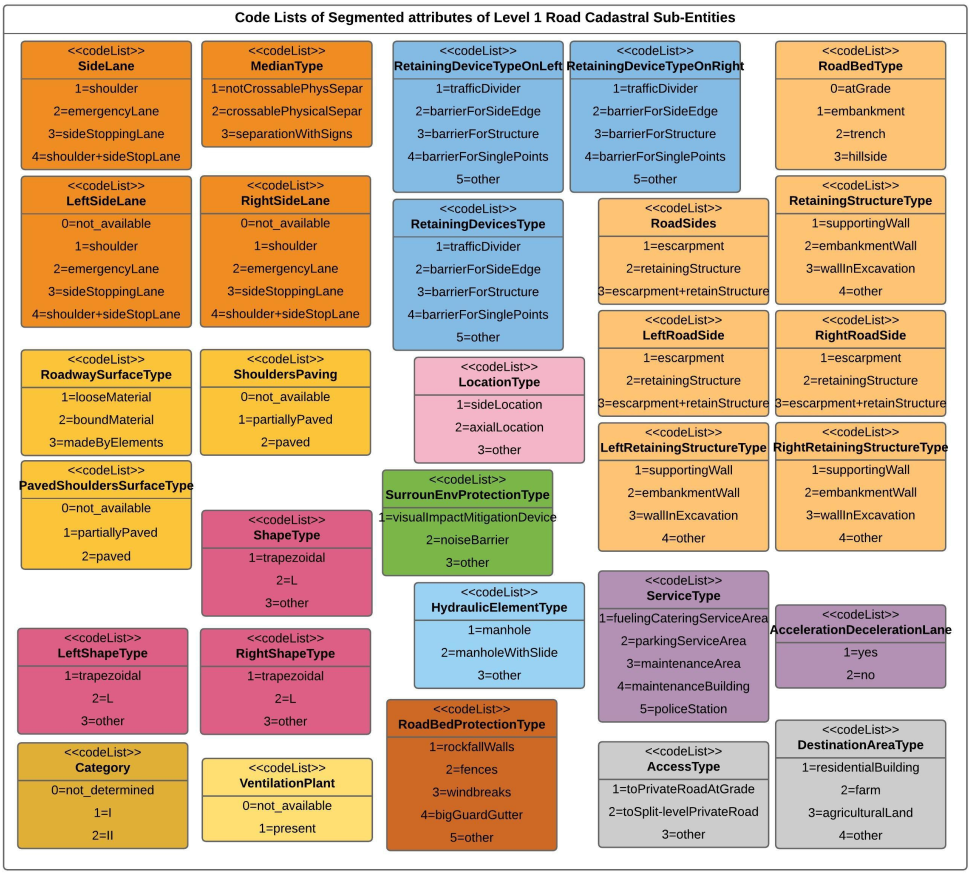


Figure 45. Code lists of Level 1 Road element's Segmented attributes grouped according to Sub-entities

3.5.3 Road Cadastre expandability by law

"Data contained in the Road Cadastre are the basic information that any other information should refer to and that will be contained in the Road Information Systems" (Act of June 1, 2001)[80] implemented and used by each road institution. Several authors have discussed Road Cadastre expandability as one of the most relevant functionality/requirement. Provincia di Brescia (2010) explains additional data to be add to road cadastral information by law as relating to: any "road event" (e.g. geometric characteristics, artifacts, signs and furniture), administrative management (i.e. concessions, public land occupations and advertising, ordinances, and special transports), management of road safety (including data on traffic flows and road accidents from the Osservatorio Incidentalità – i.e. the national road accidents observatory) as well as routine maintenance, with the analysis of correlation elements between road accidents and the status of the road network (ibidem). Also Di Mascio et al. (2004) highlighted such expansible nature of the Road Cadastre, remarking that all additional road-related data – such as maps, traffic data, accidents, status of conservation of structures like bridges, tunnels and viaducts, paving and complementary works, environmental monitoring, signage, distance markers, and financial aid received - must be provided by road owner institutions, and refer to the Road Cadastre basic dataset within Road Information Systems (SISs).

Data from all SISs should be then collected into the National Roads Archive set up at the Central Government's Ministry of Infrastructure and Transportation, which - as a decision support - would also include data on traffic, accidents, and geometrical and structural features of roads from other sources as indicated by the New Road Code (Art. 226, paragraphs 1 to 3) and the Implementing Regulation (Art. 401). According to the New Road Code (Article 226, Paragraph 1), in fact, each road, properly classified, must be registered in the **National Roads Archive**, fully computerised, and divided into five interconnected sections relating to:

1. **technical and legal characteristics of roads** (with the related data concerning the road itself, the functionality of its trunks, the technical geometric and structural infrastructure, the characteristics of vehicles circulating, any traffic restrictions - also temporary - and all occupations, appliances, buildings, crossings, in accordance with Articles 20 to 33 of the Code);
2. **vehicular traffic**;
3. **accidents**;
4. **road practicability** (i.e. the suitability of a road for use by specified types of vehicles);

[80] From Annexes to the Act of the Ministry of Public Works on June 1, 2001, "Procedures for setting up and updating of the Cadastre of roads in accordance with art. 13, paragraph 6 of the Legislative Decree n. 285 of 30 April, 1992, as emended".

5. **noise and air pollution**.

3.6 Current road cadastral applications in Italy

Currently in Italy just ANAS and six regions out of twenty have produced their own Road Cadastre (SITECO, 2008). They are based on the dataset established by law, but enlarged and customised in accordance with specific local needs. Further local Road Cadastres have been implemented in several provinces and few municipalities. Burchi et al. (2009) and SITECO (2008) - while discussing tools and techniques for road data surveying, collecting and managing - provided an assessment of several regional Road Cadastres in Italy. Finally, ANAS (1998) described its own Road Cadastre pilot project in Lazio (the central Italian Region with Rome as a capital), in order to highlight its points of strengthen and weakness, and select additional non cadastral data to implement a Road Cadastre meeting ANAS requirements.

3.6.1 SISs: some examples

Some examples of Road Cadastre at regional, provincial ad local level are described here, in order to highlight peculiarities of systems used in comparison with the legal Road Cadastre.

3.6.1.1 The Regional Cadastre of Piedmont

In the North of Italy, Piedmont is one of the Italian regions that implemented its own Road Cadastre by law: the "Road Integrated Informative System" (SICS - Sistema Informativo Integrato Catasto delle Strade), so-called as aimed at encouraging interoperability among Region, Provinces, and Municipalities of Piedmont, allowing them to operate on a single graphs of the Piedmontese roads network.

The system has been widely described by Cina et al. (2009) and Delponte et al. (2009), and includes:

- a proprietary graph of the detected roads (road elements and junctions), topologically connected, in shapefile and GDF format;
- roadside assets (i.e. section, planar and cross geometry, and elevation, bridges, tunnels, overpasses, gutter, embankments, road body protections, environmental protection, lighting, parking areas, restraint devices, appurtenances service, hydraulic structures, signs and markings, milestones, advertising systems, accesses and driveways, and trees), with its absolute location (coordinates X, Y, Z of start and end points of each event) and relative location (milestone and relative distance in metres), detailed data and images;

- road-way tracks (one point every 3 metres) with relative images of each point (front image, and 45° and 90° side views) in .jpg format;
- and round-trip videos in .avi format.

It is composed of: **a database centralised** on the UNIX-Oracle server at the CSI-Piemonte (i.e. Consortium for the Information System of Piedmont) where data is stored in an SDO Geometry format (a unique spatial data type by Oracle, allowing capturing locations and shapes of spatial objects), and published in SDE format (.sde files store database connection information); **a management system**, implemented via a client/server solution, and accessible via web by client workstations; and **a web-based consultation system** with a service-oriented architecture, which uses open-source solutions as open layers for map display.

The system allows browsing any kind of data: geographical, of contest and multimedial (e.g. movies and photos of the road areas), alphanumerical (e.g. tabs of pertinences), and also interactive maps allowing reporting functions based on geographical queries, statistics, production of roads geometry and printing (Delponte et al., 2009). Delponte et al. (2009) identify the strenght of the system in the proposal and validation process of the graphs modifications: it provides topological analysis by the system on the graph's consistency during the editing stage, and the interaction between the road management bodies and the central manager, through a mechanism of redlining.

In addition to the tasks laid down in the Act, the Regional Road Cadastre of Piedmont was mainly aimed at a common database shared among nine bodies: the Region and the eight Provinces (Burchi et al., 2009). The data integration among its database and other DBs (of the Traffic Observatory, the Road Accidents Observatory and the Regional Unique Street Map, i.e. Stradario Unico Regionale) would define the Regional Information System of Transportation (SIRT, i.e. the regional graph of roads) aimed at planning interventions on the road network (ibidem). Therefore, the Piedmont Region can access to all provincial data as well as locate and resolve points of conflict, and transmit data to the National Roads Archive at the Ministry of Infrastructure and Transport (Delponte et al., 2009). The system makes also Provinces able to view, update and modify the DB of their own road network and consult data of other Provinces. A further goal is joining the Piedmontese Road Cadastre System to the SIGr "Regional Geographical Information System": the only regional geographical database, complying with the INSPIRE European Directive (described in Chapter 2) (ibidem).

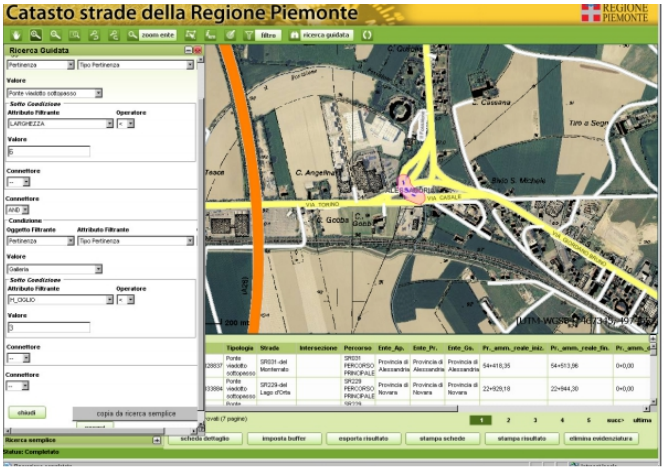


Figure 46. The consulting mode display from the Road Cadastre of Piedmont Region (Del Ponte et al., 2009).

3.6.1.2 The Provincial Cadastre of Bologna (Emilia Romagna)

The Information System of Roads of the Province of Bologna (in Emilia Romagna), implemented within the SIGMA TER project[81] mainly to improve safety standards of the provincial road network, is based on a database shared among local authorities according to a federated system approach. It aims at improving safety standards of its road network. The basic graph and data updates on provincial roads (and even state roads and motorways) have been developed by the Province, while municipalities update data on municipal roads (urban and suburban). The DB collects different information describing the road network in structural, functional and administrative terms. Software components were designed to improve local authorities' access to the editing of the DB functions consistently with their level of computer competence by management applications (i.e. standard for the Provincial institution, advanced for expert users editing the graph, and one for municipal roads), a consultation app for basic users (Web-based client) and a communication infrastructure providing the integration and coordination of all activities (Web Service). The system contains information on the road asset (geometric characteristics, artifacts, signs, and furniture), administrative data (concessions, public land occupations and advertising, ordinances, and special transports), data from the Observatory of Accidents, and traffic flows. For each road element of the Province of Bologna specific survey forms were drafted to collect data on road surfaces, road markings, traffic signs, safety barriers, artifacts and degradations, plano-altimetric and geometric characteristics of roads. Also, it allows evaluating for each road a descriptive degree of degradation from punctual physical parametres, that, related to the road function, helps in defining a priority of intervention coefficient.

[81]The project, promoted by the Region of Piedmont, aimed at building a technology infrastructure to allow the exchange of cadastral data between local authorities and the Land Agency, as well as its integration with other local databases for the provision of services to citizens professionals and businesses.

3.6.1.3 The Local Road Cadastre of La Spezia (Liguria)

The municipality of La Spezia (in the north-eastern Liguria region) implemented its Road Cadastre by reusing a software promoted by the Information System Integrated Territorial Service of the Province of La Spezia and entirely based on free software/ OpenSource technology. This solution "ad hoc" is based on the development OpenSource GISClient web application, released under GNU/GPL-based mapping server, UMN MapServer, and PostgreSQL/PostGIS-based GeoRDBMS.

3.5.2 The ANAS Road Cadastre

Alongside with road information systems implemented by public road owner administrations, ANAS has been developed the own Road Cadastre to meet the specifications defined by the New Road Code and its Implementing Rules (Law n. 495 of December 16, 1992), and customise the system according to specific road management needs. It was also developed taking into account both CEN/TC 278 standards (on roads, transport and telematics) and CEN/TC 287 (geographic information), studies by the EEC on uniform standards for European Road Inventories (in accordance with RADEF - Road Administration Data Exchange Format, mentioned in Chapter 2), and those by the Ministry of Public Works to define road design guidelines (ANAS, 1999). ANAS Guidelines (1999) describe the system as based on a GIS software (i.e. ArcInfo server-side, and Arcview client-side for departments and users in general) with a DBMS (Database Management System) by Oracle® embedding data from the survey forms and requirements of no redundancy, and a graph of the whole road network formed by road centrelines. The graph is produced by TeleAtlas® company, a Dutch company with operational headquarters in Belgium, operating throughout Europe, which distributes two different products: StreetNet (a detailed graph referring to urban areas and derived from existing maps, generally at 1: 2,000 map scale) and ®RoadNet®. The latter has been chosen as a base for the ANAS Road Cadastre. It refers to suburban areas and usually derives from regional technical maps at 1:10,000 mapscale, properly verified and updated).

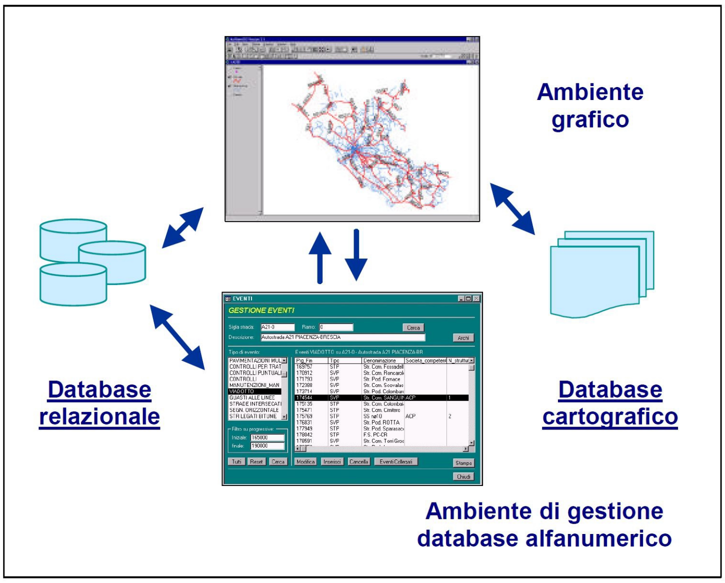


Figure 47. ANAS Road Cadastre structure (source: ANAS, 1999)

At the urban level RoadNet® only uses the road axes as a synthetic representation of the whole road network and its connection to the city centre, with an accuracy of 1:10,000 (like its source map) and a maximum ground fault declared of 15 m.[82] The TeleAtlas® graph is primarily aimed at "car navigation" applications[83] as well as management of fleets of vehicles, accessibility studies and the optimisation of routes.

In order to be compliant with European standards, the ANAS Road Cadastre has been based on UTM map projections (the European mapping standard for medium-scale maps mostly used for Regional Technical Maps, and by IGM, whose new editions abandoned Gauss Boaga).[84]

In accordance with the legal Road Cadastre and CEN/TC 287 standards, the ANAS Road Cadastre represents the road network by three different LoDs (ANAS, 1999): Level 2 - whose accuracy corresponds to a map scale of 1:100,000 or less (e.g. 1:250,000) - is used as a support of modelling (e.g. search of the shortest paths, and extrapolations of traffic flows, etc.); Level 1 - based on 1:10.000 scale maps accuracy - supports the Road Cadastre, as its structure tipically allows associating road geometry with road management data (e.g. accidents and road surface); and an hypothetic additional Level 0 (based on the 1:5,000 scale map accuracy) represents planimetrically the real world, with the road surface as a set of polygonal, and surrounding details (such as buildings, trees, and contour lines), supporting property management and urban planning.

[82] ANAS (1999) specifies that a greater precision would not allow retrieving existing material, and would have made it necessary to start from scratch in the project, with times and costs not bearable.

[83]In cars of the latest generation allow both identifying, by a satellite link, the vehicle's position on a digital paper displayed on the dashboard, and requesting to the software the optimal path for reaching a given destination.

[84] ANAS (1999) highlighted that the use of UTM also facilitate the re-projection operations, which with the UTM are made directly by system commands, whereas with the projection Gauss Boaga require specific routine and non-standard processing.

3.7 Summary

In Italy standards related to the road sector are numerous, concern a number of different topics (road classifications, roads and intersections geometry, road equipment and even road ownership and responsibilities): they are different depending on they refer to the existing asset or new roads of the asset to be built and classified. Moreover, such standards can be grouped by topic, but also by the date when they entered in force (different chronological stages correspond to different design and construction practices in use at that time and sometimes also so far, for specific cases).

Road classifications and design standards are of main interest of institutions managing roads and road designers: as shown in the Chapter, in fact, road technical classes are linked to administrative classes, design features by standards and regulations, and also road network categories (all established by different laws). Road maintenance standards are mainly aimed at providing instructions respectively for: 1) road managers (institutions) to prepare formal documents (analyses of degradation and interventions planning) to be added to roads projects, 2) and technicians to make road degradation surveys and evaluations, and identify the most proper maintenance intervention. Most of them have been drawn by the "Study Commission for standards relating to road construction materials and construction and maintenance roads" of the National Research Council (CNR): so far they are a reference for public administrations, designers, and operators. Local standards have made more complex and variegated the set of road-related regulations and specifications referring to each stage of the life cycle of road infrastructure.

The Chapter, while illustrating the legal framework by a review on Italian road standards, highlighted the multi-factorial nature of the topic and its main issues (later adressed in Chapter 5), as well as the multi-sectorial and interinstitutional nature of the Italian Road Cadastre. That provided important requirements for a better management of data - then illustrated in Chapter 7 - through the complete life-cycle infrastructure projects that might enrich the current Road Cadastre dataset by law.

The potential benefits of adopting road cadastral standards would include: the improved quality of asset records; the reduction in costs for the creation of asset data; paying less for services with reduced supplier's costs; lower software development costs; an open digital environment that enables innovation in development (e.g. 'apps'); sharing asset analytics across different organisations; enabling detailed benchmarking nationally – all across a range of infrastructure sectors, both public and private.

The examples reported of regional, provincial and local Road Cadastres in Italy show different characteristics and aims (e.g. maintenance or safety), and also ANAS has developed its own Road Cadastre independently (in accordance with the legal Road Cadastre and international standards, but customised according the specific needs of the road management company).

Moreover, with regard to structure and dataset, the Chapter shows that the legal Road Cadastre meets a number of international standards. Nevertheless, as also later described in Chapter 5, Caroti and Piemonte (2010) explained that the groups who set standards do not include those organisations who will eventually be tasked with the daily population of databases. Thus, their application in practice is often limited and in many cases (within the SISs) they are replaced by local standards. Moreover, according to ANAS (1999), the GDF standard unsatisfactorily covers issues related to the description of the road network, as it does not address problems relating to roads classification, geometries' description, the structure of the related databases aimed at road management (and hence considering accidents, road surface status, signage, etc.).

The present Chapter also illustrated what the Italian government requires the local authorities to record about roads, what is required to be maintained, and so forth. Hence, it confirms how complex the problem of road maintenance is. Also expandability, presented by law as a fundamental requirement of cadastral systems, is not standardised at each level.

3D aspects are not considered neither in the legal Road Cadastre nor in the local SISs: only ANAS is working on this by implementing some applications for road maintenance purposes. All that will be addressed in Chapter 5.

Chapter 4

Different applications of the Road Cadastre. Existing and proposed uses and users [22]

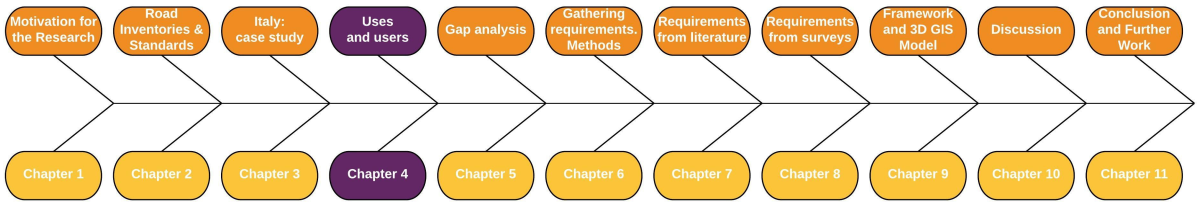


Figure 48. Overview of Document Structure showing context of this Chapter

According to the New Road Code (1992), the primary purpose of the Italian Road Cadastre is to define the consistency of the national road network in a compatible and integrated way - and within a medium-term perspective - with the Land and Buildings Registers. The Guidelines by ANAS (1999) - already valid - highlight its multiple aims in a practical perspective: from the point of view of who manages road networks on the whole national territory like ANAS, the Road Cadastre can be used to know the quantitative and qualitative consistency of road assets (statistical functions), to manage its maintenance (scheduled maintenance), to verify its functionality (traffic and accessibility patterns), to monitor road works (works information system), to manage road concessions, collections of fees and litigations on the extension of urban sleepers (management functions), to plan new road works and assess their environmental impact (spatial analysis functions), and much more, such as the management of exceptional transport, accident statistics, environmental monitoring and so forth.

Burchi et al. (2009) have also emphasised the importance of the Road Cadastre as a very useful tool for all road-owner administrations both at the large-scale (Regions and Provinces) and at the urban scale (Municipalities), as it is able to carry out more efficiently the road classification for the purposes of the Road Code and the Traffic Plan, and allow some assets that normally are difficult and expensive (e.g. the control of public space occupation, or the census and management of man-made road utilities and advertisements signs). It makes faster and more effective the management both of roads (including construction and maintenance) and of its utilities and equipment, such as signage, public lighting, advertising and others, and also helps administrations in managing road accesses, public space occupation, traffic ordinances and road traffic (ibidem). All above are activities typically carried on by administrations that can perform them with less waste of human and financial resources by a digital Road Cadastre (ANAS, 1999).

The expandability of the legal basic road cadastral structure with further data added within local Road Information Systems (addressed in Chapter 3) increases the current multiple uses of the Road Cadastre, and makes it able to meet the aims illustrated by the ERF (2014) with regard to the road asset management. In this way, Road Cadastres can provide information to many different stakeholders involved in managing accessibility and mobility (in order to efficiently handle traffic evolution and avoid congestion) (Litman, 2016; El-Geneidy and Levinson, 2006), safety (through the control of road surface, markings, road signs, and road restraint systems) (Luoma and Sivak, 2012; Harvey, 2010), and road noise (by data on road surface and noise reducing devices and systems) (Dintrans and Préndez, 2013; Naish, 2010). The management of environmental impacts can be also better addressed using data on CO2 emissions (Gately et al., 2015) as well as on delayed maintenance - as it causes an increased pollution when generating traffic congestion (Sundeep et al., 2016). Sustainable infrastructures (i.e. characterised by recycling, local raw material supplies, durability, or climate resilient materials) may also be planned by using expanded road cadastral data (Italian Ministry of Traffic and Infrastructure, 2016). Also new developments deriving from the advent of modern vehicles and Intelligent Transport Systems (ITS) are going to enlarge road datasets in order to include new data and to link basic Road Cadastres to other databases (ibidem).

ERF (2014) and ANAS (1999) also emphasised the road cadastral potential aim (related to road asset management) of supporting sustainable funding through a life-cycle approach and providing information in order to calculate road usage costs. ANAS (1999) in particular noted that Road Cadastre is helpful to provide detailed information on the road life cycle including:

1. the design stage (composed of the preliminary analysis of traffic and the feasibility study to design a new road, a conceptual project of the road in numerous variants - each based on different aspects preliminary determined - and the selection of the most suitable variant),
2. subsequent preparatory activities (e.g. obtaining the sites, selecting the suitable technology to be used, determining the activities and the schedule),
3. the construction stage (when activities are controlled, recorded and adjusted to the plan - or the plan is adjusted to them),

4. the maintenance stage (i.e. checking the road state, performing and recording maintenance activities).

Further stages can also be included into the road life-cycle, such as providing roads with equipment, updating infrastructures in accordance with more recent standards (or if levels of service, road owners or managers change) and disposing roads collapsed or dilapidated, as widely shown in Chapter 1 and Appendix 1.

ANAS (1999) has focused on the potential uses of Road Cadastre also in further analyses aimed at identifying seismic risk areas, areas subjected to different types of constraint (e.g. areas of archaeological interest) and also roads having specific functions (e.g. those connecting the regional capitals to the sea or linking provincial capitals each other): all that supports both land and urban planning and management of risks and emergencies. Meteorological characteristics (like snow, rainfall, and fog) are associated to the routes producing statistics data helping road administrations to improve road safety design and maintenance by proper forecasts.

Also the INSPIRE Data Specifications on Transport Networks (2014) has highlighted a number of use cases and applications at the European, national, and local levels – both in the public and in the private sector - that encourage the user extensibility of road systems data to many field: i.e. asset management, design&planning, incident management, construction, emergency response, disaster management, environmental impact assessment (including noise), estate management, capacity planning, flow modelling, traffic control and traffic management in car information systems, routing, journey planning, navigation, rerouting&diversions, maintenance and network operation.

This section presents a literature review of the multiple uses and users of road inventories that actually fits with the issues widely described in Chapter 1. Researchers and institutions, while illustrating different purposes of road inventories in order to meet requirements from standards, practices, users, and even research works focused on complementary but related topics. They relate both to different stages of the road life cycle and to specific aspects, and include:

1. Preliminary analysis and preliminary design (Section 4.1),

2. Road asset management and preservation (Section 4.2), including road maintenance (Section 4.3),

4. Road safety, including signage management (Section 4.3),

5. Environmental monitoring (Section 4.4),

6. and Intelligent Transport Systems (Section 4.5), which also relate to road traffic management, and hence to points 2 (e.g. structures monitoring), 4 (e.g. speed control),

and 5 (e.g. traffic-air pollution monitoring) listed above.

Further road cadastral aims (also dealing with road management), such as the management of advertising and properties, have been addressed in Section 4.6.

4.1 Cadastre for preliminary analysis and preliminary design

Every infrastructure project begins with existing conditions, and massive amounts of data. Gathering and preliminary understanding the constraints of nearby assets and landforms along with regulatory considerations can be decisive for the feasibility and the financial viability of a road project (Autodesk, 2012).

Art. 14 of the Presidential Act no. 207 of October 5, 2010 (i.e. the Implementing Regulation of the Act no. 163 of April 12, 2006) established the minimum contents of the feasibility study, which must include the analysis of the status quo; the functional, technical, operational, economic and financial nature of the work to be carried out; the analysis of alternatives; the verification of environmental, historical, archaeological, and landscape constraints, and the identification of appropriate measures to safeguard the environmental protection and cultural and landscape values (ITACA, 2013). Therefore, data related to road projects refers to the administrative, technical, economic and financial feasibility of the project, and certainly must deal with technical and design aspects, as well as legal-administrative and financial.

As neither the Public Procurement Code, nor the national standards provide an adequate framework of the feasibility study contents, in Italy many regional institutions have produced regional guidelines for feasibility studies of road infrastructures or public buildings (Regione Lombardia, 2014: Regione Liguria, 2001; Regione Piemonte, 2012) that can find into the Road Cadastre a fundamental support.

As highlighted by a feasibility study report (Lorenzo, 2008) of a road to be built in Empoli (i.e. a municipality of Tuscany, central region of Italy), the preliminary feasibility analyses of a road project requires a general overview and description both of the places that would be affected by the intervention (including possible constraints on the areas) and details of the intervention itself (with objectives, functions and issues of the new road infrastructure well illustrated). Different project ideas have to be described together with a rough estimate of the costs, exposing their feasibility. The compatibility of the road with urban planning policies and spatial planning has to be evaluated as well as the benefits brought to the existing and arising service buildings (ibidem). The enhancement of existing infrastructure and environmental protection are also assessed as well as the preservation of the territory's land use in order to avoid creating obstacles to the development of the property and its residential and agricultural vocation. The feasibility study aims at a smooth integration (both planimetric and altimetric) of the road projected in the area, paying particular attention to the materials' type and durability, as well as to the road management in terms of maintenance planning. By acting on both the geometric characteristics of the road and the marginal elements and furnishings, the study also aims at achieving high standards of road service and safety. Moreover, it verifies the protection of the water network in the areas crossed by the connection and minimisation of environmental effects, and aims at avoiding serious consequences on the built and natural environment (already described in Chapter 1 and Appendix 1).

All above shows the multifactorial nature of one of the activities that Road Cadastre can support, while the Guidelines to produce feasibility studies of Piedmont Region (2012) also highlights the different kind and wide range of data required: from the map to the cadastral data of lands and buildings of the area, to the expropriation costs and lansdcape verifications (also by the use of photographs of the site of construction).

4.2 Cadastre for Road Asset Management and preservation

According to the Organisation for Economic Cooperation and Development (OECD), the "Asset Management" applied to the road sector can be defined as "a systematic process of maintaining, upgrading and operating assets, combining engineering principles with sound business practice and economic rationale, and providing tools to facilitate a more organised and flexible approach to making the decisions necessary to achieve the public's expectations" (OECD, 2001). The same definition is given by the PIARC TC 6 Report, produced by the World Road Association (or PIARC),[85] an international body which defines, develops and promotes policies and practices for a safer and more efficient management of the use of road transport networks, in a context of integrated sustainable transport. In practice, an asset management system (AMS) will include all the processes, tools, data and policies necessary for the effective management of all the assets for which road administrations are responsible. It comprises physical road infrastructure such as road surfaces and bridges as well as human resources, equipment and materials, and other items of financial and economic value (OECD, 2001).

In USA, MAP 21, the Moving Ahead for Progress in the 21st Century Act - an Act signed into law in 2012 to authorise funds for Federal-aid highways, road safety programs, transit programs, and other purposes - also emphasised the asset management as a strategic and systematic process of operating, maintaining, and improving physical assets. Such process is described as focused on engineering and economic analysis, based upon quality information, and

[85] Such body was established in Paris in 1909, and formed by the road administrations of 118 governments and members (individuals, companies, authorities, organisations) from over 140 countries, in order to promote international cooperation in the field of roads and road transport.

aimed at identifying a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the lifecycle of the assets at minimum practicable cost (Meyer, 2016). A similar definition is given by the American Association of State Highway and Transportation Officials' Subcommittee on Asset Management in FHWA (2016), while ERF (2014) emphasised the Road Asset Management nature of a permanent process, aiming at cost effective maintenance, upgrading and operation of physical assets. Such purposes find a urgent motivation in the critical status of roads worldwide illustrated in Chapter 1 and Appendix 1: hence, they require proper systems to manage the operations required.

Given the importance of the topic, the OECD's Road Transport and Intermodal Linkage (RTR) Research Programme for the 1998-2000 period included a mandate for the establishment of an Asset Management Working Group,[86] in order to:

- develop a common definition and identify the appropriate AMS components,
- document the state of implementation of asset management practices and programmes in OECD Member countries, including the identification and measurement of benefits of applying AMS,
- review the data and analysis requirements, including accounting principles and capitalisation methods, used in successful AMS,
- consider the type of indicators used to measure the performance of a road network/transport system in the implementation of an AMS and suggest options (ranging from essential measures to those able to provide some benefit),
- develop strategies to facilitate the implementation of AMSs – i.e. new skills for personnel, new thinking for all levels of management, public involvement, newly oriented goals, and other.

Importantly, more recently, in March 2013, the European Union Road Federation (ERF) published a Manifesto on Road Asset Management (RAM), titled '*Keeping Europe Moving – A Manifesto for long-term, effective management of a safe and efficient European road network*'. It provided some policy recommendations and called on decisions makers at European, national and local level for actions, in order **to invest in the maintenance of roads for the preservation and improvement of the road asset.** Therefore, it stated to:

- **establish a complete inventory of the European road network,**
- conduct regular surveys,

[86] The Asset Management Working Group was chaired by Mr. Neville Potter (Australia) and also included representatives from Belgium, Canada, Czech Republic, Finland, France, Hungary, Italy, Japan, Mexico, the Netherlands, Poland, Sweden, Switzerland, the United Kingdom, the United States.

- provide sufficient funding for timely maintenance and improvements,
- develop a sustainable road's policy and invest in research and innovation,
- implement at all levels coherent and balanced policies for the preservation of the road asset.

As noted by OECD (2011), in many countries, road administrations are now required to implement standardised asset inventory, valuation and depreciation approaches and enhance the information provided as part of their annual financial statements. A review of current practices to manage road assets are in Mathew et al. (2012). In that strategies to harmonise road asset information around the globe by defining road data structures, description of data content, data exchange mechanism, and interoperability specifications are addressed.

The role of the Road Cadastre is fundamental in the development of Asset Management, which has in data collection, management, and integration one of its key aspects (FHWA, 2014; Pantelias, 2005). As noted by FHWA (2014), data needed for this purpose require detailed inventories, and comprise aggregated overall network performance indexes and overall network characteristics (i.e., overall interstate mileage, total number of bridges, and other). The utmost implementation efforts have created common databases to minimise data storage and enhance interoperability between different management systems (FHWA, 2014).

As highlighted by FHWA (2009), the way in which transportation agencies collect, store, and analyse data has evolved along with technologies: mobile computing, advanced sensors, distributed databases, and spatial technologies have enabled data collection and integration procedures to support the comprehensive analyses and evaluation processes required by Asset Management. However, in many cases, the data collection activities have not been designed specifically to support the Asset Management decision processes, and by the new technologies agencies collect very large amounts of data and create vast databases not always useful or necessary for supporting decision making processes. Moreover, although agencies emphasise the importance of collecting and integrating data, little effort has been placed on linking the data collection to the agencies' decision making processes (ibidem).

In order to meet the requirement of Road Asset Management (RAM), data recorded would be related to the RAM functions, which, according to ERF (2014) include: providing a clear picture of the current condition/performance of the road network, estimating the value of the asset, maintenance needs and costs, predicting future demand of traffic and service needs and prioritising objectives related to the desired quality and performance of the road network, setting up funding scenarios for the regular and timely maintenance and upgrade of the road asset, and defining and implement the RAM Plan.

In order to achieve such goals, it is evident that one of the key aspects of asset management is integration: AMSs provide an integrated approach to all administration costs, be they road user, works, administration, environment or social costs, and the use of existing administration data sources. AMSs integrate existing management systems for individual assets. This merger provides road administrations with consistent system-wide data, enabling the allocation of available funds across competing road surface, structure and other infrastructure needs (Transport Association of Canada, 1999).

In the light of above, asset management systems generally include inventory information for the asset and condition measures that allow both data collection and storage and data analysis and interpretation. Data come from a wide range of sources, both from within and outside a road administration and also supply information into various parts of an administration where it may be combined with data from other systems. Importantly, AMSs include all relevant components in life-cycle cost analyses. They ensure the integrity of data (relating to finance, planning, engineering, personnel and information management), enhance data accessibility and provide data compatibility, taking care of reporting useful information on a periodic basis, ideally in real time, in order to facilitate iterative analysis processes that can be performed on a regular basis (OECD, 2001). Within this framework, the Road Cadastre is an helpful base and data provider for carrying on performance monitoring, analysis of maintenance options and programme optimisation.

4.2.1 Cadastre for Road Maintenance

Given the great importance of roads in the development of countries (as described in Chapter 1), their efficiency and durability have been a urgent issue addressed by governments, department of transport, technicians and researchers. A FAO document (1998) on road design and construction focused on sensitive watershed defined road maintenance as essential in order to preserve the road in its originally constructed condition, protect adjacent resources and user safety, and provide efficient and convenient travel along the route. Burningham and Stankevich (2005) wrote a report for the World Bank in which they explained the importance of road maintenance - that since 1994 PIARC (1994) defined as “activities to keep pavement, shoulders, slopes, drainage facilities and all other structures and property within the road margins as near as possible to their as-constructed or renewed condition”. It includes minor repairs and improvements to eliminate the cause of defects and to avoid excessive repetition of maintenance efforts, and not includes rehabilitation, building shoulders, or widening roads (Burningham and Stankevich, 2005). The World Road Association - PIARC (2014) produced an executive summary on the importance of road maintenance. Road surface deterioration and causes have been addressed by Harral and Faiz (1998), and Adling and Gupta (2009), while van Rijn (2006) and Hiep (2009) focused on maintenance strategies and planning. Authors like Salih et al. (2016) and Burningham and Stankevich (2005) distinguished in routine, periodic, and urgent road maintenance, put the accent on calculating costs for providing funding, and highlighted the need for revising standards for improving roads.

Routine maintenance comprises small-scale and works generally conducted once or more a week or month (Burningham and Stankevich, 2005) "to ensure the daily passability and safety of existing roads in the short-run and to prevent premature deterioration of the roads" (PIARC, 1994). Periodic maintenance covers large scale activities on a section of road at regular and relatively long intervals "to preserve the structural integrity of the road" (WB Maintenance website): they require specific identification and planning for implementation, specialised equipment and skilled personnel and are more expensive than routine maintenance works. Finally, urgent maintenance deals with repairs that cannot be foreseen but require immediate attention. Importantly, if the sections to be rebuilt constitute more than 25 percent of the road's length, the work is not maintenance, but rehabilitation. Maintenance activities, grouped for frequency required, are summarised in the table below:

Routine maintenance	**Periodic maintenance**	**Urgent maintenance**
Roadside verge clearing Grass cutting Cleaning of silted ditches and culverts Patching Pothole repair Regrading every six months (gravel roads)	Preventive, resurfacing, overlay, and pavement reconstruction Resealing and overlay works Repaving every eight years (paved roads) Re-graveling every three years (gravel roads)	Repairs of collapsed culverts Interventions on landslides blocking a road

Table 10. Kinds of maintenance activities relating to different frequency.

As highlihted by the World Bank, road maintenance involves all agencies and institutions associated with roads at national, regional, district, and local community levels as well as road users and other stakeholders in identifying road issues and planning road interventions. Other stakeholders include organisations dealing with tourism, health care, rural development, agriculture, and mining; road user associations; community or nongovernmental organisations; and businesses. However, Salih et al. (2016) noted that, even though the need for maintenance is broadly shared globally, it is still not being adequately addressed, with more costs as a consequence for both road administrations and road users (in terms of fuel and vehicle maintenance, travel time, and accident costs). Environmental impact is also related to the lack of road maintenance, as mentioned in Chapter 1 and then also illustrated. For this purposes, Road Maintenance Management Systems have been created. Mubaraki (2010) illustrated its five main components (i.e. Pavement Management System (PMS), Bridge Management System,[87] Non-pavement Management System, Database Management System, and Maintenance Follow-Up Management System) that show also in this case the multifactorial nature of the topic that might find a support in the Road Cadastre.

4.2.1.1 Evaluation of road degradation

As illustrated in Chapter 1 and Appendix 1, the unceasing road degradation requires to be costantly monitored in order to avoid collapses and cracks with enormous costs and discomfort for citizens: with this aim, in the age of ITC and smart cities, sensors and other advanced technologies are currently studied, and the management of the large amount of data with different formats provided by them is a new challenge. With this regard, automated detection of road defects for enhanced road surface condition assessment have been studied by Radopoulou and Brilakis (2015b), who experimented an algorithm for automatically detecting patches, potholes and three types of cracks in video frames captured by a common parking camera. Their study contains a literature review on research methods proposed for evaluating road degradation, such as crack detection (Gavilán et al., 2011; Ghanta et al., 2012; Jing and Aiqin, 2010), real-time crack analysis (Huang and Xu, 2006; Maode et al., 2007; Sy et al., 2008), crack classification (Moghadas Nejad and Zakeri, 2011; Salari and Bao, 2011; Ying and Salari, 2010) and crack sealing (Haas, 1996; Kim et al., 2009). Detecting potholes (Koch and Brilakis, 2011; Lin and Liu, 2010), tracking them in videos (Koch et al., 2012b) and measuring their properties (Koch et al., 2012a) are also mentioned as well as methods for road patches (Radopoulou and Brilakis, 2015a; Battiato et al., 2007; Cafiso et al., 2006; Yao et al., 2008) and for detecting a range of defects at the same time (Zhou et al., 2006). Such review highlights that in the literature there are no methods able to detect both the type and location of road defects with a single approach. Moreover, many road defects share similarities and it is very common to mistake one for another. Hence, a Road Cadastre provided with multiple data (e.g. geometry, descriptions, images, surveys) integrated might be helpful.

[87] Regione Lombardia (2005) mentions various examples of BMS worldwide (such as in Japan, Finland, New York, Ontario, and others) like BRIDGIT and PONTIS software.

4.2.1.2 Maintenance scheduling

As reported by Salih et al. (2016), the World Bank estimated that $45 billion worth of road infrastructure had been lost due to the absence of adequate maintenance in those 85 developing countries and such a loss could easily have been avoided by spending $12 billion on preventive maintenance. In a document titled as "*Summary regarding the status of road maintenance in the international arena, in Italy and in Lombardy Region*" (2005) the regional administration notes that, nationally, maintenance is still primarily an "emergency run", according to the so-called "worst-first" approach. As also noted by Salih et al. (2016) and Mubaraki (2010), worldwide, it is considered to be a political advantage to be in favour of investing money in constructing new roads with the consequence of the lack of funding for ordinary and extraordinary maintenance. Funds are devoted to maintenance without following any priority criteria and often any degradation of road body is resolved in a complete revision of the surface layer (Regione Lombardia, 2005). On the contrary, ERF (2014) highlights that the preventive approach offers advantages regarding cost-efficiency, road safety or noise reduction. It is beneficial to public spending, because the costs of preserving a good quality network are optimised in the long run. The following diagram demonstrates that, by committing regular funding and taking regular action, the total cost is significantly less than waiting for major decline in standards.

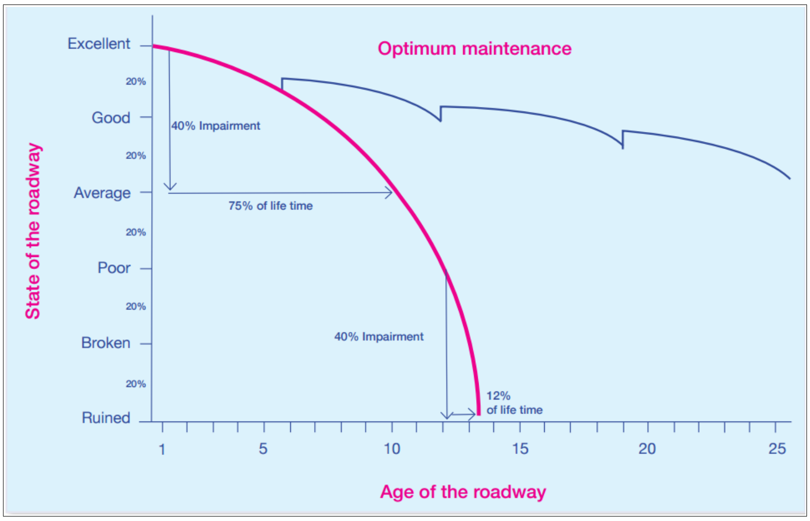


Fig. 49. Diagram of the state of a roadway depending on its age and life-time depending on maintenance (source: ERF, 2014)

The importance of the Road Cadastre as a tool predictive of the maintenance requirements is essential in a programming activity, also in terms of design, and allows moving from a logic of maintenance to rear to a logic of scheduled maintenance (source: http://sit.spezianet.it/catasto-strade and http://www.cittametropolitana.bo.it/viabilita/Engine/RAServePG.php/P/259011080410/T/Il-

Catasto). In this perspective the Road Cadastre is a preliminary tool for analysis and preliminary design and a tool for maintenance scheduling (ibidem). That requires the availability of the data necessary for the proper management of maintenance and the creation of the Road Cadastre for road maintenance. It should incorporate all archive and network status data (periodically monitored) (Regione Lombardia, 2005) ascompleteness and relevance of databases - as provided by the Act of June 1, 2001 - is a basic requirement to guide all decisions, both at the policy level and to identify an appropriate design solution (ibidem).

Moreover, with regard to the only road surface, Walker (2002) noted that "experience has shown that there are three especially useful steps in managing urban roads: 1. Inventory all urban roads, 2. Periodically evaluate the condition of all road surfaces, 3. Use the condition evaluations to set priorities for projects and select appropriate treatments". A comprehensive PMS involves collecting data and assessing some road characteristics: roughness (ride), surface distress (condition), surface skid resistance, and structure (pavement strength and deflection). Road managers can combine this condition data with economic analysis to develop short-range and long-range plans corresponding to different budget levels. However, many urban agencies lack the resources for such a full-scale system, and since surface condition is the most vital element in any PMS, urban agencies use the simplified Pavement Surface Condition Index (PSCI) rating system to evaluate their roads. Walker (2002) again notes that ratings combined with other inventory data (such as width, length, shoulder, pavement type, construction history, and others) can be very helpful in planning future budgets and priorities.

In order to manage road maintenance (and road safety related to it), the Road Cadastre is an indispensable tool to evaluate, for each road, a descriptive index of the degree of degradation, obtainable from most punctual physical parametres related to the importance and function of the road, and to locate resources on the network as needed, by defining a coefficient of intervention priority (Provincia di Bologna, ...).

4.3 Cadastre for Safety

http://ec.europa.eu/transport/wcm/road_safety/erso/data/Content/national_databases.htm

Over decades, attention to road safety has been emphasised by several congresses and committees concerned with safety that produced both acts (e.g. the Highway Safety Act of 1966 (USA) and standards (e.g. the AASHTO publications adopted by the Federal Highway Administration (FWHA), such as *Highway Design and Operational Practices Related to Highway Safety* (1974), *Enhancing Highway Safety in an Age of Limited Resources* (1982), *Highway Safety Design and Operations Guide* (1997) and *Roads Safety Information Analyses – A Manual for Local Rural Road Owners* (2011) that also highlights data collection and analysis steps up to the latest ones.

Recently, documents as the *Guidance on State Safety Data Systems* by FHWA (2016) have indicated rules for safety data collection, integration, and analysis addressed to the USA Departments of Transport (DOT) of each State in USA in order to submit a Highway Safety Improvement Program (HSIP). Such initiatives moves from MAP-21 that requires DOT to: 1) establish a subset of roadway data elements - and a subset of model roadway elements (a.k.a. Model Inventory of Roadway Elements (MIRE) fundamental data elements (FDE)) - for all public roadways (including local roads, that are useful to the inventory of roadway safety), 2) and ensure that States adopt and use such subset to support program planning and performance management. The subset proposed includes elements: 1) classifying and describing roadway segments (e.g. beginning and end point descriptors), 2) identifying roadway physical characteristics (e.g. median type and ramp length), 3) and describing traffic volume. FHWA compiles the information collected in each HSIP report and produces an HSIP National Summary Report that needs data. (source: http://safety.fhwa.dot.gov/hsip/reports/). This proposal aims at improving States' ability to estimate the expected number of crashes at roadway locations, enhance safety analyses for predicting crashes and improving safety investment decision making through the HSIP, and hence estimate the allocation of safety resources: further potential Road Cadastre's uses.

In the literature crashes are described as a result of a single cause, but influenced by: 1. the human element, 2. the vehicle element, 3. and the road element. Roads should be designed to minimise driver decisions and to reduce unexpected situations through uniformity in road design features and traffic control devices. Therefore, when designing a road, it is important considering both road characteristics and design and psychological factors related to drivers' perceptions or judgments.

The most relevant design factor contributing to safety, in fact, is the provision of full access control, reducing number, frequency, and variety of events to which drivers must respond. Also speed is often a contributing factor in crashes, though related to road conditions. The safest speed for any road depends on design features (particularly those ones reducing the variance in speed of vehicles, e.g. grades, speed-change lanes, grade separations, and good signing and marking), road conditions, traffic volumes, weather conditions, roadside development, spacing on intersecting roads, and cross-traffic volumes. Number of lanes of divided roads, median width, shoulder width, alignment, grade found, design of horizontal curves, combination of sharp curves and steep grades, rumble strips added to shoulders, clear recovery areas (helping when forgiving roadside), guardrails and barrier systems, as well as traffic control devices (i.e. signs, marking, and signals) for information, warning and guidance are considered in road safety design as well as intersections (with total traffic volume, amount of cross traffic, turning movements, type of highway, type of traffic control needed, design of the crossroad sight distance, and the utilisation of islands and channelisation). In roadside design, two major elements should be controlled by the designer: roadside slopes and unyielding obstacles. On existing roads, AASHTO recommends the following priorities for treatment of roadside obstacles: to remove the obstacle or redesign it so can be safely traversed; to relocate the obstacle to a point where it is less likely to be struck; to reduce severity of impacts with the obstacle by using an appropriate breakaway device; to redirect a vehicle by shielding the obstacle with a longitudinal traffic barrier and/or crash cushion; to delineate the obstacle if the above alternatives are not appropriate. Advertising or other roadside signs should not be placed where they would interfere with or confuse the meaning of standard traffic control devices. Advertising signs with bright colours or flashing lights are especially objectionable in this respect.

In Europe (Leonardi, 2009) all Member States - Italy included – had to enact by December 19, 2001 legislative and administrative rules in accordance with the 2008/96/CE Directive on the road safety management. The subsequent Act n.35 of March 15, 2011 ("Implementation of the 2008/96/CE Directive") specified the factors to be taken into account in the impact assessment on road safety for infrastructure projects (as cited in the Annex I of the *Directive on the evaluation of the road projects' impact on road safety* attached to the Act). They include the plano-altimetric characteristics of the road infrastructure and identification of: the volumes and types of traffic, the number of accidents, deaths and injuries relating to specific trunks (accident analysis), and of the types of road users (including pedestrians, cyclists and motorcyclists). Additionally, Annex II contains requirements regarding road safety checks for infrastructure project:

- at the draft design stage (i.e. analysis of the geographical situation; analysis and verification of functionality 'infrastructure within the network; analysis of the plano-elevation of the new infrastructure conditions (speed project, axle geometry, number and type of lanes, types of intersections and/or exits, free visual verification); and type of traffic permitted in the new infrastructure);
- at the final design stage (i.e. analysis and verification of the track; harmonisation of signs and markings (signaling coordination); lighting infrastructure (axis and intersections); assessment of the context of the infrastructure margins (vegetation, fixed obstacles at the road side); analysis of service appliances (service areas, parking and parking); analysis of road restraint systems (road safety barriers) particularly focused on identifying the factors which may reduce the harmfulness' of vulnerable users;

- at the detailed design stage (i.e. analysis of the safety of users in special circumstances (lack of visibility, poor lighting, weather conditions are not optimal); intelligibility of the signs and markings; analysis of the road surface conditions);
- in the first phase of operation (i.e. assessment of road safety in the light of actual behavior of users).

The Act (art. 2) establishes that in Italy the responsibility on road safety is of the Ministry of the Infrastructure and Transports that will rely of the ANAS S.p.A. for supervision and safety inspections (i.e. an ordinary periodical verification of the characteristics related to the safety of the parts of the road network open to traffic and defects that require maintenance work for reasons of safety). However, since 1999 in Italy the law 144/1999 established the National Plan of Road Safety with the aim of reducing the number and effects of road accidents using, for example, both road infrastructure monitoring and Road Safety Information Systems, a sort of digital map registers requiring firstly the creation of a Road Cadastre to be produced (Vella, 2008).

Currently, the Road Cadastre alphanumeric data relating the road asset are correlated with accident data and the results then analysed on the basis of scientific research, legal standards and the common experience for many purposes (from studies to road planning and improvements) (Provincia di Bologna, …). The integration of data is also emphasised by the Italian Ministry of Infrastructure (2016): it noted that road safety, aiming at the ambitious European goal of zero mortality, requires an integrated and synergic approach that combines infrastructure security by-design and active safety of driving systems of vehicles and vehicle-to-infrastructure communication systems.

4.3.1. Cadastre for Signage management

In 2001 the Directive of the Italian Ministry of Public Works on the "Proper and uniform application of road standards in matter of signs and installation and maintenance criteria" highlighted the relationship between the road maintenance and management and road accidents. In particular, road signs location and maintenance is fundamental as an inadequate signage is a cause of the road network inefficiency and increases the uncertainty in the guide that is one of the main causes of accident rates (Operaegis: http://www.operaegis.it/index.php?option=com_content&view=article&id=1663&Itemid=585). ISTAT (Italian National Institute of Statistics) analysis data on road accident rate, distraction or indecision are among the most common causes of accidents and many road accidents derive from the lack of road signs, their inadequacy with respect to road and traffic conditions, their late or insufficient visibility, irregular placement, wear of materials or lack of maintenance, or installation in conditions that are different from the legal requirements (art. 38, paragraph 7 of the Road Code) (source: http://www.mit.gov.it/mit/mop_all.php?p_id=06130). Nevertheless, almost all of the road managers do not know the quantity and quality of signage systems within their competence and not take proper means allowing the proper management of such a huge amount of technical and administrative data (Operaegis: http://www.operaegis.it/index.php?option=com_content&view=article&id=1663&Itemid=585). All above requires an information system collecting the quantitative and qualitative data and handling the medium and long term planning of maintenance. In order to make the maintenance management of the signaling assets efficient and effective, tools encouraging information sharing among all the "actors" involved, whether they be technical, administrative or political are required.

4.4 Cadastre for Environmental monitoring

Devkota (2015) observed that, despite of social and economic benefits of road networks, they are also perceived as negative ecological effects on culture: transportation infrastructures affect the ecosystems' structure and function, with direct effects on their components, and species. In their study on the assessment of road transport environmental impact, also Macias and Gadziński (2013) have highlighted roads as one of the main types of human activity affecting the environment in a significant way. Over last two decades, many studies have been conducted with this regard, and authors such as Forman and Alexander (1998), Trombulak and Frissell (2000), Seiler (2001), Spellerberg (2002), Carr et al. (2002), Forman et al. (2002), and van der Ree et al. (2011) have explored the influence of roads on ecosystems and landscapes. An extensive overview of works devoted to the transport traffic impacts on the environment can be found in Macias and Gadziński (2013), Daigle (2010), Spellerberg and Morrison (1998), and Spellerberg (1998) with descriptions of the effects of roads on habitats (fragmented as a consequence) (Heilman et al. 2002; Donaldson and Bennett, 2004; Jaeger, 2007; Jaeger et al., 2007; Jaeger et al., 2008; Bata and Mezősi, 2013), wildlife and plants (Underhill and Angold, 2000; Sherwood et al., 2003; Tang et al., 2014), biodiversity (Byron, 1999; Ledec and Posas, 2003; Geneletti, 2003; Votsi et al. 2012), air (André and Hammarström, 2000; Bignal et al., 2004; Krzyzanowski et al., 2005), water (Mangani et al., 2005; Klimaszewska et al., 2007; Polkowska et al., 2007), and soil (Grigalavičiene et al., 2005; Aslam et al., 2013). Therefore, transport infrastructure planning must take into account that roads influence the environmental quality, decreasing it (Garcia-Montero et al., 2010); nevertheless, according to Macias and Gadziński (2013), though a wide literature on the environmental road impacts, the assessment methods are not deeply developed in practice in landscape planning, and a better and comprehensive understanding of the environmental impact of roads, forecasting its effects and counteracting them are required (Hoang et al., 2005). Within this framework, the use of GIS for modelling the impact of roads gives new opportunities.

As addressed in Chapter 2, the relationship between roads (and road data) and the environment has been highlighted by the INSPIRE European Directive. It includes the "road transport" class among the feature classes (and related dataset) of a spatial infrastructure proposed for improving the environmental impact policies in Europe. Because road location and design decisions have an effect on the development of adjacent areas, it is important environmental variables to be given full consideration. (MANUALE).

Also Tsunokawa and Hoban (1997) have emphasised the relation between road construction and environment: when planning new roads or changes in width or alignment, sensitive natural environments should be identified early in the planning process so that alternate routes and designs may be considered (ibidem). Data on areas of ecological interest should be collected and crossed with road data so that, wherever possible, road developments should be located more than one kilometer away from them to avoid impacts on flora and fauna. During the road design stage the availability of environmental data overlaid to - or crossed with - road data would help to minimise water crossings, leave buffer zones of undisturbed vegetation between roads and watercourses, avoid groundwater recharge areas, and not to build major roads through national parks or other protected areas. In this perspective, a Road Cadastre GIS-based may also be very useful in visualising the spatial relationships between ecosystems, the distributions of their component species, and a proposed road alignment (ibidem). Applications in monitoring the effects of road development have been used for a long time: in Ethiopia, aerial photographs and satellite images were used to monitor and analyse changes in the environment of a road between 1980 and 1993.

With regard to the DB structure of the legal Road Cadastre, currently, records describing relationships between a road and the terrain only relate to the "Road Body" table, where records on the road section (on embankment, in the trenches, on halfway) and the presence of escarpments, or supporting walls separating the road from the terrain are included.

4.5 Cadastre for ITS and road traffic management

As precised by the Directive 2010/40/EU, ITS "integrate telecommunications, electronics and information technologies with transport engineering in order to plan, design, operate, maintain and manage transport systems". Through the application of ICT to the road transport sector they aim at improving environmental performance, efficiency (energy efficiency included), safety and security of road transport (including the transport of dangerous goods, public security and passenger and freight mobility). ITS deal with Traffic management, Public transport, Traveller information, Electronic payment, Road Weather Information, Commercial vehicles, Emergency management, Vehicle control and safety, and Information Warehousing. The only Traffic management area includes: Traffic Control, Incident Management, Travel Demand Management, Operations & Maintenance, Environmental Conditions Monitoring, Automated Dynamic Warning & Enforcement, Non-Vehicular Road User Safety.

In order to handle the Traffic Management area, the report "*Intelligent Transport Systems and traffic management in urban areas*" by Civitas (2015) suggests to make a structured inventory of the current network (or supply side of the system) that could be organised by using a GIS tool or traffic model suite, and/or by using local knowledge combined with data that are available or can be collected.

In this framework, road data and dataset will be updated: as noted by the Italian Ministry of Infrastructure (2016), current road design standards (adequate to the XXth century motorisation and to the technological characteristics and operation of vehicles in production since World War II) will keep abreast of new vehicles and new technological equipment of both vehicles and infrastructure, as well as the immense wealth of historical roads (some of which, as not suited to current road design standards and used in derogation to them, could become technologically adapted to new vehicles).

In Italy the New Road Code requires the creation of a road traffic monitoring system, aimed at establishing archives and national registry to facilitate increasing safety levels of the entire national network, but also to allow: traffic control, passenger information, the management of tolls, the stop control (controllo della sosta), the fight against infringements, the driver assistance, the level crossing surveillance, tunnel safety and protection of structures, the maintenance of the roadway, and support studies and research.

4.5.1 Road traffic management

ANAS (1998) also includes road traffic management (that today can also benefit of ITS) among the aims of the Road Cadastre: it may help to generate traffic models by road graphs, organise road traffic surveys, and implement data base of road accidents. The use of technology and real time analysis are able to lead to a smooth traffic management: e.g. by digital road map of the city enabled by connecting Traffic Management System (Traffic signals and Traffic Command centres) with a GIS. Singh (2014) emphasised the importance of using smart analytics of data from sensors and traffic signals to provide drivers with real time information on a busy road, reduce traffic pile and manage traffic flow much better. Singh (2014) also noted that smart analytics can reduce traffic congestion on a busy road and advising drivers by using real time data from sensors and traffic signals. Information from these systems are displayed in real time on digital screens, or can be sent by SMS to car drivers while driving towards a place or guiding them to less congested roads or available parking slots, saving lot on time and fuel (ibidem).

Obaidat and Nicopolitidis (2016) have conducted an overview on ITS users in the field of transport: they highlighted that drivers can benefit of advanced traveller information systems providing them with real-time information: e.g. transit and routes ad schedules, navigation directions, and information on delays due to congestion, accidents, weather conditions, or road repair works. With regard to public transportation automatic vehicle location allows trains and buses to report passengers their position (hence, real-time arrival and departure information). Public transport vehicles also take advantages from advanced management transportation systems focusing on traffic control devices: e.g. traffic signals, ramp metering, variable message signs providing data in real-time on traffic status as well as ITS-enabled transportation pricing systems (as they can indicate fee-based express lanes and calculate fees on the basis of vehicle miles travelled). The following tables respectively illustrates ITS applications grouped into categories with related data and users (Tab. 11), and users groups with ITS of main interest (Tab. 12).

ITS Category	Specific ITS Applications	Data related	Data type	Users
1. Advanced Traveller Information Systems (ATIS)	Real-time Traffic Information Provision	Information about delays due to: congestion, accidents, weather conditions, or road repair work		Drivers Police Emergency services
	Route Guidance/Navigation Systems	Transit routes and schedules Navigation directions		Drivers Drivers
	Parking Information			Drivers Managers of parking places
	Roadside Weather Information Systems			Drivers Police Emergency services
2. Advanced Transportation Management Systems (ATMS)	Traffic Operations Centres (TOCs)			
	Adaptive Traffic Signal Control			
	Dynamic Message Signs (or "Variable" Message Signs)	Variable message signs		Drivers

	Ramp Metering	Traffic volumes Travel times	Video or loop detection	Road managers Police
3. ITS-Enabled Transportation Pricing Systems	Electronic Toll Collection (ETC)			
	Congestion Pricing/Electronic Road Pricing (ERP)			
	Fee-Based Express (HOT) Lanes			
	Vehicle-Miles Travelled (VMT) Usage Fees			
	Variable Parking Fees			Drivers
4. Advanced Public Transportation Systems (APTS)	Real-time Status Information for Public Transit System (e.g. Bus, Subway, Rail)	Trains' and buses' position Arrival and departure information		Passengers Transportation managers
	Automatic Vehicle Location (AVL)			
	Electronic Fare Payment (for example, Smart Cards)			
5. Vehicle-to-Infrastructure Integration (VII) and Vehicle-to-Vehicle Integration (V2V)[88]	Cooperative Intersection Collision Avoidance System (CICAS)			
	Intelligent Speed Adaptation (ISA)			

Table 11. ITS applications grouped into categories with related data and users.

Private users	**Institutional operators**	**Public transport operators**	**Logistic operators**	**Public safety operators**
Intermodal route planner Availability/Reservation/Payment of parking areas Traffic information (accidents, congestion, etc.) Information on road maintenance (e.g., street cleaning) Information on taxi areas, bus stops amd	Supervision and control of traffic Crisis management Innovative srvices for city logistics Information to local travellers, passengers, and logistic operators Collection of information on user behaviours and new mobility patterns	Planning (frequency, timetables, type of vehicle) Rescheduling for abnormal events Real time information provision to drivers	Electronic tolling Dymanic traffic management (management of variable speed limits, reservations and parking guidance, support for real-time navigation) Real-time information systems Driver assistance (e.g. Warning systems, stability and driving	**Civil protection:** Knowledge of the territory and definition of the risk scenario Definition of the defense structure identifying, and mapping all the resources available to deal with emergency Management of actions in case of emergency

88 They enable communication among assets in the transportation system, for example, from vehicles to roadside sensors, traffic lights, and other vehicles.

timetables, car sharing, mo-bike Proximity services (notification entry in limited traffic zones, availability of parking spots, information centres, pharmacies or points of public interest, events, museums)	Analysis user satisfaction level with respect to mobility metrics Information service for users (e.g. visitors, workers, landed vehicles, of given areas)		style control) Integrated multimodal travel planning tools Monitoring services for the co-modal transport of goods	Provision of adequate information to citizens about the degree of risk exposure **Firefighters:** Provision during fires, uncontrolled releases of energy, sudden or threatening structural collapses, landslides, floods, and othe rcalamity Definition of the defense structure identifying, and mapping all the resources available to deal with emergency

Table 12. ITS application of interest of different users (source: Obaidat and Nicopolitidis (2016))

Singh (2014) also noted that smart analytics can provide ambulances with information about traffic, free routes, time on the way to hospital and GIS mapping of all roads leading to hospital; moreover, they can help to prevent and catch crime, as all information from CCTV, sensors on the road, criminal database and information from Police command center is continuously fed to analytics platform, which keeps analysing the information and takes decisions.

4.6 Other relevant aspects

ANAS (1998) has also highlighted further aims of the Road Cadastre that can be achieved by GIS.

4.6.1 Advertising management

Art. 23 of the New Road Code deals with publicity on the road and vehicles. It stated that: "Along roads or in sight of them, it is forbidden to place signs, cartels, posters, advertising or propaganda systems, advertising horizontal signs, light sources that are visible from transiting vehicles on the roads and that - as their size, shape, colour, design and location - can lead to confusion with road signs, or can make it difficult to be understood, or reduce the visibility or effectiveness, or cause visual discomfort to road users, or distract their attention endangering traffic safety; in any case, such facilities must not constitute an obstacle or at least impediment to the movement of disabled persons. Reflective cartels and other media advertising are also prohibited, as well as illuminated sources and advertising that can produce glare. On traffic islands of channelised intersections it is forbidden the laying of any other installation by the required signage." The Code (art. 6) states standards on size, characteristics, and location of advertising signs along roads, relevant bands and gas stations, forbids them along international routes, motorways and primary extra-urban roads and accesses, while permits them in service or parking areas (if authorised by the road owner and not visible from the road) (art. 7). Touristic and cultural advertising as well as public service advertising are allowed whether authorised like above. (art. 7).

In Italy, ANAS, as managing a large part of the national road network, has to produce general plans indicating all permissible sites for advertising plant. That requires the census and check of existing facilities, and the detection of a number of features relating to the placement of advertising facilities (e.g. road signs) as required by standards. Such Plan and the proper management of the system are important both as required by law and to fight illegal placements, and protect an important source of income for institutions managing roads.

The setting of the Plan results fro the information collected within the database in accordance with the specifications by the Ministry of Public Works (circular no. 1381 of 03/17/1998 published in the Official Gazette 82 of 04.08.1998) and the internal documents (41/98 and 94/98) by ANAS. On the basis of such regulations, some ANAS compartments have started the census work, identification of alternative positions, removal and relocation of plants not conforming to standard. In this perspective the Road Cadastre may be a basis for standardising the available information of the various compartments, comparing experiences and situations, applying budgets and compiling aggregate statistics. Moreover, tipically the constraints for placing advertising signs are spatial (the minimum distance of placement of such signs from road elements depends on the road class and the speed limit) and can be well managed by a system such as the one set for the Road Cadastre (**Appendix**).

Once both the location of the constraints on the road (e.g. warning road signs, points of tangency of curves, intersections and tunnels) and geometrical characteristics of the track are known, it is possible using GIS-specific functionality: e.g. to build "a circular area of radius 250m around the warning road signs" or "a 10 m broad band, which is 3 m from the roadside". As well, all existing signs that conflict with these indications of constraints can be selected.

4.6.2 Property

As established by the New Road Code, the National Road Archive should also contain detailed information on occupations, appurtanences, buildings, and crossings. As pointed out by ANAS (1998), such information cannot be expressed only as events related to a kilo-metric progressive on a linear path and should refer to a more detailed map scale. Hence the Road

Cadastre has to integrate maps representing such information level. This also meets the owners and management bodies requirements to maintain an updated information system concerning properties, concession areas, buffer zones, and others, and presumably based on cadastral maps (at 1:5,000 or 1: 2,000 map scale). This information layer will be built according to a reference scale and as detailed as the design documents, whose planimetric projections may be also overlayed.

4.7 Summary

ANAS (1999) highlighted the opportunities given by the Road Cadastre that, initially set up with aims of evaluation of the whole road network consistency and of road management and maintenance, shows a wide flexibility in its uses: it derives from the match between its multipurpose nature and the expandability of its basic structure stated by the Italian standards, as illustrated in Chapter 3, in order to enrich and complete the various data required within the multi thematic National Road Archive.

As described, Road Cadastre data provide information that can be used for planning road surface maintenance by Pavement Management System (PMS) software, for managing advertising and concessions, and recording road accidents as a statistical information supporting new roads' planning and corrective actions on existing roads. Such applications involve surveys and data whose structure is easily framed among the Road Cadastre data. Also the maintenance scheduling of structures, the integration with data on property recorded within the Land Registry, or those more directly related to planning, involve primarily highly demanding data collection tasks, such as a census of all the structures, their static evaluation, repair designs, restructuring and programmable updating over time.

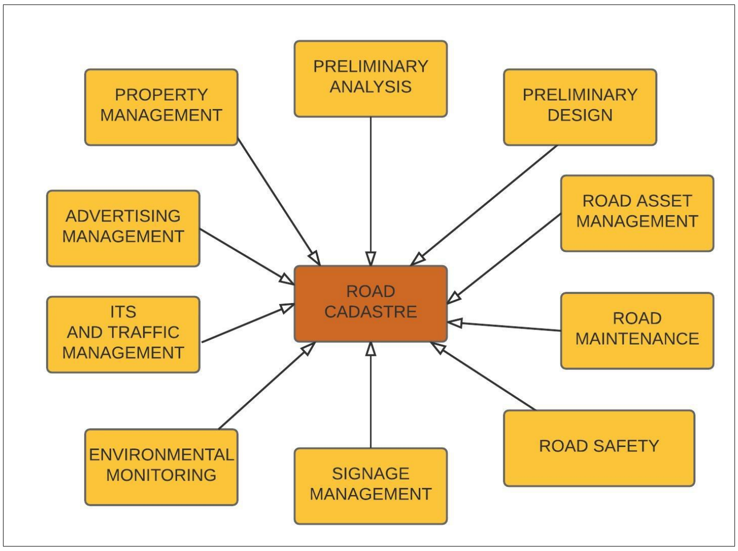


Figure 50. Current and proposed uses for a Road Cadastre

Chapter 5

Needs and opportunities for a 3D Road Cadastre

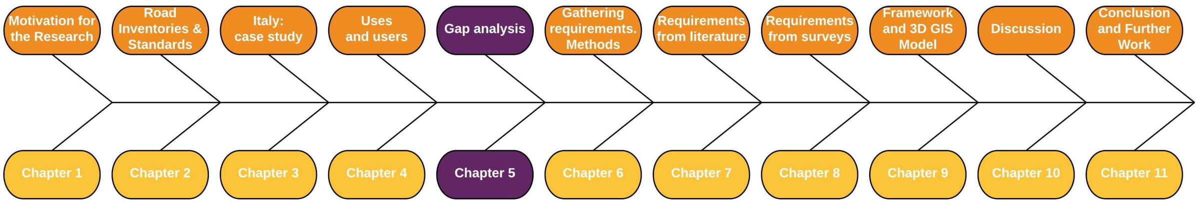


Figure 51. Overview of Document Structure showing context of this Chapter

Although in 1992 the New Road Code imposed all road owners to establish and update their own digital Road Cadastre (Art. 13), it has been a very slow process of translating into reality (Burchi et al., 2009). Most of the Northern Regions launched interesting initiatives, such as research projects, publications of specifications and standards (SITECO, 2008). Many of them (such as Piedmont, Lombardy, Veneto, Friuli-Venezia Giulia, Emilia-Romagna, and Liguria) have implemented their own Road Cadastres or financed their setting up in provinces managing roads of regional interest, whereas other regions in the South and Centre of Italy in general are at a less advanced stage. At provincial level many Provinces in the North have already surveyed the roads under their jurisdiction (also by regional funding), while such achievements in the Centre-South are still few. Such delay has been widely explained by ANAS (1999), SITECO (2008), and Vella (2008) who illustrated the main difficulties in implementing Road Cadastral systems in Italy.

This Chapter describes the current state of Road Cadastres in Italy, and highlights limitations and weaknesses of systems already implemented. In particular, in the light of the advent of 3D models for road infrastructures and of 3D GIS potential in describing and analysing spatial phenomena (both illustrated addressed in Chapter 2 – Section 2), needs ad opportunities for a 3D Road Cadastre have been investigated to properly formulate the research questions and look for solutions to the current gaps.

Several "3D situations" relating to roads and the surrounding environment have been illustrated with the help of graphical representations, and an evaluation of the current legal Road

Cadastre has been made focusing on the most relevant issues emerged from the literature and respectively relating to:

1. data quality and updating,
2. road representation and LoDs,
3 data integration,
4. interoperability and compliance with international standards,
5. adequacy of the systems to users needs (in terms of: a) data and structure, b) multiple uses and users and accessibility, c) and compliance with Italian road design and maintenance standards for documenting the full life-cycle of roads).

The dataset of the legal Road Cadastre, based on 2D, has been analysed and th lack od specifications for describing 3D situations and road components have been emphasised.

All above have been aimed at showing the reader the complexity of properly managing data of road situations (e.g. overlapping) where multiple z is involved, or that in general are difficult to be managed in 2D. From the gap analysis some research questions emerged – as mentioned in Chapter 1 - and have been explained in Section 5.3. in order to orient the choice of the research method and the workflow.

5.1 Current state of Road Cadastre in Italy: difficulties in its implementation

In Italy legal specifications to set up and update Road Cadastres by the Ministerial Act of June 1, 2001 have been systematically implemented **only by private road operators** (i.e. ANAS and Motorway Concessionaires) (SITECO, 2008), whereas, so far, **only few Public Administrations** have implemented their own Road Cadastre despite legal terms expired in 2006 (Vella, 2008):[89] currently, just ANAS and six regions out of twenty have produced their own road inventory relating to the regional road network (SITECO, 2008; Burchi et al., 2009; ASTRAL, 2016), while a few Road Cadastres have been implemented at provincial level by involving private companies for surveys, data collection and the road cadastral systems' implementation.

Due to the Italian legislative gap of ten years - between the Road Cadastre institution in 1992 and its implementing specifications in 2001 - some road administrations experimented some systems looking at the European Directives, but using a subjective interpretation, with the result of a **lack of coordination in collecting and recording the information, an extreme heterogeneity of data, and databases often not comparable with each other** (Vella, 2008).

[89] The Act of June 1, 2001 required the Road Cadastre implementation by 2003 for motorways and national roads, by 2004 for regional roads, by 2005 for provincial and suburban local roads, and by 2006 for local roads (Vella, 2008).

Even after the implementing rules' publication in 2001, the road cadastral implementation in Italy met a number of difficulties: the timing provided by law (2 years for implementing the Road Cadastre of motorways and national roads, 3 years to register regional roads, 4 years for provincial and local suburban roads, and 5 years for local urban roads) was unrealistic as the lack of funds and operators and the wide consistency of the national road network (currently almost 21,000 km, as reported by the ANAS website) (Vella, 2008; ANAS, 1999). Also, by the Act each institution should forward road cadastral data to the General Inspectorate for Road Traffic and Road Safety for **validating the consistency with the national geodetic networks** (SITECO, 2008): all this took a long time, as well as the **implementation of the General Roads Archive**, in which all Road Cadastres should converge (SITECO, 2008).

From a technical point of view, road surveyors had to address further difficulties such as the **absence on some roads of milestone markers**, requiring their installation before the reliefs, and **not well defined road and land properties and boundaries** (Vella, 2008). **Updating road data** required a huge effort in terms of technical, human, and economical resources - the latter reduced since 2004 by the lack of refinancing of the National Road Safety Plan (SITECO, 2008) - with enormous expenditure of time and costs that administrations could not afford (Vella, 2008). In particular, municipalities faced many difficulties, due to both the **poor fitness of the Act's specifications to properly describe urban roads** and the **high extension of municipal road networks** (SITECO, 2008). As a consequence, a delay in an homogeneous implementation of Road Cadastres throughout the country occurred; its lack also prevented a point-by-point monitoring of road infrastructures and the implementation of Road Safety Information Systems (i.e. a sort of digital map registers) as established by the Road Safety National Plan (Law 144/1999) in order to reduce number and effects of road accidents.

The situation has improved since the CONSIP Agreement of 2006, providing public road owner authorities with services aimed at the creation of Road Cadastres (Burchi et al. 2009): by administrative simplicity combined with low costs, it allowed many Regions, Provinces and Municipalities to survey their road asset and equip themselves with management information tools (SITECO, 2008). Many Municipalities implemented their own Road Cadastre mainly when they activated Global Services, by also including services of roads census and management of information systems in their Contract Specifications: by referencing to national standards they tried to ensure homogeneity and quality of the database (SITECO, 2008). As local Road Cadastres were mainly used by Municipalities for road maintenance purposes, they were based on the requirements established by law for basic information, but also extended and customised in accordance with specific maintenance local needs (hence, adding extra non cadastral information not provided with specifications by law whose lack does not guarantee uniform data for the whole road network of the country).

5.2 Evaluating current road cadastral issues

All above highlighted that **interoperability, data quality and updating** have been the main difficulty in implementing Road Cadastres since the law entered in force. As shown by the literature review and interviews conducted with road designers and managers (as shown later in Chapter 9), so far many road cadastral issues have not been solved yet.

5.2.1 Data quality and updating

Data quality and updating are one of the most critical issues relating to road cadastral cataloguing: as Caroti and Piemonte (2010) noted, road network graphs are often pre-existing to the relief works aimed at the Road Cadastre implementation; they usually derive from the union and homogenisation of different sources (e.g. the Regional Technical Map (medium map scale), commercial databases, designs and large-scale surveys from urban planning offices and SIT of municipalities), and often data do not correspond each other with a lack of referential integrity and topology not always correctly defined. Moreover, road property is not always clear, mainly due to property disposals (e.g. road properties transferred from ANAS to Regions and Provinces), frequent modifications of signs and road concessions, alterations of trunks and routes, with consequent displacements or lack of milestones and difficult correspondences between reality and administrative data (Vella, 2009; ANAS, 1999). Boundaries of properties (beginning and end of the road) are not always clearly registered, and the property boundary of several road coincides with the road axes. Also, by law each cadastral data should be defined by the road it belongs to, the conventional progressive mileage (i.e. the distance from a milestone used as a reference), and attributes describing each road event (ANAS, 1999).[90] However, so far, in Italy not all the roads are registered and even classified, standards for classification - by the Act of November 5, 2001 - do not refer to existing road, but only to the planned ones,[91] and, with regard to the existing asset, geometric parametres not always match with the technical and functional ones expected for several road classes (in accordance with New Road Code's classifications) (Villani et al., 2016). Also, within the Road Cadastre DB all information refer to

[90] A road event is any road phenomenon represented in the database, including both occurrences usually associated with it (e.g. car crashes, slowdowns, declining visibility due to smoke or fog) and stable phenomena (e.g. geometrical characteristics of the road, the conditions of the road surface, and road signs).

[91]By the D.M. 6792 of November 5, 2001 “Norme funzionali e geometriche per la costruzione delle strade” and D.M. of April 19, 2006 “Norme funzionali e geometriche per la costruzione delle intersezioni stradali”. In the absence of classification standards for existing roads, other agencies have provided a classification of its own, referring to the Standards of Ministerial Decree 6792/2001 "Functional and geometric guidelines for road construction” applied only to the construction of new road sections, or to the draft standard of March 2006 to upgrade existing roads (Cataldo and Villani, ...).

conventional measures deriving from milestones location or paper documentation (maps of urban sleepers, project documents, and other): however, as roads may change features and track during their lifetime and milestones may be moved, conventional progressive mileages (derived from the mile-stones position) very rarely coincide with the geometric progressive (obtained by measuring the actual development of the road centreline). In order to solve this problem, the ANAS Road Cadastre manages the dual information, and anytime can transform the conventional progressive in geometric progressive and vice versa.

Data quality issues also deal with road elements connecting roads owned by different institutions: that requires the involvement of road owners that - according to the Act of June 1, 2001 - should agree on the way of representing boundary elements and assign them an identification code associated to only one of the two institutions. Moreover, according to Vella (2008), very often a misunderstanding occurred about the Road Cadastre contents in comparison with the National Road Archive: e.g. road signs should not to be included into the Road Cadastre that should contain only "the geometric characteristics and appurtenances of roads" as well as "plant and permanent services relating to the road traffic demand".

Moreover, data quality issues have been addressed also in implementing the National Road Archive with regard to the naming of roads: road names must be unique and unambiguous to allow the exchange of information and comparisons, whereas so far there are many exceptions and unevenness names have been assigned by road manager institutions. The Italian Ministry of Infrastructure has proposed standards aimed at defining a universal coding (valid for each road level, from the motorway to the local road), exemplified in some tables (internal code), and linked to a synthetic code, for easier use and storage.

As already mentioned, road data cataloguing issues also include difficulties in **updating** changing data (e.g. signage, and details of the institutions managing each road) or that are not accurate (e.g. the position of milestone markers after road changes) or clearly defined (e.g. property boundaries, i.e. start and end of the road) (Vella, 2008). With this regard, Zhang and Couloigner (2005) highlighted that a road network has strong topological relationships making difficult to maintain the data consistency through the space and time domains, road events are so many and frequent that road database updating would benefit of automatic road extraction (that is still under research), and special visualisation techniques for representing change information (that are discrete) have to be developed for road network.

5.2.2 Road representation and LoD

As described in Chapter 2 with regard to standards on ITS and Transport Network, also in the Italian Road Cadastre road networks are represented by a graph, structured by arcs and nodes, each provided with related information (ANAS, 1999) of different kind depending on its level of detail (see Chapter 3).

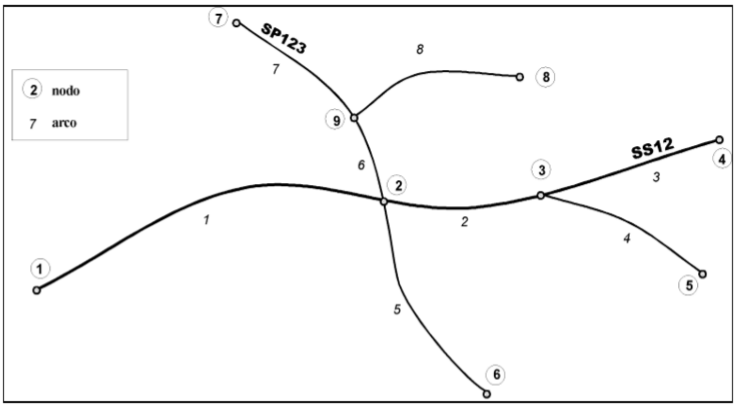


Figure 52. Nodes-Arcs road network organisation: Road network organised into 8 arcs and 9 nodes (ANAS, 1999)

Such representation has a high degree of generalisation with complicated situations in clearly identifying road parts and elements as a consequence: each component of a road, in fact, is not represented in detail and it is linked (not always) as an attribute to the main entities. Hence, as shown in Chapter 3, for example, a road stretch divided into two roadways by a physical separation is normally represented by two distinct road elements at Level 1: in this case, common elements like medians or embankments are registered as attributes and repeated for each element. If the two carriageways have parallel and co-planar axes (and are symmetrical to the axis of the median), they can be represented by a single road element with the physical separation indicated as an attribute: in this case the location of roadways compared to the road axis is defined by the codes (+, -); moreover, further codes must specify whether a generic attribute is located to the right or left hand compared to each roadway view in the direction of the increasing progressive. Also, service roads must be represented by road elements in their own right. The situation is not simple for users and for uses different from car navigation. Moreover, at Level 2, also the junction geometry is not represented in detail: it is necessary to encode its type (e.g. roundabout) and associate it with a single node (also recording node by node the allowed maneuvers as attributes). The same junction, instead, at Level 1 is represented by a set of many nodes and data cannot be linked to a single node. However, for navigation purposes, maneuvers should be also encoded on this graph, but the situation is complicated for using the Road Cadastre for further purposes.

The 2D graph also does not highlight differences of height (elevation) and the distinction among junction satin (incrocio a raso) and overpasses is only made possible by 2D data (attributes). The same problem relates to road components (e.g. retaining walls) at more detailed scale (that the graph does not consider). ANAS proposed to solve this issue using DB tables describing each junction both by the list of all its arcs and nodes, and by a point approximately at the junction centre, able to identify it and connect information to it. In order to distinguish between junction satin (incrocio a raso) and overpasses, the importance to register differences in height (elevation) has been remarked. In a hypothetical Road Cadastre with three levels, ANAS has also suggested their total functional autonomy, with database and applications completely separate, but with the possibility of comparisons and combined representations among the three levels: e.g. able to perfectly overlay Level 1 road axes to maps at scale 1: 2000 (Level 0), or derive at Level 1 the kilometric progressive associated with a land parcel overlooking the street (registered in scale 1: 2000, i.e. a map scale corresponding to Level 2).

Other representation issues refer to datum and geographical projections: according to ANAS, Level 2 requires a complete representation of the road network by a road graph deriving by a TM12 projection (a single cylindrical non-standard projection that uses as a director meridian the 12th east meridian (central meridian for the national area), while hydrography, land use, and terrain model are represented by UTM projection. The graph used as the basis of the ANAS Road Cadastre describes all the main roads of the Italian network with remarkable detail and accuracy, as it refers to 1:10,000 map scale, with 15 m maximum error on the ground. It is organised in regional 'tiles', but, as the system provides a re-aggregated version with the entire network reconstructed as a continuous throughout the national territory, the detail and richness of the information of the graph make it **extremely heavy to handle, not allowing fast processing, and limiting their usefulness in modelling and simulation applications** (ANAS, 1999).

5.2.3 Data integration

In the light of Chapter 4 that highlighted a number of multiple uses and users of Road Cadastres (both current and potential), the integration of road cadastral data with further information might improve road safety, managing road interferences with underground utilities and archaeological findings, and monitoring structures, road traffic, related air-pollution as well as relationships and mutual influences with the environment. Nevertheless, so far standards providing specific dataset and procedures have not been implemented, and local road information systems customise their own Road Cadastres according to local needs (see Chapter 2 and 3). Moreover, the Act of June 1, 2001 required the integration between the Road and the Land Cadastres, but currently that is critical to achieve as the legal Road Cadastre is numeric vector (i.e. data is registered in absolute coordinates, in metres land), whereas the Land Cadastre is digital (less accuracy): also, although the mandatory requirement about their integration, there are no instructions about that (Vella, 2009). However, SITECO (2008) defined essential to integrate Road Information Systems with maintenance management software, and the budgeting and accounting of road works in order to associate maintenance activities to the roads on which they are carried out, and to cross-check technical characteristics and actual management costs of all roads. Moreover, a further gap relates to the management of different life cycle stages of road infrastructures (including roads building, maintenance, management of roads property, but also dealing with land planning, environmental monitoring, road safety, and navigation) that requires topological congruence, and standardised database provided with denomination and other type of data and segmented attributes.

5.2.5 Road infrastructure interoperability and compliance with international standards

Another road cadastral issue relates to the compliance with standards: as ANAS (1999) noted, data from regional, provincial, local and ANAS Road Cadastres should converge with each other and into the National Road Archive, with continuous information exchanges both to and from the National Cadastre, and mutually among the various management bodies. Also, the National Cadastre, in turn, will have to interact at European level with GISCO (Geographic Information System of the European Community), DG7 (Direction of transport of the EU), TERN project (a Trans-European road network, already described in the Appendix 2), and others by transmitting synthetic and standardised information on the situation of the own road network, and receiving data on the bordering networks situation (ibidem). Chapter 2 has highlighted the relevant work of standardisation bodies to implement standards concerning the map projection reference (proiezione cartografica di riferimento), the organisation of cartographic data, the organisation of the graph, and the structure and encoding of the data contained in the cadastre. Nevertheless, with regard to the European road infrastructure, Sandgren (2004) noted that "road administrators capture and maintain road and traffic information, and have agreed on some information exchange standards", but **lack of "a common system to make all this wealth of information available"**. Also national mapping agencies capture and maintain road geographic data, but once again, despite the existence of data exchange standards, there is a **lack of a content standard** and **a global system** to **make all this data available in an interoperable way**. Private sector players, data brokers and service providers have to find the data they need at agencies and authorities around the different EU countries, and also to invest to integrate the information obtained into their own information systems. This effort is duplicated every time a "new player" wants to set up an information based system that has to rely on road data. A well-functioning infrastructure for spatial road information on a pan-European level is fundamental for the development within areas of intelligent transport systems, mobility management, traffic and management, as well as traffic safety, environmental and society planning and many other areas" (Soares and Matos Martins, 2012).

As addressed in Chapter 2 and 4, international standards constitutes an important reference for the basic Road Cadastre (organisation of the graph), but in many practical cases Road Cadastres implemented in Italy made only marginal reference to this standard, as mainly meeting "car navigation" requirements. As illustrated in Chapter 2, Caroti and Piemonte (2010) observed that though INSPIRE Directive will push states to a great effort of standardisation of their geographical database and IntesaGIS[92] has already written many technical specifications in accordance with internationally recognised standards, such standards have not been applied by local authorities. According to ANAS (1999), problems of organisation and coding of road information systems within the general framework of GIS are too specific to be covered in detail within an overall standard. Though at European level CEN/TC 278 defined the GDF standard for the organisation and exchange of road information in order to address the problem and with regard to the structure of the graph, GDF is mainly spreading industrially. Companies distributing commercial graphs provide data even in this format, and large software companies such as Microsoft have declared their interest (ANAS, 1998); however, as the influence of auto industry, it has been linked mainly to car navigation requirements that do not always coincide with those of road network management, and was not adopted by any road administration yet: several administrations contacted by ANAS during a survey on this topic, even explicitly said that they did not intend to take it into consideration, and also ANAS remarked that GDF standard does not cover issues related to roads description for road management (e.g. road classification, geometries' description and the structure of a DB for road management that should include data on the road surface status, accidents, and signs). Moreover, though road administrations are the main database users/creators, they have not been asked any feedback on such standards, public offices do not have enough resources for transferring existing files to new formats, employees are not enough skilled. Importantly, standards at high level do not take into account specific needs of local authorities and in most cases there is no room for flexibility: hence, such specifications remain only policy documents and do not become normative references.

[92]IntesaGIS is an agreement approved by the Conference of State, Regions and Autonomous Provinces in 1996 and involves different central government departments and state agencies (including the AIPA, Authority for Information Technology in Public Administration), the Regions and Autonomous Provinces, Municipalities (ANCI), the Provinces (UPI), the Mountain Communities (UNCEM) and Companies for the management of public services (CISPEL). Its aims eas to develop coordinated interventions to digitalise territorial data of the whole country within 6-8 years for improving functions of local, regional and national administrations. Its guidelines were aimed at the implementation of regional information bases, starting from topographic database and the connection of these with specific updated cadastral archives and the implementation of a Topographical Database of General Interest, also in accordance with the INSPIRE Directive requirements of interoperability and compliance with common international standards (see Caroti and Piemonte, 2010).

5.2.5 Adequacy to users needs

Road institutions that started first to record roads within their own Road Cadastre evaluated the guidelines for implementing the Road Cadastre too rigid (Vella, 2008). The lack of adequacy of road cadastral data required by law and the serious difficulties in managing them have been highlighted by users together with issues in accessing to information.

5.2.5.1 Adequacy of data and structure

With regard to data collecting and updating, ANAS (1999) emphasised the distance between road cadastral data required by law and the real requirements for road management. The legal Road Cadastre, in fact, requires a **huge quantity of data** from accurate and very detailed surveys - "just because technical instruments allow it" (ibidem) - with a number of measured attributes (and consequent high costs) that do not really meet the users needs, and that in the future will be very difficult, long, expensive, and - according to ANAS - also useless to update. As many and specialised operators and technical systems are required for collecting such detailed data, road institutions - not always provided with them - must charge external technicians to do surveys: data are received by work-teams not skilled for managing both them and the complex procedures related. Current systems are not light and easy-to-use.

From the point of view of designers, dealing with projects of both new road infrastructure and road adaptations or maintenance, the review of the Italian standards and Road Cadastre's **legal technical specifications do not always correspond to users expectations also with regard to the kind of data provided, as they need very simple and concrete non-cadastral information**, like levels of service (for design), the road surface or structures details (for maintenance), or the design of the road section type (for both). Also, the legal oad Cadastre does not include data that users particularly appreciate: e.g. videos made while surveying, allowing quick and easy "virtual inspections" of roads, and providing photogrammetric measurements useful to estimate the works to be performed.

In 2001 legal alongside the geometric information encoded in the Act, Road Cadastre specifications did not include signage and advertising signs nor the instructions to detect such features (that imply **greatest bureaucratic and technical efforts** (SITECO, 2008), and that now can be performed by new technologies (MMS, etc.)).

Some **inadequacies** are highlighted by users also relating to the structure of the Italian Road Cadastre. For example, the Act of June 1, 2001 included the **enclosed traffic area** among the three main road cadastral entities at Level 1 in accordance with the GDF standard. Nevertheless, Magni (2004) noted that very often such entity is not used in Road Cadastres, whereas, in order to describe road traffic, only junctions and road elements are preferred as they are more easily to be modelled and managed within the road graphs associated to the Road Cadastre.

5.2.5.2 Multiple uses and users and accessibility

The Italian Road Cadastre also deals with issues related to data accessibility and use by multiple users: for example, it is GIS-based, whereas normally road projects are drawn in CAD (or modelled in 3D with 2D CAD output). Although CAD files can be implemented and entered into a GIS saving the planimetric appearance (as long as all items are correctly geo-referenced), but usually loss of information content occurs (ANAS, 1999). Moreover, GIS is too much difficult or expensive to road designers, who require a light and user-friendly system, able to retrieve relevant information within a GIS environment without loss of information connected (e.g. contour lines dimensions and spot heights, closed polygons for paved areas).

With regard to accessibility and costs, regional Road Cadastres are not still many and however they have been implemented by private companies with expenditure of high costs. Also ANAS made a big investments on surveys and data capture and the graph they use is a **proprietary graph** that, though modified and adapted, comes from information provided by the TeleAtlas company. Therefore, it cannot be distributed without buying the license from the supplying company (ANAS, 1999); also, as the costs incurred, ANAS provides just some data to road designer, leaving the most o them for internal uses. Hence, a freeware graph would enable road authorities and private with limitated possibility of expenditure of using applications and data bases for various purposes and to any user to access to road web applications.

5.2.6 Compliance with Italian road design and maintenance standards

The set of road standards in Italy is very disaggregated: there are many standards for different purposes, legislative gaps producing uncertainties on road classifications and design, and a unique framework where road standards are coordinated and complete would be required. In addition to data on the geometry of roads and intersections, the Road Cadastre does not include further information provided by these standards (and that might be useful to describe the full life cycle of roads for their better management): e.g. the whole framework of road-related standards (both the most recent and those in force at the time of the construction of the infrastructure), as well as all concerning signs, road barriers, galleries, and what goes beyond the road itself (such as environmental data, urban plans, constraints, and land use).

Compliance with Italian road design standards. The basic Road Cadastre provides only partial data really useful for road design: among these the number of lanes (with further road elements) and their width and size (important as related on the traffic volume and the upper limit of the design speed range – not mentioned among road cadastral information). By the graph associated to data, Road Cadastre allows checking the size of the cross section that by standard has to be kept unchanged for the whole length of the road, also in case of artificial structures (tunnel, grade-separation structure, bridge, viaduct, etc.). Road design standards also provide the composition of the carriageway (number of lanes in both directions) and the limits of the design speed interval for each road category and for any possible related service road, but such information is not included in the road cadastral database.

Importantly, the basic legal Road Cadastre does not take into account time. On the contrary, as seen in Chapter 3, different road standards were used to build roads built (distinguishing those dating back before 2001 from the recent ones): over time road classification has changed many times together with the institutions responsible for road management, roads have been designed in accordance with different design guidelines and standards, and continuously updated to meet new requirements relating to safety, environment impact, and others (also because of the increasing traffic). Hence, depending on its time of construction, each road has different physical characteristics and require adaptation with different level of priority. Today, for example, roads built in the '60s have inadequate minimum bending radii (Monutti, 2013)[93]. Therefore, in order to update the most ancient roads in accordance with the most recent standards, it is important to know the time of construction of roads whose geometric characteristics depend on. Morever, Monutti (2013) noted that the CNR technical standards adopted by the '90s were good design standards for roads and intersections. Nevertheless, as they had no binding force, they have never been properly implemented by Italian designers. Hence, the only period of road construction may be purely indicative of the road features expected to be found (in relation to the standards in force at that time), and further data (e.g. from surveys) are required.

With regard to roads built after '90's, at that time road standards had binding force and road designers and managers are obliged to adopt the design procedures provided by law both for new roads and for updating the existing ones. Nevertheless, in the latter case, standards are often difficult to apply (Monutti, 2013): hence, on existing roads and for archaeological, social, economic and environmental reasons, the Act of November 5, 2001 would allow design solutions in derogation of the adopted standards (but projects should be supported by specific safety analyses and reports and authorised by the public administration). In the light of above, the

[93] In 1963 in Italy there was 1 vehicle for each 8 inhabitants.

subsequent Act n. 67/s of April 22, 2004 established to apply it only for new roads design; nevertheless, until the publication of specific standards, the Act of 2001 must remain as the main reference for updating projects of existing roads. All above highlights a complex situation to manage differences between new roads and existing ones. Also design standards for road intersections (Act of April 19, 2006) are mandatory for projects of new intersections, whereas they are a reference for the projects of existing intersections.

Compliance with Italian road maintenance standards. According to SITECO (2008), public authorities have decided to adopt the Road Cadastre not only to comply with the Act of June 1, 2001, but in general to pursue a new approach to network maintenance. A steady consolidation of the Road Cadastre derives from the use of the database for the management of infrastructure and its maintenance, whereas its non-use as a management tool is considered one of the major risks of failure of such projects (ibidem). However, the legal Road Cadastre does not include any specific data referred to road maintenance, whereas ANAS Road Cadastre and some PMS used by local administration have added some related information. With regard to time factor, even Italian road maintenance standards have not mentioned it for a long time: in the '80s the Italian catalogue of road degradations by NCR did not consider modifications of defects over time nor the link among defect, causes and interventions techniques. Today they are instead very important and - as emerged by the interview to the ANAS road manager reported later in Chapter 8 - have been included in new inventories and applications on road maintenance. No specifications are including in the Implementing Rules of the Road Cadasre ith regard to photos and comments on the physical characteristics of road deterioration (even if required by the CNR catalogues and the others used in Europe and mentioned in Chapter 3). Moreover, after transferring road responsibilities at local level by law, standards became even more numerous: e.g. in Lombardy promoted by its own functional road classification, the Road Cadastre and geometrical-functional standards (by the Regional Law 9/2001) and regional legal documents in 2006 such as **"Road surfaces maintenance standards and criteria"** and the **"Catalogue of road surface deterioration"** were (Crispino et al., 2008; Reg. Decree January 25, 2006; General Direction of Infrastructure and Mobility of Lombardy, 2005a: Catalogue).

5.3 Basic needs for a 3D Road Cadastre

As Yuan (2008) highlighted, mega-cities feature many complicated 3D-transportation structures such as flyovers, tunnels, ramps and viaducts. As urban spaces continue to burgeon upward and down-ward, modern road-network systems grow in multidimensionality and dynamism (relating to turning restrictions, speed limits, one-way instructions, limited width, emergency and movable lanes, such as bridges) while the traffic-control systems of many are executed at lane level. Yet these roads are still represented as two-dimensional data. However, as addressed in Chapter 2, in the last few decades 3D data models have been explored to describe reality and the interest in their application in the road field has been growing.

In the literature many studies have addressed the needs of describing and representing real-world as three-dimensional. With regard to roads, Vosselman (2003), while addressing 3D reconstruction of city models from airborne laser altimetry data, highlighted that for city planning and tourist guidance purposes a complete modelling of the urban environment including 3D reconstructions of roads and trees is needed (as they have a large impact on how city is perceived). Camay (2014) focused on the optimisation of road construction by virtual reality technology as it allows visualising in 3D the whole road and the environment around in a scale 1:1, and controlling the position of traffic signals, SOS telephone cabs, noise-protection road walls, safety exits, tunnels height or eventual bridges during the virtual visit of the road, as well as the visibility of the whole road (from its start till the end) by the driver: an help for technicians, architects and civil engineers in order to modify their plans before starting constructing the real road, avoiding mistakes and reducing costs.

Currently, the dataset of the Italian Road Cadastre includes attributes relating to the third dimension of some road components. It registers: the maximum height of escarpments and supports, free height of tunnels and overpasses in the centre and on the edge of the road platform, the maximum depth of gutters and also the slope of the escarpments. Nevertheless, such information are related to elements then represented in 2D by the road graph. Importantly, also the ANAS Road Cadastre graph includes **2D spatial primitives** where (x, y) coordinates are associated to an elevation value. It represents the geometric centre of development of each track (double roadways are represented by two roads), major intersections (those split-level, involving two or more ANAS roads and roundabouts, represented by the axis of all intersection branches) and secondary (identified by a single point). However, whether considering road descriptions and components as illustrated by road design manuals and standards but also visible in everyday life, there are many different cases that would make useful a three-dimensional documentation and analysis of roads: citing Stoter (2004) when speaking about 3D cadastre, we can call them road-related "3D situations" or shortly "3D road situations".

5.3.1 3D road situations : some relevant examples

3D road situations can be defined as situations related to road infrastructures where parts or components are located on top of each other, are stratified or interlocking one another, and/or are part of complex structures whose components have mutual spatial relationships that can be understood only in three-dimenson. The same relates to the relationship among roads and the surrounding and underground contexts.

Overlapping and interlocking infrastructures are complex situations that graphs currently represent as two-dimensional (projected on the surface) with the only additional attribute of the height aimed at distinguish the real position of road points (Fig. 53). Structures (Fig. 54) are quite only named and located on the graph, totally ignoring their huge complexity and their multiple components that make them more similar to buildings (and hence requiring a similar approach to their description, especially for design and maintenance purposes). Moreover, underpasses and tunnels, as located under the surface, remain unseen on air photographs, as well as their road equipment, and other (included underground utilities).

Figure 53. Overlapping and interlocking situation in Russia

Figure 54. Structures: bridges, viaducts, overpasses, underpasses, tunnels

In the reality, roads are not lines projected on the ground level (Fig. 55): **road bodies** are positioned **above or below the ground surface** in accordance with the morphology of a territory, and movements of land (excavations and reports) (Fig. 56)[94] are required for road constructions.

[94]The source of Figures 56, 57, 58, and 59 is: http://www.lbalberti.it/public/AS2011-2012/classi/5AETA/Varie/Elementi%20costruttivi%20strada.pdf

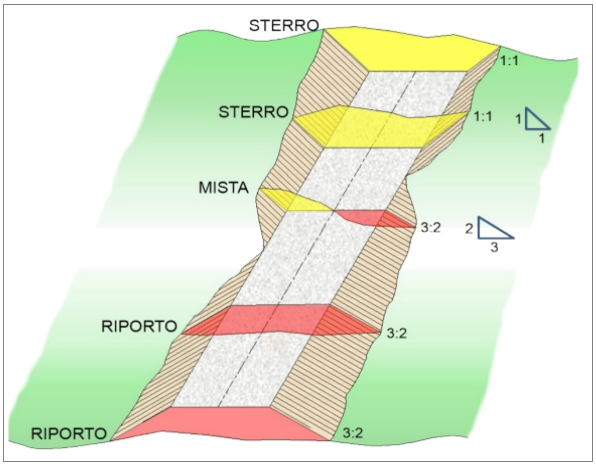


Figure 55. Spacial alignment of the road (source: http://www.sapere.it/enciclopedia/strada.html)

Figure 56. Excavations and reports for building the road body

The road artifact includes the road bed, connected to the ground by means of earthworks **(embankments or escarpments)** or concrete (walls or viaducts), as a stable support of the overlying superstructure (which consists of the foundation and the road surface) (Fig. 57). Their **relationships with the environment** (both **natural** - Fig. 58 - and **man-made -** Fig. 59) are critical and require realistic spatial descriptions: as shown in Chapter 1 and Appendix 1, influences of the geological subsurface or inconveniences related to the space below should be considered, as subsurface activity may damage surface property, and causes collapses, with slowdowns or interruption of traffic flows and connections among places as well as injured and dead.

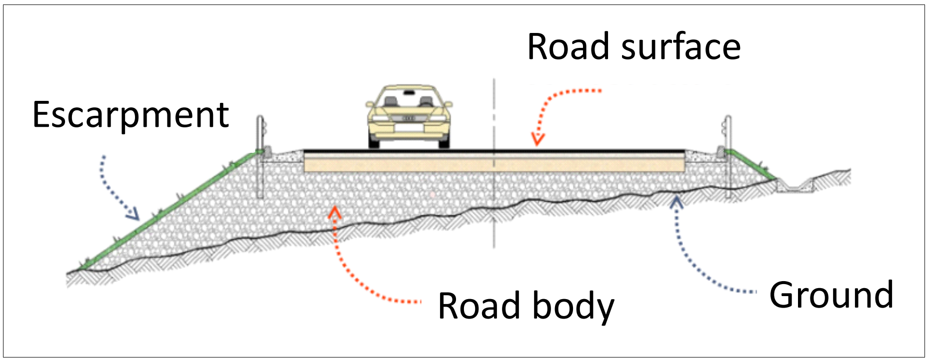


Figure 57. Road elements and relationships with the ground

Figure 58. Road elements and relationships with the natural environment – Bosnia and Herzegovina_Olja Latinovic (source: Montgomery et al., 2015)

Figure 59. Road elements and relationships with the built environment - London's Edgware Road flyover at its opening in 1967 (source: https://www.theguardian.com/cities/2015/apr/28/end-of-the-car-age-how-cities-outgrew-the-automobile)

The strong danger of instability in the presence of large embankments or large trenches (trincee), or otherwise in slopes in excavation/earthwork embankments (scarpate in sterro), makes difficult including roads into the environmental context, and requires the construction of **retaining walls** (Fig. 60) - called "of counter-scarp" (sottoscarpa) or "scarp" (controscarpa) or "for counter" (di controripa) depending on their position - which significantly reduce the volume of the embankment. Such walls have no supporting function, but stabilise the slope. As they are vertical elements linking the road surface to the sloping terrain retaining it, they cannot be described as simple lines, and are also connected to the calculation of terrain volume (and related costs).

Figure 60. Retaining walls

The road surface, aimed at allowing the traffic flow and transmitting and spreading the car load to the underlying road body (and then to the ground) is composed of many different layers whose width and materials can be modified over time by maintenance works (Fig. 61).

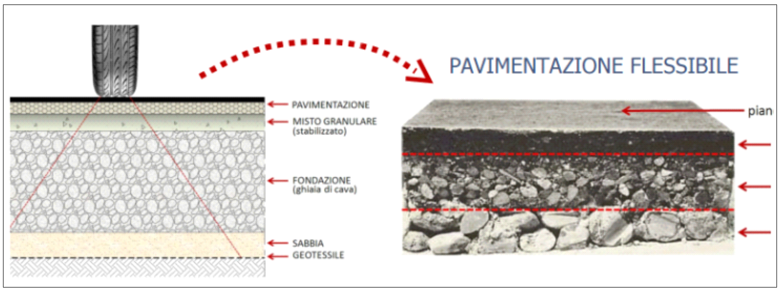


Fig. 61 Road pavement layers

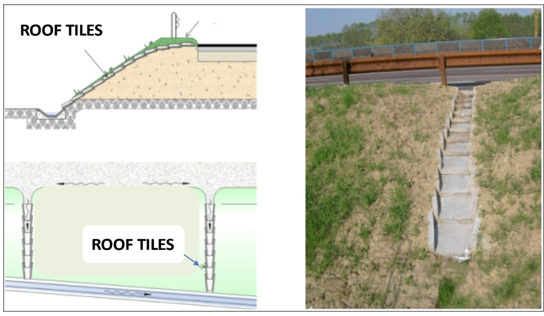


Figure 62. Water disposal systems

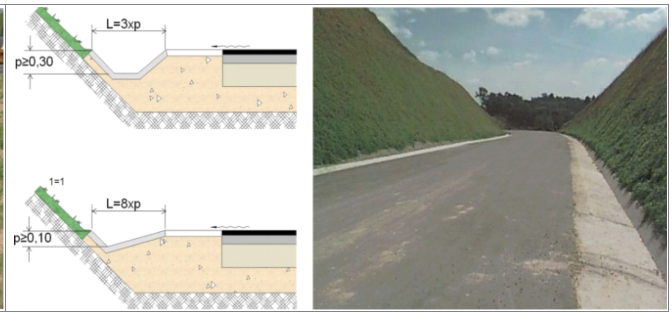


Figure 63. Gutters

Further road elements like **gutters** (Fig. 63) in the reality are not coplanar with the road surface as well as road equipment related to drainage like **water disposal systems** (Fig. 62), **vertical signs** and **traffic lights** (Fig. 64)**,** and **safety barriers** (Fig. 65) that can be made of metal (guardrail) or concrete (New Jersey barriers) and have different height. Their data are also related to time of construction and standards in force a that time.

Figure 64. Road equipment /vertical signs, traffic light systems

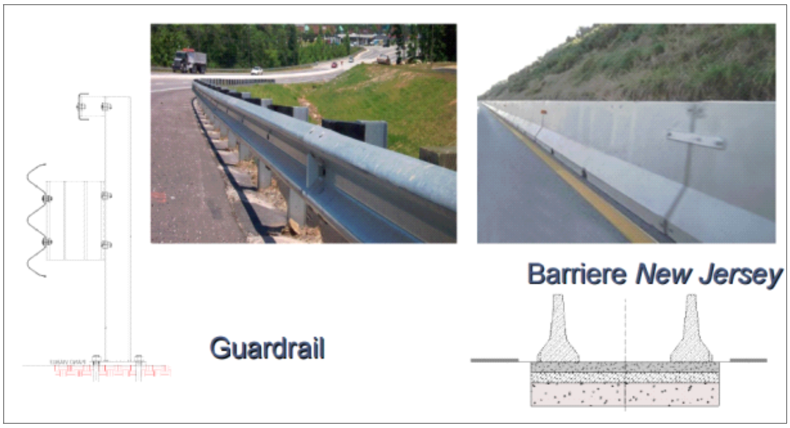


Figure 65. Safety barriers

In addition to structures like tunnels and underpasses that are respectively covered by terrain and located under the road surface level, road design, construction and management activities deal with a number of further elements: **road utilities** - such as lines for telecommunication, electricity distribution, natural gas, cable television, fiber optics, traffic lights, street lights, storm drains, water mains, and wastewater pipes (Fig. 66) - and **road facilities** like parking (Fig. 67), that may lie **underground**, and whose data (not cadastral) are owned by different institutions and not often easily available to road users.

Figure 66. Pipes and underground utilities

Figure 67. Underground parking

In the first case, agencies managing underground utilities provided their operators with special detectors to find underground cables covered by metal, but such system does not work with other materials and underground information are very limited and not shared among different institutions, with a higher risk of interferences.

Currently, as the lack of such information in 3D, many problems can occur at the construction stages: road workers can be faced up some overlap problems because of not having necessary and updated geometric data located on maps especially during excavations works inside municipality's borders. 3D data of such objects and their spatial relationships - properly collected in a centralised system or linked to it - would help to plan road works avoiding interferences among works and objects managed by different institutions in different moments and stages of the life cycle of any manmade construction. Moreover, in historical contexts, **interferences** can occur also **with archaeological findings in the subsoil** (Fig. 68).

Figure 68. Interferences with excavations for building underground – Caracas underground (on the left), and Athens underground (on the right)

With this regard, in Italy institutions like the SSBAR (Soprintendenza Speciale per i Beni Archeologici di Roma), by the SITAR project, records into a WebGIS data (administrative, from surveys and others) on archaeological findings collected during roadworks. That allows them to draw a map of archaeological potential of the urban and suburban areas as a predictive tool for protecting the cities archaeological heritage, and to orient urban and suburban planning of designers and institutions with regard to both buildings and road infrastructures constructions.

5.3.2 Gap analysis: 3D road cadastral representations and LoDs

In Chapter 3, Figure 43 showed by a diagram all road components of road elements described within the Road Cadastre at Level 1. Most of them are represented in the previous paragraph among the so-called 3D road situations. Nevertheless, Road Cadastre's graph and dataset refer to 2D (or 2.5D if we consider the z coordinates as the attributes indicating the height of some element). Figure 44 in Chapter 3 also described information provided for each of them. The following table aims at providing a gap analysis on what 3D data the theoretical model by law misses, in the light of above:

Potential 3D Road components	**Related data recorded by the legal Road Cadastre**	**Legal data that may be better modelled in 3D**	**Notes** **3D data missing:**
Road Element Section *(Sezione dell'elemento stradale)*	- Presence, type, and width of road sections parts as sidelane, roadway, median, sidewalk and cycle lane - Number of lanes of roadways	✓	Further elements: e.g. height, relationship with the ground and the surrounding context
Road Surface *(Pavimentazione della strada)*	- Type (material)	---	Further elements of the road platform in addition to shoulders
	- Shoulder (if existing and if entirely or partally paved)	---	
Roadbed *(Corpo stradale)*	- If at grade, embankment, in trenches	✓	3D documentationof the relationship with the ground and the surrounding context
	- If delimitated by escarpments (and which gradient and max height)	✓	
	- If delimitated by retaining wall (and which type)	✓	
	- Max elevation from the road surface	✓	
Bridge *(Ponte)* Viaduct *(Viadotto)* Underpass *(Sottopasso)*	- Denomination (official and conventional)	---	Further elements: e.g. components
	- Category (I, II,etc.)	---	
Tunnel *(Galleria)* Overpass *(Sovrappasso)*	- Denomination (official and conventional)	---	Further elements: e.g. relationships with the ground, lighting systems, signs and underground utilities
	- Free height at the centre and at the roadside	✓	
	- If existing ventilation plant	✓	
Road Gutter *(Cunetta di margine)*	- Type, i.e. shape (also per side)	✓	Further elements: e.g. relationships with the ground and the surrounding context, aquifers, and underground utilities
	- Max width	---	
	- Max depth	✓	
Road Curb *(Arginello)*	- Only width (and side)	---	Further elements
Roadbed protection *(Protezione del corpo stradale)*	- Only type (if rockfall walls, fences, windbreaks, etc.)		Height, components, relationships with the surrounding context, and further elements
Surrounding environment protection *(Protezione dell'ambiente circostante)*	- Only type (if facilities for the mitigation of visual impacts or noise barriers, etc.)	✓	Further elements
Lighting System *(Impianti di illuminazione)*	- Only type of lamps (side)	✓	Hheight, components, relationships with the surrounding context, and further elements

Bys *(Piazzola di sosta)*	- Only width		Signs, relationships with the surrounding context, and further elements
Retaining Device *(Dispositivo di ritenuta)*	- Only type (median, barrier, etc.) an side	✓	Height, components, relationships with the surrounding context, and further elements
Service Pertinency *(Pertinenze di servizio)*	- Denomination (official and conventional)	---	Especially if buildings: relationships with the surrounding context, and further elements
	- Type (gas station, parking, bys, area of building for maintenance purposes, etc.)	✓	
	- Area		
Hydraulic Element *(Opere di continuità idraulica)*	- Type (manhole, etc.)	✓	Components, relationships with the surrounding and underground context, and further elements
Access *(Accessi)*	- Access type (at grade, split-level or other)	✓	Relationships with the surrounding context, and further elements
	- Fall	✓	
	- Function of destination area (houses, farms, agric lands, etc.)	---	
Milestone signal *(Cippi o segnali chilometrici)*	- Only the corresponding kilometre	✓	Artifact and surrounding context

Table 13. Gap analysis on the representation of 3D elements in the legal Road Cadastre. Missing 3D data

With regard to roads representations, as shown in Chapter 2, standards on road transport define three different LoDs: they do not relate to 3D roads representation. The Italian Act of June 1, 2001 providing implementing specifications for Italian road information systems, though considering all three levels mentioned above, specifies that among them Level 1 is the one to be really used as a basis of the Road Cadastre: moreover, also in the Italian case graph and dataset are 2D based.

As explained in Chapter 2 with regard to 3D models for roads, the implementation and management of 3D data and representations have been addressed by some recent BIM for infrastructures and experimental 3D GIS (e.g. by Sivan Design). It requires an investigation on LoDs whose number is different depending on the model used (e.g. BIM or 3D city models). This topic is also new and relevant to the implementation of a 3D model with road cadastral purposes.

5.4 Gap analysis results and research questions

The previous Sections have highlighted a very complex situation relating to Road Cadastres, dealing with a "galaxy" of multifactorial topics and issues that are difficult to be properly managed. The gap analysis here conducted lead to the main following observations.

- The Italian Road Cadastre should contain a list of all the roads surveyed by road owners/managers, but currently: a) **many roads have not been registered yet** as the road network in the country is very consistent, **too many data** are required by the Act o June 1, 2001, and local administrations **lack of the necessary human specialised and economical resources** to survey and rcord them; b) so far, **the classification of the whole national road network is not complete** and is made particularly difficult by the **lack of classification standards for the existing roads** (the ones dating back before 2001 were built according ancient and not mandatory design standards and geometric criteria).
- When the Road Cadastre was established, advanced technologies for detection like laser scans, MMS and sensors, were not used by road administrations, and road cadastral elements were referenced also to distances from milestones (changing position over time) with issues in data quality. Moreover, at that time 3D research works had to be still extended to the road sector and third dimension had not been considered yet.
- The Italian Road Cadastre should work as an archive management with a hardware and software architecture allowing road asset management and maintenance operations (Provincia di Brescia, 2010), but **data** provided by it **are not adequate for such purposes**: they are too general, not properly describing both all road components included into the current system and further elements that road management and maintenance operations involve (as shown in Chapter 3). 3D is not included, but the awareness for the potential of a three-dimensional management of infrastructure is growing. New technologies and research approaches are moving towards the implementation of new systems for registering and representing roads in an innovative way: in the AEC sector the interest for n-dimension (including space, time, costs, and other aspects) are overcome both two-dimensional information systems and traditional 3D models for visualisation.
- For each road the Road Cadastre should contain all the road features to be included into the National Road Archives (hence related to 5 specific themes as provided by the Art. 226 of the New Road Code: 1. technical and legal characteristics of the roads; 2. vehicular traffic; 3. accidents; 4. typology of the dump tracks (mezzi d'opera)[95]; 5. pollution). Actually, **the road cadastral dataset is not based on the Archive topics: just basic information are standardised**, then letting each road administration to

[95]According the New Road Code (1992) dump tracks are: those vehicles or combinations of vehicles (trailers and driving semi-trailers) a)specifically equipped and classified as these, in a specific registration certificate, b) used for the transport of used or resulting materials in building and road construction, mining, etc.

implement a larger dataset according to local needs (with consequent **problems of interoperability**).

- Each road belongs to a technical class on the basis of precise design data/criteria described in Chapter 3. However, the legal Road Cadastre only includes technical road classes, but not also technical data related to them: collecting both within the same system (or mutually linking data within different DBs) might help to have a synoptic view of all the road features and facilitate checks and updating data required to proper classify (or declassify) each road.
- European and international standards have been drawn to be implemented also at national level and aimed at allowing interoperability among road systems, but in the practice in Italy they have not been applied. The Road Cadastre has implemented three Levels of the graph and data in accordance with the GDF standards, but as noted by ANAS (1999), GDF - as mainly based on the requirements of car navigation - has not fully adopted. Also, although the enclosed traffic area is one of the three Level 1 entities prescribed by the Act of June 1, 2001 in accordance with the GDF standard, actually it is not used: road junctions and road elements are preferred by users for describing road traffic. Moreover, European standards have proved inadequate as set by groups not including organisations dealing daily with the population of databases, and have been mostly replaced by local standards using local parametres and data.
- In the road sector, the most urgent requests refer to the need of management and integration of heterogeneous data (today even including point clouds, data from sensors, and others), 3D analysis, road full life cycle management, and interoperability. All this will be compared in Chapters 8 with results from literature and questionnaires and interviews.

In the light of above, and as 2D GIS has been used as the main tool for Road Cadastres so far, the main question this work aims at answering is: "Can managing data in a 3D GIS benefit large infrastructural projects over their full life-cycle, from initial design to Road Cadastre?".

In order to answer this questions, the research aimed at answering to the folowing subquestions:

- What standards apply to data management for large infrastructure projects and Road Cadastre?
- What are the needs of the users of this data at each stage of the life-cycle (and/or for different purposes/uses)?
- What needs should be modelled in 3D and what should be represented in 2D or by PDF, photo and other?

5.5. Summary

Pressure on land and the need to reduce the occupation of areas as well as the need to overlay physical obstacles (like rivers, or mountains) and reduce travelling time, have lead to an increasing use of bridges, tunnels and overlapping and interlocking construction, whose links are ramps, overpasses and underpasses. Split-levels crossings, by avoiding the direct crossings of vehicles, also facilitate traffic and road safety and in Italy are the only type of interesection admitted on motorways and main suburban roads. The number of tunnels, cables and pipelines (water, electricity, sewage, telephone, TV cables), underground packing places, building above roads/railways and other cases of multilevel infrastructure and buildings has grown considerably over decades.

In this context, the current Road Cadastre seems to be inadequate to manage roads situations even more complex as well as all the potential uses of a road information system as explained in Chapter 4: graph and dataset are based on 2D road data and not fully adequate to the purposes provided by law; users do not find information to be used for design, maintenance, and management; 3D is not considered, whereas the function of road components and the mutual spatial relationships among them and with the surrounding contexts highlight the need for 3D road data and representations and stimulate to verify the potential of 3D road data models to really meet road cadastral purposes.

However, an upcoming interest for three-dimension in many field of life (including 3D cadastre in general) and the increasing 3D approach in other domains (e.g. urban planning) also by 3D GIS encourage investigating on a 3D approach to road cadastral registration (and its technological implementation). Hence, a challenge for Road Cadastres should be extend road cadastral registration into the 3D dimension, also allowing to register overlapping and interlocking constructions that are currently projected on the surface and documented by 2D information. Moreover, 3D road representation and related LoDs are another important issues that will be addressed both in the model proposed in Chapter 9 and the subsequent discussion in Chapter 10.

In the light of the previous Chapters, this work aims at clarify whether managing data in a 3D GIS can properly document roads, benefit large infrastructural projects over their full life-cycle, from initial design to Road Cadastre, and meet real users needs.

Chapter 6

Research method for requirements gathering.

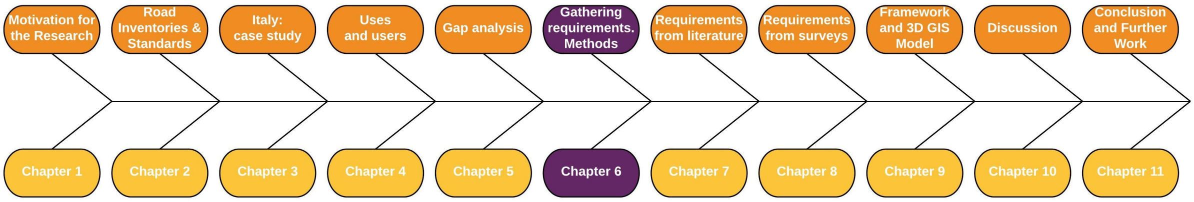


Figure 69. Overview of Document Structure showing context of this Chapter

Osang et al. (2013), Peter (2015), and Tamil Arasan and Valarmathi (2015) noted that data collection is an important aspect of any type of research study. Inaccurate data collection can impact the results of a study and ultimately lead to invalid results. Ghauri and Grønhaug (2005) and Mattsson and Rodny (2013) have clearly distinguished between two different fundamental methods for data collection in research that represent different techniques for capturing relevant information for a specific research question: they can be qualitative and quantitative (or mixed). Newman and Benz (1998), Creswell (2003), and Saglam and Milanova (2013) have illustrated both.

Abawi (2008) defined the quantitative method as "a process of inquiry based on testing a theory composed of variables, measured with numbers, and analyzed using statistical techniques" and compared it with the qualitative method described as "a process of building a complex and holistic picture of the phenomenon of interest, conducted in a natural setting". As noted by many researchers, the quantitative method is mainly based on testing, measuring, and experimenting to arrive to a result (Mayring, 2002): it explains phenomena by collecting numerical data that are quantified, tested, verified and analysed using mathematical methods such as statistics, according to an objective approach (Aliaga and Gunderson, 2002; Ghauri and Grønhaug, 2005; Mattsson and Rodny, 2013). In comparison, the qualitative method does not use measurements to arrive to a conclusion (Ghauri and Grønhaug, 2005; Mattsson and Rodny, 2013): as Marying (2002) noted, it aims at understanding the researched phenomenon, and uses a more subjective approach and data interpretation to achieve an explanatory conclusion (Ghauri &

Grønhaug, 2010). Also Saglam and Milanova (2013) focused on the different purposes of both methods distinguishing between a quantitative approach, searching for standardisation, reproducibility, and measurability by a cause-effect relationship, and a qualitative approach aimed at understanding and interpreting behaviours, contexts, and interrelations. Many authors emphasised qualitative research whose main strength can be found in: its ability to create knowledge about new phenomenon and complex interrelations not yet researched thoroughly or at all (Seipel and Rieker, 2003), the importance given to the context and the verbal access to data (Hoffmann-Riem, 1980), and the circular and interactive research process (Saglam and Milanova, 2013).

This chapter, including its subchapters, is intended to clarify how the research has been conducted and to describe the research methods that have been used. Moreover, the chapter provides a deeper insight into the details regarding data collection through the literature review, interviews and observations, and accounts for the reliability and validity of the outcome.

6.1 Research approach

Sharp et al. (2011) have suggested a number of different approaches that can be taken as part of a requirements gathering process, including interviews and workshops, as well as focus groups and studying documentation. A number of these have been employed within this research and are described here.

With regard to geographic information, Furtado (2006) explains that the success of any infrastructure for spatial information directly depends on the active participation and commitment of GI producers and users. With regard to the road sector the practice of involving stakeholders for gathering data and requirements has been already implemented: e.g. for the implementation of MIRE road information system, as illustrated in Chapter 2. More recently it has been encouraged also in Italy, where the Ministry of Infrastructure and Transport (MIT) launched the Smart Roads initiative (Annex to the DEF 2016 National Plan ITS) based on the engagement of stakeholders to promote both the development of national standards for applying digital innovation to roads (digital transformation of infrastructure) and the adoption - by infrastructure managers - of minimum technology standards to make "smart" road infrastructure. In this context, the document titled as "*Functional standards for Smart Roads*", published by the Italian Ministry of Traffic and Infrastructure (2016), is a guidance to collect from different stakeholders all the specifications needed for gathering, processing and distributing data on road circulation, traffic and structural safety as well as road infrastructure data.

In this thesis the same approach has been used, and requirements gathering has been based on two main sources: a wide literature review and surveys with expert users (questionnaires and interviews) mainly focused on Italy as a case study.

The literature review conducted in Chapters 2, 3 and 4 represents a theoretical foundation on which the subsequent analysis has been based. It has been aimed at collecting road data, functionalities, uses and users of road information systems. The case study regarding the Italian Road Cadastre (presented in Chapter 3) also provided basic data by law. Observations on planning and design as well as construction requirements have been also collected from Italian standards, and compared with existing road inventories described in Chapter 2. In addition to this, this research aimed at capturing data through questionnaires and interviews. They have been carried with different stakeholders - as described in the next sections - in order to gather real requirements of road users - particularly, 3D needs - for the implementation of a Road Cadastre for large infrastructural project, able to describe roads along their full life cycle, and to provide different stakeholders with information related to their specific use of the Road Cadastre. As the research is aimed at investigating how 3D GIS can be helpful in the implementation of a flexible and integrated road information system usable throughout the entire project chain, from design to production, by different users, different points of view by various experts have been considered fundamental. For his reason and in consideration of the multifaced aspects, issues, uses and characteristics of road information systems emerged from the analysis of the background, the research method used in this research work is mainly qualitative.

6.2 Qualitative research method: collecting requirements by questionnaires and interviews

As noted by Gill et al. (2008), qualitative research, as well as requirements elicitation, benefit from interviews and questionnaires to get information directly from people involved in the research topics addressed. They are very helpful to collect needs by users. Standardisation bodies confirm the importance of working groups of experts on specific topics, each bringing the own personal competence and experience. Nevertheless, as shown in Chapters 3 and 5, sometimes the involvement of stakeholders in gathering requirements is not enough if that is not followed y practical tests involving users for validation.

Questionnaires can provide evidence of patterns among large populations (Kendall, 2008): moreover, because of large sample sizes, according to Oppenheim (1992), they are usually viewed as a more objective research tool able to produce generalisable results. However, according to Bryman (2008), the measurement processes used create an artificial sense of accuracy disconnected from everyday real life.

The interview, instead, is a managed verbal exchange (Gillham, 2000; Ritchie and Lewis, 2003) used "to gather descriptions of the life-world of the interviewee with respect to interpretation of the meaning of the described phenomena" (Kvale, 1983).

According to Kendall (2008), in comparison with questionnaires, qualitative interview data often gather more in-depth insights on participant attitudes, thoughts, and actions. Gill et al. (2008) remark that the purpose of the research interview is to explore the views, experiences, beliefs and/or motivations of individuals on specific matters, and consider it most appropriate where little is already known about the study phenomenon or where detailed insights are required from individual participants. Richman et al. (1999) and Yin (2009) emphasised the interpersonal nature of the interview context where participants can ask for clarification, elaborate on ideas, and explain perspectives in their own words; however, the interviewer can use questioning to lead or manipulate interviewee responses (ibidem). The absence of neutral conditions have been highlighted also by Fontana and Frey (2000) and Silverman (2000) (2006) due to the personal interactions which lead to negotiated and contextually based results, with a partial and incomplete understandings of a participant's point of view as a consequence (Lankshear and Knobel, 2004). A wide literature review about that can be found in Harris and Brown (2010).

Different kind of questionnaires and interviews can be used.

Siniscalco and Auriat (2005) noted that a questionnaire is defined as 'standardised' when each respondent is to be exposed to the same questions and the same system of coding responses. Foddy (1993) distinguished between close-ended questions (limiting the respondent to the set of alternatives being offered) and open-ended questions (allowing the respondent to express an opinion without being influenced by the researcher). Questionnaire design technique is addressed by Gillham (2012).

Face-to-face interviews, as the synchronous communication in time and place, have long been the dominant interview technique in the field of qualitative research. As described by Bernard (1995), they may be arranged differently. Structured interviews rely on a categorisation of questions and a predefined format focusing on systematic sampling together with quantification and statistical approaches. Unstructured interviews allow the respondent to discuss more freely while involving opinions, feelings and behavior in the answering process: the interviewer provides guiding questions whose answers will be interpreted afterwards. Semi-structured interviews (also called "conversations with a purpose") are a qualitative method of inquiry where open questions are pre-determined. Compared to structured interviews (just requiring 'yes' or 'no' answers or a pre-determined set answer), they allow further and in-depth responses. Unlike the unstructured interviews (that leave the interviewer free to address the topic proposed), they do not move far from the main topic and aims at capturing information related to opinions, feelings and behaviors: this interview design is well suited for inductive research (Ghauri and Grønhaug, 2010). As Ritchie (2003) notes, individual interviews (the most used) allow detailed subject coverage and investigation of people's personal perspectives. Paired (or triad) interviews are in-depth interviews to two or three people at the same time, helpful when they form an occurring unit; they allow both individual depth and comparisons and interactive or joint reflections. Focus group or group discussion stimulate debate and comparisons, but do not allow such in-depth understanding.

Brookhart and Durkin (2003) and Lai and Waltman (2008) highlighted that questionnaires and interviews are often used together in mixed method studies investigating: that allows benefiting from their different and possibly complementary strengths and weaknesses (Harris and Brown, 2010). To complement the above in-depth interviews, a questionnaire-based approach is widely used to collect information from a large number of people, who are able to answer in their own time also from different locations. This approach is best used for factual data to be analysed quantitatively and systematically. Also Harris and Brown (2010) remarked that structured questionnaires and semi-structured interviews are often used in mixed method studies to generate confirmatory results despite differences in methods of data collection, analysis, and interpretation. Such multi-method approach of integrating qualitative and quantitative health services research by using questionnaires in qualitative interviews found the definition of 'Questerviews' coined by Adamson et al. (2004). It has been used in this research.

6.3 Research workflow

In order to define a conceptual approach and model for the implementation of a smart road inventory based on 3D GIS, this study started from the collection and analysis of requirements (especially in a 3D context) related to road networks. These have been collected from literature, existing models, and users, with Italy as the focus of the study, and in particular Sicily as the focus of more detailed practical work. The workflow has been developed also in accordance with the INSPIRE Data Specifications "*Methodology for the development of data specifications*", and is summarised as follows:

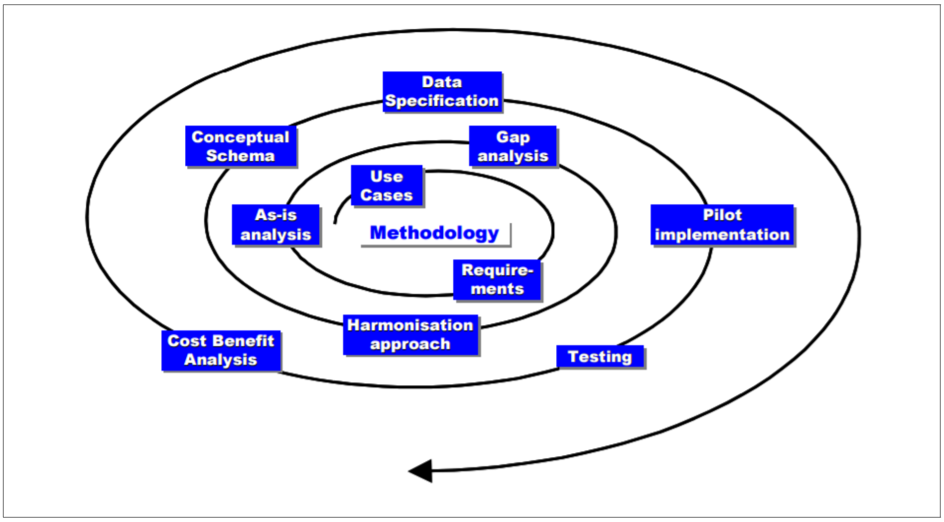


Figure 70. Spiral development process (source: INSPIRE Directive)

The process described above exemplifies a modelling approach where the user requirements, in our case mixed with the literature and standards, are first modelled on the conceptual level and then converted to specifications on the implementation level. This thesis addresses this workflow by the pilot implementation stage, whereas testing and cost-benefit analysis will be addressed as further work.

6.4 Research design

The research design constitutes the framework for how to collect and analyse data. It comprises a plan to relate the research problem to relevant both theoretical and empirical research (Ghauri and Grønhaug, 2010). In order to answer to the main research questions as addressed in Chapter 5, it concerned the selection of the literature (manuals, standards, scientific reports, articles, books and documentation), and of the road information systems and software to analyse, the selection of the expert users grouped into different categories (as emerged from Chapter 4) for the surveys, and the design of questionnaires and interviews (in terms of typology – i.e. using open questions, face-to-face semi-structured interviews both individual and trial, and so forth). With regards to the research problem, as mentioned, this study has required the involvement of road designers to evaluate the Italian Road Cadastre as well as other people within other companies providing further experiences from different points of view.

6.4.1 Literature review

The literature study aims at creating the theoretical foundation on which the analysis is based. A preliminary overview relating to standards on road infrastructures was first conducted to understand the complexity of the road registration process. The aim was also to permit comparison between the results of the investigation into the users' perspective on the problem and the requirements outlined by the standards-based, which have been defined to guarantee interoperability among users. Examples of road catalogues and inventories from different countries have been studied with a particular focus on the Italian Road Cadastre (including aims, datasets, and techniques for recording and accessing data) also to understand the legal requirements for a Road Cadastre in Italy.

Also to design the questionnaires and interviews, a preliminary literature review of manuals for road design and the analysis of drawings of road projects was carried out to identify "3D road situations" - i.e. situations where 3D data could be helpful.

A short literature review on 3D GIS theory has been considered as well in order to understand 3D GIS's potential benefits in the description of 3D spatial road situations.

6.4.2 Data Requirements Review

As current road inventories include data relating to existing roads only, a literature review relating to the data required for new road projects was also carried out to identify information required to support the road building process: in fact, that is useful with the population of the road inventory dataset. Road maintenance is closely related to many other road issues (e.g. safety, road ownership, road services, civil and environmental protection) and deals with roads both existing and to be built: therefore, manuals on road maintenance were also reviewed (such as the guidelines on the Road Asset Management by the European Union Road Federation (2014)).

A preliminary study covering different road components and layers, on the relations between road infrastructures and the terrain, and on the objects standing on the road surface and underground has helped to define the 3D situations relating to roads.

6.4.3 Review of the existing models (bespoke and off-the-shelf)

Existing models such as some GIS-based inventories and Italian Road Cadastres (the regional Road Cadastre of Piemonte (North Italy), the Provincial Road Cadastre of Bologna (Emilia Romagna), the Local Road Cadastre of La Spezia (Liguria), and the Road Cadastre made by ANAS for the national road network) have been analysed. Data structures and functionality for road inventories are also included in off-the-shelf software aimed at helping road owners to implement their own cadastre: therefore, some of them (e.g. "Catasto Strade-Geoweb Framework", as well as 3D GIS Strade by 3D GIS company from Padova, Italy, and Roads 3D-GIS by Sivan Design) have been considered along with BIM (Building Information Models) used for civil engineering and infrastructures (Infraworks 360 and AutoCAD Civil 3D by Autodesk).

In addition, other existing road asset management and maintenance software packages have been considered (PMS - Pavement Management System, a software planning interventions surface that includes a digital archive about the status of road surfaces). The data structure and functionality of the models above have been compared with the Italian Road Cadastre as defined by law to highlight similarities and differences among aims, datasets, and techniques for recording and accessing data of both systems: i.e. between the theoretical model and its real application (that is based on the real needs and capabilities of users). In particular, the review of the existing ANAS Road Cadastral System has been studied.

6.4.4 Questionnaires

These were designed to collect information on current road inventory functionality and limitations from current road users, as well as to identify their needs with regard to 3D road data and general inventory systems. Road users were selected from stakeholders involved in various stages of the road life cycle (both construction and maintenance).

Eighteen questions (both closed - often added with checklists and multi-option variable - and "fill-in-the-blank" and open-ended) have been prepared for questionnaires, and added of explicative pictures about 3D road situations.

To date, the questionnaires have been distributed to a group of respondents from one Italian engineering consulting company providing highly integrated specialised engineering services as part of a pilot study. The company has a technical staff of about 600 people - about 100 of them working in Italy - and Regional branches also in Africa and Middle East, works both in Italy and abroad on planning, design, and project and construction management of works relating transportation infrastructure, environment, and main civil structures, and over fifty years it has carried out more than 700 projects in Italy and abroad for a value of more than100 billion US$. Specifically, the questionnaire was given to 9 road designers from a team of this company that is based in Sicily (Italy). This included 2 project managers (1 engineer and 1 quantity surveyor) and 7 designers (6 engineers and 1 quantity surveyor) dealing with projects design (both new construction, and upgrading and maintenance).

The purpose of the questionnaire was to collect information about the knowledge of, and use of the current Italian road inventory by a sample of road designers, eliciting their opinion on its limitations and also on the potential of the Road Cadastre, along with details of further data needed by road designers but not currently included (in particular from the perspective of a potential 3D road inventory).

The questions (open ended and closed, and with explanatory images where required) were focused on the following topics (Table 14):

a) Existence of a Road Cadastre in your region
b) Any use of road cadastral data in the activity of road design
c) Adequacy of the dataset provided by the Road Cadastre (as established by the Italian law), and improvements suggested
d) Benefits of a 3D Road Cadastre and requirements
e) Integration between road projects' data and Road Cadastre's data: whether useful, which data needed
f) Integration between 3D road models and the Road Cadastre - whether this would be useful and if so what 3D data would be needed
g) Whether any standards and laws exist that establish a requirement for a 3D description of roads
h) Whether they know of any projects that are collecting road data in 3D

Table 14. Topics of the questionnaires

The sample of the questionnaires can be found in Appendix...

6.4.5 Interviews

The interviews conducted in this research have been mainly semi-structured and the aim has been to allow for the respondents to elaborate on the topics in order to gain as much information and new insights as possible. The most of semi-structured interviews - both individual and paired or triad (for people of the same work unit) - have been carried out face-to-face with road stakeholders based in the same country (Sicily). An only interview (with an archaeologist of Rome) has been carried out on Skype.

A list of eleven questions has been compiled beforehand to elicit information directly from some samples of expert users respectively involved in:

1. Road design (including new roads planning and projects of updating, adaptations and maintenance),
2. Road management (including construction and maintenance),
3. Underground utilities management,
4. Preventive archaeology and Archaeological Territorial Information Systems both in urban and in suburban contexts.

With regard to Road design, semi-structured interviews were carried out with the CEO (individual interview) and three project managers and designers (individual and triad interviews) of the same Italian Civil Engineering company where questionnaires were distributed. In comparison with the questionnaires the purpose was to collect more detailed information about the type of road data required and motivations; design, construction, maintenance, management of roads, underground utilities, and accessories (e.g. signs, barriers, etc.).

Road management (including construction and maintenance): ANAS is the most important private institution that manages roads in Italy. Currently it is the only institution to have implemented a Road Cadastre in Sicily, which includes 4,000 km of roads. An individual interview was conducted with the Operational Manager of the ANAS Road Cadastre for Sicily.

Underground utilities management sector: the respondent was an engineer from a company dealing with the water systems management in a municipality in Sicily.

Archaeological institution: the respondent was an archaeologist from the Soprintendenza Speciale per i Beni Archeologici di Roma, director of many excavations also in urban contexts in Rome and coordinator of SITAR project for the implementation of a management system for protection of Archaeological Heritage. Archaeologists deal with data related to road infrastructures contexts in the case of new constructions or maintenance interventions of roads (which require excavations), with the purposes of preventive archaeology and support to urban planning. They deal with all those, who do underground work, including ANAS. In urban historical contexts, they are especially involved when telephone, high voltage and gas cables, and all utilities in the roadways are changed (often daily): in fact, works must be authorised by the Superintendency after a preventive excavation. Currently they use 2.5D GIS (with CAD added with elevation values) for documenting excavations.

In general, the questions addressed the same topics of the questionnaires, but they went in-depth about opinions and motivations, and more details and explanations were asked to the respondents. Assuming that in Italy just a few of institutions that own or manage roads have created a Road Cadastre, the interviews focussed on collecting more detailed information about the type of road data required, and further questions were focused on:

a) Difficulties encountered by road owners when implementing the legal Road Cadastre
b) Current use of CAD and GIS relating to road projects/construction/maintenance/management – in particular the use of 2D CAD drawings
c) Dataset adequacy of the Road Cadastre for /or adequacy of current approaches when documenting 3D road situations and relationships between roads and environment
d) Potential usefulness of 3D GIS for Road Cadastre
f) Need of CAD (2D)
g) Relevance of International Standard: relationship, real usefulness and real execution with regard to roads and Roads Cadastre

Table 15. Further topics of the interviews

Lastly, the interview with professionals involved in the underground utilities management was more focused on 3D needs, underground interferences, and need of data integration, while the interview with the archaeologist in Rome has been focused on intereferences and requirements for preventive archaeology in built contexts (especially when underground structures have to be built).

The interviews have been conducted like a conversation allowing the respondent to freely elaborate on the topic. General questions have been posed to all respondents to capture their experience-based knowledge on the research topic and their evaluation of the current Road Cadastre. Specific questions have been posed to different stakeholders to obtain peculiar information on work procedures and specific requirements and issues. All interviews but one (with the underground utilities manager) have been recorded in order to ensure that no essential information was lost. These recordings have then been transcribed in full in order to be able to properly quote the respondents. The reader should be made aware of the fact that all interviews have been conducted in Italian and that the answers have been translated to English, which means that the choice of words and phrasing are affected by the authors' ability to translate (as well as the Italian Road Cadastre dataset and features from Italian standards).

6.4.6 Analysing the resulting data

The outputs of the various processes described here were transcribed and analysed for specific references to data and functionality requirements for Road Cadastres, both for 2D and 3D cases. Analysis involved both quantitative methods (in a small part and mainly with regard to some closed questions or questionnaires, as the diagrams of Chapter 8 show) and qualitative approaches (from results of interviews and users observations) in order to make coparisons among all results. Qualitative analysis firstly involves gaining an overall impression of the data and examining it at high level for patterns and trends. Data have been grouped by a process of categorisation and summarised according to a replicable method (Sharp et al., 2011). The number of summary tables reported in Chapter 7 and 8 show the long and meticulous approach that have been carried on to analyses all sources of information that are numerous and different.

6.4.7 Comparison between the Italian Road Cadastre data structure and users needs

The needs of the stakeholders, collected via the questionnaires and interviews, have been compared with the Road Cadastre data structure and contents proposed by standards, in order to highlight where the standards meet the requirements gathered, and also identify missing elements and possible improvements (including 3D development). A number of tables with such comparisons have been produced in order to highlight results from different point of view: i.e. considering different data required (2D and 3D), format of data, source, use, and user. That aimed at exploring in particular which 3D data a Road Cadastre should provide to road users/stakeholders for describing, representing, analysing, and managing road infrastructures at each stage of the life-cycle.

Importantly, such data have been also compared with data structures of INSPIRE Directive and softwares currently used with specific purpose.

6.4.8 Definition of a model and prototype

The results of the comparison have been used as guidelines to draft a preliminary conceptual model extending the current Road Cadastre to meet the identified needs of stakeholders, as well as to frame a broader approach to road data management. Many approaches have been explored to find the main suitable for the case study analysed (to be then extended to further cases). In this process, again summary and comparison tables have been used and then transferred into diagrams and schemes.

The three main stages for the implementation of the model (conceptual, logical and physical, as illustrated in Chapter 9) have been based on the requirements gathered also in terms of dataset and physical structure.

Case research provides the opportunity to study contemporary phenomenon in real life contexts. Hence, a prototype of the model has been tested on a webGIS platform, as shown in Chapter 9, in order to experiment 3D GIS in for road cadastral purposes and evaluate if 3D GIS applications can be used for documenting bot existing road asset and road infrastructure projects for different cadastral purposes.

6.5 Summary

The qualitative research method has been adopted for carrying on this research. On the basis of the analysis of background on road information systems (existing and experimental), technologies used (particularly, aimed at 3D road description) specific and thematic road software, GI and road related standards (at international, European and national level), different components of the road artifact relevant in 3D road situations, and road cadastral uses, the research benefited from surveys with expert users, through questionnaires and interviews. Importantly, as respondents had different knowledge and come from different professions, semi-structured interviews have allowed choosing what questions to ask each respondent in order to maintain a level of relevance. The analysis of requirements gathered, grouped by categories and compared according to type of data, source, user, use, and so forth have been oriented to implement a 3D Road Cadastral model taking into account the multifactorial nature emerged from the research work and assess potential of 3D GIS for different road cadastral uses.

Chapter 7

Requirements gathered from literature review

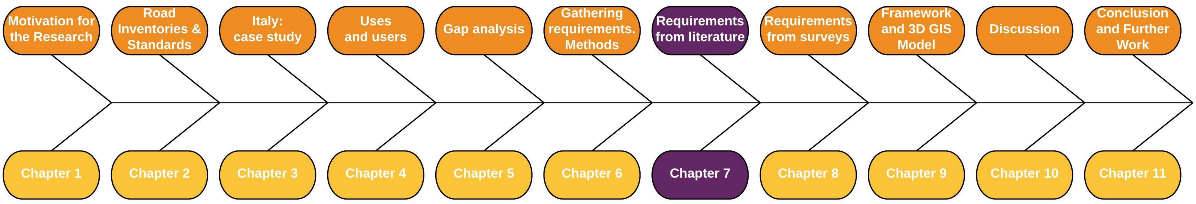


Figure 71. Overview of Document Structure showing context of this Chapter

The literarure review conducted in Chapter 2 has highlighted a number of different sources providing potential road cadastral requirements in terms of type of data and functionalities of road information systems, which derives from standards, studies and existing databases and inventories. With this regard, Chapter 3 has focused on the Italian case. Chapter 4 demonstrated that the current Italian road cadastral dataset should/might fit to many uses, whereas Chapter 5 emphasised its current limitations: e.g it does not include data and functionalities required by daily situations (see Chapter 1 and Appendix 1), current and potential uses (see Chapter 4), and standards and the literature (see Chapters 2 and 3). Importantly, even the legal National Road Archive (where all Italian Road Cadastres' information should converge) requires to Italian road institutions road data relating to five main topics that currently are not covered by the legal Road Cadastres dataset.

Hence, on the basis of the literature review (Chapter 2 and 3), the potential and current uses of the Road Cadastre (Chapter 4) and the gap analysis conducted (Chapter 5), this chapter illustrates the main requirements from the literature on road classifications, design, maintenance and management (including safety and traffic control), and compare them with the current structure and dataset of the Italian Road Cadastre as established by law. It aims specifically at defining a set of road features (also in 3D) to be modelled for cadastral purposes. It also collects from the literature functionalities requirements for implementing a road information system fitting to road cadastral uses during the whole road life-cycle.

The first section illustrates National Road Archive requirements (from the legal text), while sections from 7.2 to 7.5 address requirements from various literary sources grouped into the five topics provided by the Archive (i.e. technical and administrative, design, traffic management and ITS, and safety reqirements). Results, as mentioned, are also compared by summary tables with the current road cadastral data.

7.1 Requirements for the national road network management: the National Road Archive data

As mentioned in Chapter 3, the National Road Archive is a support tool for technical and political decisions on planning and programming of new infrastructure and the existing network adaptations, as well as interventions aimed at road safety and intermodality. It was established by art. 226 of the Road Code in order to include the list of all the roads of the Italian road network and related data coming from all Road Cadastres implemented in Italy by law. Currently, it is limited to the main data of the network of national interest. It is fully computerised and divided into five interconnected sections with direct access, able to provide an overall or selected set of data. For each road it requires the following data (currently not included into the basic legal Road Cadastre, as shown by the Table below):

Requirements from the Road National Archive (New Road Code, 1992)	Required by the legal Road Cadastre
Technical and administrative categories (status) and related data for each road	**Partially**
Practicability in the various road sections	No
Geometric and structural features	Yes
Circulating vehicles characteristics	No
Any traffic restrictions (also temporary) and occupations	No
Appurtenances	Yes
Buildings	No
Crossings	Yes
Vehicular traffic by road category for each road	**No**
Vehicular traffic for different routes, time, and category of vehicles	No
Incidents	**No**
Exact incident location	No
Extent, mode and damages to property or people type, and administrative sanctions	No
Identification data of vehicles involved	No
Personal data of vehicle owner and people involved, with type and year of release of driving license.	No
State of viability by dump tracks	**No**
Pollution	**No**

Monthly data from monitoring devices (by road owners)	No

Table 16. Data required for the National Road Archive implementation and comparison with the legal Road Cadastre

The following paragraphs describe what to model also in accordance with the thematic sections of the National Road Cadastre, relating to the multiple road cadastral purposes.

7.2 Road technical and administrative requirements

As addressed in Chapter 3, road classes are fundamental to the road identification and are related to different road characteristics: within a denomination or identification code they include a variety of features. Nevertheless, as argued in Chapter 4, actually the real features of many roads do not always correspond to the legal classes assigned. Such features have to be evaluated in order to establish the administrative and technical class of each road and decide whether it would be kept or should be changed over time (depending on specific parameters). Chapter 4 has highlighted difficulties in classifying roads, especially those existing. Hence, a first requirement coming from Italian standards relates the collection and storing within road information systems of all features determining the class of each road.

Administrative road classes by the New Road Code of 1992 depend on the following data (partially included into the current Road Cadastre):

What to model (Data identifying administrative road classes by the New Road Code of 1992)	Required by the legal Road Cadastre
Administrative Class	Yes
Identification code	Yes
Owner	Yes
Responsible	Yes
Territorial area	No
Technical class included	Yes
Town inhabitants	No
Connections (A is linked to B)	No

Table17. Requirements from the legal definitions of the adminstrative road classes (source: New Road Code, 1992)

Technical road classes by the New Road Code of 1992 are already included into the legal Road Cadastre. They depend on multiple data provided by the Italian road design standards (Act of November 5, 2001) and relating to geometry, technical features (such as speed limits), users categories admitted, and dimensions of different road components. In the light of above, within the Road Cadastre their code and denomination should be also associated with all the technical features provided by corresponding road design standards and later described.

What to model (according to the technical classification by the New Road Code of 1992)	Required by the legal Road Cadastre
Road Type	Yes
Functional class	Yes
Independent carriageways (or any impassable median) (min)	Yes
Number of lanes for each carriage (min)	Yes
Paved shoulder on the left	Yes
Emergency lane or paved shoulder on the right	Yes
Intersections	Yes
Private accesses	Yes
Fence and user-assistance systems (reserved and marked)	Differently named
Special service/Parking areas	Yes
Deceleration/Acceleration lanes	Yes
Service road	No
Sidewalk	Yes

Table 18. Requirements from the legal definitions of the technical road classes (source: New Road Code, 1992)

With regard to the data allowing the **technical/functional classification of existing road**, standards by the National Research Council (D.P. CNR N. 13465 of September 11, 1995) established the elements to be surveyed, by which tools and how to provide data.

Requirements from CNR standards of 1995 for road classification (technical elements to be surveyed)	Kind of data to be provided	Source	Required by the legal Road Cadastre
Road platform total dimension (cm)	(cm)	Surveys by instruments with centimetric accuracy	Yes
Road section (existing) (including number of lanes, medians, shoulders, etc.)	Graphic schemes in 1/100 scale for uniform trunks		Yes
Road axis features: circular curve radii, variable radius curves, longitudinal gradients		Surveys by celerimetric non-precision conventional tools, high-efficiency direct methods, and maps (min scale 1/5000)	No
Roadways cross slope of for each curve		Surveys by celerimetric non-precision traditional tools,	No
Unobstructed sight distance (min every 100 m)		Analytical and/or photographic methods	No
Type of intersections with reference to the type of connected roads	Graphic schemes in 1/1000 scale		Only graph and attributes
Typology of safety barriers, by the Ministerial Act LL.PP. n° 223 of 1992 and			Yes

subsequent integrations and modifications			
Any crossing of inhabited centres	Urban plan		Graph
Average daily traffic for vehicle categories allowed			No
Existence and location of service areas and/or parking			Yes
Load or shape limits on structures			No

Table 19. Requirements for the technical/functional classification of existing road (source: D.P. CNR N. 13465 of September 11, 1995)

7.3 Road design requirements

The Act of November 5, 2001 defined the features required for designing road, as follows:

Requirements from the Act of November 5, 2001	**Required by the legal Road Cadastre**
Road Type	Yes
Territorial area	No
Denomination (Main road; Service Road)	Yes
Number of lanes in each direction	Not theoretical
Lane width (m)	Not theoretical
Min median width (m)	Not theoretical
Min left shoulder width (m)	Not theoretical
Min right shoulder width (m)	Not theoretical
Min inner margin width (m)	Not theoretical
Min side width (m)	Not theoretical
Min radius (m)	Not theoretical
Design speed range (km/h)	No
Speed limit (km/h)	No
Max gradient (%)	No
Transverse coefficient of adhesion	No
Level of service	No
Service capacity per lane (vehicles/h)	No
Road users categories admitted	No

Table 20. Road design requirements (source: Act of November 5, 2001)

As illustrated in Chapter 2, in Italy in 1980 the Official Bulletin of the National Council of Research (CNR) n. 77 provided the first "Instructions for drafting road projects". This was followed by the Law 109/1994 on the Public Works (the so-called "Merloni Law") and its Implementing Regulation Act (D.P.R. n. 554 of December 21, 1999) that defined a list and characteristics of documents and data required for all construction projects (including both building and infrastructures) during three different stages (preliminary, final and executive). Finally, the Act of November 5, 2001 by the Italian Ministry of Infrastructures and Transport established "Functional and geometrical standards for road design". The following data (derived from GIS and CAD) is requested (Table 21):

Requirements from the Merloni Law (1994)	**Project stage**			**Kind of data**	**Required by the legal Road Cadastre**
	Preliminary	**Final**	**Executive**		
Environmental, archaeological, historical, topographical, geological, hydrological, hydraulic, geotechnical and interference investigations, related reports and graphic designs, Project Technical Reports and Environmental Impact Reports	✓	✓	✓	PDF from text	No
Maps at different scales: from 1:100.000 to 1:500	✓	✓	✓	PDF from GIS or CAD	No
Altimetry drawings. Longitudinal profiles at different scales (from 1:25.000 to 1:100) and Cross-sections (1:100)	✓	✓	✓	PDF from CAD	No
Photos	✓			JPG or similar	No
Interchanges and intersections	✓	✓		PDF from CAD	No
Location of construction lots, interferences and permits		✓		PDF from text	No
Main road structures and plant		✓	✓	PDF from CAD	No
Signage and Expropriation of lands		✓		PDF from CAD	No
Special Specifications, Environmental Monitoring, Maintenance Plan, Other documents		✓		PDF from text	No

Table 21. Requirements from Merloni Law (1994)

Similarly, Table 22 refers to road data requirements from the D.P.R. n. 554 of December 21, 1999:

Requirements from D.P.R. n. 554/1999	**Required by the legal Road Cadastre**
Administrative and Technical road category	Yes
Speed limits, Design speed range and speed diagrams	No
Constructive elements of road (roadway, shoulder, pavement, etc. with size, position, spatial relationship)	Yes
Geometry of the road axes and Geometrical and traffic features of road sections	Partially
Road structures (bridges, tunnels, etc.)	Partially
Barriers and lighting elements	Yes
Signage	No

Table 22. Requirements from D.P.R. n. 554/1999

In addition to the technical features by law, D'Apollo (2015) highlighted further technical requirements of roads, not included in the New Road Code: for example, with regard to motorways (A) - a special type of vehicular road, aimed at the fast driving in safety conditions (D'Apollo, 2015) – he included additional requirements like a series of geometric and constructive conditions (e.g. provision of junctions with access ramps pushed aside from the main traffic flow), the positioning of emergency phones at certain intervals along the track, an appropriate horizontal signaling (dotted white lines to delimit the width of the lanes and continuous white line to delimit the space for traffic, defining the aisles and emergency pitches), a drainage commensurate with the medium atmospheric conditions of the geographic area of reference, and essential safety elements such as reflectors, sound strips, and road surface able to avoid aquaplaning (ibidem). Moreover, motorway have tollgates for the payment of the access (a contractual relationship between the operator and the user who in turn expects vigilance and maintenance) (ibidem).

With regard to intersection, Esposito et al. (2007) mention road design standards requirements that include

a) una completa conoscenza dell'area su cui deve svilupparsi l'intersezione;

b) le caratteristiche geometriche in prossimità del nodo, dei rami confluenti, per lunghezze variabili, a seconda dei casi da una ad alcune centinaia di metri;

c) la velocità di riferimento o di calcolo per il dimensionamento degli elementi geometrici;

d) I dati di traffico

7.4 Road traffic management and ITS requirements

With regard to traffic related information also required by the National Road Archive, the Road Cadastre dataset does not provide any specific data (apart the **geometry**). Studies on road information system aimed at the road traffic management (reviewed in Chapter 2) mention the following data:

Requirements from studies on road information systems (from Chapter 2)	Required by the legal Road Cadastre
Road geometry (e.g. planar geometry, elevation, lane sections)	Yes
Plane features	No
Speed limits	No
Objects surrounding the road	No
Priorities of intervention	No

Table 23. Requirements from studies on road information systems (from Chapter 2)

From the review of ITS systems in Chapter 4, CIVITAS (2015) provided data required to this purpose, while Ezell (2010) highlighted data required by using some ITS applications:

Requirements features for ITS (CIVITAS, 2015)	**Required by the legal Road Cadastre**
Road network	
Road capacities	No
Speed limits	No
Intersection characteristics	Partially
Important parking locations (including capacity)	Partially
Public transport	
Routes	No
Important transfer points/stops	No
Frequency	No
Intersection priorities	No
Cycling	
Cycling lanes and their characteristics	Partially
Intersection priorities	No
Legacy systems	
Traffic lights and type of control	No
Information panels	No
Parking information systems	No
Intelligent Transport Systems and traffic management in urban areas	No
Static and dynamic signs (e.g. for environmental zones)	No
Mobility patterns	
Identification of areas of trip generation (residential areas) and trip attraction (jobs, retail, leisure, hospital, parking)	No
Origin-destination relations, if possible differentiated by time of day (morning peak, evening peak, weekend, rest of the day)	No
Modal split figures	No
Traffic volumes on important routes, if possible differentiated by time of day	No

Table 24. Requirements features for ITS (CIVITAS, 2015)

Requirements features for ITS (Ezell, 2010)	Required by the legal Road Cadastre
Real-time Traffic Information Provision	
Information about delays due to: congestion, accidents, weather conditions, or road repair work	No
Route Guidance/Navigation Systems	
Transit routes and schedules	No
Navigation directions	No
Parking Information	
Parking Information	No
Roadside Weather Information Systems	
Roadside Weather Information Systems	No
Dynamic Message Signs (or "Variable" Message Signs)	
Dynamic Message Signs (or "Variable" Message Signs)	No
Ramp Metering	
Traffic volumes	No
Travel times	No
Real-time Status Information for Public Transit System (e.g. Bus, Subway, Rail)	
Trains' and buses' position	No
Arrival and departure information	No

Table 25. Requirements features for ITS (Ezell, 2010)

In addition to road design standards requirements (also including road traffic information like **speed, traffic volume** and other), for example, in order to design monitoring road traffic systems, the Guidelines of the Italian Ministry of Infrastructure and Transports (2001) require a relational database containing the following data:

Requirements from the Guidelines of the Italian Ministry of Infrastructure and Transports (2001)	Required by the legal Road Cadastre
Spatial references in the area (i.e. the monitored elements of the road system: e.g. section, trunk, corridor)	No
Basic time references (i.e. month, day, time spans within a day)	No
Aggregate time references (i.e. the time frame within which the monitoring is performed)	No
Minimum traffic parameters to be detected (in the absence of specific standards): number of circulating vehicles, per lane, per direction, date and time of the vehicle passage, speed, classification	Only cassification
Flow, speed and density (number of vehicles contained in a trunk of unitary length infrastructure at a predetermined time)	No
Presence/transit of vehicles, queue lengths, level of traffic-congestion, travel times	No

Events influencing the road traffic (accidents, bottlenecks, turning maneuvers, lane changes),	No
Vehicles characteristics (total weight, axle weight, length, height, classification by type, identification, number of passengers)	No
Transit units (cars, vehicles used for freight transport, two-wheeled vehicles, other vehicles, pedestrians)	No
Vehicle infringements or defects (speeding, failure to stop at the stop sign or red traffic lights, no parking, contradiction march, defect of the headlights, flat tires)	No
Meteorological parameters and environmental conditions (fog, ice, wind, rain, and snow)	No
Concentrations of pollutants	No
Sound pressure levels	No

Table 26. Requirements from the Guidelines of the Ministry on traffic monitoring systems (2001)

Moreover, a monitoring road traffic project requires different documents that the Guidelines specify, as follows:

Requirements from the Guidelines of the Ministry on traffic monitoring systems	**Projects stages**		**Required by the legal Road Cadastre**
	Preliminary	**Final**	
Reports			
Reports on purposes of the projects, environmental feasibility, available areas, stages of the project, and technical features	✓		No
Reports on design criteria (in particular with regard to security, functionality and economy of management), the inclusion of the intervention on the territory, and details on: topography, geology, hydrology, landscape		✓	No
Drawings/ Tables			
Map at scale 1:25.000 (orography, transport system and existing services), 1:5.000 (relevant sites), different scale (special artifacts required)	✓		No
Part of the land/urbanplan with the exact indication of the intervention sites; map at scale 1: 2000 (description of the concerned areas); c) maps, sections and profiles at scale 1: 100 (all the punctual works)		✓	No
Tables (activities, quantity, and resources used: workers and equipment)	✓		No
Costs			
	✓	✓	No
Specifications			
		✓	No

Table 27. Requirements from the Guidelines of the Ministry on traffic monitoring systems (2001) – Kind of data grouped depending on the project stage

In particular, in order to produce the final report, according to are required the following data:

Requirements for producing the final report from (Guidelines of the Italian Ministry on traffic monitoring systems, 2001)	**Required by the legal Road Cadastre**
Geometric features	
Arc Lenght	Yes
Cross section (dimensions and shape)	No
Roadway width	Yes
Number of lanes and directions	Yes
Median	Yes
Shoulders	Yes
Special lanes	Yes
Sidewalks	Yes
Stop areas	Yes
Slope, tortuosity, percentage of road trunks with visibility for overtaking	No
Number of intersections	Yes
Number of the motorway toolbooth lanes	No
Functional features	
Road category	Yes
Owner	Yes
Medium speed	No
No flow travel time	No
Type of intersections (beginning and final node of road elements)	Yes
Data on traffic light cycles	No
Presence of roadworks and influences on the road traffic	No
Toll rate	No
Parking regulation and pricing	No
Regulation of the operation of loading and unloading of goods	No
Pedestrian crossings	No
Road surface and maintenance conditions	Partially
Lighting systems	Partially
Presence of significant settlements	No

Table 28. Requirements for producing final reports from the Guidelines of the Italian Ministry on traffic monitoring systems (2001)

The characteristics above are not an exhaustive list, but gives a framework of data to be modelled. They also include information on how the urban transport system beeing used. They can be compiled using statistical data, monitoring systems (e.g. from cameras or detectors at traffic lights), and traffic models. Sources of information that can be added to this are data from Google Maps ('typical traffic'), service providers, social media and local knowledge.

7.5 Road safety requirements

Road safety design, monitoring and management is very complex, as such field is interconnected with many others: road design, maintenance, weather conditions, etc.

The literature review addressed in Chapter 2 illustrated studies on road inventories aimed at road safety whose data are required to be compliant with analysis tools such as Safety Analyst,[96] the Interactive Highway Safety Design Model (IHSDM), and other procedures by the new Highway Safety Manual (Lefler et al., 2013; Lefler et al., 2010). As the topic is very large as well as the quantity of related data, they provided additional databases linked a main DB including: **speed data, roadside fixed object, signs, automated enforcement devices, railroad grade-crossing and bridge descriptors, land use elements related to safety, and safety improvements.**

Existing systems for safety management have also included the following data:

Requirements from existing road information systems (from Chapter 2)	Required by the legal Road Cadastre
Road network and surrounding area configuration and details	
Road characteristics including data on road cross-section and geometry: number and width of lanes, presence and type of shoulders and median, vertical and horizontal and vertical alignments, rural/urban designation, and functional classification pedestrian and cyclist facilities	Partially
Intersection details (e.g. intersection location, type, and layout, as well as control type) and interchange ram data	Partially
Motorway interchange/ramp (location, interchange type and ramp characteristics)	Graph
Barrier data (e.g. barrier type, post type, rail height, and terminal type)	Partially
Road condition	No
Weather condition	No
Traffic data (traffic volume, including annual average daily traffic (AADT))	No
Crash data (e.g. location, type, day and time of crash; vehicle types, occupant details, crash severity, and weather conditions)	No
Traffic control type and Vehicle Identification Number (VIN) (with model of the vehicle, body style, body type, curb weight, and wheelbase)	No
Costs for an agency's road network, percentage change in accidents per annum, average annual accidents saved, expenditure per accidents saved per annum, and first year of return.	No

Table 29. Requirements from existing road information systems (from Chapter 2)

[96]Safety Analyst software - described in Chapter 2 - requires typical data including: crash data (e.g. crash severity, crash location, day and time of crash), road condition, weather conditions, and vehicle types involved; road inventory data such as road length, horizontal and vertical alignment, number of lanes, speed, traffic volumes, heavy vehicle proportions; intersection details, such as layout characteristics, area type (rural/urban), traffic control type, traffic volumes through the intersections; interchange ramp data; cost data) (Candappa et al., 2014).

Further requirements have been defined by the Guidelines for road safety analysis by the Ministry of the Infrastructure and Transports in order to guarantee safety conditions on new roads (2001). The following summary table groups them according to phases:

	Preliminary project	**Final project**	**Executive project**	**Pre-opening stage**	**Existing roads**	
General aspects	✓	✓	✓	✓	✓	
Road function (if defined and compliant with the class assigned)	✓	✓				
Integration into the existing network	✓	✓	✓	✓		
Traffic (road features adequacy, traffic volume forecasted)	✓	✓			✓	
Number and type of intersections/interchanges	✓					
Rest areas and lay-bys (number, size, location, input, output, visibility)	✓	✓				
Lay-bys					✓	
Environmental conditions		✓	✓	✓	✓	
Surrounding landscape			✓	✓	✓	
Services			✓	✓	✓	
Safety devices			✓	✓	✓	
Maintenance and emergency vehicles			✓	✓	✓	
Dazzling night	✓	✓	✓	✓	✓	
Accesses (location)	✓	✓	✓	✓	✓	
Appurtanences (distracting advertising signs or lighting)	✓	✓	✓	✓	✓	
Geometry	✓	✓	✓	✓	✓	
Track/layout	✓					
Design speed		✓	✓	✓	✓	
Planimetric track and Altimetric track	✓	✓	✓	✓	✓	
Plano-altimetric coordination		✓	✓	✓	✓	
Visibility		✓	✓	✓	✓	
Cross section	✓	✓	✓		✓	
Drainage			✓	✓	✓	
Escarpments				✓	✓	
Intersections at grade		✓	✓	✓	✓	
Location/spacing		✓	✓	✓	✓	

Visibility and Ease of understanding		✓	✓	✓	✓	
Auxiliary/channeling/acceleration and deceleration lanes		✓	✓	✓	✓	
Maneuvers		✓	✓	✓	✓	
Intersections regulated by the right of way, Signalised intersections, Level crossings and Roundabouts			✓	✓	✓	
Split-level intersections		✓	✓	✓	✓	
Location/spacing		✓	✓	✓	✓	
Visibility and Ease of understanding		✓	✓	✓	✓	
Acceleration and deceleration lanes		✓	✓	✓	✓	
Ramps		✓	✓	✓	✓	
Ancillary facilities			✓	✓	✓	
Signage and lighting			✓	✓	✓	
Road markings and Delineation			✓	✓	✓	
Road signs			✓	✓	✓	
Speed limits			✓	✓	✓	
Traffic lights and Lighting			✓	✓	✓	
Margins			✓	✓	✓	
Unprotected obstacles			✓	✓	✓	
Adequacy of the barrier classes			✓	✓	✓	
Transitions between different types of barriers			✓	✓	✓	
Terminals of the barrier			✓	✓	✓	
Terms of installing barriers			✓	✓	✓	
Interaction between safety barriers and other objects			✓	✓	✓	
Road paving			✓	✓	✓	
Texture and Road paving condition				✓	✓	
Adherence and water film			✓	✓	✓	
Weak users	✓	✓	✓	✓	✓	
Network effects			✓			
Pedestrian crossings and paths, Cyclists and Motocyclists	✓	✓	✓	✓	✓	
Parking and rest areas	✓	✓	✓	✓	✓	
Traffic calming interventions			✓	✓	✓	
Speed bumps			✓	✓	✓	

Mini-roundabouts and Raised intersections			✓	✓	✓	
Lane narrowings and horizontal deflections			✓	✓	✓	

Table 30. Requirements from the Guidelines for road safety analysis by the Ministry of the Infrastructure and Transports (2001)

Road safety conditions influence the classification in derogation of existing roads defined by CNR standards of 1995 (D.P. CNR n. 13465 of September 11, 1995): "Criteria for classification of existing road network by art. 13, paragraph 4 and 5 of the New Road Code". In order to classify existing roads, the following road safety data and a safety report are required. Data (that are non-cadastral) relate to:

- the **accident rates of the last five years** (including absolute frequency and location of accidents and their consequences, i.e. number of injuried, and dead);
- the **technical characteristics** of the infrastructure (including road geometry; signs and any limitations; type, conditions and characteristics of road surface; safety devices and installations);
- the **mode of use** of infrastructure (e.g., medium daily traffic flow per year, and **speed** actually practiced by users on the different elements of the track);
- the **environmental conditions**, (e.g. distance from buildings and situations at roadside, particular climatic factors and any element that may increase the risk of accidents).

In addition, the safety report has to include data and documents, as follows :

Safety road requirements from CNR standards (1995) for classification of existing roads (technical elements to be surveyed)	**Kind of data to be provided**	**Required by the legal Road Cadastre**
Data capture stage (on road, traffic ad incidents) and investigations	Report	No
Examined track	Diagram	No
Collisions by critical incidents type	Diagram	No
Homogeneous trunks[97]	Planimetry (1:5.000) and profile (1:5.000/1:500)	No
Trunks with a high accident rate	Planimetry (1:2.000) and profile (1:2.000/1:200)	No
Defects surveyed and causes	Comparative framework	No
Evaluation of safety conditions	Report	No

[97] Different road trunks are defined "homogenous" when road technical fetures, level of traffic, traffic control, and prevailing environmental conditions are maintained in a restricted field variability. At least, they have to be 1 km long in the suburban area and 100 m in urban areas.

Table 31. Safety road requirements from CNR standards (1995) for classification of existing roads (technical elements to be surveyed)

According to the Annex IV of the 2008/96/CE Directive on "Road infrastructures safety management", accidents reports have to include

Requirements from the Annex IV of the 2008/96/CE Directive "Road infrastructures safety management"	**Required by the legal Road Cadastre**
Accident data: location (also georeferenced by GPS) with images and diagram, date and time, type of accident, type of collision, driver maneuver	No
Data on the infrastructure (environment, road type, type of intersection and junction, number of lanes, markings and signs, road surface, lighting, weather conditions, speed limits, road side obstacles)	No
Crash severity with number of injuried and dead, time between the accident and its registration, or the arrival of emergency services	No
Data on people involved in the accident (age, sex, nationality, alcohol level, drugs used, use of safety devices)	No
Data on vehicles involved (type, age, country, presence of security devices, date of last periodical technical check according to standards in force)	No

Table 32. Requirements from the Annex IV of the 2008/96/CE Directive "Road infrastructures safety management"

6.2 Road Maintenance Requirements

The maintenance plan with a set of checks and interventions to be run at fixed time intervals over the whole real estate life cycle has been required by the **Act 554/99** and the **Act n. 163 of April 12, 2006, in** accordance with the **UNI 10874:2000 standard ("Drafting criteria for manuals of usage and maintenance" of real estate – including roads)**, as a part of the "executive project". **CNR "Guidance for Editing Road Projects"** of 1967 required a maintenance planning schema of the road including timing for periodical interventions, implementation procedures, possible alternatives, and cost estimation - only if specifically required. **CNR standard of April 20, 1988 (Guidance on planning for road maintenance)** required surveyors to compile a paper form with **historical data, periodic surveys, evaluation of data collected**, and to compare with the List of main degradations (both of the surface and the structure) , Examples of indicators of the severity of some defects, Examples of evaluation of the status of road surfaces, and Levels of degradations.

Both ANAS (1999) and Bertoluzza (2005) include **road and structures defects (with location, measurements, photos, and descriptions), historical data, drawings, surveys data, evaluation of degradation, maintenance works**.

The European Union Road Federation (ERF) (2014), by the document titled as"Road Asset

Management - An ERF position paper for maintaining and improving a sustainable and efficient road network", provided guidelines to create a data structure for road maintenance and to implement a road inventory to be updated regularly; moreover, the "Transport Notes of the World Bank" (Burningham and Stankevich, 2005) require financial information (Table 34).

Requirements from the ERF (2014)	**Required by the legal Road Cadastre**
All the constructive elements of Roads (Asphalt lanes,Walking path, Parking area, etc.)	Partially
Equipment (Signs, Street lighting, Barriers, etc.)	Partially
Structures (Bridges, Tunnels, etc.)	Partially
Historical data on construction and Use of roads	Partially
Elements related to the management of public transport services, energy, water and telecommunication (only urban roads)	No
Requirements from the Transport Notes of the World Bank (2005)	**Required by the legal Road Cadastre**
Surface (paved, unpaved)	No
Type of maintenance (Routine, Periodic, Urgent), Work type and Description	No
Financial Unit Cost	No

Table 34. Requirements from the guidelines on road asset management by ERF (2014) and Transport Notes of the World Bank (Burningham and Stankevich, 2005)

Chapter 8

Requirements gathered from questionnaires and interviews

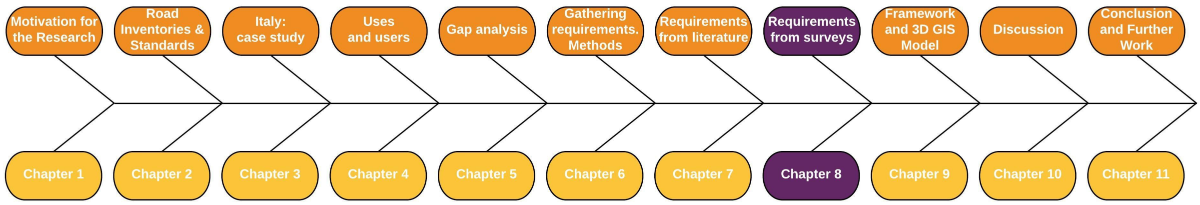


Figure 72. Overview of Document Structure showing context of this Chapter

In the previous chapter road cadastral requirements for Italy have been gathered from literature (standards, papers and guidelines). In addition to that, questionnaires and interviews have been carried out with different road users (according to the qualitative research method defined in Chapter 6) in order to gather their real needs relating to both current and potential uses of the Road Cadastre (see Chapter 5). These surveys were aimed in particular at determining:

1. what to model for implementing a Road Cadastre able to meet real different users needs;
2. which features should be modelled in 3D according to users;
3. whether and which 3D GIS functionalities are required by road users to make the current Road Cadastre really useful to them.

This chapter, hence, illustrates such results deriving both from questionnaires distributed to a pilot group of 9 road designers of an international engineering company based in Italy (as described in Chapter 6) and from semi-structured interviews respectively conducted with:

1. the CEO and three senior road engineers (project managers and designers) from the engineering company mentioned above;
2. a road manager from ANAS who is responsible for the ANAS Road Cadastre in Sicily;
3. an engineer from a local company distributing water to all the municipality of Palermo (Sicily) as involved in underground utilities management;
4. and an archaeologist of the Special Superintendency for the Archaeological Heritage of Rome. The latter is also leader of the head of the SITAR (Archaeological Territorial Information System of Rome) project on preventive archaeology, aimed at recording data

from excavations that in urban contexts are made for building subway lines, buildings foundations, roads and underground utilities repairs.

The first section of the chapter reports opinions on the status of the Road Cadastre and its current uses by questionnaires and interviews respondents, while the second one describes different expert users' requirements for a Road Cadastre grouped as follows: 1. general data, 2. specific 3D data, 3. functionalities required and 3D Road Cadastre benefits in the various road-related fields of activity of respondents.

8.1 Evaluating the current Road Cadastre – status and current use

In addition to the gap analysis addressed in Chapter 5, results of questionnaires and interviews to road designers have highlighted further road cadastral gaps that are mentioned here.

8.1.1 Results from questionnaires

Preliminarily, through the questionnaires, an assessment of the Road Cadastre status has been asked to the pilot group of 9 road designers within the same road engineering company. Results are summarised in the diagram below (Fig. 73).

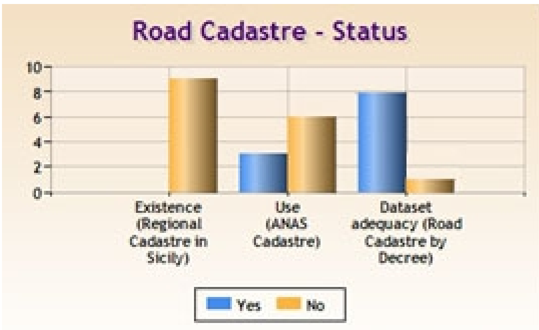


Figure 73. Evaluation of the Road Cadastre by the road designers' pilot group

At the beginning of the survey, 8 out of 9 respondents evaluated the current legal Road Cadastre and dataset adequate for road design, though the full implementation of the Act of June 1, 2001 (which specifies how to create and update basic Road Cadastres, as seen in Chapters 1 and 3) has not yet been achieved. All the respondents were aware that a Regional Road Cadastre has not been implemented in Sicily yet, and they currently can use only the ANAS Road Cadastre (i.e. the only one available to them). However, within the group, 6 out of 9 respondents (4 road engineers under 40, and 2 senior road engineers over 40) stated that they do not in fact use road cadastral data at all, whereas the remaining 3 senior road designers (i.e. a quantity surveyor, an engineer, and a project manager-quantity surveyor - all over 40), declared to use it for road design, road alterations/upgrading and properties identification purposes (in the latter case to identify any expropriation of land required for building new roads).

8.1.2 Results from interviews

Interviews with road designers confirmed their main uses of Road Cadastre data, i.e. for managing projects of road maintenance, upgrade, and new construction, but always relating to existing roads (as – they noted - "road cadastral data do not fit in the design"). However, according to them, data provided from ANAS Road Cadastre is too limited, as it includes only a 3D polyline (i.e. the three-dimensional road axis) and the location of the main road structures (bridges, viaducts, and tunnels). Also, information are provided in formats (e.g. GIS shapefiles) that road designers are not used to handle (or even are not able to use at all, as they are more familiar with CAD).[98]

ANAS managers, who mainly deal with road management and maintenance, on the contrary, consider the ANAS Road Cadastre an effective tool allowing them to manage the whole process of planning, financing and management of works, to forecast costs, and to establish objectively the priority of interventions. Also, it meets requirements from both standards and road managers/maintainers needs: graph, geometry and geomatics section are totally in accordance with the Act, while additional data (such as maps, ortho-photos, and additional survey information not required by the Act) enriched the basic Road Cadastre. However, most of such data are aimed at internal uses. Moreover, they consider their Road Cadastre appropriate for maintenance purposes but less useful to road designers who only use it in the preliminary stage of the project (but always need additional aerophotogrammetric and topographical data) and the design stage (but only for a small phase of the project). With regard to the legal Road Cadastre, requirements such as geomatics and what relating to geometrisation (e.g. geometries, entities like faces, nodes and edges, and projections of the geoid) are considered fundamental by road managers as envisaged by European Directives. However, the implementing specifications by the Act are considered difficult to implement in the daily practice because of the wide road network and the extremely huge effort of human, technical and economical resources that road surveys require in order to collect data by law.

The distribution of water for sale for domestic, commercial, and industrial use implies the management of pipes underneath, including excavations of roads for underground utilities construction and maintenance. Nevertheless, the interview with the engineer from the company in charge of this service in the city of Palermo highlighted that so far Road Cadastre's data has not been used at all by any technician of the company.

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98 Road designers interviewed have started to use qGIS or Map regarding the use of cartographic information of for converting shapefiles to other formats compatible with AutoCAD, that is easier for all.

The interview with the archaeologist highlighted that even archaeologists do not make use of the Road Cadastre: in order to better reference archaeological finds located both under the buildings and the ground (and the roads), they only use the Cadastres of Buildings and Lands.

8.2 Expert users' requirements for a Road Cadastre

8.2.1 Data required

8.2.1.1 Requirements from road engineers (designers/maintainers) – from questionnaires

The set of questions progressively led respondents to define requirements for making the Road Cadastre really useful for road design activities. Additional non cadastral data have been suggested by senior road designers as follows:

- **data from road design standards** (required by a senior road engineer),
- **dates** respectively **of road construction** and of the **last maintenance intervention** (by the quantity surveyor/project manager),
- and a register of the **main ditches, manholes and river works** (by the quantity surveyor).

With regard to the kind of data, one of the senior road engineers would like a complete map of the infrastructure including underground utilities and topographical surveys of road structures.

8.2.1.2 Requirements from road engineers (designers/maintainers) – from interviews

The semi-structured interviews carried out with road designers have highlighted that, in relation to road life-cycle stages, they may be involved not only in designing new roads, but also in updating and adapting existing infrastructures (e.g. for the entering in force of new standards, the alteration of existing routes, the strengthening of pre-existing road links, and other). Hence, road designers' requirements reported in the Table below have been distinguished depending on the case: those relating to new roads (planning) from those referring to existing road infrastructures (updating or maintenance interventions).

Requirements from road designers – from interviews	New roads design	Existing roads		Required by the legal Road Cadastre
		Updating	Maintenance	
Environment and context				
Survey of the terrain	✔	✔	✔	No
Geological surveys, Ground movements monitoring data, Core sampling data, Landslides and high risk areas	✔	✔	✔	No
Environmental, landscape and archaeological constraints	✔			No

Standards and spatial plans of locations traversed by roads	✔			No
Crossing of and concessions relating to pipes	✔	✔	✔	No
Landscape/areas crossed by roads	✔			No
Roads (geometry and further data)				
Geometry		✔	✔	Yes
Topographical and structural survey	✔	✔	✔	No
Profile, and cross trend; gradient and side slopes	✔	✔	✔	No
Road components (e.g. foundations, road body)		✔	✔	Partially
Roadsides		✔	✔	Partially
Materials	✔	✔	✔	No
Structural data		✔		No
Time of construction	✔	✔	✔	No
Geometric, structural and geomechanical standards	✔	✔	✔	No
Road surface (thickness, materials (not detailed), defects: type, extension, time)			✔	No
Level of service		✔		No
Traffic congestion		✔		No
Speed limit	✔	✔		No
Road owner (especially when they are many)	✔	✔	✔	Yes
Structures (geometry and further data)				
Geometry (also internal, e.g. for tunnels) with dimensions and location		✔	✔	Partially
Surveys[99] (including decks,[100]piles supporting the deck, pier caps (pulvini),[101]foundations)		✔	✔	No
Structural data		✔	✔	No
Size of elements (e.g. thickness of deck and slabs)			✔	No
Details (e.g. joints[102] and supports (of beams))			✔	No
Data on any significant deterioration and instability of viaducts			✔	No
Relationship with the geometry of the road			✔	No
Any photographic survey data			✔	No
Elements related to safety/maintenance				
Location	✔	✔		Yes
Geometric aspects (e.g. visibility issues, visible areas)	✔			No
Safety standards	✔			No
Road surface conditions (details)			✔	No

[99] both aerophotogrammetric data and details.
[100] It is composed of main and secondary beams, and slabs.
[101] They are elements of transition between the pile and the deck.
[102] i.e. elements of transition between slabs

Safety barriers (e.g. location, consistency with new standards, type, time of installation, repairs)	✔		✔	Partially
Redirecting profiles (in tunnels)[103]	✔		✔	No
Signage and signs (specifying whether redone or updated, placed, maintained, moved, deleted)			✔	No
Accident-related data (number and type of road accidents, vehicles and injuried/dead, weather conditions, road surface status, radii of curvature, gradient, visibility issues, unobstructed view of the space)		✔		No

Table 35. Data required by road designers and comparison with the legal Road Cadastre

With regard to new projects, the main requirement by road designers is the **survey of the terrain** (non-cadastral): from that, road design software (e.g. PROST) processes the 3D model of the road, and outputs maps, profiles and cross-sections every 10 or 20 metres in CAD format as required by Italian standards. Other software manages the structural calculation.

Relating to existing roads to be maintained or updated, road designers also would like additional non-cadastral data of the **road platform**, in order to assess and analyse the "as built" situation. Road maintenance and road safety design require preliminary road status and road safety analysis (to evaluate road conditions over time and ensure road design consistency with the required safety standards): for these purposes road designers need **details of road surface and barriers** to be recorded and monitored as well as **defects of structures, movements of the ground, and areas** identified by CAI (Italian Alpine Club) as **landslides or high risk zones**: a visual study to identify by aerial photos those **areas crossed by roads** should be included. Respondents find difficult to obtain data of road surface and road body composition that should be collected during maintenance interventions: in this case, **data from core sampling** (and **different layers of the subgrade**) would be required within a GIS, as well as **repairs to barriers**. Foundations data are also of interest even if stored just as an historical archive including, for example, foundations drawings (design stage), structural calculations, and data related to the construction stage: as they are underneath and not detectable, once built, they are not update-able.

Time is also crucial to document the history of road infrastructures and their characteristics over years.

8.2.1.3 Requirements from road managers – from interviews

Most of road managers requirements relate maintenance and include **surveys of**

[103] They are a kind of concrete element with a shape aimed at redirecting the vehicle (e.g. in tunnels where there is not any barrier), but tey are not exactly a real protective element.

structures, date and images of the relief, ortophotos, images in real view and by Google Map, video from capture systems for mapping the entire roadway, and **maps** by De Agostini publisher and IGM (Military Geographical Institute) also to understand the evolution of roads, and identify old routes and who is responsible for them. **Monitoring data of defects and road surface conditions** are also required in order to plan and manage extraordinary maintenance. For this purpose, **digitased forms with photos, descriptions, variations of defects and a ranking about priority of interventions** should be recorded. Data on **barriers** are also useful.

8.2.1.4 Requirements from underground utilities managers – from interviews

Technicians carrying on gully sucker interventions need to record **location, date and type of road interventions, the claim number**, as well as the **date of handover** from the water company performing by itself provisional road repairs with cold asphalt to the company contracted by them for making permanent restorations and final works (in order to assign responsibility of the works). Such data (i.e. **who made the excavation, when and what size**) currently are recorded within the GESCA software (Gestione SCAvi, i.e. excavations management). The **identification of the road** (whether existing or new), **pipes type, diametres of the cable and materials used** are also required as well as the **distance of each water outlet from the wall, the depth of the tube, and the distance from the wall to the main line** from which the bleeding takes space.

8.2.1.5 Requirements from archaeologists – from interviews

From the point of view of archaeologists, roads construction and maintenance require excavations to be documented by **administrative data** (i.e. institution, responsible, area, e.g. if suburban or within historical centres, and other), **scientific data, photos, and drawings**. In order to produce a report about the intervention, archaeologists also need **topographical data**, and a **textual, graphical and photographic description of the area of the excavations and of archaeological findings** has to be delivered to the Superintendence. Important data to be recorded also relate to **different layers of the ground properly dated**, and the **maximum and minimum elevation of** each group of close archaeological findings with the same chronology and function (so-called **"archaeological part"**).

Drawings in CAD with two-dimensional representations of objects (layers, findings, and other) geo-referenced and provided with elevation values just recorded (2.5D documentation) are currently required, while **historical maps, satellite images, ortho-photos, and surveys** would be preferred.

8.2.2 3D Road Cadastre benefits and requirements for 3D data

8.2.2.1 3D Requirements from road designers – from questionnaires

Among the questionnaire respondents there is agreement on the usefulness of a 3D Road Cadastre both for design and maintenance tasks, as it would allow a visual control of the infrastructure, preliminary testing of the track (in terms of safety and visibility), and avoiding or solving interference issues among overlapping built parts (e.g. roads and underground utilities). Respondents required in 3D:

- **plano-altimetric information, geometry and further data on both roads and structures** (bridges, viaducts and tunnels) to support road design and have access to full information in the case of future road maintenance or subsequent road design;
- **plant/utilities data** (e.g. electrical system), and **underground utilities** (e.g. water pipes) to also learn about projects by other institutions and avoid interference;
- details about **barriers,** linked with **speed limits** for road safety design purposes,
- and **signs** and barriers again for maintenance purposes.

With regard to road components, all respondents would integrate the current Road Cadastre with **road projects' data** (mainly describing the road and its component also in 3D).

Pictures on 3D road situations described in Chapter 5 have been proposed to road designers and Figure 74 shows the ranked elements of road structure that questionnaires respondents would like in 3D.

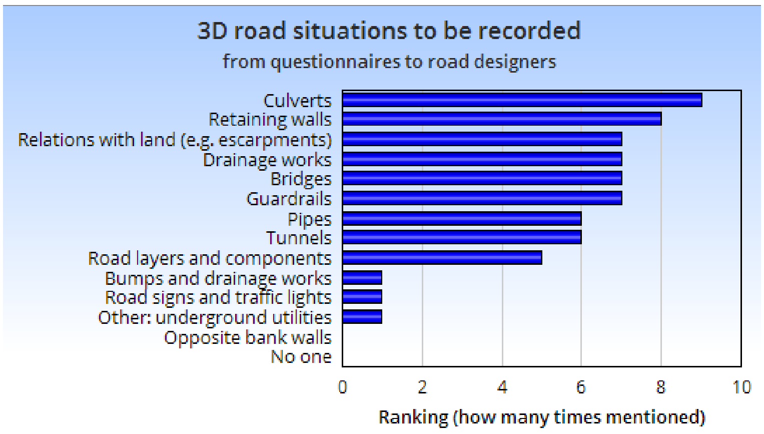


Figure 74. Road Designers' Priorities for 3D Road Description

8.2.2.2 3D Requirements from road designers – from interviews

All the interviews respondents agree on the usefulness of a Road Cadastre provided with a three-dimensional geometric model of roads for road design purposes. According to the CEO of the Engineering Company, a 3D model would be important to study the relationship between the road infrastructure and its environmental context. Senior road designers and project managers within the same company consider the 3D Road Cadastre helpful to measure elevation (feedback on the altimetry) directly on the model, to perform feasibility studies, to characterise the composition of road structure, and to test the road functionality also making a performance evaluation of it. It also would help to establish roads levels of service - as they derive from a planimetric study and elevation (in addition to geometry, traffic, and other data).

With regard to 3D data, road designers firstly require - both for new roads design and existing roads maintenance - a **three-dimensional geometric survey of the road (including the paved upper surface, embankments and trenches escarpments)** or the "blacks package" (pacchetto dei neri):[104] it aims at defining the road layout, i.e. the **horizontal and vertical alignment of the road platform, with roadsides and all road components** (including the road body, embankments, barriers, and structures), straight sections, curves, the paved upper surface, embankments and trenches escarpments and what other related to the structure of the road. That would allow checking roadsides in relation to the axis, and having precisely the trend of the cross-platform with obstacles on the roadsides, retaining devices, and barriers in order to do evaluations, preliminary expeditious studies, and road safety analysis. **Topographic survey** and **3D data** would be very helpful if added to aero-photogrammetric survey data, especially in the case **of bridges, viaducts and tunnels** where shape and internal details - **utilities systems and signage** included - are not visible. Three-dimensional **relief by laser scanning** and 3D data of the **road surface** would be also needed (though both differences between planned and as-built configurations and frequent repairs make difficult updating data).

Importantly, road designers would not use 3D at a map scale of 1:2000, 1:1000, or 1:500 as supposing difficulties with resolutions and tolerances coming from maps at 1:10.000 and 1:5000 map scale, "unless to use data from flights and a representation with a map scale of 1:5000, and then a 3D survey of the road by tools like drones allowing using higher map scales".

8.2.2.3 3D Requirements from road managers – from interviews

According to road managers, using 3D GIS to document roads would enable more detailed analysis of each structure and directly from the GIS. In the case of variants of road projects, it would provide an immediate view of the **morphology of the area, the geometry of the existing infrastructure** also showing how it may be varied. Maintenance activities would also benefit from 3D GIS for documenting and analysing **minor structures (e.g. walls) and road surfaces** along a road stretch.

Currently, normally as-built drawings only refer to structures (not road trunks, whose road

[104] It includes all that is paved (the upper par of the paved road with all the layers – they are called "the blacks" because of the firts layers of bitumen – or, however, the paved part, which is basically the roadway).

surface and section elevation are the minimum requirement). Nevertheless, a **representation of the road detected by laser scanner** would provide additional non cadastral data to do analysis of what is visible from the roadway, allowing seeing and analysing **road surfaces and walls**, measuring their size, having the dimensions of **tunnels**, measuring the **curbs**, and all that is visible in the plan; survey data of all that is not visible on the road surface as well as **underpasses, manholes, walls of counterscarp**, and all the structures perfectly sized are also required. The aim is acquiring *una tantum* geometric information that does not change less than collapses, and constantly monitoring thicknesses, lengths, defects and variations over time, comparing them with a manual of defects by ANAS. The description of the **road package** would be also of interest as well as the **representation of the variants** of the projects (redesigning).

8.2.2.4 3D Requirements from underground utilities managers – from interviews

According to underground utilities managers, a **3D road model with underground utilities** would help to identify electric cable pipes, fiber-optic, water, and drain (as it enters into tunnels), and understand if they are correctly positioned, providing 3D information about minimum distances and depths. Currently, in fact, cables detector are used to find cable underneath, but it only works when they are coated with metal nets and not with polyethylene. Moreover, if underground utilities cannot be connected with existing road networks, manholes are required for inspections and related data are needed.

8.2.2.5 3D Requirements from archaeologists – from interviews

Currently, archaeologists use 2D drawings (i.e. cross section of the ground) with bands of different colour indicating the location of archaeological finds, in order to document the stratigraphy[105] of roads and avoid a number of unnecessary excavations or designs that then must be modified. Hence, for this purpose, as they investigate and document all the underground aspects related to road infrastructures in certain contexts, they would like a 3D model representing the **road and the ground layers** (with archaeological findings at least indicated). As they need to know the minimum and maximum elevation of the archaeological system (or **"archaeological sediment thickness", i.e. a volume** beyond the details relating to what is inside), a queryable 3D model of the road would be essential: understanding by a three-dimensional volume how and at what level archaeology findings are (i.e. the "archaeological potential") would be the first crucial data for everything related to road design. Hence, in their opinion, two levels of detail might be used: one, more general, only documenting the thickness

[105] Archaeological stratification or sequence is the dynamic superimposition of single units of stratigraphy, or contexts.

of the archaeological ground (what depth - that may vary along a route - archaeological finds begin and also end); a further level of detail might define the findings that are below the road surface. Relationships with what lies outside of roads might also be of interest.

8.2.3 Functionalities required

8.2.3.1 Functionalities required by road designers – from questionnaires

As Fig. 75 shows, all questionnaire respondents would like an **integration between the current Road Cadastre and 3D road models** in order to have access to roads modelled in 3D from the Road Cadastre itself and design more quickly complementary or neighbouring projects (especially urgent interventions relating to ditches, manholes, and other). In order to confirm road maintenance plans, support their planning, and compare data over time, 8 out of 9 respondents would also like to see within the Road Cadastre the **integration between 3D and 4D representations of roads**, resulting in a single model able to describe the infrastructure's life cycle. Finally, 3 senior designers out of 9 respondents require: **the extension of the Road Cadastre to roads not managed by ANAS, the integration with all cadastres,** and **an improved compliance of the Road Cadastre to the existing standards**.

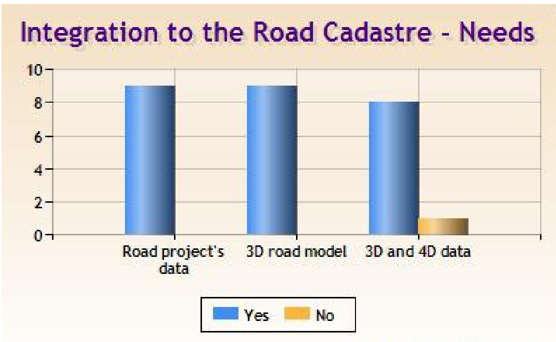


Figure 75. Kind of integration to the Road Cadastre required by road designers

8.2.3.2 Functionalities required by road designers – from interviews

According to the CEO of the engineering company, the main function of the Road Cadastre is allowing access to information for a full knowledge of the road asset of a country. For this purpose, he would ask for a **queryable 3D model** (not only aimed at display functionalities).

Within the same company, project managers highlight that road design would require **a tool provided with a multi-purpose database of all road components and enabling analyses**: the preliminary project (i.e. the first stage of design), in fact, must include a status quo analysis of the road describing its current situation, and a preliminary road safety analysis that links data on road geometry, visibility issues, unobstructed view of the space and other, as required by standards. In addition, road designers should be allowed to establish immediately that viaduct “x” is “y” km long, and has “w” and “z” characteristics, or how many bridges are on the road trunk “a”, also making comparisons. In this perspective, they essentially require GIS functionalities. Moreover, they find useful **display functionalities of a 3D model** to check roadsides in relation to road axis, the trend of the cross-platform with side obstacles, retaining structures, barriers, and so forth. Senior road designers and project managers in particular require a database **with 3D mapping at a scale suitable to support road preliminary project**, and GIS functionalities like **querying all information also by links with other information**. Also, they would like “**to click on a specific structure in 3D**, **and visualise pictures and summary tables** (e.g. of viaducts)”. However, **spatial analyses and display functionalities** that a 3D GIS would enable should match within **a tool easy-to-use also to not advanced GIS-users**, as usually road designers only use AutoCAD and road design software. Importantly, **an open tool that**, once implemented, **can be continuously updated and added with data** is required.

8.2.3.3 Functionalities required by road managers – from interviews

Road managers prefer **a GIS-based tool** to manage the Road Cadastre's graph and update it constantly. However, as they also have to provide not advanced GIS-users with road cadastral data (and turn GIS files into tables and CAD files that road designers can use), they would like a GIS tool **more accessible to all users** (i.e. “lightened”, with fewer functions). In particular, they would find interesting using 3D GIS just only to **query data** on roads and structures **by a click on the model**, or check the road package along a road segment (e.g. by **linking the model to a .pdf** with the drawing of cross sections with layers and components). A simpler system might be easily handled also by surveyors for road cadastral updating (e.g. by recording data and photos in real time using tablets, and extracting data directly from a table digitally compiled by operators). As institutions do not always inform in real time ANAS about new road constructions carried out by them, making difficult to update the graph constantly, the system required should also be **centralised, multi-user and collect data of any kind of roadwork.**

With regard to the **levels of detail or zoom** functionality, it should be possible using the centreline 3D polyline or road section deriving from road projects, and, in alternative, a **basic as-built 3D model of the road platform** (obtained by detecting the existing and using modelling software), **additionable with all the layers needed** (including defect-change of the structure). Various levels of zoom would allow seeing and analysing the road in detail with different layers for each type of structure (e.g. walls, manholes, and other).

8.2.3.4 Functionalities required by underground utilities managers – from interviews

Data integration is the most crucial requirement from underground utilties managers. In particular, they would like to use a tool allowing **sharing information among different institutions** in order to facilitate the coordination of interventions. An **easy-to-use model** would be preferred as, currently, employees of the company handle data in EXCEL format.

8.2.3.5 Functionalities required by archaeologists – from interviews

Currently, the various agencies involved in planning use different systems (often proprietary), and in most Italian regions - except for Tuscany, Apulia, Friuli and few others - spatial landscape plans aimed at coordinating different actors have not been adopted yet. Moreover, photographs, drawings and scientific reports on excavations or archaeological finds underneath must be requested with permission to the Superintendence (while all cartographic and shorthand documents are open and free). Hence, archaeologists would like a **centralised system** for collecting and having access to data on excavations (roadworks included), in order to facilitate communications among different actors involved in planning. **Any data recorded should be available on the web also to users that are external** to each single body, in order to make the update continuous and constant. In particular, **a Road Cadastre shared among different institutions** (especially those managing or repairing road-related underground utilities) **and mutually linked to archaeological web platforms with GIS and DB** (like the one implemented by the SITAR Office in Rome and Verona) would be required as allowing:

1. road designers and managers to be aware of the existence of underground archaeological findings to be preserved in the case of roadworks (and what elevation and how much extended they are),
2. archaeological Superintendences, road builders and maintainers of roads and utilities respectively to authorise and do roadworks without archaeological monitoring (as they already know from previous excavations data if the depth of the archaeological finds location is less then the depth of the roadwork to do),
3. all the institutions managing plants and utilities to coordinate different interventions, or make a single excavation (and a single road repair) to do various utility maintenance work (with the result of road segments closed just once for works and less traffic congestion),
4. all stakeholders to have (almost in real time) a general update about road situations and alterations at level, above and underground.

8.3 Summary

In order to meet real different road users needs during the road life-cycle, questionnaires and interviews have been carried out with various categories of expert users. Surveys highlighted that in regions like Sicily, where institutions have not implemented their own Road Cadastres, road designers are limited to making use of data from the ANAS Road Cadastre (that are mostly aimed at ANAS internal uses, and too limited or unfit for other road users needs). Hence, in these cases we definitively have to distinguish between a theoretical Road Cadastre (i.e. the legal one by the New Road Code) and the only existing one (by ANAS), whereas Regional, Provincial, and Local Road Cadastres (to be implemented by law) often (like in Sicily) do not still exist. In any case, currently Road Cadastres refer only to existing roads.

Data required by expert users	Road designers		Road managers/ maintainers	Underground utilities manager	Archaeologists
	Q	I			
Geometry		✔	✔		✔
Data from surveys	✔	✔	✔	✔	✔
Drawings in CAD or PDF		✔	✔	✔	✔
Reports/Forms in PDF		✔	✔	✔	✔
Standards in PDF		✔			✔
Tables in EXCEL, ACCESS, etc.		✔		✔	
Maps	✔	✔	✔		✔
Photos (in JPG, etc.)		✔	✔		✔
Ortophotos		✔	✔		
Satellite images			✔		
Google images			✔		
Videos			✔		
3D model	✔	✔	✔	✔	✔

Table 36. Data required by expert users – from questionnaires and interviews

3D Features required by expert users	Road designers		Road managers/ maintainers	Underground utilities manager	Archaeologists
	Q	I			
Geometry	✔	✔	✔		✔
Road platform	✔	✔	✔		✔
Roadsides		✔			
Road components	✔	✔	✔		
Culverts	✔				
Retaining walls	✔		✔		
Bumps and Drainage works	✔				
Structures	✔	✔	✔		
Barriers	✔	✔			
Signs and traffic lights	✔				
Road layers	✔		✔		
Underground utilities and manholes	✔		✔	✔	✔
Terrain	✔	✔	✔		✔

Table 37. 3D Features required by expert users – from questionnaires and interviews

Non cadastral functionalities required by expert users	Road designers		Road managers/ maintainers	Underground utilities manager	Archaeologists
	Q	I			
Integration with 3D road models	✔	✔	✔	✔	✔
Integration with 4D road representations	✔		✔		✔
Integration or links with other databases	✔	✔	✔	✔	✔
Extension to road not managed by ANAS	✔			✔	
Integration with all cadastres	✔				✔
Better compliance with standards	✔				
Data retrieving from the 3D model		✔	✔		✔
Multi-purpose/multi-users system		✔	✔	✔	
GIS-based tool			✔		✔
Analysis		✔			
3D visualisation		✔	✔	✔	✔
Management of Levels of detail		✔	✔		✔
Easy-to-use (users)		✔	✔	✔	✔
Easy to update (implementers)		✔	✔		
Data accessibility on line		✔			✔
Open accessibility		✔			✔
Expandability		✔	✔		
Centralised system				✔	✔

Table 38. Functionalities required by expert users – from questionnaires and interviews

With regard to data requirements, information on road structures such as viaduct, tunnels and bridges (with survey geometry and details) and construction elements of roads (with size, position, and spatial relationship) are the only data from the legal Road Cadastre also mentioned by literature and all stakeholders. In addition to this, all the stakeholders would add the time of roads construction, as it is related to standards and practices then in force and can give information not only about the physical structure of the road but also about structural and technical features. Characteristics of materials and construction standards (geometrical, structural, and geomechanical) that also depend on the time of construction, should be registered.

Both designers and maintenance engineers would like non-cadastral maps, photos, orthophotos and data from new survey techniques (e.g. laser scans). Geometry (included in the legal Road Cadastre) is also requested as well as information on structures under the road surface (e.g. underpasses, manholes). Road equipment (e.g. signage and lighting elements) and road traffic and accident data are required for maintenance and upgrade, with information on maintenance works, road surface quality, and "as built" drawings also listed.

Relating to the needs of only road designers, as the interviews highlighted, they primarily need additional (non-Cadastral) data to support preliminary multifactorial analyses and feasibility studies: that includes the survey of the terrain to produce a 3D road model, environmental data for monitoring the movement of the ground around roads, legal documents and urban plans to know constraints and land uses, data on the existing trunk roads (e.g. maintenance, geometric information to study issues of visibility and line-of-sight), and also speed limits and road safety analysis to ensure road designs conform to safety standards. Additional requirements include: plano-altimetric information to support design, as well as barriers, data on plant (e.g. electrical system, waterworks) and underground utilities to check any clashes. Road designers involved in road maintenance would include date of construction and of maintenance interventions to the basic Road Cadastre, as well as a register of the principal ditches, manholes, construction of embankments and riverbank protections, and a comprehensive map of infrastructure (underground utilities included). Road concessions should be also documented.

ANAS road managers, dealing with road management and maintenance in particular, are mainly interested in administrative data and road maintenance data (e.g. road surface quality). To support this the ANAS Road Cadastre includes not only all data by the Act of June 1, 2001, but also advertising signs for road management and maintenance and monitoring data of defects in roads and structures to help prioritise interventions.

All stakeholders would like a 3D model of terrain and road and would use 3D data to document drainage, wires, power lines, gas, optic fibres and any other network of services to prevent service interruption.

Road designers and managers agree that a 3D GIS model of the road might be an easier and more manageable tool for users not at ease with traditional 2D GIS: however they would prefer a simpler tool, with less functionality, just to query the model directly and in 3D. Interview respondents also noted that maintenance activities would benefit from 3D GIS for documenting and analysing minor works (e.g. walls) and road surfaces (that ANAS currently records after maintenance interventions on paper).

All stakeholders require new functionalities to solve problems related to accessibility of data to different users, data updating and data integration and sharing to coordinate interventions.

Chapter 9

Building a framework for a use/user centred 3D road cadastral system

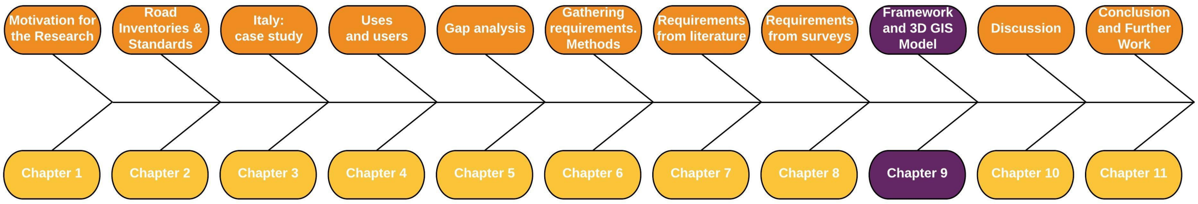


Figure 76. Overview of Document Structure showing context of this Chapter

From the results obtained and illustrated in Chapters 7 and 8, a framework for a 3D GIS road cadastral model, able to describe road infrastructures during their whole life-cycle and meeting the real needs of road users, has been implemented. On the basis of the requirements collected and relating to the Italian case study, it aimed at defining a model enabling:

1. storing and querying of heterogeneous data on roads (including appurtenances and the surrounding context);
2. interactive visualisation of the model and access to data through a single interface;
3. 3D multi-user analysis (in turn than the traditional multi-scale approach, typically based on various levels of detail of the representation and the information provided);
4. and online information sharing.

In order to design it, different aspects have been considered and are described in this chapter. Section 9.1 gives an overview of the whole workflow while Section 9.2 focuses on the cognitive framework defined in the previous chapters of this work and aimed at designing a proposal for a 3D Road Cadastre. In particular, it collects the main results from the literature review and surveys with road users in terms of data (especially 3D), LoDs and functionalities required according to different road cadastral uses, and summarise them through several schemes. The following Sections are focused on the three stages of implementation of the model: this includes conceptual aspects, a logical framework, and a physical model (composed of a 3D road model, a DBMS for storing road information, and a Web-GIS platform for accessing to selected data). A first outline and implementation of an application prototype has been illustrated using a road project being implemented in Sicily as a demo. In this case the example relates to road design and has been presented to show some functionalities of the road information model proposed for this use. Other examples relating to different road uses should be carried out as a further work.

9.1 The workflow

An information model can be defined as the formal definition of objects, its attributes, their mutual relationships and rules giving insight in structure and coherence of information within an organisation or system (Bulens and Vullings, 2003; Pilouk, 1996). It requires two main steps: the design phase (including all the abstraction processes), and the construction phase.

The design phase aims at answering two basic questions:

1. what aspects of reality (real world objects and the relationships between them) are to be modelled,
2. how they should be represented in the model.

The abstraction of reality is transferred into a representation scheme.

This stage is followed by the design and implementation of the data model structure (in accordance with the collected requirements) and the user interface in order to enable the construction and use of the model, able to provide the functionalities required.

The implementation of a model for a 3D Road Cadastre, hence, required:

1. The definition of the cognitive framework for the 3D road information system design, including:
    - a process of decomposition of the road artifact into its components (3D "feature classes"), as mentioned in the literature and by expert users,
    - a synthesis of the results (i.e. road requirements from Chapters 7 and 8) mutually compared, putting in relation 3D road components and data related ("What"), the way of representing road objects ("How"), different road data users ("Who") and uses "(Why"),
2. Modelling
    - conceptual modelling,
    - logical modelling (3D database project),
    - physical modelling, including:
        - 3D basic graph for large scale road analysis,
        - 3D model for detailed analysis and as an index for retrieving data,
        - export of the model geometry from the modelling software into a DBMS,
        - implementation of further DB tables and database according to different road

cadastral uses,

- import of the system within a webGIS used as a GUI for different users,

- connections with other database.

3. Test with a prototype.

9.2 Definition of the cognitive framework

As a preliminary stage for the 3D road information system design, the road artifact has been described as composed by its 3D components grouped by function into “element groups” or “macro feature classes”.

3D graphical representations (as the following figures show) have been used to point out different road components, their location (above, under and at the same level of the road surface), adjacency and inclusion, in order to verify and highlight respectively hierarchies and spatial relationships among elements.

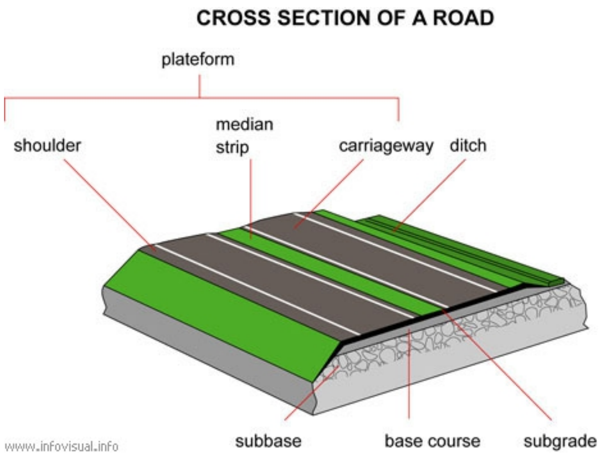
Moreover, results from Chapters 7 (requirements from literature) and 8 (requirements from questionnaires and interviews with expert users) have been matched and compared mutually and with the legal Road Cadastre. Summary and comparisons tables of 2D and 3D data requirements distinguished by different uses/users have been used to define: what to model (and what in 3D) within the Road Cadastre and for which purpose/use; they have been also aimed at defining how to provide users with information (i.e. which kind of data - e.g. text, .jpg .pdf, and other - should be retrieved from the model according to different uses and road life cycle stages, levels of detail, and functionalities as required by different expert users; that also includes links to other external information or DBs).

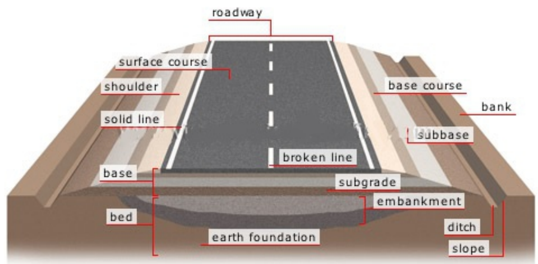
9.2.1 3D Road components (topographic objects) and spatial relationships:

As already mentioned in Chapter 3, with regard to the Italian case, the New Road Code and its Implementing Act, as well as design standards and road construction specifications mention and define different road components. As described in Chapter 3, most of them are already included into the legal Road Cadastre, but Chapter 5 showed the limitations of their road cadastral description as such features are geometrically defined in 2D (or in 2.5D by the addition of the “z” coordinate - i.e. elevation - as an attribute). Moreover, related data are also too limited for the multiple road cadastral uses, as highlighted by Chapter 4.

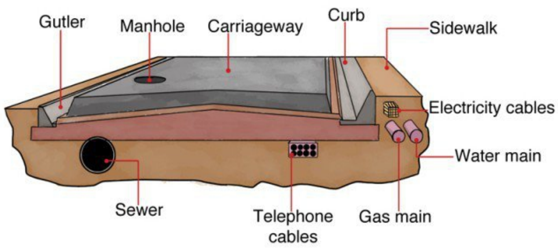
Therefore, road components, already illustrated in 2D within Chapter 2 (Fig. 27) with regard to Italian standards, have been analysed as 3D objects by the following graphical representations (cross sections in perspective and axonometric views). While highlighting the three-dimensional nature of the road body (Figg. 77 and 78) and the underground and surrounding environment (Fig. 79 and Fig. 80) with spatial relationships (as already argued in Chapter 5), they illustrate all road components to be modelled in 3D as required by road users.

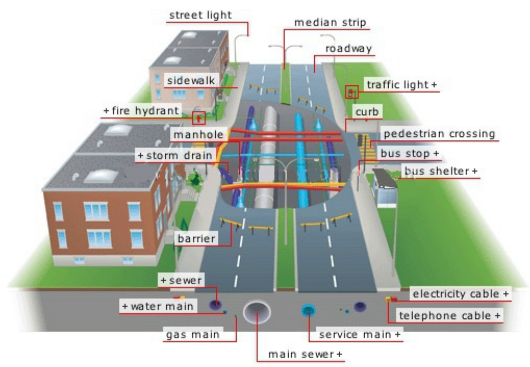
Such representations refer to both the diagram of Chapter 8 (Fig. 74) - regarding the ranking of the road components to be modelled in 3D within the Road Cadastre (resulting by the questionnaires to road designers) - and the contents of interviews with different expert users summarised in Table... of Chapter 8.





Figures 77 and 78. Cross sections of the road body and related components in axonometric and perspective view





Figures 79 and 80. Graphical representations of elements located underground and surrounding the road

Such components have been grouped into "element groups" or "macro feature classes" and described by schemes as follows:

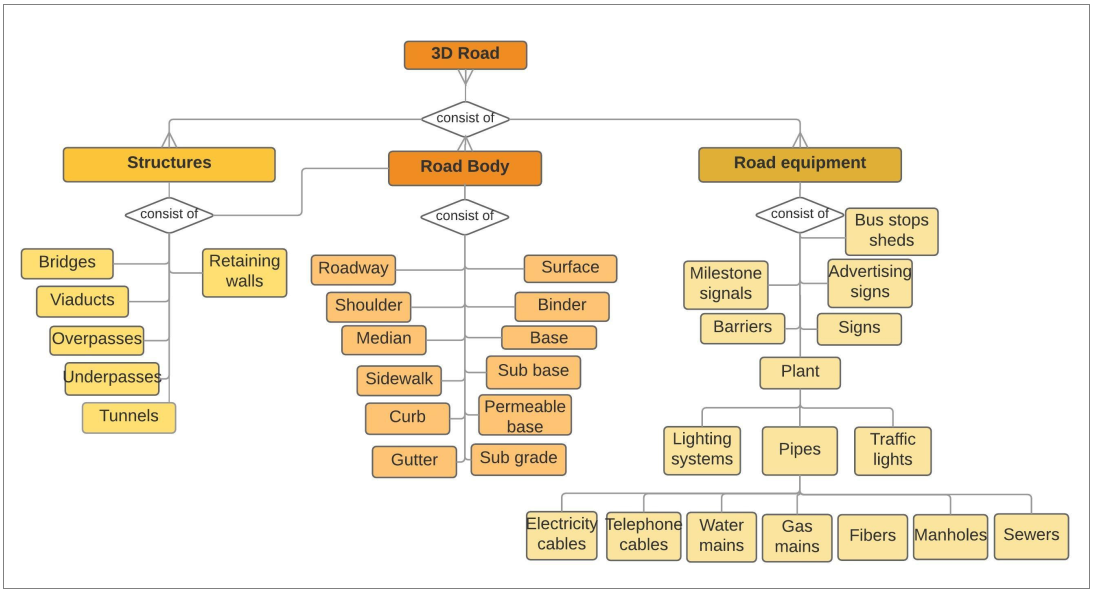


Figure 81. Diagram representing 3D road components grouped into "structures", "road body's components" and "road equipment" (sources: the legal Road Cadastre, requirements from literature - Chapter 7 - and surveys with expert users - Chapter 8).

The diagram above represents schematically three main groups of feature classes required by the literature and surveys with expert users that should be documented in 3D. They include:

1. **simple road trunks**, identified by the road body,
2. **structures** as special constructions (divided into: a) minor structures, such as retaining walls, and b) major structures such as viaducts, tunnels, bridges, and others); they also include the road body as one of their components (as well as piles, beams, foundations, side walls, and other),
3. and **road equipment** (including road safety elements like barriers, as well as signs and plants).

In Fig. 81 the road body is divided into different parts including the elements of the platform (i.e. the horizontal surface raised above the surrounding ground): the roadway (part reserved for vehicle traffic) with shoulders (between the roadway and the ditch), side lanes (like emergency lanes or stopping place such as bys), medians (separations between two roadways), ditches (channels carrying away water), and others. It also includes the different layers of the road surface (i.e. the top layer, the binder course, the base course, the sub-base, the permeable base), and the subgrade (as described by road designers and also illustrated by drawings and .dwg files of road projects provided by them during the interviews).

Relationships among the road object and the environment (both man-made and natural) (see Fig. 82) are represented in the diagram below:

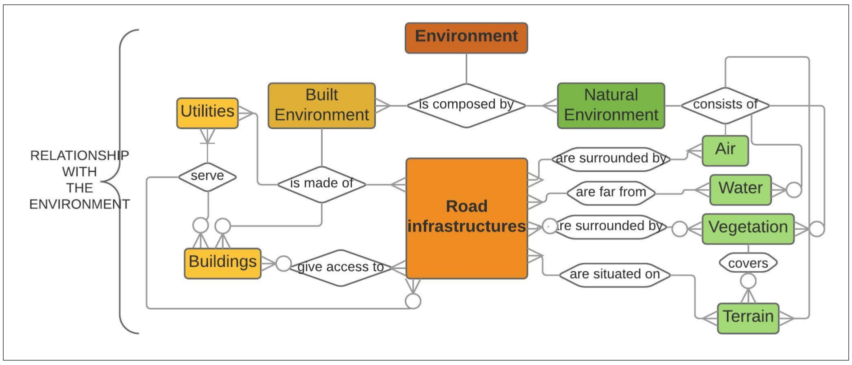


Figure 82. Diagram representing the relationship between road infrastructures and the built and natural environment

A 3D description of such elements and their spatial relationships has been also required by all expert users that currently can only use Digital Terrain Models (DTM). ANAS road managers, for example, during the interviews showed that they use DTMs included within the ANAS Road Cadastre, while road designers provided several .dwg files of road projects as a material for this research including a 3D polyline representing the road axis (as a basis for modelling the whole road by PROST software) and a DTM as a separate layer.

These diagrams above have been aimed at representing the main road-related elements mentioned in this research and verifying the possibilities to establish vertical relations among road features (hierarchy) as will be later addressed.

9.2.2 Users' requirements from surveys compared with the existing cadastral law and literature

In order to complete the cognitive framework, in addition to the diagrams above representing in general the 3D road elements required in the literature and by road users, summary and comparisons tables have been implemented. In particular, they collect and specifically compare requirements from the literature review (illustrated in Chapter 7) with the results from both the questionnaires issued to road designers and the interviews with different categories of expert users: i.e. road designers, maintainers and managers, as well as underground utilities managers and archaeologists (as described in Chapter 8). The following tables, hence, aim at highlight different data (2D and 3D) required depending on the Road Cadastre's use and users.

The table below focuses on who requires what. Within it requirements from different users are not only mutually compared, but comparisons have been also made with standards from the literature and the current legal Road Cadastre. In the table, results are grouped into:

1. **topographic objects to be modelled,** including "road elements", "road structures", "road equipment" and "environment") (see also Fig. 80 and Fig. 81),
2. and **kind of data**, distinguishing between:

a) **geometry**,

b) and **non-geometric data.** The latter includes both **raster** (such as maps/papers/reports, and results of surveys) and **attributes.** Attributes are grouped into the table below both according to different **purposes** (e.g. design, construction/maintenance, and safety) and as **general non-geometric attributes** (juridical, fictional and abstract).

In the table "RD" refers to "Road Designers" while "RM" means "Road Managers/Maintainers"; "UUM" stands for "Underground Utilities Managers" and "A" for "Archaeologists".

Requirements	Existing Cadastral Law	Literature Review	Surveys RD	Interviews			
				RD	RM	UUM	A
Topographic objects							
Road Elements							
Constructive elements of roads: roadway, median, curbs, surface, etc. (road body's components from Fig. 80)	✓	✓	✓	✓	✓		
Interchanges/intersections/accesses		✓		✓			
Road structures	✓	✓	✓	✓	✓		
Road Equipment							
Barriers	✓	✓	✓	✓			
Signage		✓	✓	✓	✓		
Lighting elements	✓	✓		✓	✓		
Plant/utilities data	✓	✓	✓	✓		✓	
Advertising signs					✓		
Underground utilities			✓	✓		✓	
Environment							
Terrain (and relationship with roads)		✓		✓		✓	✓
Environmental data and monitoring		✓		✓			
Kind of data							
Geometry							
Geometry (planar geometry, elevation, lane sections, coordinates)	✓	✓		✓	✓	✓	✓
Plano-altimetric survey			✓	✓			✓
Measurements of roads, tunnels, walls	✓	✓		✓	✓		
3D model of terrain and road				✓	✓	✓	✓
Non-geometric data (raster)							
Maps/Papers/Reports							

Maps (also thematic: e.g. geological, geotechnical, archaeological, hydraulic, constraints, quarry sites and storage), cadastral plan		✓		✓	✓	✓	✓
Urban plans				✓			✓
Legal text		✓	✓	✓			✓
Design reports and drawings		✓				✓	✓
Structural calculations				✓			
Results of surveys							
As built				✓	✓	✓	✓
Ortophotos				✓	✓		✓
Photos		✓		✓	✓		✓
Laser scans				✓	✓		✓
Underpass survey data				✓	✓		
Non-geometric data (attributes) grouped for purpose[106]							
Design							
Level of service		✓		✓			
Traffic congestion		✓		✓			
Speed limit		✓		✓			
Construction/Maintenance							
Road surface quality		✓	✓	✓	✓		
Time of construction/ maintenance			✓	✓		✓	✓
Maintenance works		✓		✓	✓	✓	✓
Detailed defect monitoring					✓		
Materials				✓		✓	
Costs		✓					
Safety data							
Road surface quality		✓	✓	✓	✓		
Sight distance		✓		✓			
Road traffic and accidents		✓		✓	✓		
Speed limits		✓	✓	✓			
Summary tables of data				✓			
Other non-geometric data (attributes) (juridical, fictional and abstract)							
Administrative data (road owner, road manager, road classification)	✓	✓			✓	✓	✓

Table 39. Partial summary (ad exemplum) of requirements for documenting roads

9.3 Phases in geospatial modelling

In order to implement the 3D road information model, three stages of data modelling has

106 Only few road cadastral purposes are here reported as an example.

been followed:

1. The **Conceptual Model** describes the real world on a conceptual level, defining its specific domains: it comprises a general scheme describing what should be included in the model (i.e. only those objects of interest within the context of the model) (Peuquet 1984; Maguire and Dangermond 1991) and identifies the highest-level relationships between the different entities.
2. The **Logical Model**, or data structure, describes the model on a functional level, focusing on the relations between the relevant objects comprised in the model and describing the data in as much detail as possible, without regard to how they will be physical implemented in the database. All the elements needed for the construction are set out without stating the actual size or type of each element of the model. The functionality is defined by the use of the model.
3. The **Physical Model** describes the model on a technical level. It deals with the implementation of the logical model in a certain technical environment: i.e. it represents how the model will be built in the database. Physical models show all table structures, including column name, column data type, column constraints, primary key, foreign key, and relationships between tables. Within it the actual size and type of each element of the model are specified. In this research the physical model will be mainly focused on the modelling of road components and the transferring of data into the DBMS (both geometry and attributes) as well as its implementation within the WebGIS platform.

9.3.1 Definition of a conceptual approach and model

A conceptual model is an abstraction or simplification of reality to help us to better understand real world systems, facilitate communication and integrate knowledge across disciplines (Heenskerk et al., 2003; Ford, 2009). With regard to the 3D Road Cadastre, it has been implemented by testing different approaches and going through progressive addition of information and subsequent simplification.

9.3.1.1 First approach: a hierarchical omnicomprehensive multi-scale model

In the light of the cognitive framework described above, the comparison between the current Road Cadastre structure and the requirements collected from the literature and road users (and focused on 3D) lead to the omnicomprehensive diagram described in Figure 82. According with this first approach, an hierarchical 3D object structure has been firstly designed, going from a large scale to a medium scale to a small and detailed scale. Within it:

1. **Relationships among road infrastructures and the environment** (terrain, air, vegetation, water and the built environment) are emphasised;

2. **Road events** (such as road accidents and maintenance works) and **Non-spatial elements** (like road owners, speed limits and standards) are included;

3. Roads are illustrated as composed of **entities at different Levels Of Detail (LODs)**.

Importantly, the Level of Details identifying the entities within the model follow an opposite numeration in comparison with the one used by both standards (see Chapter 2) and the Italian Road Cadastre (see Chapter 3): in fact, while the latter use a descendant order for moving towards a more detailed level, in this research levels of detail are identified by an increasing number when becoming more detailed. The reasons will be explained and discussed later in Chapter 10.

In order to start from the current legal Italian Road Cadastre's basic structure and then integrate it, the diagram in this first approach included Level 1 entities currently used as the Road Cadastre basis (also in accordance with CEN standards). Nevertheless, as mentioned above, they have been re-named as Level 2 entities, as they are preceded by a more general LoD (LOD1) that includes the enviromental context. Further LoDs have been also proposed to detail basic road cadastral entities into multiple different road components (taking into account the cognitive framework described above with regard to 3D road components).

Importantly, this approach is mainly based on **spatial and non-spatial relationships among elements**: in the diagram, in fact, road components are not grouped on the basis of the same functions (e.g. road body layers, road equipment, pipes, etc.) but by the same elevation on the road surface (above, under, or at level), in order to emphasise spatial relationships and the importance of distinguishing multiple z by using 3D models.

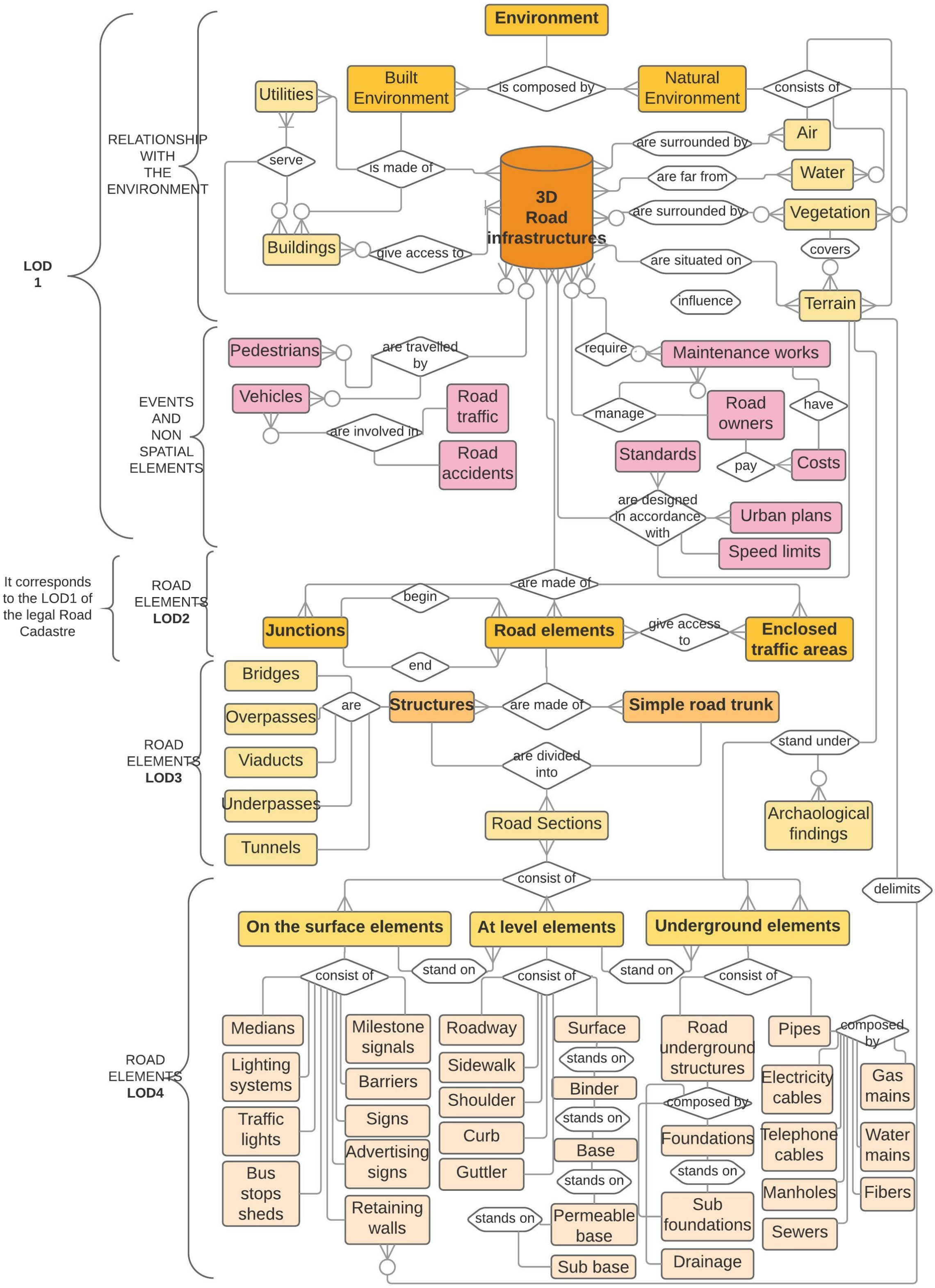


Figure 82. Relationships between road infrastructures and various components (environment, events, non-spatial elements and road components), and among elements at different LoDs and elevation (above, under or at the level with the road surface).

The approach described takes into great account the environmental features. That in accordance with several standards already illustrated in the previous chapters, such as: the INSPIRE Directive described in Chapter 2 that emphasises the role of road infrastructure within the environmental context and also in relation with other transport networks and facilities; safety design standards that require data on weather condition as well as data on vegetation - e.g. location and height - to check visibility and line of sight on the roads; road design and management standards and requirements (e.g. terrain condition, weather condition as well as air quality in order to design/manage traffic flows and keep low levels of road traffic-related air pollution), and so forth.

The model generically includes road events; nevertheless, point and linear referencing are not considered. On the contrary, as showed in Chapter 2, the INSPIRE Directive includes linear referencing, Chapter 3 described the graph of the Italian Road Cadastre as characterised by road elements with segmented attributes and also the ANAS Road Cadastre (mentioned in Chapter 3) uses the dynamic segmentation.

Importantly, the model described according to this first approach does not consider uses and users.

9.3.1.2 Second approach: a functional feature classes model

From the first approach a second approach derived, as a synthesis and a simplification of the complex and multiple relationships among all the elements previously considered. It is an object-related approach, based on grouping road and environmental components (both physical and abstract) into categories or families mainly based on their function. Hence the components above have been grouped as follows:

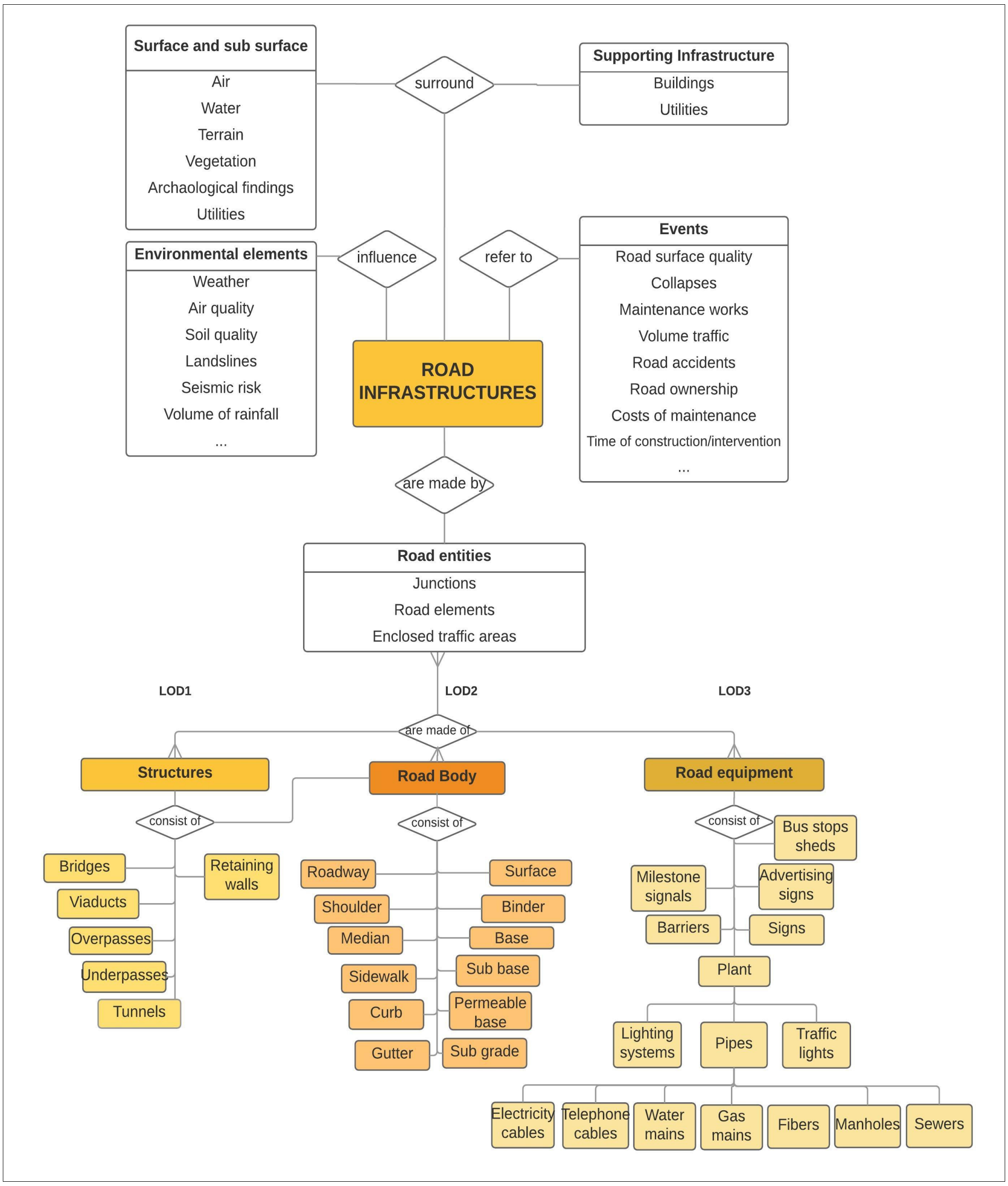


Figure 83. Diagram based on functions and categories (partial representation only including Level 1)

The second approach tries to synthetically include the main important spatial elements required to be represented in 3D, and comprises: a) road infrastructures and their entities (also at different levels of detail), b) environmental elements and c) supporting infrastructures, d) surface and subsurface elements, and e) road events. The latter include both point and linear events (even if not distinguished). Importantly, this second approach shows a missing important element that emerged from the literature review and surveys with road users and that is one of the most complex and peculiar aspects characterising road infrastructures: again, even this approach does not include uses and users.

All above highlighted that the implementation of a model for a 3D Road Cadastre that is non necessarily fixed and unique should be investigated.

9.3.1.3 Third approach: a meta-model. A cluster of clusters

As illustrated in the previous chapters, literature and stakeholders often require the same elements relating to roads but just taking a different focus for what is the most important in the group. Therefore, a new table was generated to analyse each element required by them according to various factors mentioned above and not included in the previous diagrams. It includes:

1. the **element** or **feature class** (e.g. road element, curb, barrier),
2. the **element group** or **macro feature class** that each element belongs to (e.g. road, equipment, structure),
3. its **'man-made' or 'natural'** nature,
4. its **elevation** (whether it is at level with the road surface, above or below it),
5. the **source** (e.g. which standard, interview, survey requires it),
6. the **level of detail** (LoD) with relating geometry, topology, semantics and graphic primitive,
7. the **cartographic representation scale** normally used in 2D maps, according to different ranges as illustrated by ANAS (1998),
8. the required **representation** (e.g. vector such as GIS and CAD, raster like ortophotos and maps, or 3D model and PDF) and relating scale,
9. the **user group** that would use the element (e.g. road designers, road maintainers, road managers, safety designers, drivers),
10. the **data use** (e.g. study of feasibility, road/environmental/tourism&route planning and monitoring, emergency management and response, road maintenance, safety management, evaluation of interferences, sight distance, GPS and in-car navigation, street directories, facilities), and so forth.

In accordance with different planning levels, new levels of detail have been also hypothesised to be possibly matched with corresponding 3D datasets.

ENTITY	DESCRIPTION	ELEMENT GROUP	LEVEL (above, on, below)	MANMADE (M)/ NATURAL (N)	SOURCE	USER GROUP (Designers = D; Maintenerss = Maint.; Managers=M)	USES	ROAD CADASTRAL LOD	GEOMETRY	TOPOLOGY	SEMANTICS	GRAPHIC PRIMITIVE	REPRESENTATION SCALE (LOWER)	REPRESENTATION SCALE (UPPER)	REPRESENTATION
Road element	A homogeneous road trunk	Road entity	Above On Below	M	INSPIRE Italian Law on Road Cadastre	All	Car naviga tion Road manag ement	**2**	The **axis** of a carriageway road trunk	1 edge and 2 nodes		Simple line feature	1:10.000	1:200.00 0	GIS CAD
						All	Car naviga tion and Traffic	**1**	The **axis** of a **single** carriageway road trunk	1 edge and 2 nodes		Simple line feature	1:5.000	1:10.000	GIS CAD
						All		**0**	A **single carriageway** road trunk (delimited by margins)	2 edges and 4 nodes		2 lines or a polygon	1:2.000	1:5.000	GIS CAD 3D Mod.
						D Maint. M		**new**	A **solid** of the single road trunk	n edges and n nodes or n surface s		n lines or n areas or 1 solid	1:200	1:2.000	3D Mod. PDF
						D Maint.									
Junction	The end of a road element	Road entity	Above On	M	INSPIRE Italian	All		2	The **point of intersection**	1 node	1. Roundabout 2. Exit road	Point	1:10.000	1:200.00 0	GIS CAD

			Below		Law on Road Cadastre				of more road elements or the interconnection between a road element and a traffic area		3. Intersection				
						All		1	The points of intersections	n edges and n nodes	1. 1. Normal roundabout 2. Mini-roundabout 2. 1. Bifurcation 3. 1. Railway crossing at grade 2. Border crossing	n points and n lines or a polygon	1:5.000	1:10.000	GIS CAD
						All		0		n edges and n nodes		n points and n lines or a polygon	1:2.000	1:5.000	GIS CAD 3D Mod.
Enclosed traffic area	Area for vehicles' movements, but where traffic flows are not defined	Road entity	Above On Below	M	INSPIRE Italian Law on Road Cadastre			2		1 node	1. Enclosed square 2. Parking area	Point	1:10.000	1:200.000	GIS CAD
								1		n edges and n nodes	1. 1. Unstructured Traffic Square 2. Pedestrian Square 3. Another Type of Enclosed Traffic Area 2. 1. Parking Place 2. Parking Building	n points and n lines or a polygon	1:5.000	1:10.000	GIS CAD

								0		n edges and n nodes		n points and n lines or a polygon	1:2.000	1:5.000	GIS CAD 3D Mod.
Roadway	Part of a road used by vehicular traffic	Road element	On	M	INSPIRE Italian Law on Road Cadastre	All		2					1:10.000	1:200.000	GIS CAD
								1					1:5.000	1:10.000	GIS CAD
								0					1:2.000	1:5.000	GIS CAD
Shoulder	Portion of the roadway contiguous with the travelled way	Road element	On	M	Italian Law on Road Cadastre			0			1. Graded 2. Usable		1:2.000	1:5.000	GIS CAD 3D Mod.
Median	Portion of a highway separating opposing directions of the traveled way	Road element	On	M	Italian Law on Road Cadastre	M		0					1:2.000	1:5.000	CAD 3D Mod.
Curbs		Road element	On	M	Italian Law on Road Cadastre	M		0					1:2.000	1:5.000	CAD 3D Mod.
Pavement		Road element	On	M	Italian Law on Road Cadastre	M		0					1:2.000	1:5.000	CAD
Road structure		Road element	Above Below	M	Italian Law on Road Cadastre, Merloni Law	All		2			1. Bridge 2. Viaduct 3. Overpass 4. Tunnel 5. Underpass		1:10.000	1:200.000	GIS CAD

					(1994), ERF (2014)			1			1. Bridge 2. Viaduct 3. Overpass 4. Tunnel 5. Underpass		1:5.000	1:10.000	GIS CAD
								0			1. Bridge 2. Viaduct 3. Overpass 4. Tunnel 5. Underpass		1:200	1:5.000	GIS CAD 3D Mod.
Intersectio n Road node Junction		Junction	Above On Below	M	INSPIRE Italian Law on Road Cadastre	All		2					1:10.000	1:200.00 0	GIS CAD
Barrier		Road equipme nt Safety	Above	M	Italian Law on Road Cadastre, Merloni Law (1994), ERF (2014)	All		2			1. Guardrail 2. Bridge rail 3. Jersey barrier 4. Impact attenuator		1:10.000	1:200.00 0	CAD
						M		1			1. Guardrail 2. Bridge rail 3. Jersey barrier 4. Impact attenuator		1:5.000	1:10.000	3D Mod.
						Maint.		0			1. Guardrail 2. Bridge rail 3. Jersey barrier 4. Impact attenuator		1:200	1:5.000	3D Mod.
Road speed bump	Raised devices, parabolic in shape, placed across the road to slow traffic	Road equipme nt Safety	On	M		Maint.		0					1:200	1:5.000	GIS CAD 3D Mod.
Signage		Road	Above	M	Merloni	M		0					1:200	1:5.000	GIS

		equipment/Safety	On		Law (1994), ERF (2014)	Maint.									CAD 3D Mod.
Electrical/ ITS systems		Road equipment/ Safety/ Plant	Above	M		M Maint.		1			1. Electrical 2. ITS	Points Lines Polygons	1:5.000	1:10.000	GIS
								0			1. 1. Lighting system 2. Luminaries 3. Junction box 4. Signal 5. Ramp Meter Signal 6. Ramp meter cabinet 7. Variable/ Changeable Message Sign (portable/permanent) 8. Under Bridge Deck Lighting 9. Sign lighter 10. Navigation/ Obstructing Lighting 11. Signs (Neon, Back Lit, Fiber) 2. 1. ITS Cabinet 2. Over-Height Detector 3. CCTV 4. Data Station (Clear Zone) 5. Highway Advisory Radio Tower (Transmitter)		1:200	1:5.000	

											6. Emergency Phone 7. Bridge Electrical Control 8. License Plate Reader 9. Temperature sign 10. Crosswalk Flasher 11. Flashing Beacon (RRFB) 12. Weather station 13. Queue detection 14. Gate 15.Gate controller				
Plant/ Utilities		Road equipment/Plant	Above Below	M		M		2			1. Pipes 2. Regulatory Outfalls 3. Storm Water Facilities				
Underground Utilities		Road equipment/Plant/ Environment	Below	M		M D Maint.		2			1. Underground tank 2. Pump vault				
Advertising signs		Road equipment/	Above	M		M Maint.		2							
Terrain		Environment	Below On	N		M D Maint.					1. Wetland 2. Riparian zone 3. Mitigation site 4. Ditch 5. Swale				
Landscape area		Environment	On	N		M Superintendence									
Slopes and		Environ	Above	N		M									

Slide Areas		ment	On Below			D Maint.									
Vegetation		Environ ment	On	N/M							1. Tree (isolated, grouping) 2. Shrub 3. Ground cover				
Rock Outcroppin g		Environ ment	Above	N											
Utilities/ Plant		Environ ment		M							1. Irrigation facility 2. Fish Passage Facilities 3. Stream Crossing 4. Wildlife Passage Facilities				
Air		Environ ment	Above	N		M					1. Air pollutant 2.Greenhouses gas emission				
Water		Environ ment		N/M							1. Sea 2. Lake 3. River 4. Pond				

Table.... Summary table of requirements from the literature and expert users

The table above includes some examples of different entities relating to road infrastructures and Road Cadastre's uses. It comprises all kind of elements emerged by sources (literature review and standards) and road users (questionnaires and interviews). This third approach aims at considering the contribute of all the factors influencing the 3D road description (and addressed in the previous chapters) including uses and users, and clearly highlights the multi-factorial nature of the Road Cadastre model. The summary table implemented, hence, results in this third approach in **a meta-diagram** deriving from the current Road Cadastre structure compared with the multiple technical and social requirements collected, and focused on 3D.

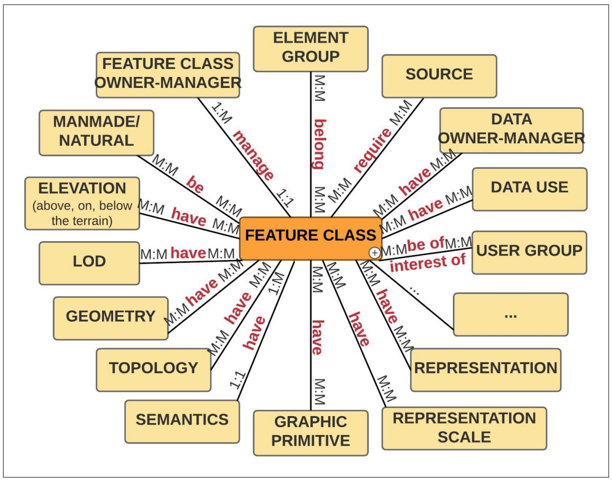


Figure 84. Meta-model for a 3D Road Cadastre: a cluster of clusters

As the diagram shows, the majority of the relationships represented are many:many - e.g. one source is associated with many elements, and an element can be required by more than one source. This approach, far from to represent a fixed model, aims at reflecting the flexibility and multi-use required to the Road Cadastre that at conceptual level can be represented as **a meta-model** or **"a cluster of clusters"**. From it a number of physical models reflecting the potential users may be generated, showing how useful each individual element - 3D in particular - is to different groups. Such model is open and might include also further elements, such as source of data (i.e. sensors, GPS, photogrammetry). It also comprises different road owner/manager and data owner/manager groups that - as described in Chapter 3 and 5 with regard to local Road Cadastres or transferring of responsibilities among institutions by law - may be different or change. This model, deriving from the table above and the previous observations, represents the proposed conceptual data model of this research.

The 3D model proposed includes a wide range of different data (Fig. 85). Within the model spatial entities (i.e. environment, road infrastructures and the elements they are made of) are modelled in 3D and queryable providing data as text, images and maps as PDF and JPG files, which can be linked to a road, a section of road or a specific element in the model. This mixed data types approach is fundamental as the questionnaires and interviews, as well as emerging Smart Cities and ITS requirements, highlight the importance of a flexible approach to modelling. Thus, not only does 3D enable realistic modelling of real world objects, the 3D environment also facilitates access to other data, serving as a data indexing mechanism.

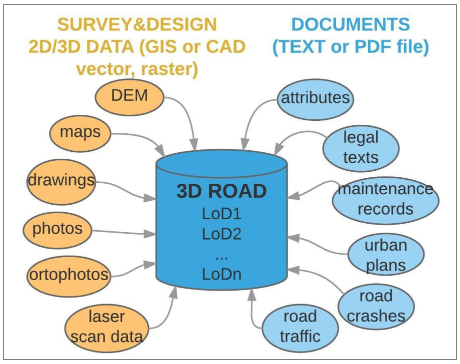


Figure 85. High Level Overview of the 3D Road Cadastre.

9.3.1.4 Levelsof details relating to the meta-model

In comparison with the first two approach, the meta-model does not look for a fixed hierarchical structure, as the same LoD can be differently considered by different users depending on various road cadastral potential uses (as further discussed in Chapter 10). Nevertheless, some aspects addressed in the first two approaches cannot be ignored. Hence, in addition to the relationships among different domains characterising the model, a second abstraction relates to the relationships among road components at different levels of detail. In order to meet the users requirement for a simple and easy-to-use 3D road cadastral systems, such number of scales and related levels of detail for each element - in turn related to many different domains described by the meta-model above - a simplification of the system is required in terms of representation. A part of the table above (in particular, the entity "Road element") has been focused: multiple scales are normally used in the traditional cartography and corresponds to different levels of detail for example when referred to buildings.

Entity	**Road element** (a homogeneous road trunk)				
Element Group	Road entity				
Manmade/ Natural	Manmade				
Elevation (from terrain)	Above, On, Below				
Source	Italian Road Cadastre Act, Merloni Law, Interviews, Questionnaires	Italian Road Cadastre Act, Merloni Law, Interviews	Italian Road Cadastre Act, Merloni Law, Interviews	Merloni Law, Interviews, Questionnaires	Merloni Law, D.P.R.554/1999, ERF 2014, Interviews, Questionnaires
LoD	2	1	0	-1	-2
Geometry	The **axis** of a carriageway road trunk	The **axis** of a **single** carriageway road trunk	A **single** carriageway road trunk (delimited by margins)	A **solid** of the single road trunk	N **solids** of the main road components
Topology	1 edge and 2 nodes	1 edge and 2 nodes	2 edge and 4 nodes	N edges and n nodes or n surfaces	N edges and n nodes or n surfaces
Graphic primitive	Simple line feature	Simple line feature	2 lines or a polygon	N lines or n areas or 1 solid	N lines or n areas or n solids
Representation scale	1:10.000-1:200.000	1:5.000- 1:10.000	1:2.000-1:5.000	1:200-1:2.000	1:100-1:200
Representation	GIS, CAD, maps, ortophotos	GIS, CAD, maps, ortophotos	GIS, CAD, maps, ortophotos	3D MODEL, PDF	3D MODEL, PDF
User group	Road Designers, Road Managers, Drivers	Road Designers, Road Managers, Drivers	R.Designers, R.Maintenairs, R.Managers, Drivers	R.Designers, R.Maintenairs, R.Managers, Safety designers	R.Designers, R.Maintenairs, R.Managers,Safety designers
Data use	Study of feasibility, Planning, Environmental planning &monitoring, 4 wheel driving, Tourism&Route planning, GPS navigation, Environmental planning, Emergency management&response, etc.	Road design, Environmental monitoring, In-car navigation, Facilities, Street directories, etc.	Road design, Environmental monitoring, etc.	Road design, Road maintenance, Evaluation of interferences, Sight distance&Visibility, etc.	Road design, Road maintenance, Safety, Evaluation of interferences, Sight distance&Visibility, etc.

The table above illustrates many hypothetical scales used in the traditional cartographic representation of road networks and levels of details associated: LoDs 2, 1 and 0 follows the legal Road Cadastre criteria; however, in order to have more detailed representations of roads - also in accordance with Italian standards for delivering projects (i.e. Merloni law) - further Levels of Detail should be added (e.g. named as LoD -1 and LoD -2 in the table, just to follow the typical sequence of road cadastral LoDs, whose identifying number decreases with more details). However, in order to implement a 3D Road Cadastre not too complex (in accordance with real users requirements), the 5 levels described above can be easily reduced to a few (with the possibility of selecting from the more detailed one the only layers and information required according to different uses): LoD2 an LoD -2 from the table might be kept with an intermediate LoD

According to LoD 2 (in the table), the road element is a line corresponding to the axis of a carriageway road trunk (centrelines). It is a representation fitting to many GIS-T applications, as well as car navigation needs, feasibility studies of road designers, map users (e.g. drivers), and road managers for analysis at largest map scales. It is also useful for referencing point and line events on it, as underlined by Kayondo Ndandikol et al. (2013), while proposing an object based GIS-T data model for road infrastructure maintenance in Uganda. Also INSPIRE Directive established that "linear referencing is used to position phenomena along a linear object, using a distance from the beginning of the linear object". Theoretically such representation should be switched into intermediate levels (possibly associated with the same dataset): e.g. LoD 0 and LoD -1 in the table above. LoD1 would also represent road boundaries and area objects in order to distinguish different carriageways, evaluate properties boundaries and areas, and other; this also in accordance with the INSPIRE Directive, which considers centrelines objects and area objects as possible alternative representations of the same real world phenomena about which the user can associate their own information. LoD -1 would represent the 3D volume of the road for feasibility studies, volume calculations and safety analysis on visibility.

In addition to the basic LoD2, the use of the so-called LoD-2 (in the table) may be include data theoretically relating to LoD1, LoD0 and LoD-1, avoiding too much complex systems. At this latter level, the road is composed by n volumes; nevertheless, it allows describing both each road part (e.g. for design or maintenance needs), and the whole road body as a single volume (e.g. for forecasting costs of excavations), and the representation of the carriageway area between roads boundaries also in accordance with the INSPIRE representation of roads: the latter allows identifying properties (both of the road both of the adjacent lands), different lanes in which the roadway is subdivided as the current legal Road Cadastre already does, and identifying directions of the flows.

Level 2 graph of the current legal Road Cadastre (e.g. derived from maps at 1:200,000 scale and representing the whole national road network simplified), instead, is kept as it can be used by the Department of Civil Protection to identify the paths for the relief to an affected area and evacuation routes as well as for calculation of shortest paths, and estimates of traffic flows. Lines should be associated with attributes related to: road owner, road name, variant (i.e. bis, ter), functional class, length in km, gradient and tortuosity (ANAS, 1999), while other information required by the literature and users can be associated with a unique 3D model composed of different parts represented by different layers, queriable according to different uses.

In a first approach five different LoDs were used in accordance with the table above. For the first LoD the road axes (centreline) was considered (in car navigation, road path calculating, administrative and technical general information); two axes (roadsides, i.e. lines) are considered for the second LoD (to check boundaries and properties); a surface (polygon) for the third (to check location of single interventions,subdivision of the platform in carriageways – or travelled lanes – and other lanes, shoulders, medians, and so forth), a solid (polyedral surface) for the fourth (to consider the road bed occupation, calculate excavations, visualise 3D relationships with surrounding buildings or the structures), and n solids (polyedral surface collection) for the fifth where all road components are included. The requirements of simplicity by users and the actual uses of current LoDs of the legal Road Cadastre lead to reduce them. According to a second approach LoDs were three with a first LoD representing roads by the axes (3D lines and nodes), where also a precise positioning of objects and road events is guaranteed by the use of points (e.g. structures, or signs, hence indipendently from their size). It includes for example the DEM of the terrain (for road design at the first stage: feasibility study). The second LoD is the volume of road with the generic volume of surronding buildings (e.g. extruded by maps or deriving from laser scan data modelling). The third LoD related to the as built of the components of road networks for detailed visualisation and analysis in a georeferenced context: here roads are presented with 3D elements like sidewalks, gutters, curbs (near to the same level of the road surface and adjacent to its margins, but with a different z describing their height/elevation on the road surface level), signs, barriers, traffic lights (above the surface), as well as structures; and underground utilities (underneath) as well as archaeological finds.

In the first case, the graph includes links, nodes and points, in the second the road volume is subdivided in sections as well as the third were components are many however.

In Chapter 5 the gap analysis highlighted that ANAS considers useless the current road cadastral structure composed of three main entities, as enclosed traffic areas can be represented as particular cases of junctions. Hence, in the following scheme the basic level of detail (LoD1) for the new 3D Road Cadastre model describes the 3D road network as composed by 3D road elements and 3D junctions, as follows:

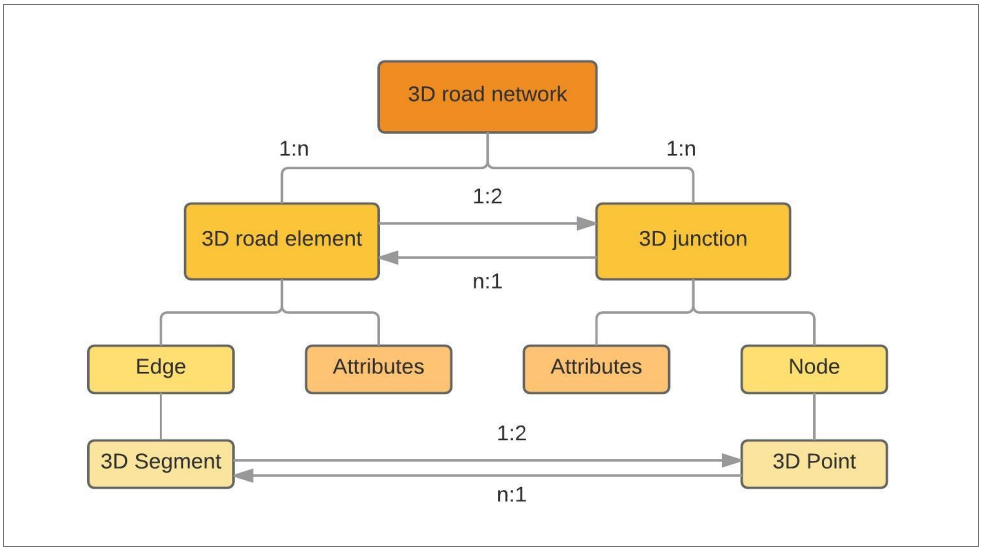


Figure 86. 3D data structure of road network at the new LoD 1 of the 3D Road Cadastre proposed

Topologically speaking, in most of GIS applications the data model commonly includes faces, edges, and nodes as topological features. The first level of detail of the model proposed comprises 3D road elements (among two junctions) to be represented by edges and 3D junctions (including both crossings and enclosed traffic areas, as required by users) described by nodes. Nodes can be identified by points; moreover, points can be identified on lines in order to represent single physical elements along a road element, or road events.

Such model is near to what road managers provide to road designers according to the interviews: when designers have to start a new project or an intervention of adaptation they are given by road managers a 3D polyline from the road cadastral GIS associated with DB tables. At this level the 3D road graph is associated to general attributes that can be of interest of all stakeholders, whereas points also help to identify the beginning and the end of segments on the road element with peculiar characteristics (of different interest for various users) or features like structures that extend from a certain length.

At a more detailed scale (new LoD2) a 3D data model is designed for the multiple 3D cadastral purposes by adding a 3D feature: volume. A volume (that is, a container or polyhedron) consists of a set of faces that enclose a 3D space. At this LoD, each 3D road element is divided into 3D volumes corresponding to each 3D segment of the road element (that can vary in accordance with the purpose: e.g. safety checks or road design). Here some features are better identified: the road platform is represented as a volume whose surface - as a face - is divided into carriageways, lanes and so forth; buildings and structures are represented as 3D volumes facilitating the check of environmental impact, distances, visibility for safety. 3D volumes of different macro layers of terrain are also represented at this level to generically identify spaces containing pipes or archaeological finds underground as required by users.

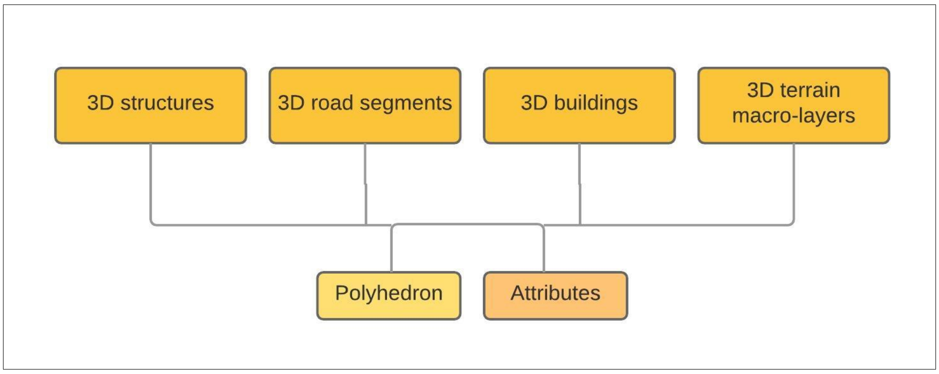


Figure 87. 3D data structure of road network at the new LoD 2 of the 3D Road Cadastre proposed

The new LoD3 refers to each single 3D road component and is aimed mainly at describing geometric characteristic and attributes of different parts of the road in detail and for various purposes (e.g. manteinance, advertising sign or sign management, safety management, and other).

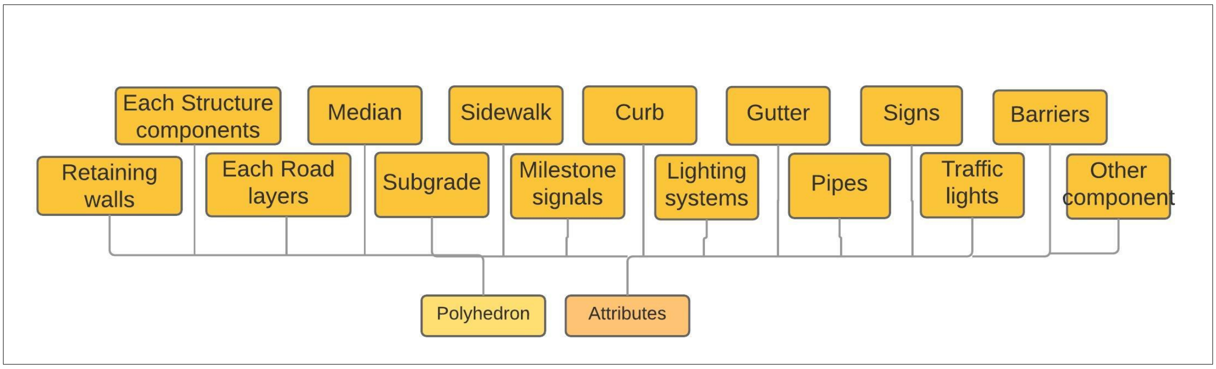


Figure 88. 3D data structure of road network at the new LoD 3 of the 3D Road Cadastre proposed

2D GIS Road Cadastre's LoDs by Italian law		**3D GIS Road Cadastre LoDs proposed**	
LOD2	Roads + Intersections	**LOD1**	3D road elements (3D lines) + 3D junctions (3D points)
LOD1	Road elements + Junction + Enclosed Traffic Area	**LOD2**	3D road segments, sructures, building, and terrain's macrolayer (3D volumes)
LOD0	x, y	**LOD3**	Each single part and component of road, structures, and utilities (3D volumes)

Table 40 Current and proposed Road Cadastre LoDs

The LoDs above can be just hypothetical and above all not fixed, as actually they will depend on the users.

9.3.2 Spatial data modelling and RDBMS in the 3D Road Cadastre

DataBase Management Systems (DBMSs) are software packages for storing, retrieving, managing, maintaining, and updating data that, because of their simple data structuring, have been using in many applications, including managing and processing roadway inventory databases. They have been emphasised by Karimi et al. (2000) in their book documenting the findings of a study to improve the collection and presentation of physical roadway inventory data through the application of existing, emerging, and transferable technology. In particular, the relational structure, as a collection of relationships between data elements representing aspects of reality based on set or relational algebra, is considered appropriate for managing complex and large quantity of different data (Date, 1986; Howe, 1989; Martin, 1983).

9.3.2.1 Logical model

The logical design of a spatial model based on the relational approach can be achieved by organising the representations of spatial objects and relationships between them into a set of tables consisting of rows and columns (that is, records and fields). It includes administrative and abstract data, geometry which comprises all the characteristics provided by law and associated with technical road classes.

The model contains a number of classes: "3D Road Element", "3D "Node", "3D Segment" "3D Point", "Polyhedron" as feature classes, as well as "Structure", "Culvert", "Barrier", "Road Sign", and what else required by users and the literature. Various dataset are included both with general data as "Administrative data", "Technical data", "Road Ownership", and specific data on the base of the use/purpose "Maintenance", "Traffic management". As described in the conceptual model, further tables regarding "Users", "LoDs", and "Representation" including Photo, .pdf and Video, can be linked to similar or different data from other tables: for example, "Surface type" and "Road condition" tables can contain data that can be used for maintenance or safety purposes, by both designers and managers, and hence that can may be queried by the model for different aims.

The following diagram represents just a part of the logical model that can be enlarged through further tables and connections to other database (e.g. the data from the Osservatoorio dell'Incidentalità with regard to road accidents).

As the Chapters on requirements showed both relating for example road design or maintenance standards or relating to laws on Preservation of Cultural Heritage and Acts regarding new road constructions and providing projects variants in the case of environmental or archaeological constraints, the model should guarantee General tables and specific tables with different LoDs. Some example of tables are reported here, while Fig. 89 describes a part of the logical model.

Bridge, culverts etc. can be identified as point or linear events

Table RoadAdmin (all uses)

RoadID	Int(6)	Unique identity of the road
Denomination/TechnClass	Char(100)	Name of the road
AdmClass	Char(25) / or Int(6)	Administrative class
TehnClass	Char(25) / or Int(6)	Tehnical class
Variant	Char(10)	Variant (bis, ter, etc.)
Owner	Char(70) / or Int(6)	Road owner
Manager	Char(70)	Road manager
ConstructDate	Date(8)	Time of construction
ConstrCompany	Char(70)	Road builder (company)
BuildCosts	Int(15)	Cost of construction
...	...	...
...	...	...

Table . Non-spatial attributes of road segments (road elements)

Table TechnFeat (useful for management and design)

RoadID	Int(6)	Unique identity of the road
Speed limit	Char(100)	Name of the road
Speed design	Char(25) / or Int(6)	Administrative class
...	...	...
...	...	...

Table . Non-spatial attributes of road segments (road elements)

Table RoadGeom

RoadID	Int(6)	Unique identity of the road
FromNodeID	Int(6)	Node ID of from-node
ToNodeID	Int(6)	Node ID of to-node
VertexNum	Int(6)	Number of inner vertices
VertexIDList	Pointer(Var)	List of vertex ID
Lenght	Int(100)	Lenght
Gradient	Int(25)	Gradient
Tortuosity	Int(25)	Tortuosity
...	...	...

Table . Spatial attributes of road segments (road elements)

Table RoadNode

NodeID	Int(6)	Unique identity of the node
X	Int(6)	X coordinate of the node
Y	Int(6)	Y coordinate of the node
Z	Int(6)	Z coordinate of the node
InArcNum	Int(4)	Number of arcs reaching the node
OutArcNum	Int(4)	Number of arcs exiting the node

Table . Spatial attributes of road node features

Table RoadPoint

PointID	Int(6)	Unique identity of the point (vertex)
X	Int(6)	X coordinate of the point
Y	Int(6)	Y coordinate of the point
Z	Int(6)	Z coordinate of the point
...	...	...

Table . Spatial attributes of road points

Table RoadSegment

SegmentID	Int(6)	Unique identity of the point (vertex)
From Point ID	Int(6)	
ToPointID	Int(6)	
...	...	...

Table Uses

UseID	Int(6)	Unique identity of the use
Type	Char(100)	Name of the road
...	...	...
...	...	...

Table . Non-spatial attributes of road segments (road elements)

Table Users

UserID	Int(6)	Unique identity of the user
Type	Char(100)	Type of the user
Name	Char(100)	Name of the user
Address	Char(100)	Address of the user
...	...	...
...	...	...

The 3D model, instead, is composed of n solid each corresponding to a different layer

Fig. 76 Part of the logical model

9.3.3 Physical models for a 3D GIS Road Cadastre

This Paragraph illustrates the physical model proposed for a 3DGIS-based Road Cadastre and composed of: 3D data models of roads, a DBMS, a WebGIS usable as an interactive graphical interface by users, and a server where the road information system is allocated and can be consulted on line by users.

As shown in Section 9.3 Paragraph 9.3.1 with regard to the conceptual model, the 3D Road Cadastre's data model can be composed of different data projects, in accordance with different road uses and users requirements. In this Paragraph, a single project will be illustrated the implementation of a prototype as an example helpful to show the various stages of the process of implementation of the Road Cadastre physical model (or better, one of the implementable road cadastral physical models). While describing the stages of system architecture, each technical component and tool used for the physical model will be described.

9.3.3.1 Stages of system architecture

The stages of the system architecture are here illustrated by a prototype implemented using data of a road project in the territory of Ragusa (an Eastern province of Sicily). It relates to the improvements of the road connections between a trunk of the State Road (SS 115) - between the villages of Comiso and Vittoria - the new airport of Comiso, and the State Road (SS 514) between Ragusa and Catania (towns at the extreme North-East of Sicily). The road project was carried on by a group composed of several companies (i.e. SIS s.r.l., A&S Engineering s.r.l., Bonifica Italia s.r.l., Co.Re Ingegneria, and Omniservice Engineering s.r.l.) that provided data for this research. Data included all 2D drawings of the road project - both in .dwg and .pdf format - that they delivered to public administrations as established by law. That includes top view (maps) and cross sections and profiles of the road at different scale, and further drawings focusing on specific topics (e.g. signs location).

With regard to 3D data, road designers also provided a .dwg file with a 3D polyline (the road axis or centreline) provided to them by ANAS, and another file with the DTM of the area of project. As already explained in Chapters 5 and 8, in fact, usually in Sicily where local Road Cadastres have not been implemented yet, road designers receive from ANAS road managers data from the ANAS Road Cadastre: as road designers mainly use 2D and 3D CAD software and are not familiar with the use of shapefiles, as emerged from the interviews (Chapter 8), ANAS road managers usually convert data relating the road cadastral graph and provide road designers with a 3D polyline representing the road axis and tables with related road data in Microsoft

Excel. Through such data, road designers will implement their road projects using specific design software like PROST as well as other programs for structural calculations.

Hence, in order to simulate the implementation of a 3D road model by road designers, in this research the initial data available to them has been used as well as the procedure that currently they should follow to produce their road model. In addition, the model should be in 3D and provided 3D data required by themselves (for road design purposes) updateable and integrated with further kind of data. The 3D road data model should be loaded into the 3D Road Cadastre platform for documenting roads for next uses, updating, or adjustments.

Data collection and modelling stage

As mentioned, the initial data to build the data model is made by:

1) the 3D polyline in .dwg deriving from the ANAS road cadastral graph converted by GIS to CAD - it might also derive from surveys in order to build a 3D graph from scratch. It is associated with tables (also deriving from the GIS based ANAS Road Cadastre) indicating the location of structures and further small data already described in Chapter 8;

2) the design (top view) of the road platform in .dwg (obtained by PROST software which processes DTM, 3D polyline and tables provided by ANAS and gives outputs in 2D as the Italian standards require). Together with the road platform, both roadsides and numbered cross lines are indicated by different layers. Cross lines are designed at regular intervals and indicate the location - on the road platform - of the road cross sections, as required by standards;

3) all numbered cross sections, at a more detailed scale and describing each road component with its measures, represented in 2D in a separated .dwg file;

4) the DTM;

5) thematic drawings (e.g. sign location on the map, as mentioned) and detail of drainage systems and components (both in .dwg and .pdf format).

In order to meet road design requirements during the different stages of road planning, as the Italian law requires and in accordance with road designers 3D needs, the project to be loaded within the 3D Road Cadastre is composed of three models with different LoDs (respectively for the feasibility study and the preliminary project, the final project and the executive project).

In order to simulate the same approach of road designers, they have been developed within a CAD environment using AutoCAD 3D: it is widely known and used by road designers and allows modelling both 3D lines and 3D points and polyedral surfaces for the volumes that will be used for the models.

The first model is the 3D road graph (at LoD1) derived from the pre-existing ANAS road graph and composed of "road elements" and "nodes" having different layers: 3D data are associated with them and also refer to both "points" (that identify point features like signs or the beginning and the end of "segments") and "segments". The project of the road data model also includes the DTM.

At LoD2, in the absence of a software like PROST - usually used by road designers to implement the road platfrom from the 3D centreline - a 3D model of the road divided in road trunks (volumes from cross section to cross section, i.e. where each polyhedron is comprised from face to face) has been implemented. 2D drawings of the top view of the road platform and its cross sections in CAD provided by road designers have been used for modelling, as follows:

1) the boundary of each cross section has been redesigned as a 3D polyline,

2) each cross section has been rotated on its axis and correctly located on the 3D polyline as indicated by the cross section number on the 3D centreline;

3) each cross section has been extruded by the AutoCAD LOFT command along the road centreline path.

The volume of the road platform resulting, hence, is composed of n solids (3D road trunks limited by road cross sections: i.e. whose beginning and end is defined by the location of cross sections). Each 3D road trunk will be associated to 3D data in addition to its geometry, as later described. At this level, the model can also include "external" 3D elements of the surrounding and underground context: i.e. 3D building, 3D structures and 3D macrolayer of the ground, as simple volume (polyhedra) associated to general data and helpful for environmental evaluation and further analysis at a medium scale.

At LoD3, the most detailed, each road trunk is a 3D solid composed of n 3D road components (both road body's components and road equipment, located both at the same level of the road surface and above and underneath). Also in this case road trunks have been modelled in 3D as described above, using the 2D drawings of road cross sections provided by road designers in .dwg format as initial data. In addition, each single road component has been modelled by the same procedure: the profile of curbs, road surface, shoulders, medians, and each layer of the road body (represented in the detailed cross sections) have been redesigned using 3D polylines associated with different CAD layers within the 3D environment. Each road component boundary has been then extruded along the centreline among two cross sections numbered as described above by the AutoCAD LOFT command. The result is a geometry collection of polyhedra.

Each road component, hence, is a LoD3 element that, in addition to its geometry, will be associated with 3D data (as later described) as well as with .pdf files with drawings, standards, and other as required by road designers according to their needs.

The following Figures show the different stages to model the road at LoD3. Fig. … shows a stretch of the road with indicated the road width with roadsides, and the location of the road cross sections properly numbered. Next to it, on the right side in the picture, the redesign of one of the two-dimensional road cross sections provided with details on road components (and imported from a separated .dwg file) can be seen.

Fig. 81 below shows the initial CAD drawing of a 2D road cross section used as a source to redesign each road component profile of each road trunk: initially it is drawn by simple lines using just a few of layers. In Fig. 82 the 2D road cross section has been imported into the file containing the initial drawing of the road platform, while Fig. 83 illustrates the stage of redesign of each road cross section using 3D polylines and a specific layer for each 3D road component.

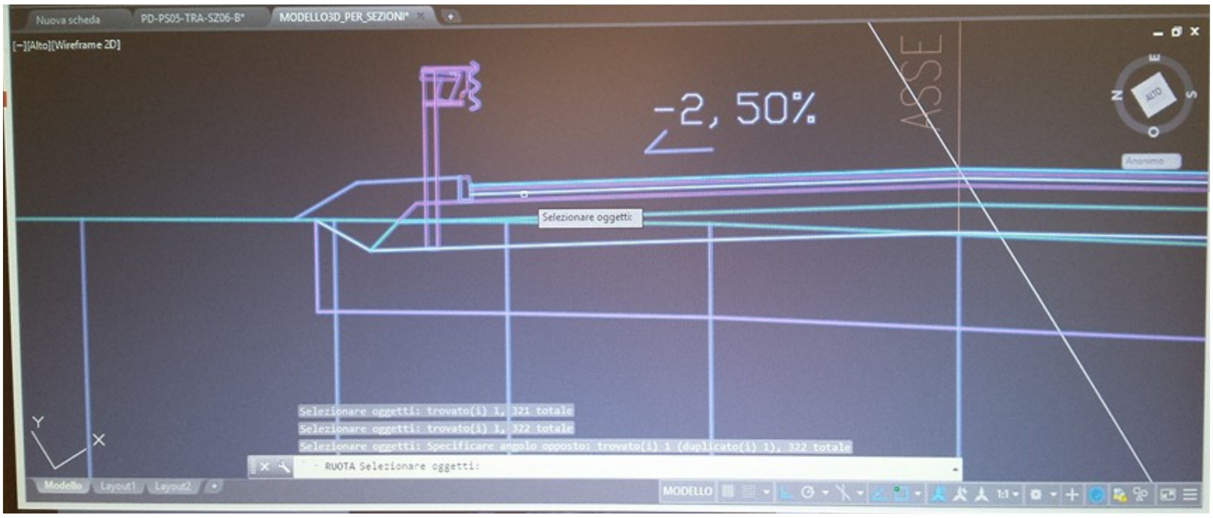


Fig. 81CAD drawing of a road cross section: a source to redesign each road component profile as a 3D polyline

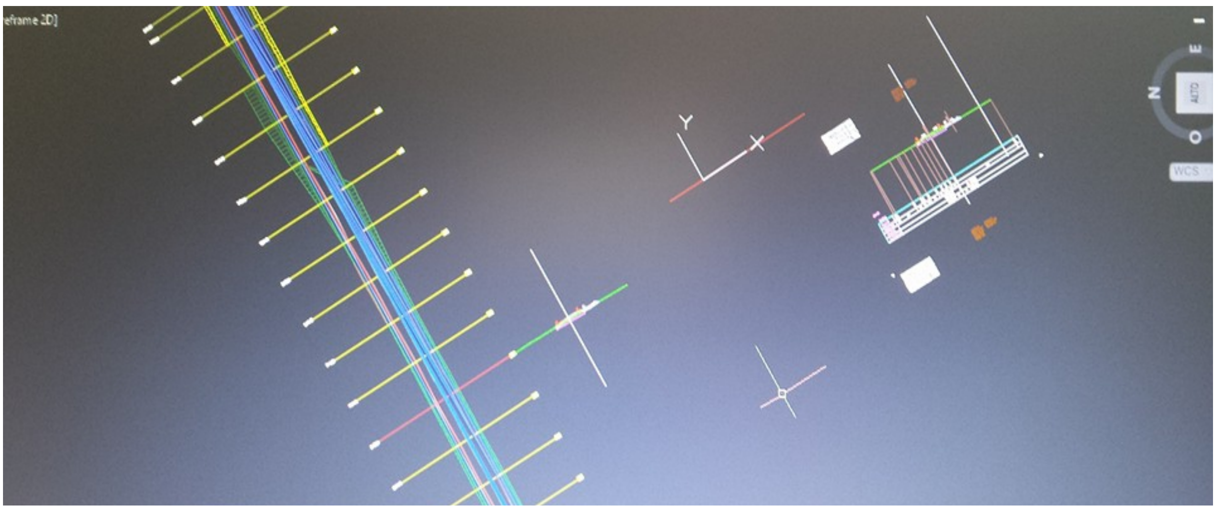


Fig. 82 Stretch of the road with indicated the width, roadsides, the location of numbered road cross sections; on the right, one of the road cross sections in 2D imported to be redesigned with different layer for each road component

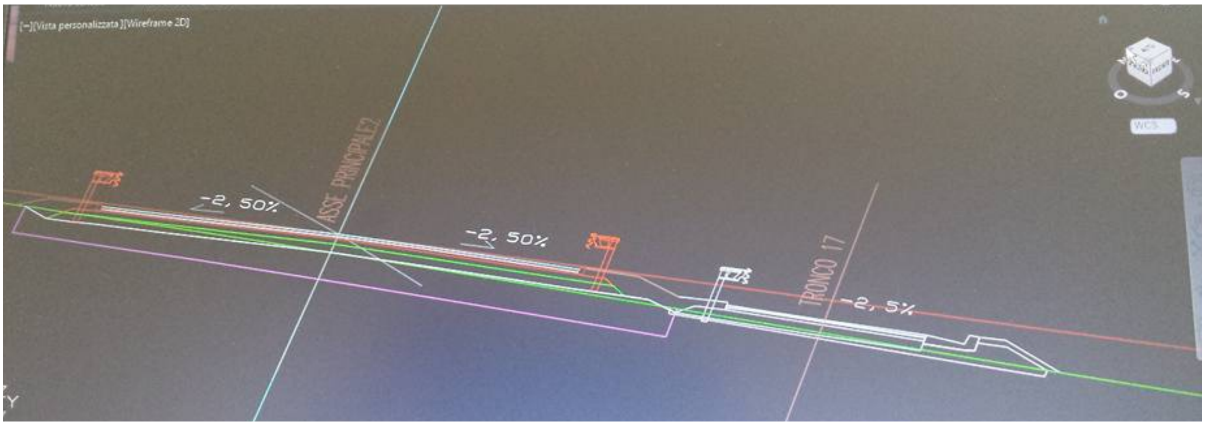


Fig. 83 Redesign stage of the cross section from the 2D drawing using 3D polylines and a specific layer for each 3D road component

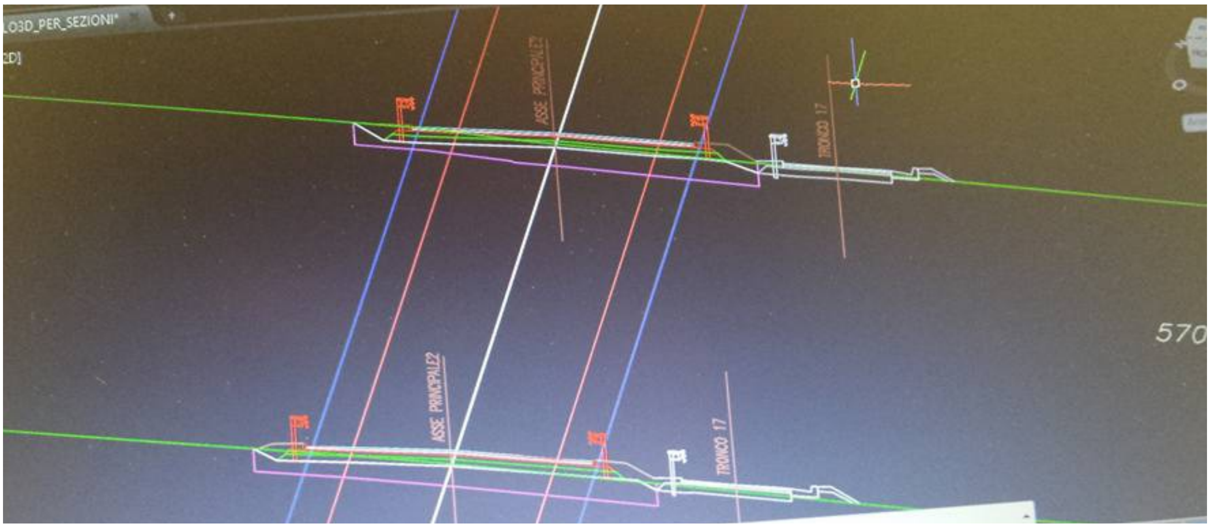


Fig. 84Positioning of the rotated 2D road cross section on the road axis

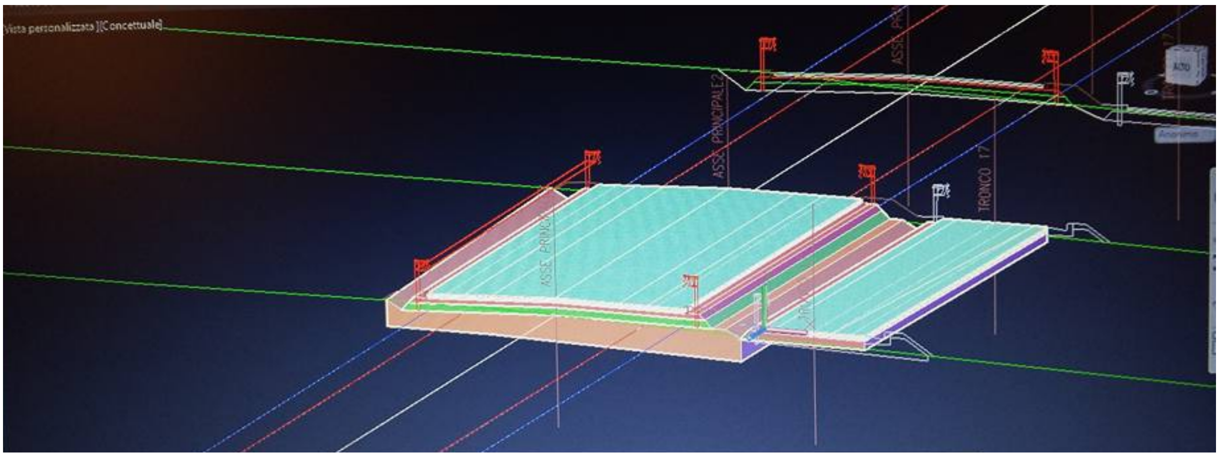


Fig. 85. 3D Modelling of a road trunk between two road cross sections with each road component separated and loaded on a different layer

The data model resulting is operationally structured by polyhedral surfaces: full 3D objects constructed from arbitrary polygons that are a commonly used geometric data structure in computer graphics, and that advanced databases like PostGIS (extension of PostgreSQL) and Oracle Spatial can store.

9.3.3.2 Export of the model geometry from the modelling software into a DBMS

The second stage consists in exporting the geometry of the 3D model from the modelling software into a DBMS. PostgreSQL by PostGIS as its spatial extension can store 3D data Well Known Text (WKT) primitives (Zlatanova, 2006),[107] with WKT defined as a form of mark-up language for describing geometries in human readable text format. In order to translate CAD 3D model geometry into text and store it into the DB, 'FME Data Inspector' has been used: it is a data integration software by Safe Software provided with an effective support for spatial data used for spatial and non-spatial datasets conversions. CAD Features were converted to the equivalent PostGIS Well-Known Text (WKT) primitives (i.e Points into WKT Point Zs, Multipatch Shapefiles into WKT PolyhedralSurfaces and TIN Zs, etc), and recorded into a PostgreSQL 9.6 database using the PostGIS extension. The same can be done with shapefile types.

The following Figures show the creation of a "Road" database, the visualisation by FME of the model recorded into PostGIS, and the tables relating each components.

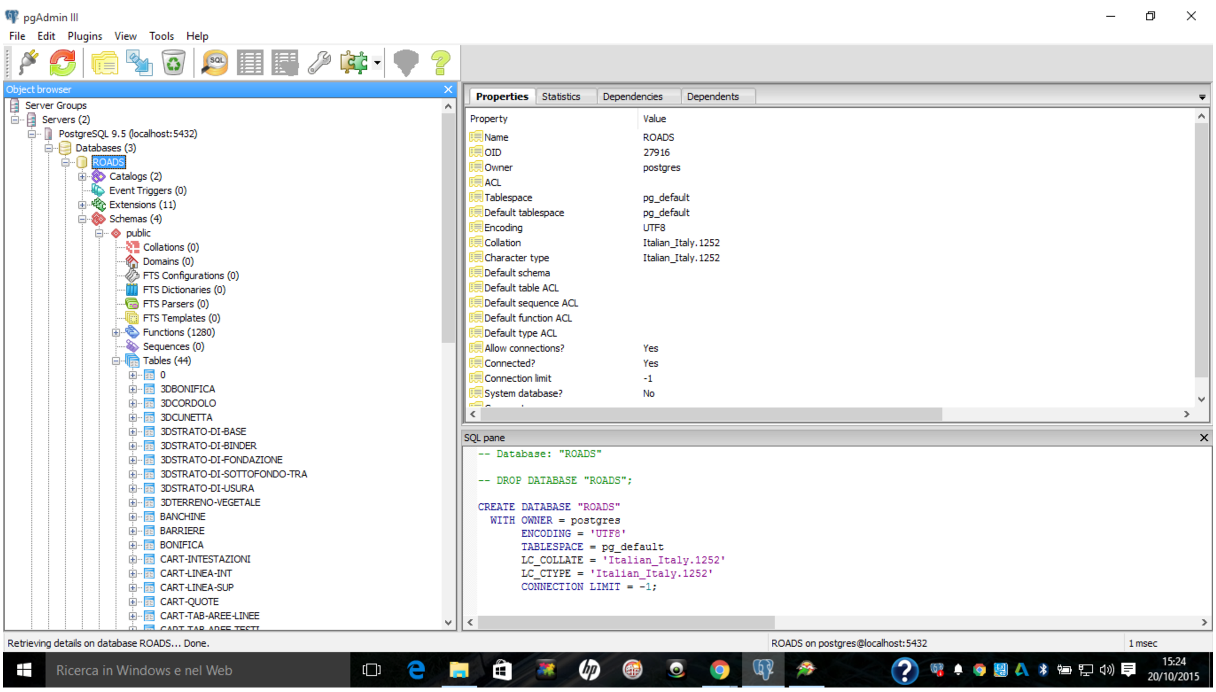


Fig. Screenshot of the database "Road" in PostgreSQL

[107]This is also allowed by other spatial databases like Oracle, IBM DB2, MySQL, and Informix.

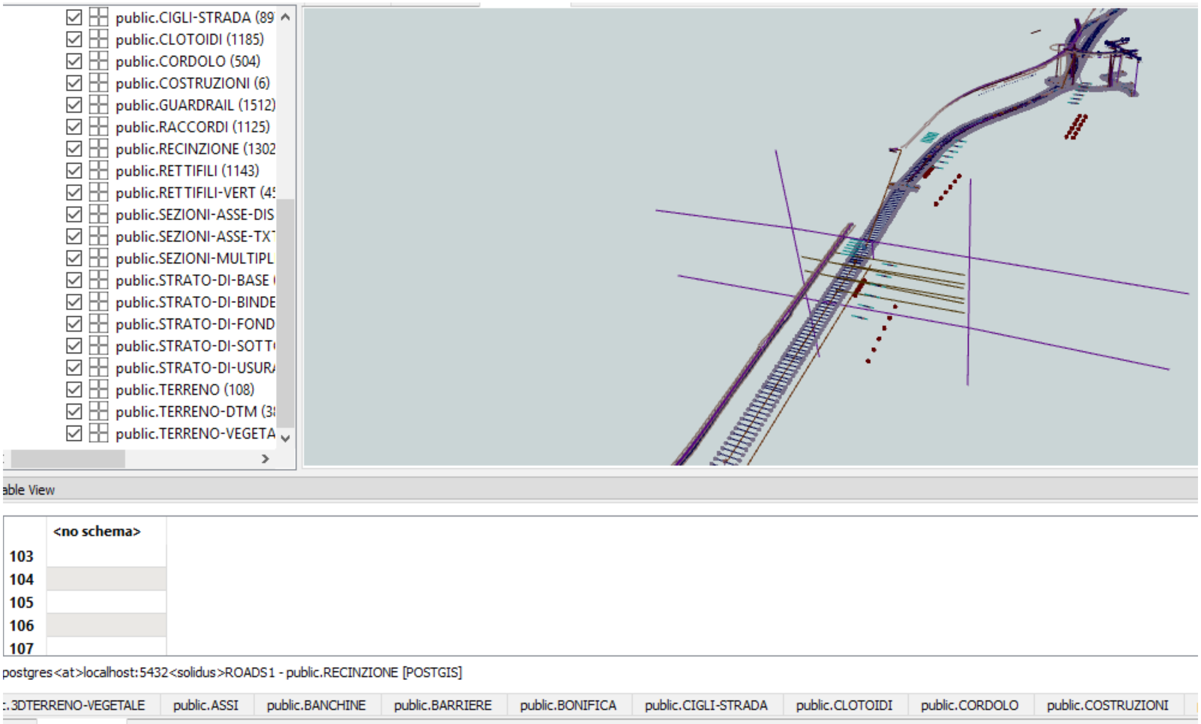


Fig. Screenshot of the FME visualisation of the 3D road model recorded into PostGIS

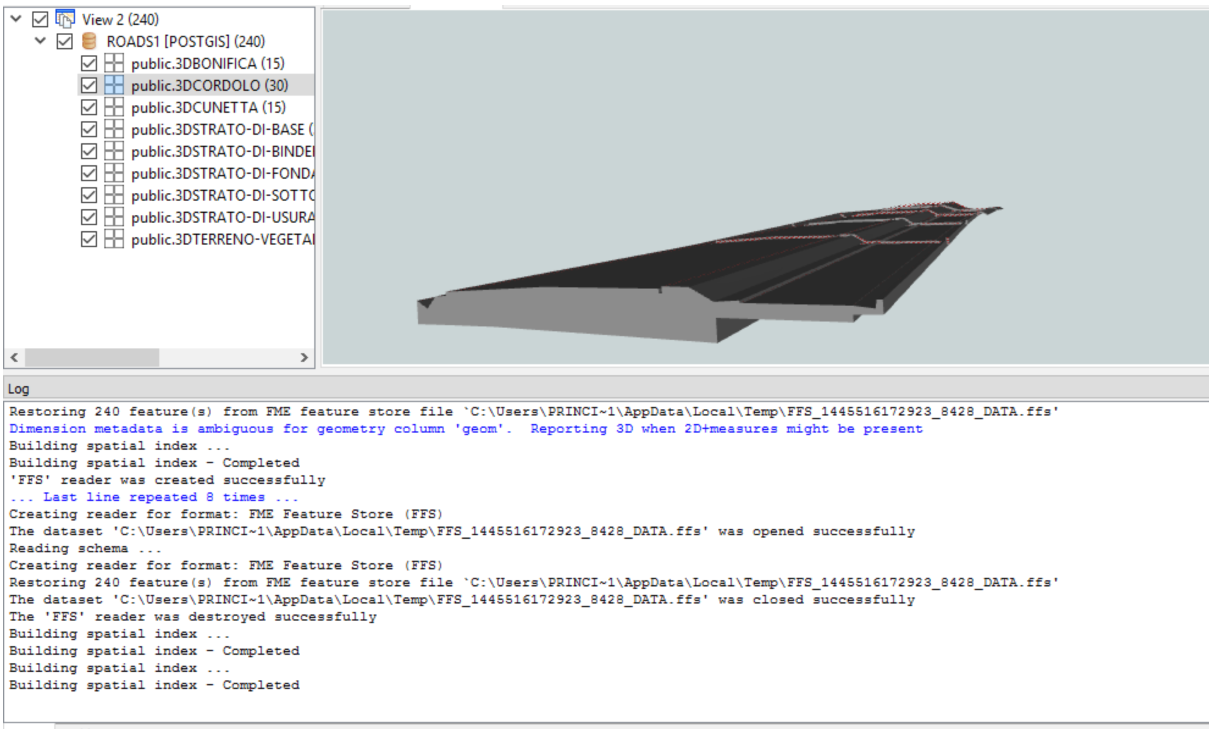


Fig. Screenshot of the FME visualisation of 3D elements (solids) from PostGIS

Within the database, each table (data layer) was updated with an ID column using a Big Serial primary key allowing for auto-incrementation. This allows the 3D GIS web system to uniquely identify geometries. Moreover, PostGIS database, supporting 3D primitives, allows the geometries' updating by SQL. In PostGIS, in fact, 'geometry from text' functions (such as

ST_GeomFromText) allows for editing 3D geometry. WKT (Well Known Text) can be written (or generated programmatically) to update the database by using an SQL UPDATE query.

The following Figures show some examples of tables of the different road components (like entities) and related geometry columns (written in WKT).

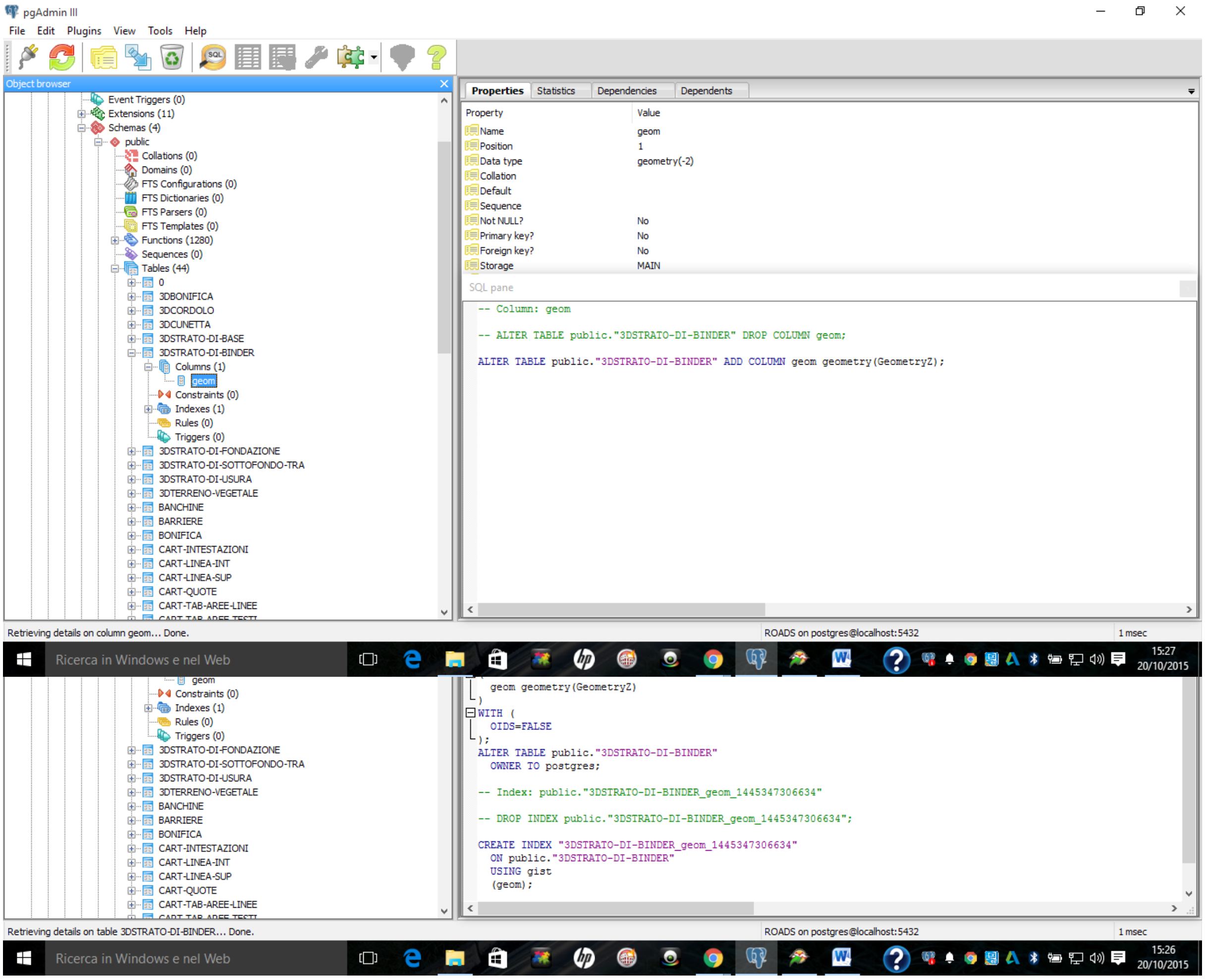


Fig. Screenshot of the database in PostgreSQL. Table of the entity "3D strato di usura"

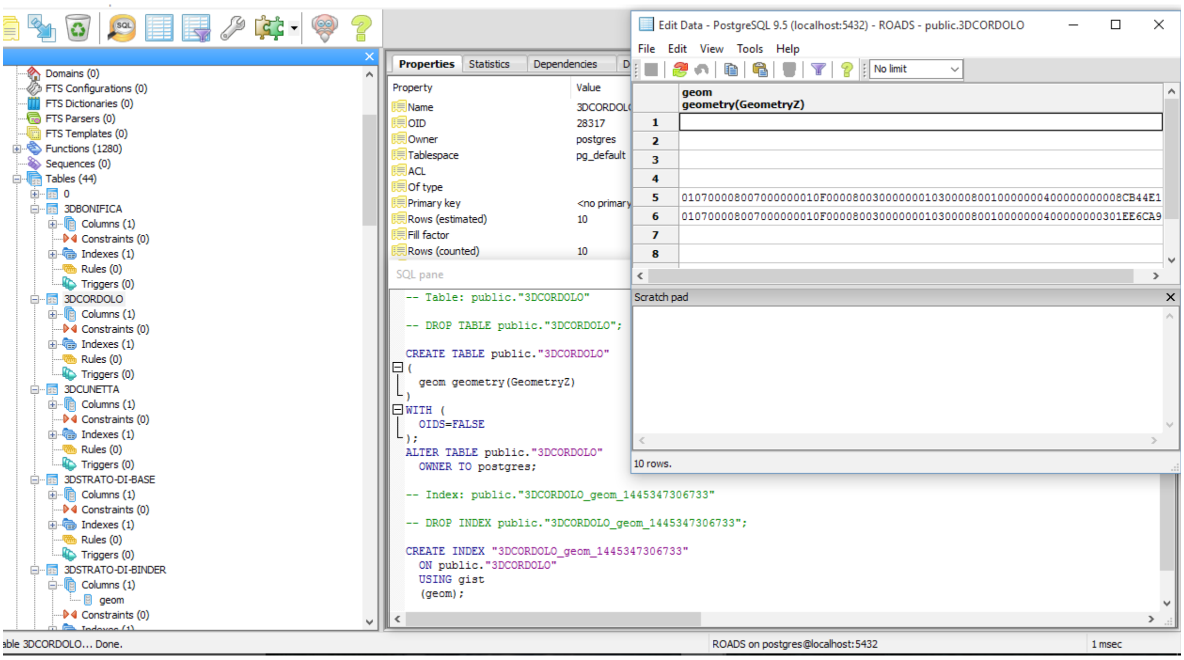


Fig. Screenshot of the database in PostgreSQL. Geometry column of Table “3D Cordolo”

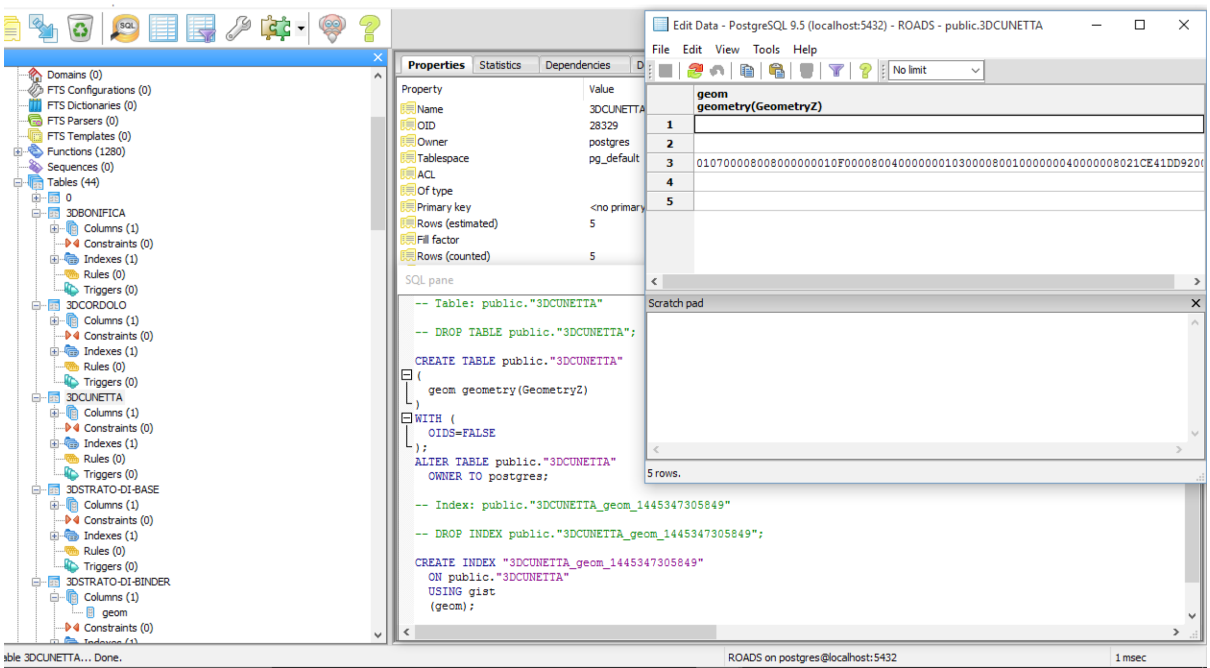


Fig. Screenshot of the database in PostgreSQL. Geometry column of Table “3D Cunetta”

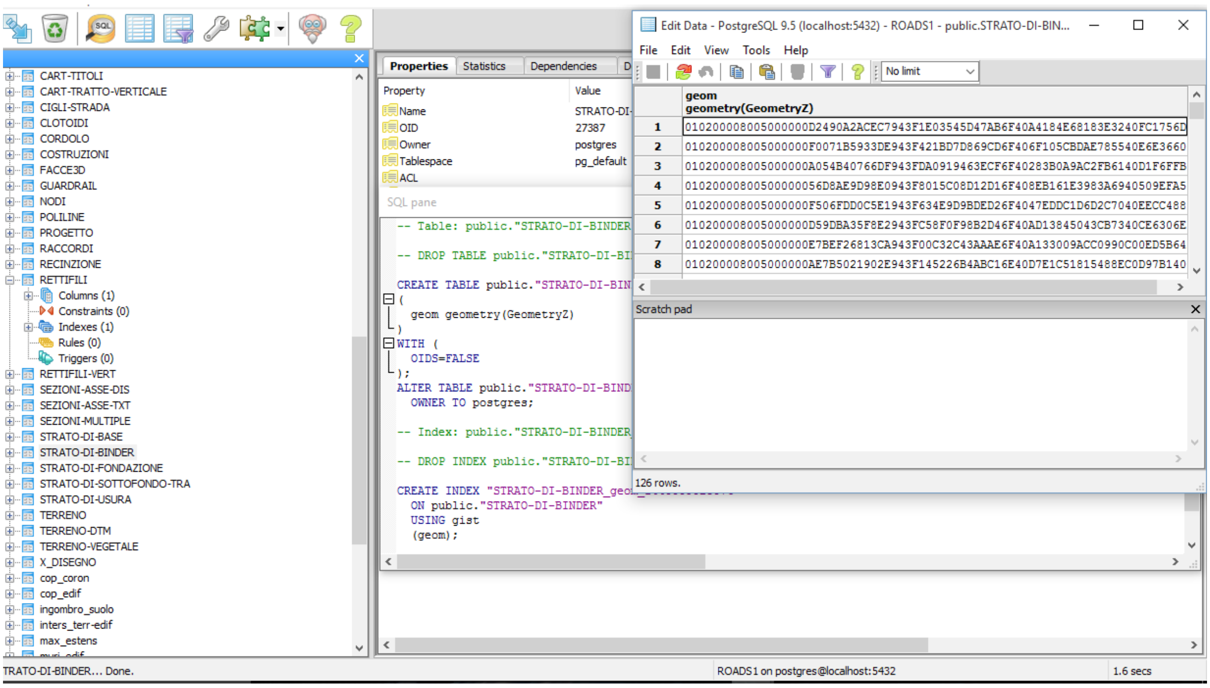


Fig. Screenshot of the database in PostgreSQL. Table "2D Strato di binder"

On the basis of this example, several case studies can be addressed and implemented (and will be studied as a further work), building different databases of the road model in accordance with the use of data (e.g. road design, road maintenance, road safety, evaluation of potential interference with pre-existing underground utilities and so forth).

Choice of a WebGIS among existing systems to be used as a GUI

As shown in Chapter 2, 3D has become the development direction of research on reality modelling and GIS. The recent developments of web tools like HTML 5 (the fifth revision of the Hyper Text Markup Language) and WebGL (a engine for rendering 3D graphics in the web using a JavaScript API[108]) have been extended 3D GIS potential to webGIS, a distributed information system (Fu and Sun, 2011) based on the integration of the Internet and GIS (Dragicevic, 2004). Its server-client architecture allows the user (client) to access and use the web application on the server by a web browser or a desktop/mobile application (ibidem). It also allows 3D GIS operations natively in the browser.

In the light of above, in order to meet functionalities requirements for a 3D Road Cadastre describing the full life-cycle of road infrastructures gathered from the literature and users (as seen in Chapters 8 and 9), the physical model proposed has been completed with an existing 3D web GIS to be used as an interactive interface: in order to obtain a 3DGIS-based data model of roads that is queryable, updateable, linkable to other databases and shareable on

[108]API stands for Application Programming Interface and is a set of subroutine definitions, protocols, and tools for building application software: a clearly defined methods of communication between various software components.

the web. An opportunity to use all these functionalities is using a WebGL platform according the scheme of Lacuna software by James Milner (2014).

Lacuna, implemented at UCL in London, is an elementary and free 3D GIS plugin, with editing tools and higher functionality, moving the browser-based 3D webGIS beyond the display functionality, and allowing 3D geometric editing: in fact, in addition to the visualisation, it also enables objects selection, layer colouring, attribute retrieval, distance and surface area measurement, 3D editing, and 3D buffering. The systems layout was modelled on client side technology including:

- HTML5 (a markup language[109] used for structuring and presenting content on the World Wide Web; it includes detailed processing models to encourage more interoperable implementations, and introduces markup and application programming interfaces (APIs) for complex web applications),
- CSS (Cascading Style Sheets, a style sheet language used for describing the presentation of a document written in a markup language, i.e. how HTML elements are to be displayed on screen, paper, or in other media),
- JavaScript (a high-level interpreted programming language widely used - alongside HTML and CSS - for implementing World Wide Web contents, websites and applications; all modern Web browsers support it without the need for plug-ins),
- and WebGL (a cross-platform, royalty-free (Khronos Group, 2014), hardware accelerated 3D graphics technology built for web (Ortiz, 2010), using a JavaScript API[110] for rendering 3D graphics within any compatible web browser without the use of plugins, and supported by Chrome, Firefox, Opera and Safari),

and established technologies such as:

- PHP (short for Hypertext Preprocessor, a widely-used server side scripting language, open source and general-purpose, particularly suited for web development and embeddable into HTM),
- AJAX (standing for Asynchronous JavaScript and XML, a set of web development techniques using many web technologies on the client-side for creating better, faster, and more interactive asynchronous web applications with the help of XML, HTML, CSS, and Java Script languages),
- jQuery (a library of JavaScript),
- and PostGIS (an open source software program that adds support for geographic objects

[109]A markup language is a system for annotating a document in a way that is syntactically distinguishable from the text

[110]JavaScript API hooks into the canvas element of HTML5 to display graphics (2D and 3D).

to the PostgreSQL[111] object-relational database).

Lacuna also shown the suitability of WebGL and Three.js with a spatial database backend as a platform for 3D web GIS. Three.js is a JavaScript library simplifying the production of 3D scenes by the WebGL graphics renderer and provided with fundamental elements that are manipulated to achieve a functioning and interactive scene. As mentioned, the system is underpinned by a PostGIS database to produce 3D geometries on the HTML5 canvas element.[112] Geometries (written in WKT strings) are brought into the scene from the database using PHP and Structured Query Language (SQL) and converted into Three.js geometries in the scene (e.g. THREE.SphereGeometry for points, THREE.Line primitive for lines, while for other type of primitives like PolyhedralSurfaces customised Three.js geometries were created).

Once uploaded the code of Lacuna on a server, it is possible to create the projectMetadata table on the road model in the database and populate it with the required information. Within the code, PHP can connect to PostGIS: when calling the code, the user should use Lacuna.php?projectName=name (where "name" stands for the name of the project). A test has been done using Amazon server, in order to use the 3D Road Cadastre's projects, according to the purpose.

9.3.3.3 Import of the system within a webGIS Lacuna (WebGL-based) used as a GUI

Therefore, the last stage of the implementation of the 3D Road Cadastre provides the import of the system within Lacuna.

With regard to the server-side configuration, as the original code of Lacuna only worked with its author's data, the code has been changed so that it can work with any spatial data. To make it work, a new table called "projectmetadata" has been created in the PostGIS database: this will hold the list of layers whose display is required according the use of the model, along with some other information.

An example of project creation for Lacuna by SQL has been reported in Appendix.

Once created the database of the road model, it is possible to add for each road element further data, a semantic description based on the same taxonomy of the building adopted by the DB (and therefore in accordance the hierarchical decomposition of the construction in its components and subcomponents). Taking advantage of the ability of PostgreSQL to import other formats, in the model different kind of data such as maps, drawings, PDF, reports, tables, photos, and other have been integrated.

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[111]PostgreSQL is an object-relational database (ORDBMS) – i.e. a RDBMS, with additional "object" features (optional use).

[112]According to Milner (2014), Lacuna project highlighted the applicability of WebGL (using the Three.js library) for the foundations of a relatively new technology like 3D web GIS (the first specification was released in March 2011), in comparison to more researched and developed platforms such as Flash, Java and Active X.

Examples of procedure and code used for creating tables within the database in SQL in accordance with the meta-model illustrated in Chapter 9 are reported in Appendix. By the code below it is possible to select a photo as a "representation_type" from "feature_representation_types" within the "representation table" depending on the user (e.g. the picture of a kind of barrier that road designer wants to use in its project and can be recorded into PostgreSQL and queryable from the model).

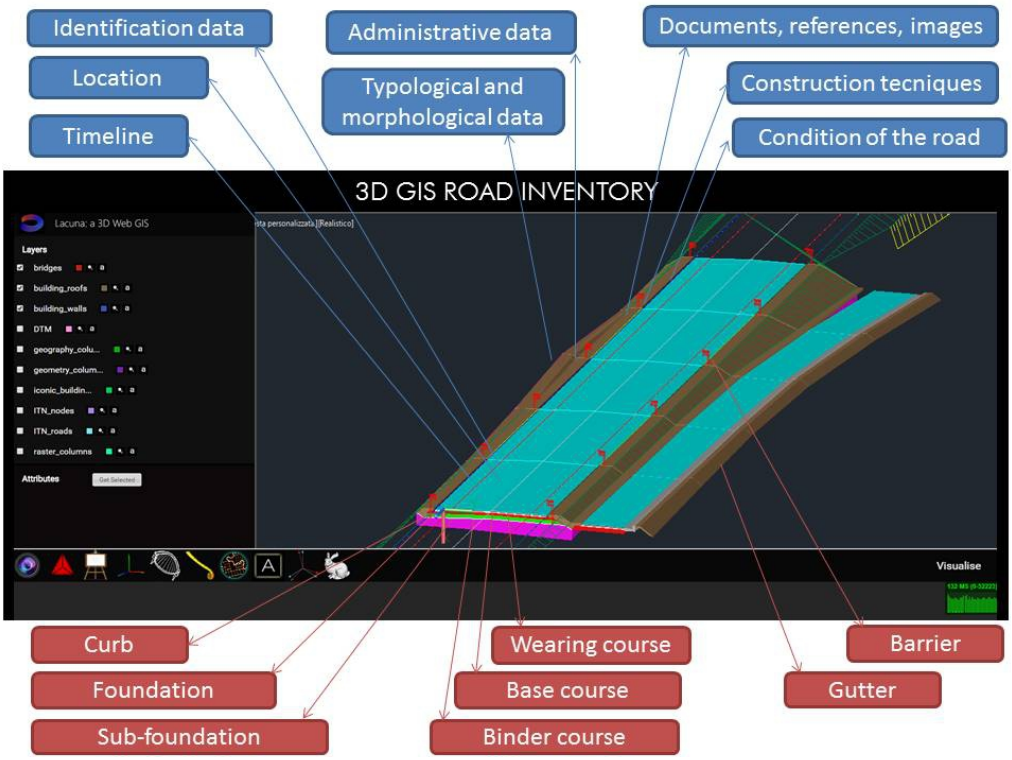

Fig. Screenshot of Lacuna interface (partial view) with the 3D road model and queryable information, and the list of layers on the left (different depending on the use and related required information)

The graphical interface of the information system, within which the 3D model is built, consists of a 3D View window (allowing visualising the model and interacting with it: e.g. querying either the model or the DB via the menu or the list of layers or direct interaction with the 3D model - e.g. click and visualise - with the help of Javascripts). Lacuna allows consulting different tables of the 3D database and a different level of detail of the model. By Lacuna, the proposed system allows various functionalities, such as the ones illustrated by Milner (2014) himself in his research work and shown in the following pictures as further functionalities to be validated for the Road Cadastre as further work. They relate to: triangulation of arbitrary geometries, selection by raycasting, multi-selection by a marquee selection methodology (variable sized HTML div element controlled by the mouse), attribute querying by taking selected object

IDs (stored in an array) and passing these to the backend PostGIS database to pull out attributes and push them into a formatted table, point distance measurement, multiple 3D buffering by Three.js's primitives Box, Sphere and Cylinder, transparency and dimensions, object level editing such as deletion, copying, translation, scaling and rotation by custom functions built-in Three.js methods, vertex level editing through wireframing geometries, and a 'closest vertex to click' function allowing for editing and updating of specific vertices. An UPDATE command is sent using PHP/SQL to update the associated geometries in the database (as WKT) (ibidem).

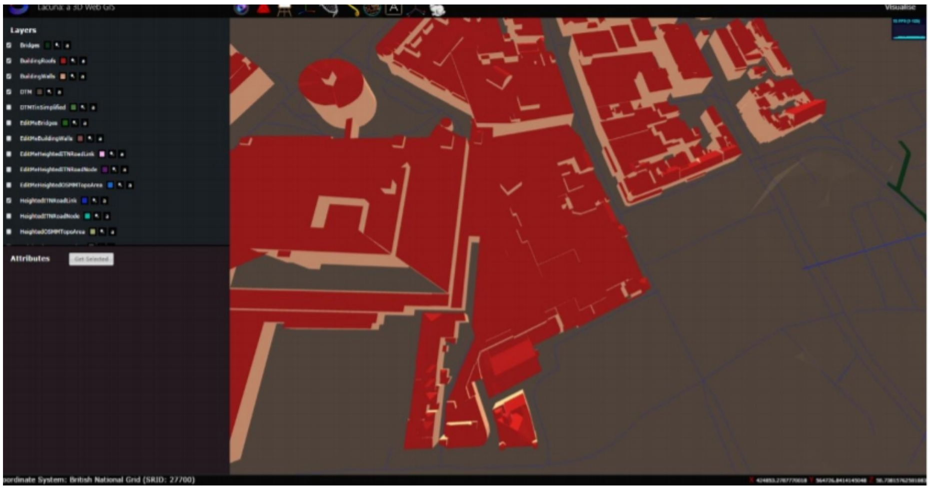

Fig. Lacuna 3D geometries visualisation into the scene (source: Milner, 2014).

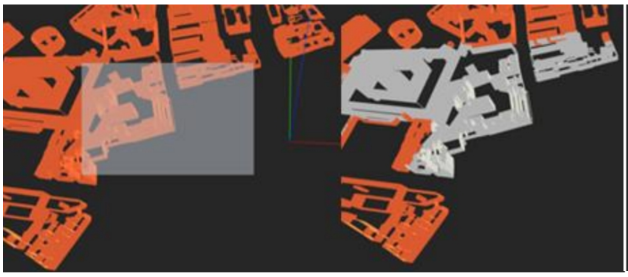

Fig. Marquee selection tool, showing how multiple geometries can be selected (source: Milner, 2014).

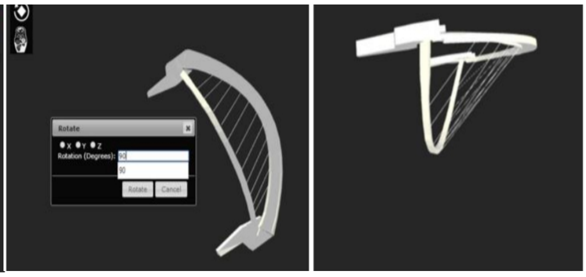

Fig. Rotation (source: Milner, 2014).

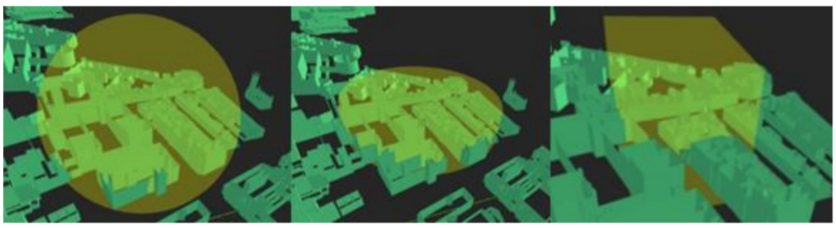

Fig. Results from three different buffer operations (source: Milner, 2014).

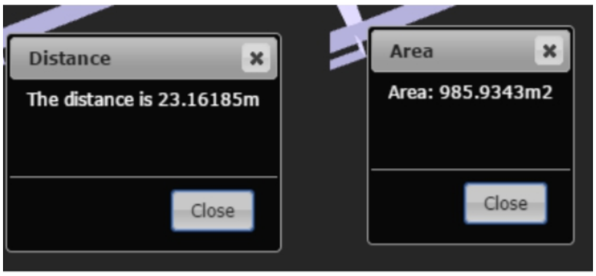

Fig. Outputs of distance and area functions (source: Milner, 2014).

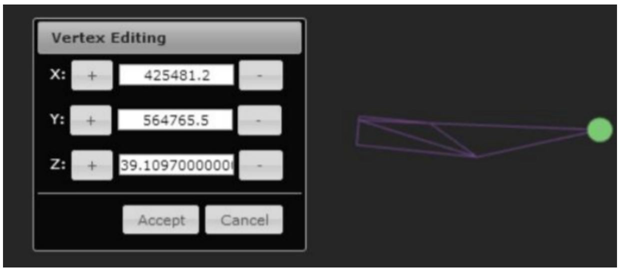

Fig. Vertex editing interface (source: Milner, 2014).

9. 4 Summary

As shown above, the model has been implemented starting from a CAD basis: a 3D polyline, which is the basic graph provided to designers by the ANAS Road Cadastre: it corresponds to the road axis. A DTM of the area has been provided as well. The software used was AutoCAD 3D as it is compliant with the output of the software (such as PROST) used by the road designers interviewed. The road cross sections included in the project have been designed using different layers for different parts of the road (e.g. gutters, foundation, barriers, and other). By extruding along the 3D polyline the profile or boundaries of each element represented in the cross section, the volume of the road - composed of different volumes (polyhedral surfaces) corresponding to each road part - has been modelled.

By the link to the database the result is a multi-scale tool that goes from the 3D model of the road to a more detailed CAD drawing of individual components of the road: this helps the engineers and maintenance teams find the information they need much more easily.

Chapter 10

Discussion

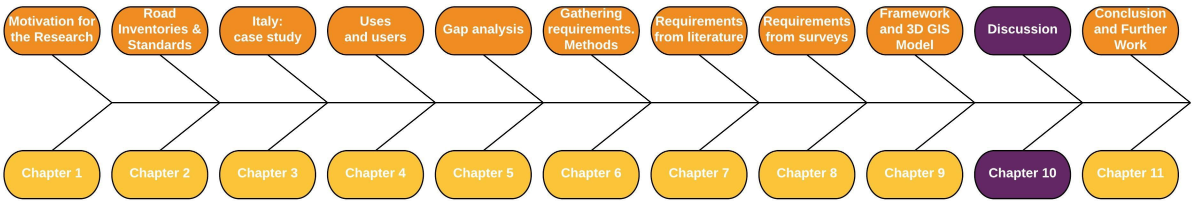

Figure 90. Overview of Document Structure showing context of this Chapter

The present work has highlighted some important aspects on the limitations of current road information systems (with particular regard to the Italian Road Cadastre) as well as the potential of 3D GIS for full life cycle road cadastral modelling.

As emerged by the literature, in Italy the Road Cadastre was established in 1992 with the procedures for its implementation published in 2001. However, so far many road administrations have not implemented their own road inventory. This research addressed some of the issues highlighted by the literature and practitioners to propose a road cadastral model more adequate to real user needs.

The qualitative method of research was crucial for gathering feedbacks on the current Road Cadastre by different road stakeholders as well as their requirements: however, difficulties have been met to find real expert users (especially of GIS). Interviews better than questionnaires (conducted with specific regard to the road cadastral situation in the Sicilian region, South Italy) allowed - while speaking - to clearly distinguish among the legal Road Cadastre and the only one implemented in the region (by ANAS), whereas the risk of questionnaires was often a misunderstanding among the legal inventory and the existing one. Semistructured interviews gave a wide overview of the main issues and requirements of stakeholders in using fruitfully the Road Cadastre; the risk was that sometimes respondents gave opinions also about requirements of other users categories. Questionnaires were extremely useful for obtaining a ranking of priority of 3D road components to be modelled. The use of pictures was very helpful to explain 3D road situations and discuss the potential of a 3D GIS model for the Road Cadastre.

10.1 Stakeholders considerations on the Road Cadastre

The research highlighted that interviewees actually have the same idea of the current theoretical Road Cadastre as a system aimed at recording all roads of the national asset.

According to the CEO of the road engineering company interviewed, the Road Cadastre is important as "a tool of knowledge of road asset consistency and condition" and a decision making tool allowing "a country to promote its own development both strategic" (in terms of planning) "and economic". However - he commented - the Road Cadastre, "especially in some regions, is totally non-existent", and where it has been implemented, it is not a real support for road designers. It should provide information not only on functional characteristics, but also on structural features of roads, materials, standards of constructions and time of construction, updates, and adjustments that are important for road designers; it should also record the various road features over time to support the development of the country: by recording data monitoring it should allow institutions to define a priority of interventions based on objective criteria to constanlty ensure a high performance of the national road asset.

ANAS road managers (that directly implemented their own Road Cadastre also with the internal support and the advanced competences of the Research Centre of Cesano, near Rome) consider the legal Road Cadastre an important theoretical base on whom implementing further datasets and applications, while other stakeholders (such as underground utilities managers, archaeologists involved in preventive archaeology, and, partially, also road designers) do not use it at all because it does not meet their own requirements. On the other hand, all stakeholders have a different opinion about the most proper use they would do of the Road Cadastre and everyone would like to find in it a tool providing data and functionalities helpful for the own specific purposes.

10.2 3D GIS utilities in implementing the Road Cadastre

The literature review, questionnaires and interviews seem to confirm that the use of 3D GIS would improve Road Cadastre for better management of data related to the complete life-cycle of infrastructure projects. With this regard, both the results from the questionnaires and the interviews confirmed the validity of the approach, with all respondents to both noting that having access to a 3D model, integrated with the road inventory/cadastral data, would be useful. Respondents to the questionnaires cited uses including:

a) feasibility studies - to assess in the preliminary planning stage the possible effects and

consequences of interference (interviews and questionnaires);
b) to have a complete set of information to support road maintenance or subsequent road designs (questionnaires) or maintenance tasks (interviews);
c) to carry out possible designs additional to the core project – e.g. relating to neighbouring areas – more rapidly, especially in case of emergency interventions (e.g. to know the sequence of ditches, manholes, etc.) (questionnaires);
d) to carry out preliminary tests on the road (safety, visibility) (questionnaires and interviews) and carry out a performance evaluation of the road structure (interviews);
e) to have a visual and practical record of the project (questionnaires);
f) to identify and resolve problems of clashes between plant, road elements, underground utilities and structures (questionnaires);
g) to access to elevation/altimetry data, and provide an immediate view of the morphology of the land, the geometry of existing works and how this may be altered (interviews);
h) to understand the composition of the road bed (interviews).

10.3 Discussing the model proposed

The model and approach proposed to be all encompassing – i.e. to model every single possible element and feature of a road network. Indeed, this may not be possible and would not take into account emerging future requirements such as ITS and Smart Cities. Instead, through its many different elements, the model aims at being consistent with the multi-purpose nature of a road inventory discussed in Chapter 4, taking into account the "multidimensional" – from 1D (linear reference) to 4D (including 3D space and time) - and "multifaced" (Ndandiko et al. 2013) nature of a road. The proposed model extends the existing road cadastre concept, which deals only with ownership and maintenance, to include 3D modelling and to cover the entire life-cycle of a road network, from conception onwards. Importantly, the model is extensible and flexible, allowing for different (but not fixed) levels of detail in the geometry and links to the attributes and other information (documents, survey results, photographs, video and so forth) – thus this supports a wide variety of existing data. The 3D-based approach also provides the potential for the 3D model to act as an index and integrator for other data – where associating data with a location in 3D space allows it to be linked to other data where this would otherwise not be possible. The ability to visualise and explore data in 3D also adds not inconsiderable value. The approach also takes into account the need to provide information in different formats to different users from one central source, allowing multiple representations if necessary – e.g. a laser-scanned survey of the terrain may be useful to a road designer planning a new road, as well as a 3D vector model of the same location to a road safety expert or the person installing signage. In this, the approach described here mirrors that of emerging BIM processes (where there is a concept of a 'single source of truth' datastore). As with BIM, this centralised source of information can assist in communication between various design teams (traffic safety, construction teams, drainage engineers, utilities engineers) and also helps to minimise re-capture of data – the 'as-built' information resulting from the road construction phase can be directly used by any maintenance engineers. Both the questionnaires and interviews revealed that there is some familiarity with GIS in the community, but both designers and maintenance engineers would prefer to work with tools with which they are familiar: a database-centric approach could permit this. In many cases, simply having access to an interactive 3D visualisation of the data, with links to further information, may be sufficient.

Maintenance activities would benefit from 3D GIS for documenting and analysing minor works (e.g. walls) and road surfaces (that ANAS currently records after maintenance interventions on paper).

10.3.1 3D display functionality and Data integration

As commented by the CEO of the road engineering company, the road is not a line: the road is a disturbing element of the territory, that "lives" within the territory and that interfaces with the territory". Hence, in order to manage roads multifactorial nature, "the Road Cadastre should be just the connection among different instances" and "the knowledge of the road asset cannot be limited to single aspects". Hence, the role of the Road Cadastre is fundamental to manage all data related. Hence, the possibility to manage roads in 3D and as an integrated tool given by the 3D Road Cadastre proposed is fundamental.

Through the model proposed the 3D Road Cadastre can be used to look at visibility issue: i.e. where a sign can be seen from, what can be located around a corner, and so forth: this could help to identify potential danger spots on roads and make use of GIS line-of-sight functionality. Currently, road inventories mainly aimed at road safety (as the ones described in Chapter 2) are not able to solve this issue.

The requirement for selecting information according to different users is enabled by the model. All stakeholders agree that the basic structure of the legal Road Cadastre does not include too many helpful data, even if the extension of its dataset within each local SIS is encouraged by law, but each institution customises differently each road cadastal dataset and interoperability is made difficult as well as the implementation of the National Road Archive.

Moreover, so far, road network classifications, descriptions and representation have been carried out with specific purposes without the possibility to exchange data or coordinate interventions. This research highlighted that separated inventories are not a solution for documenting road network.

Sairam et al. (2016) emphasised the link between 3D data and models, and data collecting: the 3D asset inventory obtained by sensors and MMS should include and whose data are stored in a GIS database. Importantly, the authors highlighted road assets located above and below the roads along pavements and the road themselves.

The model proposed can be implemented for both road projects and as built of existing roads - both loadable within the system in 3D with related data of different kind (both vector and raster). It allows documenting roads during all life cycle in order to facilitate projects of variants, modifications, updates and adjustments (for road design and safety purposes), as well as maintenance interventions, and so forth, as described in previous chapters.

More than one model can be recorded and from the same model different layers and data can be selected to retrieve different information for different purposes or make a comparison of road condition over time (recording by the 3D models possible variations).

The integration between 3D and 4D representations of roads within a road inventory resulting in a single model - as proposed in this research - is able to describe the infrastructure's life cycle and to confirm and support the planning of road maintenance programs.

The model benefit from recording data referred to a 3D model and as noted by Bryde et al. (2013) and Eastman et al. (2011) with regard to BIM, making the transition between design and construction phases more efficient among stakeholders by sharing or integrating data of the same 3D model, instead of using traditional 2D documentation. Like BIM changing of the road infrastructure can be recorded very easily at each stage, with the possibility to consult views and sections linked to the model Unlikely the BIM a minor consistency can be derive from the fact that they are not generated form the model that works as a container and an index of information.

As noted by Zhang and Couloigner (2005) the road database updating would benefit of automatic road extraction (that is still under research), and special visualisation techniques for representing change information (that are discrete) have to be developed for road network. The system proposed by different physical models and different layers associated to each road component with related data allows to record different versions of the road in order to include a sort of 4D to document road network over time.

Costs and time of the first implementation can be compensati by the integration of data that allow to coordinate works, avoiding traffic congestion and consume of fuel and pollution if used to indicate works in course, reduction of time for updating similar data from different institutions.

10.3.2 Road representation and LoDs

The present work has shown that, with regard to a 3D Road Cadastre designed as a centralised system collecting and providing different and integrated road data aimed at different purposes, road representation and LoDs are topics to be addressed as linked to the Road Cadastre's adequacy to users needs.

The fact that different road types (e.g. new and existing, or belonging to primary or secondary road networks) need different approaches, as highlighted in particular by the interviews, has raised the question whether a one-size-fits-all-roads Cadastre is appropriate. During the development of the research work, it has been better clarified that different approaches are mainly required by different uses (especially in terms of level of analysis of the information and details required). All that suggests to renounce to a fixed model (in this case to a one-size-fits-all-road-uses) for moving towards flexibility and providing different models for different types of uses.

The problem of Levels of Detail has been addressed differently: according to ISO 14825:2001 and CEN the different objects making up a GDF are conceptually divided over three different levels: Node, Edge, and Face on Level-0; Simple Features at Level-1, Complex Features (driving from Simple Features aggregations) at Level-2. The road network can be represented at two different levels, Level 1 and Level 2. Level 1 describes the Simple Features such as Road Element, Junction, Ferry Connection, Enclosed Traffic Area, Address area Boundary Element and Address Area, whereas Level 2 describes the Complex Features such as Road, Intersection, Ferry and Aggregated Way.

In a hypothetical Road Cadastre with traditional three levels (as ISO standards and the Italian Road Cadastre's standards provide), ANAS would suggest their total functional autonomy, with database and applications completely separate, but with the possibility of comparisons and combined representations among the three levels (e.g. perfectly overlaying level 1 road axes to maps at scale 1: 2000 (Level 0), or deriving the kilometric progressive associated with a land parcel overlooking the street (registered in scale 1: 2000)).

Moving from the road transport approach to an approach more focused on the physical construction (and hence with criteria of levels of analysis more fitting to describe buildings and structures) the concept of Level of Detail significantly changes.

Firstly, the main issue is moving conceptually from the cartographic approach (with map scales aimed at representing large contexts of road networks in 2D)[113] to a model of road (in 3D and with the possibility to focus on different details depending on the use): the concept of LoD is closely related to the concept of scale. However, as noted by Thompson (2009) the scale of a map is the ratio of distances **on paper** to the distances of the real world objects being mapped, and provides an indication of the size of objects and the distances between them (Longley et al., 2010). Each scale implies an own LoD, whereas, as noted by Goodchild and Proctor (1997), the representative fraction traditionally used by cartographers to characterise the level of geographic detail in a map is not well-defined for digital geographic data: in fact, as confirmed recently by Biljecki (2014), in digital maps with a more refined range of scales, the same LoD can be shared by more than one scale. Hence, the scale is more applicable to materialised representations such as printed maps, rather than spatial data in a computer representation. Nevertheless, through an analogy, the scale is also applicable to 3D physical models which size of the representation can easily be related to the real-world.

As addressed by Luebke et al. (2003), in computer graphics, the LoD approach is mainly focused on how to create and represent simpler versions of a complex model (i.e. whose geometric datasets can be too complex to render at interactive rates), e.g. by simplifying the polygonal geometry of small, distant or unimportant objects (i.e. polygonal simplification, geometric simplification, mesh reduction, decimation, and multi-resolution modelling).

In computer graphics LoD can be divided into three categories:

- discrete LoD: a data structure is created with a fixed number of LoDs for each object separately at fixed distances; a desired level of detail can be extracted from the data structure, according to the object's distance or similar criterion.
- continuous LoD: it is exactly specified, not selected among some pre-created options, and can adjust detail gradually and incrementally;
- view-dependent LoD: it uses current view parameters to select best representation for the current view.

With regard to the asset management, for example, Pantelias (2005) has pointed out that the level of detail and the depth needed for the collected data varies according to the hierarchical level of the decisions that need to be made (Pantelias, 2005). The information gathered at this

[113]The scale is a representative fraction usually expressed as 1/N or 1:N, where N is typically larger than 1: one unit on the map represents some multiple of that value in the real world (e.g., a scale of one to 100.000 (1:100.000) indicates that 1 cm on the page is equivalent to 100.000 cm (or 1 km) on the ground). A 1:100.000 scale is smaller than a 1:1.000 (i.e. as a small (coarse) scale map, on a paper of equal size it can represent a larger area than a large (fine) scale map, but less detailed). Thus 1:100.000 is small scale, 1:1.000 is large scale. In cartography, scales are classified as: 1. "large scale" with N smaller than 50.000 (e.g. 1:5.000 for a walking map of a town); 2. "medium scale" with N between 50.000 and 250.000 (e.g. a 1:100'000 country map); 3. "small scale" with N larger than 250.000 (e.g. World map at a 1:100'000'000 scale).

level is usually collected for only a reduced number of assets identified as the ones needing work, usually from the network-level analysis.

While "Level of Detail" refers to how much detail is included in the model element, in the frame of Building Integration Modelling "LoD" stands for "Level of Development", a conceptual framework describing the development of model elements at different steps during the design process (from conception to realisation), as the Level of Development Specification document by BIMFORUM (2013) highlights. In accordance with the collaborative nature of BIM projects, therefore LoD represents the degree to which project team members may rely on the information when using the model (BIMFORUM, 2013). In its overview of Level of Development, the NATSPEC BIM Paper "BIM and LOD" (2013) cites the AIA Draft Document 202 – 2012 Project Building Information Modeling Protocol Form, which states that "the Level of Development (LOD) describes the minimum dimensional, spatial, quantitative, qualitative and other data included in a Model Element to support the Authorised Uses[114] associated with such LOD". The document defines five Levels of Development whose numerical notation ranges from 100 to 500 at intervals of 100 to allow the system's users the flexibility to define intermediate LoDs, as follows: 100 Conceptual (symbol, not geometry), 200 Approxinate Geometry (generic object with approximate quantities, size, shape, location, and orientation), 300 Precise Geometry (specific object with Quantity, size, shape, location, and orientation), 400 Fabrication (specific object with Size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information) and 500 As built (for Maintenance and operations of the facility).

Therefore, the LOD concept deals with level of graphic detail/precision of modelling; it also includes amount, quality and relevance of non graphic information. and type of non-graphic information that may be embedded in model elements, linked to them or separate from (but cross referenced to) them (NATPSPEC, 2013).

Current implementations of 3D city models (e. g. CityGML) are limited to a certain number of discrete levels of detail. CityGML (a common information model and XML-based encoding for the representation, storage, and exchange of digital 3D city and landscape models) provides a standard model and mechanism for describing 3D objects with respect to their geometry, topology, semantics and appearance, and defines five different levels of detail to facilitate efficient visualisation and data analysis. In a CityGML dataset, the same object may be represented in different LOD simultaneously, enabling the analysis and visualisation of the same

[114] The term "Authorized Uses" refers to the permitted uses of Digital Data authorized in the Digital Data and/or Building Information Modeling protocols established pursuant to the terms of this Exhibit. (cf. Guide, Instructions and Commentary to AIA Document E203–2013, Building Information Modeling and Digital Data Exhibit

object with regard to different degrees of resolution. Furthermore, two CityGML data sets containing the same object in different LOD may be combined and integrated. LOD0 is essentially a 2.5D Digital Terrain Model (DTM) over which an aerial image or a map may be draped, whereas buildings may be represented by footprint and/or roof edge polygons (2D shape in 3D space). It is used for regional and landscape applications. LOD1, used for city and region coverage, comprises prismatic buildings with flat roof structures. LOD2, most suitable for city districts and projects, differentiates roof structures and boundary surfaces, while LOD3, mostly used for landmarks, denotes architectural models with detailed wall and roof structures potentially including doors and windows. LOD4 adds interior structures for buildings.

The model proposed in this thesis is very far from such concept of LoDs, as it is very difficult to fix LoDs of roads within a system that needs to be users-centred. LoDs depend on who the user is and what use he needs to do of the 3D Road Cadastre's model. Hence from the same network we can have different models and LoDs. Again, the model needs to be flexible as with regard to the same use different representation might be needed.

The approach used is a reverse generalisation that starting from an hyper-detailed model, on the basis of the users requirement looking forward a light and easy-to-use system, is progressively simplified. It takes in account the current materials that road institutions provide road users with and considers the tools generally used in Italy for road design and modelling to allow a compliance of tool.

10.3.3 Data for the 3D GIS Road Cadastre and comparison between the Italian Road Cadastre data structure and users needs

This research aims at defining a model bridging the gap between the current road cadastral standards (providing a dataset limited to data on location, width and type of road entities and components related) and practitioners requirements.

The needs of the stakeholders (including social and technical requirements), collected via the questionnaires and interviews, have been compared with the Road Cadastre data structure proposed by the standards, in order to highlight where the standards meet requirements, and also identify missing elements and possible improvements (including its 3D development). The results of the comparison have been used as guidelines to draft a preliminary conceptual model extending the current Road Cadastre to meet the identified needs of stakeholders, as well as to frame a broader approach to road data management.

This research also considered as helpful the work of Billen and Zlatanova (2003) that grouped urban real objects into: 1) **juridical objects** (e.g. individuals, institutionals, companies), 2)

topographic objects (e.g. buildings, streets, utilities), 3) **fictional objects** (e.g. administrative boundaries), and 4) **abstract objects** (e.g. taxes, deeds, incomes), all having semantic characteristics. With regard to their geometric characteristic, they are also distinguished, depending on their 1) non-complete geometric characteristics (i.e. only location); 2) complete geometric characteristics and existence in the real world; 3) complete geometric characteristics and fictive existence; 4) without geometric characteristics. Authors commented that fictional object (like municipality unit or statistical unit) do not need a 3D representation, but, on the other hand, if 3D GIS incorporates only 3D topographic objects, some analysis would be simplified or even truncated.

Importantly, in this thesis Chapter 3 in particular, illustrated what the Italian government requires the local authorities to record about roads, as well as what is required to be designed and maintained. All that confirms how complex the problem of including all such information in a unique system that is required by stakeholders. Hence, a 3D approach to 'indexing' all these different details has been considered better than the current approach of creating many files and using file names to indicate what relates to which part of the road structure.

10.3.4 Data quality and updating

As emerged by the literature review, data quality and updating are one of the most critical issues relating to road cadastral cataloguing: as explained in Chapter 5, road network graphs, often pre-exist to the relief works aimed at implementing Road Cadastres and derive from different sources whose data often do not correspond each other. Hence, a good basis for each Road Cadastral model should be a relief conducted with advanced technologies that requires new specifications. With this regard, ANAS has been using laser scanning for the survey of structures and MMS and videos for collecting data on road trunks and road equipments. Sensors for monitoring defects of structures as well as road traffic are to be also considered among the next sources of data for the Road Cadastre, especially for maintenance or management of traffic purposes. All this requires a system able to collect and manage different data for a full description of the road network during its whole life cycle and for multiple uses: the model proposed, based on GIS technology, for its potential, aims at meeting such requirement.

The interviews highlighted that data relating to some road components are difficult to be detected: e.g. roads or structures foundations as well as underground utilities that can be documented before they are covered by the ground; also, the layers of the roads whose depth is not easy to be documented exactly (especially in the case of recharges of 20 or 50 cm). Moreover, some data should be collected before the installation of road components: e.g. the identification code of barriers that is generally written on the back of the road equipment and it is dangerous to collect on the road such data once these road safety elements are installated.

With regard to the updating issues, interviews also highlighted that modifications of road surfaces - due to degradation by road traffic, weather conditions and so forth - as well as barriers conditions - due to road accidents, for example - are very fast and would require continuous updates. The same situation relates to alterations of trunks and routes, displacements or lack of milestones and modifications of signs.

Modifications of road property and road concessions should be shared between the Land Cadastres and the Road Cadastres and the model by the integration allowed by GIS would enable it. Moreover, in order to facilitate classification of roads or declassification and establishing priority of interventions data within the Road Cadastre has to be complete.

The model proposed, as a centralised integrated system, by the accessibility to the DB by different institutions aims at facilitating a continuous updating, as well as the integration of data and interoperability among institutions: information updated from one institution can be useful to another one. This would require uniform criteria and standards shared for updating data in the same way within the centralised system by different stakeholders, as currently they use different systems: road designers use CAD and specific software and produce CAD and .pdf as output, road managers can use GIS. The system currently used by the underground utilities managers interviewed are the most limited as they compile Tables in Excel and there are problems relating to data quality as their operators do not use GPS to establish the location of interventions and, once come back to the office, have to try to understand on the map the point where they made the work. On the other hand, ANAS provided its operators with tablets and GPS to take note of the defects of structures and other alterations on the roads. Moreover, from interviews, for example, road designers do not trust on data provided by others (e.g. database on details of the roads), while archaeologists require road designers and engineers to collect data and document on interventions according to precise standards.

In order to keep higher standard of data quality the model should be managed by personnel internal to companies and institutions or send data to an office in charge for the continuous updating, but as the wide range of data the possibility of updating by different users should be allowed (indicating data of the last uèdate and the name of the compiler for any check on data validity). Part of further work might consist in allowing drivers or technicians to provide road managers with information in real time (e.g. photo of barriers or signs to be maintained, sites of road accidents, location of road holes, degradation of the road surface or sidewalks with data and GPS position) to report damages and require an intervention.

Importantly, with regard to updating, the model allows loading new projects (e.g. new "as built") where alterations are recorded.

10.3.5. Compliance with standards

As this thesis has shown that GDF has not fully been adopted, as well as the inadequacy of European standards set by groups not including organisations who will eventually be tasked with the daily population of databases, and hence replaced by local standards for local cadastres using local parametres and data. Moreover, according to Yuan (2008), the use of the hierarchical road-network model based on the ongoing standard X-GDF, the next generation GDF developed by ISO/TC211, will support more advanced routing and navigation strategies, such as hierarchical routing and multi-modal navigation. It will also improve the computation efficiency and scenario representation involved in 3D-navigation during evacuation efforts. Nevertheless for the main uses of the Road Cadastre there is not mainly required.

The model proposed is more near to the approach of INSPIRE specifications for Transport Networks that, as seen in Chapter 2, at any level of detail incorporates two alternative form of representation:

- Physical topographic area objects (usually surveyed to a high accuracy)
- Centreline representations (often an approximation of the centreline)

Its contents in terms of interoperability and inclusion of features relating to the environment or other transport network are also helpful to project further work.

The research highlighted that standards on road design and maintenance are needed to implement the Road Cadastre together with standards related to all the uses that the road inventories should/might have.

Importantly, the document "Functional Standards for Smart Roads" by the Italian Ministry of Transport and Infrastructure (2016) provides a roadmap in order to produce the standards relating to: the construction of a digital model of the infrastructure, monitoring of each road elements and road surfaces (e.g. by sensors), providing dynamic data on roads (e.g. roadworks and consequences o traffic flows) and others.

10.3.6 Other issues emerged

At a large scale road networks can be seen as continuous lines whose branches are interrupted or joined with other branches by nodes (the so-called junctions or intersections). Nevertheless, the nature of road elements is not continuous. Within the Italian Road Cadastre road elements are characterised by segmented attributes alongside global attributes (the latter valid for the whole entity): actually many of their features change along a route (the width of the carriageways and of the lanes, the type and height of barriers or retaining walls, the type of road surface or the shoulder that can be paved or not). ANAS also took into great account the issues including the so-called "dynamic segmentation" of road elements where additional points (or vertices) can be included within the graph and referencing points dataset and vary or be updated. Kayondo Ndandiko et al. (2014) noted that "a GIS platform that supports dynamic segmentation will be ideal" even if currently not all GISs are capable to perform analysis based on the dynamic segmentation. They proposed a model composed of roads point events (such as location referencing point feature, culverts, road offices, bridges, photo data, road signs, point on-going activities, and black spots – i.e. a location inclined to accidents on the road) and linear events (like jurisdiction, road surface type, surface condition, traffic volume, line on-going activities, maintenance record, video data). However, point events like bridges, culverts ad black spots mentioned by the authors can also been considered as lines depending on the analyses performed on them. Importantly, linear referencing - used to position phenomena along a linear object, using a distance from the beginning of the linear object - is included in the Generic Network Model of the INSPIRE Directive) based on ISO 19148.

The situation is complicated within a 3D environment. Therefore, the 3D Road Cadastre model here proposed provided the use of points and segments alongside the road elements (lines) and junctions (nodes) at LoD1, and the subdivision of the volume of each road elements modelled in 3D into 3D road trunks (polyhedra) at LoD2. Road trunks – differently segmented - can be selected by different users in accordance to their main purpose (e.g. road safety assessments require check along road trunks with a certain length that is different from the length of road trunks assigned to ANAS road maintenance teams for monitoring defects or from the distance between two subsequent road sections that road designers have to document by drawings). This means that, though 3D Road Cadastre is a centralised systems provided information to a number of different stakeholders dealing with different datasets, several models deriving from the same road element but differently subdivided can be loaded into the 3D Road Cadastre and queried by different users.

The same approach refers to the selection of the only road objects of interest of different users, as we assume that all sighted objects and attributes are not required by all stakeholders.

All that highlighted the need for a 3D GIS based Road Cadastre that result from a set of elements and functionalities use/user centred with the road model at a basic level of detail where the road is divided into different parts, each queryable and linked to data (.dwg, .pdf etc.) or

The 3D GIS-based Road Cadastre acts with objects in a 3D space. It may include modern data acquisition methods, recording geometries within the system. By it, 3D visualisation is facilitated and allows for a representation closer to reality.

ANAS (1999) explained the segmentation of a path as consisting in subdividing the route into various sections based on the value of a certain variable quantity (e.g. number of lanes or longitudinal gradient). Therefore, each road truck can be divided into sections (segments), each of whom has 1, 2 or more lanes (recorded as attributes). In this way, it is possible to query the system and asking for data stored into a table and a view of a road with all one-lane trunks coloured in blue and all 2-lane trunks red coloured. A second segmentation might be based on the longitudinal gradient, and define segments completely different from previous ones as gradient and number of lanes are not correlated quantities. This segmentation will allow a new visualisation and graphical classification of the path. Such "dynamic segmentation" corresponding to tables is able to make more sophisticated queries, crossing the queries of various quantities (eg correlation between longitudinal gradient and frequency of accidents).

The project team have to create their own 3D data delivering a 3D model to road administration in accordance with uniform standards in order to include it into the database; it should be verified during the construction stage in order to have the as built of the roads (not only of the structures as currently occurs), while road and underground utilities maintenairs should update data in real time by using tablets and GPS. Standards are needed to make this activities mandatory for road construction companies.

IRF marks that, as each country is unique and as such has unique needs, there is no one-size-fits all solution when it comes to applying standards and specifications: nevertheless, a guidance to allow innovation and flexibility while maintaining uniformity has to be promoted.[115] Also INSPIRE data specification assume that due to different political, economic, cultural and organisational drivers, a total harmonisation across every nation is not achievable: all Member States and organisations start from different positions in terms of conceptual schemas and regional diversity will and should continue to exist. Nevertheless, a mechanism that provides technical and conceptual interoperability to support needs at European and other large cross-border and cross-sector levels is required.

The advent of regional digital road information systems for managing Road Cadastres aimed at promoting data sharing and interoperability among each Region, the provinces and, in perspective, municipalities, also enabling institutions in charge for planning and managing the road network to operate on a single instrument and on a single graph of the same roads (Regione Piemonte, 2012).

Currently very impressive visualisations are available but they do not really fit to/with the design process nor to any other stage of road life cycle. With this regard, interviews with users in particular (as addressed in Chapter 8) provided requirements going far beyond 3D-visualisation

[115](source: https://www.irfnews.org/standards-and-specs/ the website of the International Road Federation)

and that deals with semantic 3D modelling. Also 4D models (including time) are of interest to document and compare different stages of construction, road updates and variations, monitoring defects. All that requires an adequate data structure, also capable to be extended with further data and also integrated by links with other databases.

The road system is object-related and composed of small, medium and large components, located above, under and on the same level of road surface. Components have mutual spatial relationships (they are related and connected each other) also with the surrounding man-made and natural environment.

As shown by the full table of objects to be modelled contain particular detail at different scales, but:

1 this is true if we consider traditional cartographic parametres and 2D representation where detail are linked to different map scales

2 even if a correspondence between map scales and LoDs have been searched and investigated by many authors with regard to buildings and cities contexts, so many LoDs are not required by users for their purposes, as it is not the scale of representation (with related different of size and details of each element, i.e. quantity of information) to meet their needs but independently by the zoom function the selection of information (quality information) even if at the same scale (depending on the aim of their use).

Both road design and road maintenance and management also require a detailed representation currently not provided by the legal Road Cadastre. Hence starting from table... the object space and its inventory have been analysed (and partially implemented into a ìn object-oriented data structure (see the first approach to the conceptual model). Nevertheless a vertical hierarchy of components does not appear really suitable to model roads for road cadastral purposes: in fact, users need to visualise and retrieve different road data from the model that might also be at the same level of hyerarchy but just have different function.

Vertical hierarchies make more sense in the case of structures like bridges or viaducts where components are segmented like buildings.

As Ko:ninger and Bartel (1998) highlight, in the literature several LoD mechanisms are provided, respectively based on the pixel area (the number of visible pixels increases when closer to objects, while the LOD switches to a higher resolution of details when a threshold value has been reached), distance to object (the LOD switches as above depending on the distance and of different sized objects at the same distance from an observer), dependance on visual angle (the LoD decreases when lateral distance increases, with unimportant information discarded and characteristic features in the centre of the image are stressed), and explicit choice (the LoD information is definied selectively for individual objects/subobjects). The latter is the one more suitable with the Road Cadastre's description of road network for the purposes mentioned.

10.4 Contribution of the work

10.4.1 Research outcome

Road Cadastres in other countries can use the findings of this thesis that address general issues of cadastral registration in 3D situations.

The Information System proposed and placed on a server, is shareable on the net by the WebGIS Lacuna where selections, editing and analysis can be carried on as well as connections via hyperlink to PDF and other documents for architectural scale and detail. It is potentially a tool of great utility for 3D road situations documentations, 3D and 4D documentation of historical road stages (life cycle), technological investigation, monitoring, preservation and maintenance and administrative management of the asset. Through it, in fact, scholars, designers and institutions might consult and update data from all place by the Internet platform; also simple users may view and query the online road objects described and represented in 3D.

10.4.2 Stakeholders and end-users of this research

The potential stakeholders and end-users of this research fall into the following groups:

1. road owners and road management institutions,
2. road designers and builders,
3. road maintainers,
4. institutional and technical subjects involved in topics strictly related to road construction,
5. those who study road infrastructures and transport issues,
6. road users and citizens.

They can be divided in three main categories:

a. those mainly involved in roads to be built (new projects): group 2,

b. those mainly interested in existing road infrastructures (and their maintenance): groups 3,

c. and those interested in both of them: groups 1, 4, 5, and 6.

In addition to these, a further group interested in 3D GIS and 3D data (group 7), has to be considered.

The first group of stakeholders includes **institutions** - both public and private - **that own and manage road infrastructures** (public offices at local, regional, national and international level such as departments of transportation, road agencies and concessionaries). They deal with both the management of existing roads and the forecast of new road infrastructures in which they invest. They usually collect and manage road datasets providing information also to other different stakeholders and users.

The second group is mainly focused on new road projects. It includes professionals from both **road design studios** and public and private companies involved in **road construction**. The group comprises **road designers and planners** (highway and civil engineers, architects, and urban planners), as well as other professionals concerned with road projects: surveyors, geologists, geotechnical, environmental, hydraulic and seismic engineers, archaeologists, and further technicians in charge for studying the environmental context in which the road infrastructure would be built. As described in Chapter 8, they need and provide spatial data of different level of detail: they usually start from a large scale to make preliminary studies of feasibility, evaluating the relationships between the infrastructure and the context (i.e. the terrain, the environment, and the "already built"); passing through the different stages of the project, they arrive at a detailed scale to describe each constructive element of the road infrastructure and other related utilities. Data refer to the surface, the components and the underground of road infrastructures (whose mutual relations are clearer in a three-dimensional representation). Road data would need to be referred both to the project stage and the construction stage with the possibility to catch or update spatial information *in loco*: in this perspective, further end-users might be technicians and workers working in construction sites.

The third group concerns stakeholders for existing roads: it collects public and private companies involved in **road maintenance**. Like above, the group also includes different teams dealing both with the analysis of degradations and failures, and the project stage and the construction stage. The maintenance activity is aimed at preserving road effectiveness, safety, pollution reducing, etc. In addition, it comprises the monitoring of road pavements, the analysis of their spatial transformation (deformations, lack of materials, potholes, etc.), the signs location and the substitution or integration of road components and pipes underground: also in this case, the multiple "z" of overlaid road components has to be considered and an integration of different data may be required by this group of end-users.

The fourth group includes those involved in topics strictly related to road construction and mainly interested in underground layers. **Archaeological institutions**, for instance, having to deal with the preservation of archaeological finds, are interested in new road projects where underground structures are planned to be built. Their interest is also in road maintenance projects: during excavations and coring for road repairing, in fact, data recording of the soil layers allows acquiring information on the so-called "archaeological potential" (i.e. the probability that a specific area returns archaeological evidence). It benefits from road maintenance works to catch information about the consistency of the archaeological stratifications and the area they cover. It is aimed at identifying the so-called "archaeologically empty" areas usable for urban development. The fourth group comprises also public and private companies involved in **utility location** (i.e. the process of identifying and labeling public utility mains that are underground: lines for telecommunication, electricity distribution, natural gas, cable television, fiber optics, traffic lights, street lights, storm drains, water mains, and wastewater pipes; in some locations, major oil and gas pipelines, national defense communication lines, mass transit, rail and road tunnels also compete for space underground). Both these subjects need data on the third dimension because of the recording of stratifications or the management of different pipes at different levels underground/at different depths relative to the surface.

The fifth group is composed by road network foundations and organisations involved in studies and statistics about transport, road infrastructures, road safety, etc. and that need integrated spatial data. Academic researchers in the fields of road data collecting and sharing may also find useful this work as a foundation for further studies or in complement to their own research.

Another group is made of road users (e.g. drivers who want to check some specific characteristics of the route before they leave, such as the safest route, traffic and crashes on the route, line-of-sight, existing utilities on the route like lighting systems, roadside assistance, oil stations, etc.). It is also composed of citizens who need information about the relationships between road infrastructures and their properties (e.g. construction of tunnels and underpasses near their homes) or who want to know the state of conservation of roads in their countries.

Some results of this research may be useful to developers and vendors of 3D GIS software working with Object-Relational databases (e.g. suppliers of Geographic Information System (GIS) software, web GIS and geodatabase management applications, as well as companies providing City-models software and road design tools). They might be find input for developing their products.

At last, 3D GIS researchers might be interested to some aspects of this research to develop their own work whereas users of CAD, BIM and 2D GIS might better understand the possibilities of 3D GIS in the field of everyday life.

Chapter 11

Conclusion and further work

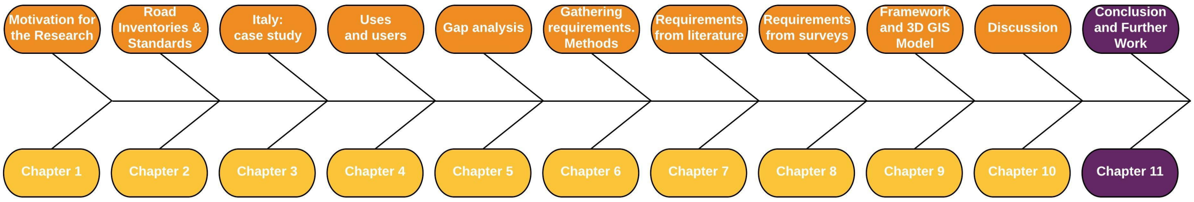

Figure 100. Overview of Document Structure showing context of this Chapter

Focusing on the case study of the Italian road inventory (called a "Road Cadastre"), this thesis firstly aimed to: a) determine whether, given its potential as a data integrator and as a mechanism to link to multiple, disparate, elements of information, the use of 3D GIS would improve Road Cadastre (for better management of data related to the complete life-cycle of infrastructure projects); b) define a conceptual approach and model for a 3D Road Cadastre for Italy (whose general principles may be extended also to other countries); c) propos a flexible system to be tested by a prototype in accordance with different specific road cadastral uses.

Requirements and opportunities for a 3D Road Cadastre and the potential of 3D GIS for full lifecycle road cadastral modelling have been the main topics of this research.

"Since many existing cadastres are still based on a paradigm that has its origin centuries ago, this paradigm needs to be reconsidered and adjusted to today's world": such consideration by Stoter (2004) on cadastres in general is central if referred to Road Cadastres and to their 3D development (whose need has been widely argued in this thesis).

Actually, as shown in this work, there is a good correspondence between the 3D-related requirements highlighted in literature (Chapter 7) and in the questionnaires and interviews (Chapter 8), further supporting the potential 3D in the context of a road cadastral system, but not reflected in the current road cadastral standards.

The present work has confirmed that traditional road cadastral registration based on 2D is not adequate for registering all kinds of road situations (as explained with particular regard to the complexity of the so-called "3D road situations" illustrated in Chapter 5) that cannot be analysed and visualised effectively. The technologies most used for road inventories (2D GISs) are not able to express multiple height values at one 2D point (Abdul-Rahman and Pilouk, 2008), hence, struggling to truly represent the three-dimensional world. Moreover, the ever increasing demand for 3D GISs and 3D geographical data has been acknowledged (Milner, 2014; Gröger and Plümer, 2012; Abdul-Rahman and Pilouk, 2008), making necessary investigating on the applications of 3D GISs (Milner et al., 2014) in a number of field included road transport, possibly going beyond the only display functionality. In order to make 3D geographic information effective, GISs are required to be able to visualise, capture, structure, manipulate and analyse 3D data (AbdulRahman and Pilouk, 2008). Road Cadastre users have expressed desire for greater and improved with 3D functionality, together with centralised containers of integrated information to guarantee interoperability, data exchange, coordination of interventions among different institutions and stakeholders. A requirement shared among road users relate also accessibility to data; in this perspective the possibility to use client-server web applications in order to access and update road data on line is considered of great interest.

3D web environments such as ESRI's CityEngine Web Viewer, Google Maps 3D Buildings, OpenStreetMap 3D and F4Maps have been implemented focusing on visualisation or navigation, whereas a full 3D GIS also requires capture, manipulation or analysis functionalities.

As illustrated in Chapter 2, most of current GIS-based road inventories use 2D or 2.5D data: in Italy Road Cadastres developed by road administrations mainly for administrative and road managing tasks, while real 3D data are not considered (though 3D representation is recognised as a helpful tool, as shown in Chapter 8): the advent of technologies for detecting roads and structure (e.g. laser scans) increased the interest for 3D modelling and also BIM (with regard to the analysis of the whole road life cycle), but only recently they have been extending to the infrastructure sector and they do not provide GIS functionalities (in terms of georeferencing and analysis): a few systems like 3D GIS Sivan Design software experimented the use of real 3D data.

The increasing need for 3D representation and description of the real world in many fields of research and everyday life has encouraged the implementation of 3D city models (i.e. digital representations of buildings and other relevant features in the urban environment such as roads and terrain) and other applications.

3DGIS with its tools and modelling techniques manage the large amount of data related underground and above spaces, produce more accurate results for 3D volumetric calculations, and support a complete understanding of objects and geometric variations in the space by the real time interactive procedures (Aydin, 2008).

As both road data suppliers ad users need a 3D GIS for storing, managing and editing information in order to make road cadastral systems describing the reality (in 3D) and meeting real users needs, a Road Cadastre collecting and providing 3D geometries and attributes of roads is needed. A light and easy-to-use system is required as designers are mainly familiar with 3D CAD software (able to edit 3D data, but not suitable to manage them).

This thesis far from solving each issue relating 3D models for Road Cadastres, has been aimed at address for the first time the topic by an interdisciplinary approach and above all using a methodology based on requirements elicitation and questionnaires and interviews (qualitative research) as also experimented in collecting data requirements (like MIRE, see Chapter 2). The effort was verify at a general level the helpfulness of 3D-GIS in roads documentation meeting real road users needs.

With the advent of smart cities[116] and smart systems, digital technologies have been increasingly used to allow interaction and exchange of information between people, systems, services, different actors and more generally "objects", including vehicles. In the road sector, it requires road systems configured as a set of mobility systems and services, managed and offered by different operators, in an integrated environment, made possible by an open and shared architecture. The trend is a progressive technological substitution of the driver's role as mediator between vehicle and infrastructure, as well as in the task of reaction and control over information coming both from the inside (vehicle) and the external environment (road traffic) (ibidem). The EC has allocated some € 30 billion until 2020 on infrastructure of which € 6.5 billion for Italy.

A 3D GIS-based Road Cadastre, joining GIS functionality to 3D road models, can improve the existing Road Cadastre in providing users helpful 3D data and analysis for road design, maintenance and any other use. It properly deals with the Z height information of 3D objects, but an adequate and standardised 3D structure and dataset are required.

Importantly, the model for a 3D Road Cadastre is an opportunity to support the loose linkage between the diverse organisational data managed by various institutions and allow the extensibility of the current road cadastre to fit into diverse applications and users needs (like the INSPIRE Directive aimed with regard to the SDI in Europe, in general).

As noted above (Chapter 6) a number of authors have investigated the potential of 3D GIS in a Road Cadastre situation. Both the results from the questionnaires and the interviews confirmed the validity of the approach, with all respondents to both noting that having access to a 3D model, integrated with the road inventory/cadastral data, would be useful.

The literature review, questionnaires and interviews seem to confirm that the use of 3D GIS would improve Road Cadastre for better management of data related to the complete life-cycle of infrastructure projects. “multidimensional” – from 1D (linear reference) to 4D (including 3D

[116]Smart roads are sustainable, high quality, innovative and inclusive infrastructures, where the traditional relationship between vehicle, driver and environment is changed by new technologies that already assist drivers in many tasks and provide a convenient aid to safety and driving comfort (Italian Ministry of Traffic and Infrastructure, 2016).

space and time) - and "multifaced" (Ndandiko et al. 2013) nature of a road. is extensible and flexible,

Over time, the use of GIS's functions of visualisation and analysis have been helpful to communities to understand and manage their environment: GISs allow storing and retrieving different kind of information (vector and raster) with their attributes and is an effective tool to assist in different stages of the visual landscape planning and decision making processes (Leitão, 1997). Land-use planners use it to assess the criteria requested to define the suitability of preserved landscape (Florent and Musy, 2001), to estimate changes in the visibility of land cover (Miller, 2001), to assess land-use impacts on biodiversity and conservation planning (Theobald et al., 2000), in visual impact assessment (Fisher, 1996; O'Sullivan and Turner, 2001) and in urban landscape planning and design processes (Ranzinger and Gleixner, 1997; Köninger and Bartel, 1998; Kodmany, 2000).

Providing interactive three-dimensional models of roads within their own surrounding area is helpful to characterise environmental sites and to allow perceiving road planned in the whole framework: road designers can make more efficient decisions because of the higher capacity in visualisation, and also governments and interested citizens may visualise the results of planned projects before their implementation (Chan et al. 1998).

As noted by Arens et al. (2003), unlikely by 3D CAD software focusing more on drawing and visualisation, Geo-DBMSs can store and manage large spatial data sets in data bases that can be accessed by multiple users at the same time and where objects can be queried by numerous other applications; nevertheless, spatial data sets usually contain 2D data, whereas more and more applications depend on 3D data. Therefore, implementing a 3D primitive in a Geo-DBMS would improve the maintainability of 3D spatial data and pave the way for more realistic applications. The GIS Technology Section of TU Delft investigated how implemented a true 3D primitive in a DBMS (Oracle Spatial) using a polyhedron as a pilot primitive, to be followed by more complex primitives, until 3D models built with features closer to the real world.

11.1 Further work

In the light of the research conducted, many issues and topics emerged that should be investigated; new scopes of research have to be considered, from data acquisition to modelling.

Future work will include understanding which data capture to prioritise to meet most requirements, then developing different physical models for 3D Road Cadastres related to the technical and social requirements emerged by further surveys with new categories of expert users, establishing how to represent each road part (e.g. as a geometry or just as a PDF or point cloud) also for further uses.

With regard to gathering requirements, this research work has highlighted a huge number of both current and potential uses of the Road Cadastre, but in this thesis requirements have been gathered from some categories of expert users as an example and to start the work. Hence, in order to complete the cognitive framework, further requirements not collected in this thesis should be gathered from further users like environmental engineers as well as people who monitor road accidents. Chapter 1 and Appendix 1, in fact, have highlighted the urgence of a continuous monitoring (especially of areas with landslines) in order to evaluate on time the danger that there may be (and save lifes and avoid costs).

Data modelling and topology theory, state of research, and issues are not included into this work, and will be part of the further research work. It should be now answer to the following questions:

- How to model 3D geo-object (topologically and geometrically) in a DBMS for a 3D Road Cadastre?
- What system architecture (computer hardware, software, data structure) is needed to support 3D road registration (3D situations, in particular)? What architecture is technologically possible?
- How can this be best implemented in 3D GIS?

The detailed implementation of the physical model linked with different databases and platforms depending on the various uses mentioned in this thesis (and used as different case studies) will be pursued further as well as its validation process by expert users.

Validity and reliability of the system proposed have to be verified in detail. As noted by Ghauri and Grønhaug (2010) validity refers to the truthfulness of findings, thus providing a measurement for how well conclusions represent reality. With regard to this research, a user evaluation will be needed to find the strengths and weaknesses of the developed system in particular with regard to each of the uses mentioned.

Reliability is a measurement of consistency and refers to the repeatability of the study (ibidem): it assesses if research procedures carried on relating to the case study can be repeated with the same results. Progressive comparisons with road inventories and standards of various countries should be carried out aimed at an extension of the model proposed to road inventories of other countries.

Performance testing and benchmarking with respect to 3D cadastral registration or other information systems should be conducted as further work.

The current work focuses on the Italian Road Cadastre as a case study on whom the methodology used and the 3D road cadastral model proposed can be tested. Detailed studies of road information systems of other countries and comparisons with them should be conducted to provide solutions for 3D registration for any Road Cadastre outside Italy.

Moreover, this thesis has not addressed consequences on countries' economies and cost/benefit analysis deriving by the use of an integrated 3D Road Cadastre by road administrations and other stakeholders: that should another topic of interest for further studies.

Importantly, the integration of GIS, CAD and BIM should be investigated as further work also with regard to the Road Cadastre proposed: as established by the New Procurement Code, BIM will be mandatory from 2019, but only for the works of value exceeding 100 million euros. By the 2021 it will become mandatory for works evaluated complex, aimed at the strategic development, and with particular safety standard, whereas by 2022 BIM will be mandatory for all works. This also will require an update of kind of data required by law (that as described in this thesis so far have been required to road designers to deliver 2D drawings and reports in .pdf format to public offices.). Hence, integration with BIM represents a further path of research to be conducted.

For each use tables of the logical model should be extended and assessed practically.

Further topics that shall be addressed include:

1. Comparing the proposed cadastral data structure as proposed by the law/your conceptual model with the needs of the users and/ or the needs of smart cities

2. exploring the the difficulties of modelling CAD data in a 3D GIS,

3. investigating in detail INSPIRE requirements for roads to compare to the Italian Road Cadastre requirements and other inventories

4. Management and publication of road inventories – technical issues

11.2 Recommendations

Data capture issues have not been addressed in this thesis, but just mentioned with regard to the kind of data that the 3D Road Cadastre might include. However, the experiences and findings in this thesis (especially from interviews) with regard to the Italian case study have highlighted that:

- though the New Road Code establishes as mandatory that all roads of the whole asset in the country are classified and documented within Road Cadastre, the wideness of resources - human, technical and economic - required for this purpose makes this goal not so easily achievable. Moreover, when the New Road Code entered into force (in

1992), many technologies for surveys (also automatic and low cost) were not widely used. Therefore, guidelines for data capture by new tools for road cadastral uses should be implemented.

- according to the New Road Code in Italy all roads of the whole asset in the country have to be classified and documented within Road Cadastres at various level (national, regional, provincial and local) and then converge within the National Road Archive. As the Road Cadastre dataset by law provided basic information, whereas the National Road Archive theoretically provides many other information grouped into five thematic groups, specifications to collect the same kind of data and according to the same criteria should be provided to all road owner institutions in order to have also standards to implement the National Road Archive;
- private companies have often to capture the data when they are building the road and, then, hand it over to the responsible institutions. Guidelines providing uniform procedures should be implemented.
- With regard to standards, the research has highlightthe need for standards for classification of existing roads, as by the Act of November 5, 2001 they relate to planned roads
- With regard to the physical system based on Lacuna, some recommendations follow to make the graphic interface more comfortable to GIS non-experts. In relation to this work, Lacuna has been demonstrated to be an interesting and powerful tool to be used for implementing road cadastral projects to be tested and possibly to develop a final 3D Road Cadastre model to be implemented by institutions. With regard to the graphic interface of Lacuna the test of the functionality of the system with regard to the project carried out for this research has lead to a list of improvements in order to meet not only the characteristics of GIS interfaces (mainly used by road managers), but also of users of CAD and 3D modelling software (like road designers):

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Appendix 1

Current road infrastructure status worldwide

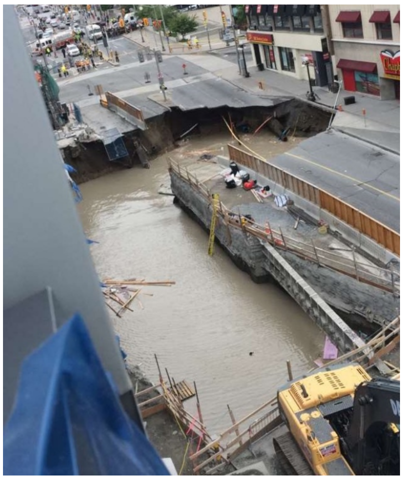
Report from newspapers

Ottawa (Canada), June 8, 2016:
Massive sinkhole closes Rideau Street in downtown Ottawa

A giant sinkhole opened up next to a major shopping mall in downtown Ottawa on Wednesday, causing a gas leak, collapsing a street and forcing the evacuation of all nearby businesses.
The sinkhole appeared about 10:30 a.m. ET Wednesday near the corner of Rideau Street and Sussex Drive, at a light rail construction site next to the Rideau Centre, about two blocks east of the Château Laurier Hotel. Soon after forming, the sinkhole spread across the entirety of Rideau Street, stretching from the south sidewalk to the north sidewalk. A van parked on Rideau on the north side of the sidewalk, as well as a light standard, fell into the hole as it grew. City officials say it was fortunate no one was hurt.

But the formation of the sinkhole, so close to the LRT site, has led to questions about what caused a water main to break and collapse the road.

Ottawa Mayor Jim Watson said at an emergency meeting of city officials it's unclear why the sinkhole formed. On Wednesday evening workers were pumping water out of the giant cavity in the road and filling it with concrete to stabilize the area and protect the foundations of adjacent buildings. The sinkhole formed near a construction site for Ottawa's light rail system, which is slated to be complete in 2018. The light rail system includes a tunnel and stations that cut underneath the downtown core.



Watson noted that the excavation work on the future Rideau Station was well below where the road collapsed. Workers were excavating the last 50 metres of the station when the road fell in, said Steve Cripps, director of the city's rail implementation office. The soil conditions in the area where the road collapsed were sandy and rocky, requiring extra precautions and different mining techniques, said Cripps.
Tom Herlihy was on Rideau Street near the Château Laurier when he heard and smelled natural gas. "A high-pressure natural gas line escaping is very distinct, it's a high-pressure whistle. You could smell it in the area immediately, and people were running away from it, you could tell something was amiss," he said. Herlihy went to an upper floor of the Château Laurier to get a better look.

"I caught the hole expanding and the car falling in and the gas just roiling the water, causing the dirt underneath the street to erode and collapse. And it's really deep," he said.
In the interim, the City of Ottawa said Ottawa public health is monitoring overall water quality, building code services are working with engineers on site to determine when it will be safe to re-enter buildings and city traffic managers and OC Transpo will be monitoring traffic in the downtown core.

The sudden road collapse that left a gaping hole in the middle of a street in downtown Ottawa Wednesday morning occurred over a vein of sand, silt and fractured rock so unstable that workers completing the light rail tunnel below had to inch along cautiously for fear of causing a cave-in.
The sinkhole occurred in the same place engineers conducting a geotechnical survey for the light rail project in 2011 discovered a 120-metre wide "bedrock valley" stretching under Rideau Street, just east of Sussex Drive.
The updated geotechnical data report submitted by Golder Associates to Capital Transit Partners, and then presented to the city, describes the valley as a natural trench in the bedrock filled with between 15 and 37 metres of loose fill, silty clay and "glacial till," or broken, weathered rock.
At its deepest point, the Rideau LRT station sits 27 metres below street level.
Samples taken from boreholes in the vicinity of the sinkhole revealed the bedrock itself was also fractured, unlike the solid limestone found along the rest of the light rail tunnel's route, according to the report, which was obtained by CBC News.
A sinkhole halted excavation near the LRT tunnel's east portal in 2014. It was filled with 700 cubic metres of concrete, then re-excavated, but the source said the voidnear Rideau Centre is much larger, and poses a greater challenge to fix.
The geotechnical report by Golder Associates only analyzed ground conditions, and didn't draw conclusions about the safety or viability of the tunnel in any one area.

http://www.cbc.ca/news/canada/ottawa/sinkhole-rideau-street-downtown-ottawa-1.3621949

Florence (Italy). May, 2016

A water main break caused this one in Florence

Dozens of cars fell into a chasm that opened near the Ponte Vecchio, in Florence, Italy, in May after an underground pipe ruptured. No one was injured.

(Maurizio degl'Innocenti/ANSA/Associated Press)

Kitchener, (Ontario, Canada) February, 2016:

A water main break caused this one in Kitchener, Ontario. (Andrea Bellemare/CBC)
Two men on their way to work at a landscaping company got a surprise when their truck dropped into a flooded sinkhole in February 2016. A crane was brought in to hoist it out of the hole.

Meridian (Mississipi, USA) November, 2015

(Michael Stewart/The Meridian Star/AP)
This chasm opened up outside a Meridian, Miss., pancake house in November 2015. Nobody was hurt, but over a dozen cars were swallowed up.

Sicily (Italy). November 29, 2015:
Collapse of a pylon on the motorway linking Palermo to Sciacca (Agrigento, Southern Sicily)

A pillar supporting the viaduct so-called “Traversa 2” of the Palermo-Sciacca freeway has dangerously cracked in the road trunk between San Cipirello and San Giuseppe Jato. Currently the road is closed from kilometer 23 to kilometer 28: five kilometres that break into two parts that area of Sicily. Police and Anas technicians are on the place for finding the effects of the partial collapse. According to preliminary information there may be a structural failure of the freeway in the area of the “Traversa 2” bridge or, as happened in June for the Himera viaduct on the Palermo–Catania highway, a landslide might caused the inclination of the viaduct pillar: as verified during an inspection, in fact, recent rains would have plunged the soil around it. Structural inspections are also underway to understand how serious the failure is and determine whether other parts of the viaduct are at risk. Already in October the Police reported the danger, but during a survey Anas Technicians had indicated that the road trunk was safe. After the rains and the soil plunged around the pylon that is tilted, expansion joints have also widened: hence the decision to close the road. The freeway Palermo-Sciacca is a busy street, mainly used by the inhabitants of the populous area of San Cipirello, San Giuseppe Jato and neighbouring areas. A closure of that road section would bring back Sicilian roads to the ‘90s. On the matter, Nello Musumeci, MP of the opposition party, said: "The regional government should demand Anas a survey of all the Sicilian roads within its jurisdiction. You can not always intervene after the collapse and do not exert a preventive action of control. Anas can not treat us like we were a colony. To be verified all the responsibility". "The failure of the pylon on the Palermo-Sciacca road is yet another piece of the infrastructure disaster of our country - the secretary general of the CISL Filca Palermo, Antonino Cirivello, said -. We don’t need colossal works to prevent it, but simply taking over the road maintenance and starting public construction works".

Sicily, October 15, 2015:

Landslide on the Palermo-Agrigento main road

A landslide in the territory of Villafrati, in the province of Palermo, has involved the SS 121 Palermo-Agrigento, which was closed between kilometre 222 and kilometre 229, preventing movement between Palermo and Agrigento and creating chaos: along seven kilometres of the main road it was impossible to pass both to the vehicles on the road and trains (as some boulders had invaded even the railway). About twenty commuters leaving from Palermo to reach their homes in the territory of Agrigento were stuck to the central train station for hours, with practically no information. Even three coaches stuck near Mezzojuso, among the means remained bogged down in the mud last night. Firefighters and Anas workers worked to free some cars and a bus stranded after the landslide. Also patrols of traffic police intervened, in addition to the police that guarded the area all night. It's another "blow" to the Palermo Agrigento, already affected by maintenance work in different sections. It’s a significant disruption, because the Palermo-Agrigento is a crucial main road for the western Sicily. And considering the problems on the Messina-Catania and Palermo-Catania highways, it was as if the island was split in four. Anas workers worked through the night to clear mud from the road: mechanical shovels and vehicles removed from the asphalt mud and debris fell from the mountain roadway. The road was re-opened the following day.

<u>Sicily, October 5, 2015:</u>

Landslide on the Messina-Catania highway. Sicilia spezzata in due: camion fermi, cibo al macero




In a crumbling Sicily, after the collapse of the Himera viaduct on the Palermo-Catania highway, a ridge a few steps from Taormina came down: a mountain of earth and debris invaded the roadways of the Messina-Catania highway, fortunately not investing motorists, but blocking the only highway now used by tour buses, Tir and trucks to move between Palermo and Catania. At the beginning of October a first landslide on the first ridge near Taormina and Letojanni occurred: stones and debris rolled on the roadway side mount.

The Consortium of Sicilian highways (CAS), often blamed for the bad maintenance of main roads, activated its technicians for the safety of the roads: men at work to clear the landslide material, and to contain somehow the shoulder of the hill. Interventions possibly poorly calibrated until now.

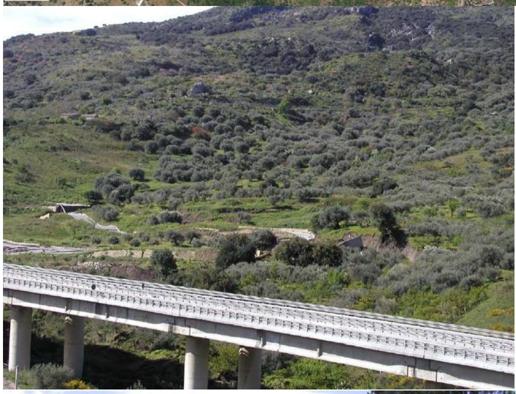
The landslide on the Messina-Catania highway (currently, the only one remained viable for commercial traffic) has effectively cut the Sicily into three parts. All the heavy vehicles are still stopped as along the main road 114, on whome traffic is diverted, there is a narrow underpass that makes the transit difficult to trucks.

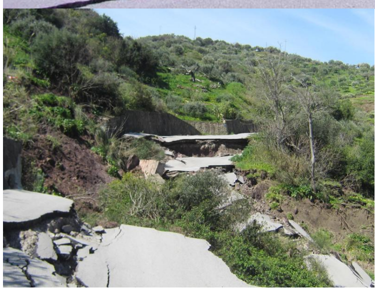
Sicily is so choked by another landslide that fell on the entire economy, on tourism, and on the

world of commerce and business: a disaster as in April the Palermo-Catania highway is broken because of a viaduct in the balance. In addition, it is dangerous for the trucks climbing both along the all bends deviation range of Polizzi Generosa, where the road surface was controlled by Anas, and on the acrobatic roadway just built with funds from the salaries of some members of the opposition party. Therefore, endless queues of vehicles are on the SS Messina-Catania, the so-called "Eastern Sicilian": the old coastal road running through all the countries of the area.
To ease the traffic, Anas has directed the lorries travelling towards the point of the landslide to another mountain road (the 185 Sella Mandrazzi main road), from the Tyrrhenian to the Ionian coast, linking Barcellona Pozzo di Gotto to Giardini Naxos, (with input at Giardini for vehicles from Catania, and entrance at Barcelona, for vehicles coming from Messina and Palermo and travelling to Catania. But it is "a path of war".
Serious disruption on the 114 Highway where traffic of cars and trucks was diverted. All the foodstuffs will be brought to pulp and almost all provinces of the island will suffer difficulties in supplying goods and basic necessities, raw materials and semi-finished products for the manufacturing industry and materials for the construction industry, from cement and iron: this is the alarm by Ance Sicilia after the closure of the Roccalumera-Giardini Naxos. The Councillor for Infrastructure asks to quickly reopen at least the sea side two-way traffic roadway: "We work, we work, but Sicilian roads are crumbling around. We can not go on like this". It is a cry of alarm also directed at the national government as in Sicily Anas has accumulated ancient delays. By the end of November, Anas roadway (7 million euro) would hopefully be completed to bypass the interruption of the Palermo-Catania highway. Other viaducts at risk, belonging to the same old highway, are under control.
"Our technical departments are mobilised. Unfortunately – as the president of the Consortium of Sicilian highways, Rosario Faraci, says - the landslide has penalised users forced to use the compulsory exit as well as the 114 highway with all the consequences. We are working with the utmost commitment. From the early hours of the morning, the forward movement of the earth has forced us to interdict traffic on both the upstream and the sea side. This is the same highway trunk that last Friday had already been affected by a large landslide: it came from the hill rising close to the motorway and created many hardships as it brought rocks and mud on the roadway. The front of the landslide has widened, creating a further reversal of soil, which necessitated the closure of a road trunk". According to ANCE, the new facts, although predictable - as the technical of the Consortium of Sicilian highways state -, lay bare the serious responsibility of the central and regional governments as well as the national deputation and Ars, who all have underestimated the importance of completing the Sicilian motorways' ring and investing effectively on the prevention of the hydrogeological instability.

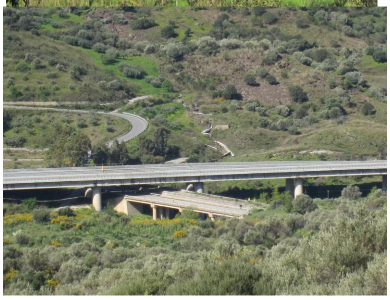
Sicily. April 10, 2015:
Collapse of the Himera viaduct on the motorway linking Palermo to Catania


AUTOSTRADA PA - CT
SP 24
AREA IN FRANA











A pillar of the "Himera" viaduct on the Palermo-Catania motorway had a structural failure due to a landslide on the road that passes under the bridge and collapsed. The landslide (ongoing for ten years) occurred at Caltavuturo and came down from the hills of Scillato on a front 400 metres broad. It affected the “24 provincial road”, which passes under the viaduct - Anas explains - and shifted the structure of the road causing a depression. No one was hurt. The landslide has involved at least three pillars of the 'Himera' viaduct, one of which is tilted causing a major shift in the roadway in the direction of Palermo. The road surface formed a dramatic dip. Therefore, cars, stopped after the collapse, were forced to go back and several motorists were stranded on the highway creating long queues. Technicians and executives of Anas, the regional civil protection, the Councillor for Infrastructure, and the mayors of the countries concerned (especially Caltavuturo and Scillato in the province of Palermo) went on site. Traffic police and the Anas staff closed a section of the A19 between Scillato and Tremonzelli in both directions to allow the technical verification. Afterwards, they closed it totally to monitor the pillars. On the second span of the viaduct engineers have positioned detection devices able to report even small movements.

The road has subsided and has formed a chasm downstream. The pylon was broken at the base and, leaning, made the carriageway supported by it leaning on the near one, where vehicles circulate in the opposite direction of travel. "The situation is dramatic - Domenico Giannopolo, deputy mayor of Caltavuturo, says -. The lane that goes to Catania rests on two pylons affected by the landslide and is not expected to be reopened quickly. Technicians are monitoring the other lane, in the direction of Palermo, to see if it suffered movements. The verification will take at least three or four days, only after you will decide whether to re-open even one lane".

Telephone lines, Telecom utilities fixed and mobile lines that rely on the fixed ones were out of order in all countries of the high and low Madonie Mountains, because of the landslide that is affecting the highway, and mainly the overlying 24 Scillato-Caltavuturo provincial road. The infrastructural failure ripped the optical fiber cables, set precisely along the same route of the motorway. A fault that also affects the Internet and telephone lines in the district of Cefalu (in the municipalities of Gangi, Geraci Siculo, Petralia Sottana and Petralia, but also in the area of Polizzi Generosa, Castellana Sicula, Caltavuturo, Cerda, etc.). The workers of Telecom are waiting to receive authorization by Anas to intervene: the intervention is not easy, as the poor structural condition of the highway. It is expected to bypass the conduit along the other unscathed lane. Lines serving the provinces of Catania, Enna and Caltanissetta pass in the same conduit.

"The front of the landslide is more than a kilometre - Salvatore Tonti, the regional director of ANAS, says -. Several million cubic metres of debris have poured, producing a devastating impact on the pylons. Probably the most damaged span will be demolished, but every foreseen at the time is premature".

The removal of the pylon is judged preliminary operation to restore the safety conditions and, if necessary, re-open the traffic on a single-carriageway. Therefore, the scope of the works to do is such that it will be prolonged over time. The concrete structure will be removed and the restoration work could last a few years and affect not only the span, but also the stretch of the SS 120-Scillato-Caltavuturo main way where the last movement occurred along the landslide opened ten years ago. Currently, Sicily is cut in two parts. The A19 has been closed in the section between Scillato and Tremonzelli, in both directions of travel. The road closure halved Sicily as traffic is diverted on the SS120-Caltavuturo-Cerda main way (also affected by landslides and subsidence). Motorists will take on average an hour longer to get from one town to another: three hours, instead of two, passing through an alternative route that bypasses the 'Himera' viaduct injured. There are also problems for the public transport of students and commuters. Many of the bus connecting Palermo to Catania are diverted via the A20 and A18 highways. The inevitable inconvenience to motorists was highlighted during a meeting in the prefecture with the mayors of the district. The hardships are so heavy that the Regional Councillor for Infrastructure, Giovanni Pizzo, requested the declaration of a state of emergency.

What's more, even the SS643 "Polizzi", which is the alternative route for light vehicles coming from the A19, has been affected by a landslide that Anas still removed at 14,150 km. In order to make it available it was partially restored and reopened with appropriate warning management and alternating one-way at km 14.150. In short, it will take years before it reverts to normal circulation. For now studying the possibility of using the old road to the construction site as link

road between the two sides of the highway. Meanwhile, those wishing to reach Catania and Palermo are forced to alternative routes that average lengthen the journey of about 45 minutes compared to the traditional way on the highway. Those travelling from Catania to Palermo must exit at Tremonzelli, continue towards Caltavuturo, reach Cerda and rejoin the highway in the industrial area of Termini Imerese. Who goes from Palermo to Catania may follow the same route in reverse or exit at Scillato, climb to Polizzi Generosa and rejoin Tremonzelli.
This emergency situation had been known for a long time however. The landslide has been active for ten years and affects the entire road trunk, parallel to the motorway at Scillato. "Nine years ago - Giannopolo says - the province of Palermo has done some surveys, which, however, but the results were never disclosed. In ten years nothing has been done. Despite our repeated warnings, there was an underestimation by Anas, the civil protection and the province".
The situation fell 15 days before, when the 24-Scillato Caltavuturo provincial road had been totally destroyed by a river of mud, dirt and debris. For a stretch of at least 400 metres the road no longer exists. In the weeks before, aware of the serious risk, the administration of Caltavuturo had sent alerts to the relevant institutions (Anas, Region, civil protection). On March 13, it signaled the danger of a new advance of the landslide on the main road. "A possible disruption as possible –the Mayor wrote - would give rise to a situation of great hardship to the people, making it difficult to reach hospitals, schools, workplaces and the possible closure of the motorway would cause the deviation on the road". Eventualities came true already on March 28, when users of the motorway were forced to remain in queue for several hours.
Giannopolo adds: "We have acquired geological surveys made nine years ago […]. If from those checks it would emerge that the landslide, which interested the pylons of the motorway, is very deep, it is clear that it would have been necessary to take action well before".
Giovanni Pizzo, the Regional Councillor for Infrastructure, says: "We asked to the national government the state of emergency. The situation is really serious. It isn't true that roads are collapsing: the truth is that our mountains are falling gradually. What is happening in Sicily is dramatic and it is the effect of the climate change: the large amount of water that this winter has hit our region is probably the cause of the disruptions that are occurring. This is not to absolve someone, and it's up to the engineers to determine the causes and any liability, if there are any. But it is clear that we are facing an emergency to deal with extreme seriousness".
The President of the Region says: "I asked the help of the Army Corps of Engineers to stop the landslide that is likely to involve the other track." After checking the damage caused by the landslide that affected the region, a meeting was held at the prefecture of Palermo for defining a contingency plan for the road. A report on the incident will be sent by Anas to the Public Prosecutor of Termini Imerese. After examining document, the judiciary will decide whether to open an investigation about the landslide that has been moving for ten years. Another information will be sent to the same attorney by police.

<u>Toronto (Canada). April, 2015:</u>
A Toronto driver had to crawl out his car window.

(Michael Charles Cole/CBC)
In April 2015, Mario Tavares got a shock when his Jaguar was partially swallowed by a parking lot sinkhole.

<u>Sicily, March 10, 2015:</u>

Landlsine on the road to Vicari (Province of Catania) (photos by Antonio Saso)












Bad weather and heavy rains have still caused landslides and roads cut off. Another landslide happened, this time on the 84 Provincial Road, called Contrada Rilievo (the main road connecting Vicari - a small town in the province of Palermo - to the SS. 121 Catanese Palermo-Agrigento). The road trunk leading to the small town in the mountains Sicani was totally destroyed. The landslide caused extensive damages to public infrastructure and private structures. Near the municipal cemetery the road has undergone a downward shift involving the walls for counter (about 3 metres high) and causing the interruption of the way. Bulges, cracks and fractures wide almost 20 cm and depth 1 metre are also present on the roadway. A pylon of the power grid has significantly tilted, losing its functionality and remaining in precarious balance. Some wooden poles of the telephone line have also suffered several damages. Private structures that have most suffered from the devastating effects of the landslide are located upstream and downstream of the damaged road.
The warehouse, the square and the small street for the deposit of building materials are heavily damaged and fractured while the structure downstream (consisting of a farm sheds) was completely destroyed.
The official reason is no structural failure as in the case of last December, but just a landslide of land that has allowed the destruction of the road in a large stretch: the intense rain and heavy rainfall occurred in those days are considered the triggering causes of the landslide while predisposing causes are attributed to the clayey soil, the steepness of the slope and the overweight of the detrital landfill.
After Bisacquino, Chiusa Sclafani and municipalities of Corleone, another small town in the hinterland remains isolated. In recent weeks the affected road trunk leading to Vicari helped to divert traffic and facilitate the works on the Palermo-Agrigento, near the previously damaged Scorciavacche viaduct. At the moment the only way to reach the village remains the one crossing Borgo Manganaro, while the other two, which are secondary, are only accessible to small vehicles.
Bad weather is hitting hard the towns of Sicani Mountains, already isolated and hard to reach.

<u>Sicily. February 23 , 2015</u>
Landsline at Villafrati (Province of Palermo)

The road trunk connecting Palermo to Agrigento (and euphemistically called 'freeway') breaks down slowly piece by piece. A new landslide, near Villafrati in the province of Palermo has caused the interruption of traffic on the SS121 Palermo-Agrigento in the direction of Agrigento, as the asphalt sank near the kilometre 230. Anas workers, the police and the traffic police intervened in the area.
On February 4, there was another collapse always near the viaduct. On the SS 121, considered one of the most dangerous roads of Italy, the section covered by the maintenance and reconstruction is about 34 km long, for a total cost of over 295 million euro. The first site was opened in 2013 by Bolognetta spa, the group of companies that was awarded the contract and whose leader is CMC di Ravenna. Completed works are expected to be delivered in 2016. The section affected by landslides (just over a kilometre that includes two viaducts) costs 13 million euro.

Sicily. January 7, 2015

Collapse of the Scorciavacche viaduct, Mezzojuso (Province of Palermo): the bridge of the SS Palermo-Agrigento opened on Christmas collapsed on January 1.

After 10 days from the opening of the Scorciavacche viaduct on the SS Palermo-Agrigento a partial crack happened. On the stretch of access to the viaduct cost 13 million euro and inaugurated on December 23, Anas announced "an anomalous subsidence of the road surface": half track was sunk, while the remaining part has a deep rift. "Fortunately – Anas writes - no vehicle was passing when the collapse of the main road occurred". The company, managing the motorway network, has decided to close the 121 main road between 226 and 227 kilometres, near Mezzojuso. The cost of the collapse, which was part of a project concerning the maintenance of the stretch of SS121 between 14.4 and 48 kilometres, cost 13 million of the 295 planned for the "Lot 2". Along the 34 kilometres interested, a number of works - including a gallery, five new viaducts, twelve junctions, in addition to restoration, improvement and seismic upgrading of the sixteen existing viaducts and bridges - are planned.

At the opening of the "Scorciavacche" viaduct, the president of ANAS, Pietro Ciucci, underlined that the timetable had been respected, "even with the advance of some stages: [...] an important step forward towards the realisation of the entire route, strategic for the Island". The works, in fact, have been concluded with about three months in advance by the contractor "Bolognetta scpa". The company group CMC di Ravenna, Tecnis and CCC had Pierfrancesco Paglini as their project leader, assisted by David Tironi, the technical director Giuseppe Buzzanca and a team of professionals. Now, after the seizure of the area, the prosecutor of Termini Imerese has opened an investigation for culpable collapse. It investigates the responsibility of those who planned and carried out the work. Prosecutors have also required the test report.

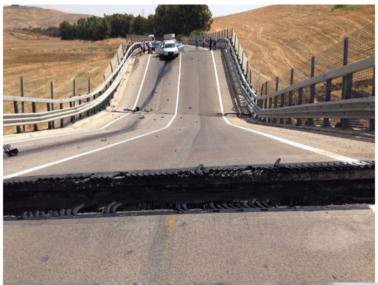
Brasile. July 4, 2014

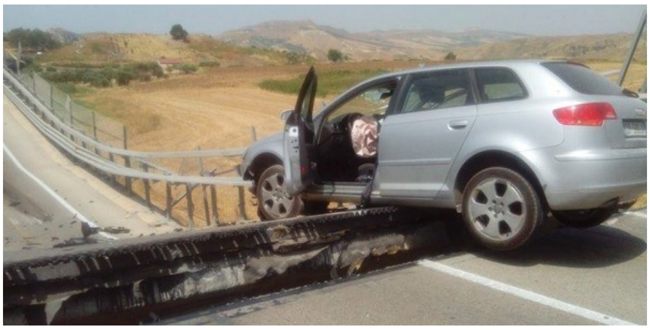
A viaduct under construction collapses

A viaduct under construction in Belo Horizonte, the Brazil's fifth-richest city, suddenly collapsed crushing a bus, a car and two trucks. A female bus-driver and a worker died; 22 wounded, including eight hospitalised, are in serious condition. The bridge, located near the Mineirao stadium, was one of the works planned for the Cup; it had not yet been completed.

Sicily. July 8, 2014:

Collapse of the Petrulla viaduct in the Agrigento's surroundings





The Petrulla viaduct on the 123 main road, connecting Licata to Ravanusa (the two largest towns of the surroundings of Agrigento), was broken in two parts. A motorist passing over it was able to go back to full speed and not remain crushed.
The viaduct Petrulla is 492 metres long and the collapsed part is one of its twelve spans. From the first checks made by Anas technicians, the collapse should have been caused by a rupture of the prestressed concrete beams supporting the deck. There had been no noticeably misshapen and such to herald the imminent collapse before. No sign of a possible failure, however, was ever emerged in recent maintenance (both ordinary and extraordinary) that affected the viaduct in recent years, with the adjustment of safety barriers and, more recently, with the replacement of the expansion joints. Meanwhile Anas is studying the actions to be taken to rebuild the viaduct and reopen the stretch of SS 123, which connects the municipalities of Licata with Agrigento and Caltanissetta. The mayors of the district ask for quick solutions and propose a bypass to replace the bridge collapsed: a hypothesis that Anas is considering. Anas, Traffic Police and Civil Defence are working on alternative routes to divert traffic.

Ottawa (Canada), February 21, 2014

Ottawa has had sinkholes before.

In February 2014, a large hole opened up in the pavement at the intersection of Laurier Avenue and Waller Street (just around the corner from the most recent sinkhole) near the University of Ottawa. This one was about eight metres wide by 12 metres deep. Work on a portion of the light-rail transit project was suspended to investigate the cause of an enormous sinkhole on Waller Avenue near the Laurier Avenue

intersection.
(Blair Gable/Reuters) ((Blair Gable/Reuters))

The first sign of trouble was noticed the night before when material from the top of the tunnel started falling and workers stopped digging and left the area. Soon after, the road collapsed. The sinkhole, which measured eight metres across and about 12 metres deep, caused minimal delays for traffic. Cement was poured into the hole to stabilize the road shortly. No injuries were reported.

<u>Kentucki. February, 2014:</u>

The Corvette Museum got a new attraction in 2014.

Noble Jr./Associated Press)

A sinkhole that opened up at the National Corvette Museum in Bowling Green, Ky., became such an attraction that the eight, mangled cars it swallowed are still on display. Dirt from the sinkhole was also put on sale in the gift shop.

<u>Ottawa, October 7, 2013:</u>

The Great Maw of St. Joseph

A sinkhole opened up on St. Joseph Blvd. in Orleans during a busy Monday morning commute in the fall of 2013. The hole was caused by a burst underground water pipe. At the time, city officials said 40-year-old concrete pressure pipe failed. Witnesses said water started spouting out and soon after the road cracked and collapsed. City workers were to turn the main off, fill in the hole and re-opened the road that night.

Montreal, August 2013:

A backhoe fell into this Montreal sinkhole

(Christine Muschi/Reuters)

In another dramatic Canadian collapse, a backhoe fell victim to an eight-by-five metre sinkhole that opened unexpectedly at the intersection of Guy and Ste-Catherine streets in downtown Montreal in August 2013.

Toledo (Ohio). July, 2013:

Sinkhole swallows car in central Toledo

(Matthew Hertzfeld/Toledo Fire Rescue)

In Toledo, Ohio, a large sinkhole appeared on North Detroit Avenue near the intersection of West Bancroft Street. The incident occurred at 12:15 p.m. The cause of the sinkhole appears to be a water main break. Driver Pamela Knox had to wait for a firefighter rescue after her car dropped into this massive sinkhole that opened up underneath her car in 2013. A water main break was to blame for the hole. Knox wasn't hurt.

http://www.toledoblade.com/gallery/Sinkhole-swallows-car-in-central-Toledo

Sicily. February 2, 2013:

Collapse of the Verdura Bridge (Province of Agrigento)

The bridge over the river Verdura, on the SS115, at km 136, collapsed. An entire masonry span of the Verdura Bridge collapsed, after dangerous signs of depression in the road occurred since the previous evening. These signs had already alerted the traffic police, firefighters and Anas operators, intervened on the place to stop the transit of vehicles. The closure of the vehicular traffic was providential, as the roadway on the right of the bridge, on the north side, collapsed entirely shortly after, around 11am. Some ANAS technicians who were putting a road sign, miraculously escaped the collapse. So far the left side of the bridge, oriented downstream to the mouth of the Verdura river and resting on reinforced concrete structures, is unscathed, although the carriageway is unusable. Great job for the city police of Ribera, who closed the passage just before theVerdura bridge. They stationed both near the Macaluso junction, and at the entrance of Ribera, to give the necessary directions to motorists about the road for continuing teir journey in the direction of Sciacca. The deviation forces to drive for about thirty kilometres on an internal road, narrow and full of curves: a disaster of unprecedented proportion in the economy of most of western Sicily, as the movement of vehicles between the provinces of Trapani, Agrigento and Palermo will suffer a slowdown. In addition, displacements' costs will worsen further, with negative consequences for agriculture, tourism and essential services. Farmers, traders and professionals are alarmed about the time of reconstruction of the Verdura bridge that is announced long. The movement of vehicles in the province of Agrigento will be revolutionised for all the time necessary to the reconstruction of the viaduct.

An assessment made in 2013 from a newspaper article by ALESSIO GERVASI and LORENZO TONDO (August 18, 2013)
(http://ricerca.repubblica.it/repubblica/archivio/repubblica/2013/08/18/strade-killer-ventimila-chilometri-di-pericoli.html)

Killer Roads: twenty thousand kilometres of dangers

Twenty thousand kilometers of asphalt, curves and chrysanthemums, to remember those who never came home from the streets of the island. Killer Roads, which, at best, hurt, but many times kill. Dangerous asphalt, often unfinished, where you know when you start but not when you arrive. Mountains of money go up in smoke and burned by too long time and too scarce materials. The result is a trail of dead endless. Thirty-six incidents a day (6.5 percent of the national total). More than thirteen thousand with serious injuries and 271 deaths each year. The last, on August 11, were mother and son: Rosa Ruccione, 74, and Sergio La Venia, 48, owner of a wine shop in Corso Calatafimi, Palermo, died in an accident on the A29 near Alcamo. The same

fate had be fallen three days before Carmelo D 'Angelo, 25, and Salvatore La Bella, 52, victims of a collision at the first light of the day on the main road to Licata.
And yet, the day before, Davide Sanna, 24, and Elio Barbiera, 30, who were driving by motorcycle on the Marsala-Trapani main road. Italian statistics say that in many cases it is due to the drug. In other cases to the alcohol, the recklessness and often the speed. But whose fault is when a motorist perfectly sober loses his life for a guardrail too low? Or for a hole that no one has covered? Some of these roads are the subjects of work to improve safety. In other instead those works are never started.
Killer asphalts
The deads on the Sicilian roads in the last six years have been more than two thousand. In the province of Palermo, the average is about seven victims each month. Almost double if compared to that of Florence. At the top of the list of "the roads of death" is the Palermo-Sciacca freeway, with nearly 15 dead in just over a year and in only 80 kilometers of asphalt: a damned road that from Pagliarelli prison runs up to the province of Agrigento. Percent the broken lives since the early 2000s to today. A cross every 800 metres. The latest is that of Salvatore Virga, just 37 years old. On July 29, riding a motorcycle, he collided with his car at the entrance of Altofonte. Too young to die, as the majority of victims of the Palermo-Sciacca roads. Many commuters, workers and students have to travel daily to the capital (Palermo) and then come back home to their families. The Palermo-Sciacca road (SS 624), managed by Anas and established in 1989, has a dangerous feature: the road does not pass through any town, so it is considered an expressway. Already, on the Palermo-Sciacca cars run fast, like on a highway. But it is not. Roadways are too narrow, guardrail are too low and long and frequent bumps make the overtaking tricky and often fatal. The majority of deaths occurs in head-on collision. A few months ago mayors of the municipalities concerned asked for help to the Regional Government to take effective measures aimed at reducing the risks on the 624 road. "We need the help of the regional government - Filippo Di Matteo, the mayor of Monreale, says. - We must meet the prefecture and Anas. We must make our voice heard and try to solve the situation became untenable". The works for the construction and maintenance of safety barriers on the trunk to Palermo began three years ago and cost more than 20 million euro: they were not able to stop the trail of death. Anas stated that "the monitoring continues, but the safety standards on the tract are respected".The committees think differently. "Anas is always passing the buck - Peter Benenati, regional coordinator and one of the founders of the national AIFVS, the' Association of Italian families and victims of road, says - Maintenance have never been made. And when a tragedy happens, their first thought is to pass the buck on the municipalities. "The truth - Benenati, who twenty years ago lost his daughter in a car accident, continues - is that the guardrail of the national roads continue to be too low, the gutters are never pulitee in case of rain you " browse "on the asphalt. This is the truth."
The road of the massacres
Driving on the SS624 to the junction of Sciacca, the asphalt connects to another "cursed", the SS 115, the "road of the massacres", which until the last year was recorded two deaths a month just in the stretch around Agrigento. Thousands of crosses that since 1950 along the path connecting Trapani to Siracusa. More than 400 kilometres that make it the longest national road of the Island. Hundreds of millions spent over the years to the safety. The responsibility is given to the lack of lighting, guardrails out of the norm and the absence of a dual carriageway for trucks that make the connection a nightmare to motorists. A few days after the re-opening to traffic of the bridge over the river Verdura, collapsed in February, the Prosecutor of Sciacca on June 21 ordered the closure of another bridge of the 115 highway, just a few metres from the Verdura bridge, to shed light on the death of young Burgio Spitaleri Alessio, 29, rushed from the viaduct with his car twenty days before. The committees already five years before had asked Anas to raise the guardrail. 120 km between killer curves and roadways full of pitfalls from the province of Agrigento to Palermo. A trip become one-way for about 300 people in the last thirty years. Dozens of unauthorized accesses, roads suddenly become smaller and junctions sadly adorned

with plaques and flowers. During the intense autumn rains, the overflowing of the Platani river, near Castronovo, floods the asphalt and the water's level is 40 centimetres high in some places. In 2011 Anas announced the works on safety of a part of it as upcoming. Works only began and twenty deaths, with a cost of 300 million euro. The date of "delivery" is scheduled for 2016. But three years is a long time waiting for those who are forced to travel daily. As Rosi Cacciatore, 47, who teaches history and geography in a school of Lercara. Every morning, from Campofranco, aboard her black Golf, she runs about 35 kilometres before arriving at her destination. "They are the longest twenty-five minutes of the day - she says - especially since two years ago, my car finished off the road due to the steep and the slippery asphalt. God only knows how the bus coming from the other lane avoided the collision". She lost a lot of friends on that road. "Some of them – she said - were forced to travel to work like me. We are tired of risking our life every day in these cursed streets".

Half a coat

In the last ten years, Sicily has invested more than two billion euro for the maintenance of its streets: 339 million for the Syracuse-Gela, 477 for the Camastra-Gela, nearly 60 million for the maintenance of highways, 815 million for the Ragusa-Catania, 222 for the Bolognetta-Lercara and 150 for the Mazara del Vallo-Trapani. Yet only a fraction of this money to date has been really turned into asphalt. An example of all is the Palermo-Messina that, after a half century of work, remains unfinished. And, more and more dangerous, in the last four years there were 610 road accidents of which 13 were fatal, with over 400 wounded, about ten a month, and twice a week. To avert further tragedies the only ones seem the magistrates who ordered the indictment of five former commissioners and directors of the consortium that ran the route. The prosecution is the attempt on transport safety. A crime which meet Benedetto Dragotta, Commissioner between 2001 and 2007, Matteo Zapparrata, special commissioner, Felice Siracusa, general manager, Gaspare Sceusa, director of the technical area and Filadelfio Scorza, project manager and safety officer.

The dramatic escalation of incidents convinced the Attorney of Patti, after using surveys for two and a half years of investigation that the responsibilities of the many misfortunes of those 185 kilometres is not the case but the CAS (Sicilian Highways Consortium), an acronym that took shape from the fusion of the "Consortium for the Peloritani tunnel", then transformed into "Consortium for the Messina-Patti " and finally "Consortium for the Messina-Palermo motorway ". Cas is the largest shareholder of the Sicilian Region; followed by the provinces of Catania, Messina, Siracusa and Ragusa, with the respective chambers of commerce and the municipalities concerned. A Moloch whose "social purposes" – it is written on the site - "the completion of work on the Palermo-Messina, Messina-Catania and Siracusa-Gela," thanks to the contributions of the State, the Region, the European Community, of the other public institutions and all national, regional, and existing and future Community providences. The work, cost 750 miri, aims and "Capo d' Orlando" towards Messina is an example: seized by the judiciary on Dec. 12, 2011 - the technical expertise certified a risk of collapse of 70 per cent – they are still closed today. Stories tormented, endless and tangled. Such as the Messina-Catania, the A18, which also includes the Catania-Siracusa-Gela, which however stops to Rosolini, about ninety kilometres from Gela. It took 25 years to build forty kilometres. A few days before the opening of the last lot, the one that leads from Noto to Rosolini, scheduled for April 30, 2008, the asphalt was seized by the courts for failure abnormal dangerous subsidences and a slit of about twenty centimetres.

Asphalt without an end

We drive along the Palermo-Catania, the A19. It is managed by Anas. It is essential to visit the centre of Sicily. It is a freeway, but perpetually under maintenance, ordinary and extraordinary. Tunnels and many viaducts do not hold up the traffic with the result that in some sections you travelled and continue to travel in alternating lanes. For ten years and for about four kilometres in the direction of Catania, hundreds of New Jersey barriers (safety devices in concrete) delimit traffic "provisionally", restricting it to only the middle lane, thus avoiding overburden the walls of the support structure, now fragile.

From January 28, the FIP industrial Spa of Selvazzano Dentro, Padova, began the works on the "structural improvement of the southern roadway of the viaduct", with the result that motorists entering the highway from the junction of Resuttano to Catania or Caltanissetta before they are forced to move towards Palermo until the exit of Tremonzelli, then return back on the opposite two-way traffic carriageway, along about 30 kilometres. The mayor of Resuttano, Rosario Carapezza, complains: "For four months we have spent twice as long to go to Caltanissetta and there are many commuters - students, workers as well as patients who go to hospital for treatment - that do not make it anymore. An unbearable increase of time and costs. We had proposed alternative solutions to Anas, also with a municipal resolution, but there was nothing to do and they have always rejected our proposals". Then he emphasizes: "The work was to end on May 20 and instead we talk about a shift in late June. What's worse is that throughout this whole chaos is only a small part of the work to be performed on the Cannatello viaduct, which I think is about four kilometres. Because these works have affected about one kilometer so far. But what happens when you have to do the other lots? ". The same on the A29 Palermo-Mazara del Vallo, managed by Anas, 119 km long. In addition to linking Palermo with its airport, Falcone and Borsellino, it also serves the airport of Trapani Birgi, and the archaeological sites of Segesta and Selinunte. A minimalist highway: toll-free but also without service areas for refueling. Built after the earthquake of Belice by Anas and managed always by the same institution. Very busy, with daily jams and accidents, especially in the stretch with the two tunnels on the outskirts of Palermo, both incoming and outgoing from the city. Dimly lit too close to junctions, it has a very deteriorated road surface and the exit for Trapani has a very narrow track with a succession of bumps. The longest tunnel, (1,615 metres), is the "Segesta", near the junction of the same name and is not equipped with the most elementary safety devices for a tunnel of this length. They are not present, in addition to emergency lanes, nor escape routes or ventilation or Sos columns. After about half-way, the view out the window, reminds the Sicilian land reform. Sixty kilometres in sixty years. They all feel.

Ottawa (Canada). September 4, 2012:

The 174 Plunge

A driver suffered minor injuries after a car plunged into a sinkhole on the Highway 174 off-ramp at Jeanne D'arc Boulevard in September 2012. The rear bumper and a wheel were all that was showing when emergency crews arrived at the scene. The driver, who crawled out with the help of a passerby, sustained only minor injuries. The hole was caused as a result of a collapsed storm sewer pipe under the highway. The city reopened one eastbound lane of Highway 174 a week later as worked around the clock to assemble a storm drain underneath the ground to replace one that failed and caused the sinkhole.

Minnesotha. June, 2011:

Floodwater caused this one in Duluth. (Brian Peterson/Star Tribune/Associated Press)

Torrential rain in Duluth, Minn., in June 2011 forced residents from their homes (and zoo animals from their pens) and caused this suburban sinkhole.

Guatemala City, Guatemala. 2010:

A sinkhole top them all (Casa Presidencial/Reuters)

One of the most infamous sinkholes in recent memory opened up after tropical storm Agatha passed over Guatemala City in May 2010, swallowing an entire entire city block, including a three-storey building.

Ottawa, 1924:

#RideauSinkhole baby photo? Rideau Street, Ottawa, Ontario. 1924 #ottnews #sinkhole (Twitter by the Library Archive Canada)

Appendix 2

Supranational road network projects: some examples and issues

In Europe, the Trans-European road network project (Fig. 1) - started in 1993 and laid out by Article 9 of Decision 661/2010/EU - aimed to include motorways and high-quality roads (whether existing, new or to be adapted), which play an important role in long-distance traffic, or bypass the main urban centres on the routes identified by the network, or provide interconnection with other modes of transport, or link landlocked and peripheral regions to central regions of the Union and improve the internal road infrastructure of the European Union (EU). Nevertheless, the process is made very complex by the fact that, currently, in the road sector (that includes various components such as networks, vehicles, and driving regulations) there are many international rules and standards, as well as several systems of road classification.

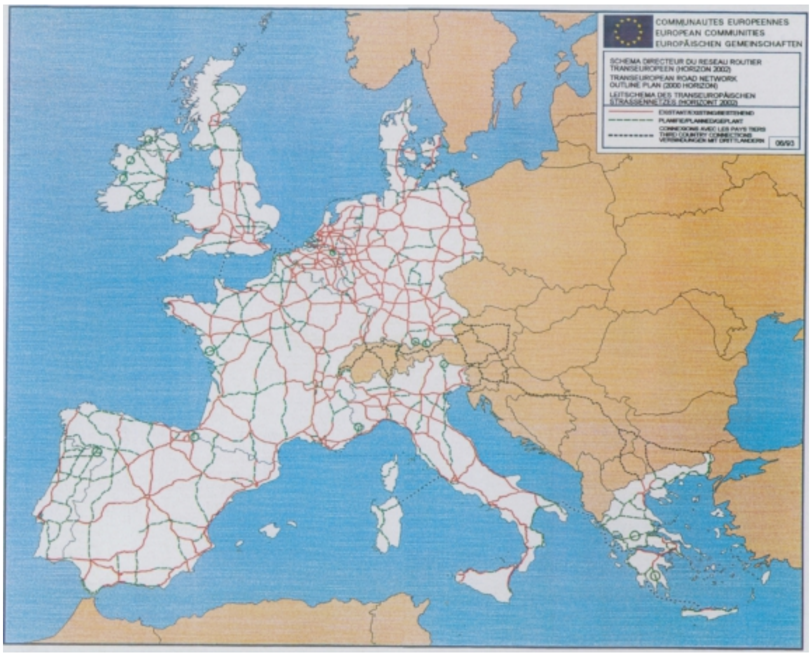


Fig. 1 – The Trans-European road network. Outline plan (2000 Horizon) – European communities. Sources: Official Journal of the European Communities

With the regard to the extra-European context, the Pan American Highways network or the Pan-Philippine Highways are some examples of the inclusion of highways into larger networks (here encouraged by governments and the World Bank to stimulate agricultural production by reducing transport costs, encourage social and economic development outside existing major urban centres, and expand industrial production for domestic and overseas markets). Similarly to the European case, the Pan American Highways network institution required studies to establish principles to govern the planning of national and international highway networks, and criteria through whom each country concerned might the construction of their own road section (Peaslee, 1974).

Another example is the Asian Highway (AH) project, also known as the Great Asian Highway: a cooperative project among countries in Asia and Europe and the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP).

Fig. 2 The Asian Highways Network

The road network aimed to improve the highway systems in Asia and to make maximum use of the continent's existing highways to avoid the construction of newer ones (except in cases where missing routes necessitate their construction). Nevertheless, as Regmi (2011) highlighted, some issues and challenges in developing the project emerge, in particular relating to: standards and condition of infrastructure, maintenance and upgrading of infrastructure, the gap between financing development and maintenance, the facilitation of border crossings, infrastructure and operation (Highway-Public/Private sector, Railway-Public), national plan and policies –think beyond borders, as well as coordination among countries and agencies.

Finally, in the African continent, the Trans African Highway project - originally formulated in the early 1970s - is a sample of network of 9 transcontinental road projects in Africa that United Nations Economic Commission for Africa (UNECA), the African Development Bank (ADB), and the African Union are still developing in conjunction with regional international communities. It aims to establish a network of all weather roads of good quality, which would provide as direct routes as possible between the capitals of the continent; contributing to the political, economic and social integration and cohesion of Africa, and ensuring road transport facilities between important areas of production and consumption.

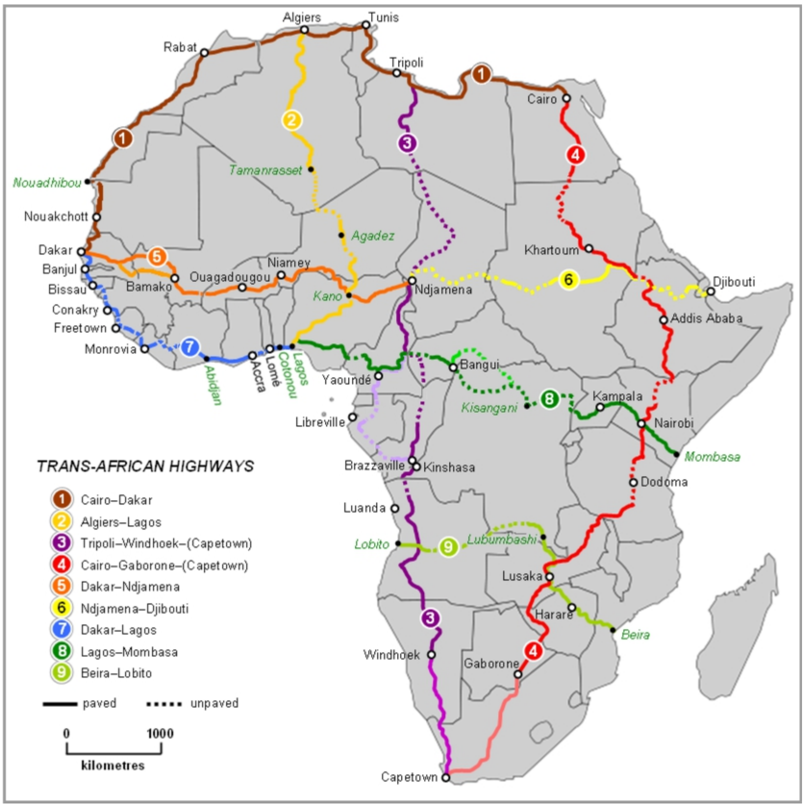


Fig. 2 – The Trans-African Highways network. Sources: Official Journal of the European Communities

The network of nine highways for a total length of 56,683 km (35,221 mi) is aimed at creating uninterrupted roads phisically linking African capitals and, hence, facilitating the physical integration of the continent: an integrated development of transport corridors spanning all African countries and providing landlocked countries access to seaports to promote trade and alleviate poverty in Africa (Adamatzky and Kayem, 2013). Nevertheless, the whole planned road system is not still complete: in addition to the physical barriers due to the missing links of the network, in 2001 the final report by UNECA mentioned "non-physical barriers affecting the inter-country road transport operations of member countries, associated to the disparities in terms of transit services, customs and other regulations arising from the policy framework of the different countries". Thus, it considered the role of RECs (Regional Economic Communities) and their transport organs "very crucial, in order to harmonise these irregularities affecting the inter-country operational activities".

One of the first conditions to reach such harmonisation is having a single road classification within the network.

Appendix 3

Road classifications in Europe

Over time, in Europe, different definitions for primary road networks have been used: E-roads[117], TERN[118], TINA roads[119], Pan-European road corridors[120], and the TEM network[121]. In individual countries and at national level, these definitions do not necessarily match motorway networks or other definitions for national trunk roads, which are often more commonly used for road user information, road programmes, etc. (Bergman, 2009). Also, some of the road classifications above were considered temporary or specific for some uses or differently identified: for example, one of the main network (E-roads) is identifiable by road signs, whereas the other main one (the Trans-European road network) is not. In this regard, as highlighted by Lars Bergman in 2009 in his report for the Conférence Européenne des Directeurs des Routes (CEDR), the European Commission has recognised that there is potential for confusion in the multiple 'European' road networks that currently exist and stated in its White Paper on transport policy (European Transport Policy for 2010): "In the long term, a common system for identifying

[117] The international E-road network is a numbering system for roads in Europe developed by the United Nations Economic Commission for Europe (UNECE).

[118] The Trans-European road network (TERN), defined by Council Decision 93/629/EEC of October 29, 1993, is a project to improve the internal road infrastructure of the European Union (EU). The TERN project is one of several Trans-European Transport Networks.

[119] Transport Infrastructure Needs Assessment (TINA) were pre-TERN-roads for accessing countries. They have been replaced by TERN-roads.

[120] The ten Pan-European transport corridors were defined at the second Pan-European transport Conference in Crete, March 1994, as routes in Central and Eastern Europe that required major investment over the next ten to fifteen years.

[121] The UNECE Trans-European Motorways (TEM) Project is a sub-regional cooperation among Central, Eastern and South Eastern European countries established in 1977. "*The TEM project has published Standards and Recommended Practice to reflect the up-to-date requirements of motorway users, the latest experience, research and development achievements in the field of motorway design, construction and operation as well as newly required safety measures in motorway tunnels. The role of these standards is to ensure that the planning and design of the TEM motorway provide for the adequate traffic flow at minimum operating cost, while ensuring harmonized conditions for motorway users, proper level of service, safety, speed and driver comfort over medium and long distances*" (CEDR/TD Management, Project Group "Planning the Road Network", 2007).

stretches of the trans-European road network is bound to be required in order to make things clearer and guarantee continuous network quality for users".

According to the Bergman's report of 2009, having a defined trunk road network for Europe is an important simplification of the system, as it allows:

a) to uniform road signing and numbering throughout Europe;

b) to increase the level of attention of governments towards maintenance level, roadside service, intelligent systems, and road standards on these routes of international traffic;

c) to encourage the governments of neighbouring states to adopt uniform principles on shared cross-border routes;

d) to give international organisations a mandate for directives on these routes only (e.g. by-passes, tunnels, hard shoulders, rest areas, police control, etc.);

e) to define a target for international grant aid or financial support and coordination of road development;

f) to obtain statistical 'European level' data on European roads per route and per country using performance indicators and applying a common location reference system, to monitor and identify priorities for further investment in infrastructure;

g) to revise the TEN-T Guidelines between member states, road administrations, and the European Commission, establishing criteria to list a priority of projects needed.

In the light of above, one single road classification system at European level is required, as well as the creation of a shareable model with specific features, allowing the interoperability among the member states of the EU. The purpose is also to develope co-modality or intermodality of the European network, and identify priorities for investment in the road network by objective performance data.

Many policies, activities and directives about transport have been moving towards this direction over time: an example of these is the Directive adopted by the EU in 2010 to progressively define at European level common interoperability standards for ITS (International Transport Systems) services (e.g. reservation services for safe and secure parking places for trucks and commercial vehicles, interoperable EU-wide eCall to bring rapid assistance to motorists involved in a collision, thus increasing road safety, real-time traffic and multimodal travel information services) (European Commission, 2012).

Each country is unique and as such has unique needs. There is no one-size-fits all solution when it comes to applying standards and specifications. (source: https://www.irfnews.org/standards-and-specs/ the website of the International Road Federation)

Appendix 4

Standards

Standard bodies

In EU Member States standards are established at international level, then adopted in European level and finally implemented national level (Bartha and Kocsis, 2011).

The main **International Standards Bodies**, involved in the development and adoption of International (i.e. global) standards, are three - all based in Switzerland - and together form the World Standards Cooperation (WSC). They are:

f. the **International Organisation for Standardization (ISO)**, a worldwide nongovernmental federation of national standards bodies. It is the principal body coordinating the development and promulgation of formal International standards in almost **all industry sectors**, except for electrotechnical and telecommunications standards. Its standards may be made national according to decisions taken at a national level.

g. the **International Electrotechnical Commission (IEC**), a non-governmental organisation coordinating the development and promulgation of International standards for **electrical, electronic and related technologies**;

h. the **International Telecommunications Union (ITU)**, an agency of the United Nations specifically responsible for coordinating standards for **telecommunications**. It is an intergovernmental public-private partnership organisation collecting 193 countries members and around 700 Sector Members and Associates (European Commission, 2012).

At the European level, currently there are only three official **European Standardisation Organisations (ESOs)**, able to develop formally recognised European standards (ENs), which must be implemented at national level. They are:

i. the **European Committee for Standardization**, also called **Comité Européen de Normalisation (CEN)**, an international non-profit association created in 1975 in Brussels, collecting stakeholders from the National Standards Bodies of EU Member States and European Free Trade Association (EFTA) countries, now including also

Eastern and Central European countries. It develops European standards and other reference documents (such as technical specifications, technical reports and workshop agreements) across **a wide range of industry sectors**; thus, promotes free trade, the safety of workers and consumers, interoperability of networks, environmental protection, exploitation of research and public procedures. CEN Standards, called EN (for European Standards in German) replace national standards when formally adopted. Therefore the work undertaken at CEN level supersedes national works, although the use of European or national standards is not mandatory in many cases (Brand et al 1993).

j. the **European Committee for Electrotechnical Standardization (CENELEC)**, a non-profit organisation established in 1973 to coordinate the development of European Standards (ENs) and other reference documents in the **electrotechnical field**. It is composed of the National Electrotechnical Committees of the EU Member States, EFTA countries, Croatia and Turkey, and cooperates with the International Electrotechnical Commission (IEC) in the development of international standards;

k. the **European Telecommunications Standards Institute (ETSI)**, an independent, not-for-profit organisation based in the south of France. It produces globally applicable standards for **Information and Communications Technologies (ICT)**, and cooperates with the International Telecommunications Union (ITU) in the development of international standards.

CEN and ISO have involved in the definition of standards through a participated process carried on by several thematic working groups: they are composed of experts in the subject drawn directly from the industrial, technical and business sectors, others with relevant knowledge, such as representatives of government agencies, testing laboratories, consumer associations, academia, international governmental and nongovernmental organizations (ISO, 2012).

With regard to **National Standards Bodies (NSBs**), almost each country within Europe has an officially recognised standardisation body, not developing (i.e. writing) standards, but coordinating and managing the process of standards development by different actors. They play a major role in assessing and responding to demand for new standards, and are also responsible for their final approval, adoption, publication, promotion and sale.

After adoption by CEN, CENELEC or ETSI, EU Member States are obliged to implement standards as national standards and to withdraw conflicting national standards. NSBs have two years to incorporate adopted standards into their national systems (Knoop and Pachelski, 2005).

ISO TC/211 mainly related to the road cadastre implementation

ISO 19100 defined fundamental GI standards to be used in every field where location is considered (road transport included): in particular, they addressed standards relating to data capture, data definition, data storage, data display, and data exchange (Kresse and Danko, 2012; Hanson and Heron, 2008) that Kresse et al. (2012) grouped into Reference model, Infrastructure standards, Basic standards, Imagery standards, Catalogue standards, and Implementation standards, as some examples show in the table below:[122]

AREA	ISO STANDARD	TOPIC OF THE STANDARD	GROUP	NOTES
REFERENCE	ISO 19101	Geographic Information (GI) – Reference model	Reference model	It establishes an **overall model for geographic information written in UML**, the Unified Modelling Language and all standards are branches of it (i.e. **every individual standard is logically linked and harmonised among the suite of standards**) (Kresse, 2004).
DATA CAPTURE	ISO 19113	GI - Quality principles	Basic standards	
	ISO 19114	GI - Quality evaluation procedures	Basic standards	
	ISO 19157	GI – Data quality	Basic standards	It provides advice on **different levels of detail** for the quality check (Kresse and Danko, 2012).
	ISO 19115	GI - Metadata	Basic standards	It provides a large basket of the formal names (or metadata, i.e. data about data) of all the elements needed in applications of geographic information, with addressing metadata for imagery (ISO 19115:2) (Kresse, 2004). It provides a schema and establishes a **common set of metadata terminology, definitions, and extension procedures** (Bartha and Kocsis, 2011).
DATA DEFINITION	ISO 19104	GI - Terminology	Infrastructure standards	
	ISO 19105	GI - Conformance and testing	Infrastructure standards	

[122] With this regard, ISO 19100 standards do not standardise the data capture procedures for a GIS, neither features catalogues and data models, but only provide guidelines and metadata elements to describe the origin and quality of the data, as well as a catalogue template to support a complete and consistent listing (Kresse and Danko, 2012). They do not standardise the way the geometry and topology are handled by the database, neither data types, nor details of the topology

DATA STORAGE	ISO 19111	GI – Spatial referencing by coordinates	Basic standards	It sets the rules for the **definition of coordinate reference systems** (Kresse and Danko, 2012).
	ISO 19112	GI – Spatial referencing by geographic identifiers	Basic standards	
	ISO 19107	GI - Spatial schema	Basic standards	It is the most comprehensive collection of **geometry classes for the features** and rules **how they are related each other** (Hanson and Heron, 2008). It distinguishes between **primitives** (i.e. geometries not including their end-point) **and complexes** (i.e. geometries including their end-point) (Kresse and Danko, 2012).
	ISO 19108	GI - Temporal	Basic standards	
	ISO 19109	GI – Rules for application schema for objects, or features, in datasets	Basic standards	It contains all the definition related to **features** (e.g. entity and attribute) and states that a feature may have **attributes** (identifying whether a feature is a point, a curve, or a surface) and **operations** (identifying whether the feature changes according to external influences) (Kresse and Danko, 2012).
	ISO 19123	GI - Coverage geometry and	Imagery standards	Together with "Spatial schema" it is a very comprehensive work for GIS geometry (Kresse, 2004).
	ISO 19135	GI - Procedures for item registration	Catalogue standards	It describes the rules for **creating registries aimed at guaranteeing standardised use of important parametres** (Kresse and Danko, 2012).
	ISO 19127	GI - Geodetic code and		It defines a specific **registry for coordinate reference systems** (Kresse and Danko, 2012).
DATA DISPLAY	ISO 19117	GI - Portrayal	Basic standards	According to it, the graphic representation is handled independently from actual data, whereas the application schema only sets the frame for the possible features (Kresse and Danko, 2012).
DATA EXCHAN GE	ISO 19118	GI - Encoding	Basic standards	It addresses how data will be exchanged between datasets (Hanson and Heron, 2008) and describes the **requirements for creating encoding rules based on Unified Modeling Language** (UML) schemas (Bartha and Kocsis, 2011).

	ISO 19130	GI - Sensor and data models for imagery and gridded data	Imagery standards	It defines the way in which **georeferencing information for the orientation of photogrammetric images and remote sensing** scenes is described and packaged (Kresse, 2004).
	ISO 19110	GI - Features catalogue	Catalogue standards	
	ISO 19126	GI - Feature dictionaries	Catalogue standards	
	ISO 19128	Web Map Server interface	Implementation standards	
	ISO 19133	Location Based Services	Implementation standards	

Table … Examples of ISO 19100 standards, areas, aims, group and descriptions

ISO 19101 "Geographic information – Reference model", is the important standard which defined a "geographic information system" as an "information system dealing with information concerning phenomena associated with locations relative to the Earth" (ISO1, 2002) – and it will be addressed in Chapter 7, while ISO 19110 "Geographic information – Methodology for feature cataloguing" provides a standard framework for organising and reporting the classification of real world phenomena in a set of geographic data.

ISO Levels of Detail

ISO 14825:2001 provides three different levels of representation (Level 0, Level 1, Level 2) for the Feature Theme Roads and Ferries.

FEATURE	REPRESENTATION	LEVEL 0	LEVEL 1	LEVEL 2	NOTES
Road					
Road Element	the centreline of a road	one or more Edges	a Line Feature	Complex Features	*In case the centreline of the road is ambiguous or discontinuous the general flow of traffic should be used as a guideline for defining the shape of the Road Element. *The Edges should fall within the curb lines
Junction	• the connection point between two or more Road Elements, two or more Pathways, two or more Ferry Connections, or a combination of either of the former; • or the intersection point between one or more of the former and the outline of an Enclosed Traffic Area; • or the end of a dead end	one single Node	a Point Feature	Complex Features	

	Road Element or Pathway				
Enclosed Traffic Area		one or more Faces or Edges (or the Polylinedescribing its boundary)	an Area Feature	Complex Features	* within it the identification of a road centreline is an unrealistic task. Also a general flow of traffic is non-existent. * at Level 0 the Face (or Edges or the Polyline) shall describe the maximum extent of the permitted area for vehicle use.
Pathway	the centrelines of a pedestrian passageway	one or more Edges	a Line Feature	Complex Features	*The Edges should fall within the curb lines (boundary lines) where applicable. *Where a centreline is ambiguous or discontinuous a different representation by means of an Enclosed Traffic Area (type Pedestrian Square) may be more appropriate. **In non-planar topology, a description of the height difference between the two Nodes stacked above each other to bound the vertical Edge shall appear.
Ferry Connection		one or more Edges	a Line Feature	Complex Features	
Address Area		one or more Faces or Edges (boundaries)	an Area Feature	Complex Features	
Address Area Boundary Element		one or more Edges	a Line Feature	Complex Features	
Intersection				Complex Features	
Interchange				Complex Features	
Roundabout				Complex Features	
Aggregated Way				Complex Features	

CEN/TC 287

Its members were delegates from 22 countries and observers from the Digital Geographic Information Working Group (DGIWG)[123], Comité Européen des Responsables de la Cartographie Officielle (CERCO)[124], and International Hydrographic Organization (IHO).

[123] Digital Geographic Information Working Group, or Defense Geospatial Information Working Group since 2008 is an organisation of member nations working for interoperability standards for geographic data exchange between various military systems and Geographic information system in general.

[124] CERCO is a forum for the heads of 35 European National Mapping Agencies. It was created in 1980 for exchanging information and for discussing geographical information issues (cfr. Dassonville, L., Vauglin, F., Jacobsson, A., Luzet, C. Quality Management, Data Quality and Users, Metadata for Geographical Information Di Wenzhong Shi,Peter Fisher,Michael F. Goodchild,

This work **in co-operation with ISO/TC 211** was carried out in order to avoid duplication of work and ended in 1999 with the publication of a list of ENVs (European Norme Vorlaufig: tentative norms): a combination of the three official languages within the CEN.

According the analysis of Bulens and Vullings (2003), it was assumed that ISO/TC211 would take over the European working-programme of standardisation of GI (for which reason two TC's were not necessary); but, since ISO standards are published, Europe has to decide how to implement them in current practice for the development of her own market. This is why the CEN/TC287 was awakened in 2003 to harmonise the ENVs producted in the '90s with the ISO TC/211 standards, developed since 1995 and bring standards within CEN and ISO together (as mentioned in paragraph 2.1.1.1).

The standards developed aim to support the consistent usage of GI across Europe, making it compatible with international usage (i.e. through a spatial data infrastructure at all levels in Europe). This is achieved by: 1. the adoption of the ISO 19100 series as European standards; 2. the development and take-up of new standards, profiles of standards in cooperation with ISO/TC 211; 3. facilitating interoperability with related standards initiatives through necessary harmonisation and associated agreements; 4. promoting the use of and education on standards on geographic information (CEN, …). "Spatial Data Infrastructure (SDI)": such term, coined in 1993 by the U.S. National Research Council, denotes

INSPIRE

The INSPIRE Directive, proposed by the European Commission in 2004, finally entered into force in 2007. It established an Infrastructure for Spatial Information in the European Community, based on the infrastructures for spatial information created and maintained by the MS. According to the Directive, the European infrastructure should be established and operationalised by individual Member States, which had two years from the date of adoption to bring into force national legislation, regulations, and administrative procedures defining how the agreed objectives would be met (even taking into account the specific situation of each Member State). As specified by the Implementing Rules, in addition to the 34 spatial data themes, the infrastructure includes: metadata and spatial data services; network services and technologies; agreements on data and service sharing, access and use; coordination and monitoring mechanisms, processes and procedures. Information should be provided for each spatial object type. For spatial objects within the scope of an Annex I/II theme, the Directive requires that key attributes, an identifier and the relationships with other spatial objects will be proper provided in addition to their spatial characteristics.

As explained in D2.5 INSPIRE document ("INSPIRE Generic Conceptual Model for

INSPIRE"), a first level of interoperability derives from using the INSPIRE Generic Conceptual Model within the different themes. It defines the elements necessary for interoperability and data harmonisation, such as rules for application schemas[125], coordinate referencing and units model, unique identifier management, multi-lingual text and cultural adaptability, object referencing modelling, multiple representations (levels of detail) and consistency, and more. The D2.6 INSPIRE document ("Methodology for the development of data specifications"[126]) defines a second level of interoperability (through a a repeatable methodology). It refers to the agreement on the shared (formal) semantics between the different themes (i.e. data product specifications for the individual themes; also conceptual information models describing relevant classes, their attributes, relationships, constraints, and possibly also operations as well as other appropriate information like data capturing information or data quality requirements) and describes how to arrive from user requirements to a data specification. The third level of geographic information interoperability is addressed by the D2.7 INSPIRE document ("Guidelines for the encoding of spatial data"), describing how the geographic information can be encoded for the transfer process between the systems of the data providers in the EU. On this basis, each Member State is expected to be able to transform its own spatial data sets to the INSPIRE data specifications and publish the transformed data via network services, using GML (Geography Markup Language) (ISO 19136) as the default INSPIRE encoding.

The framework within which harmonised data specifications for the INSPIRE spatial data themes have to be developed includes the following aspects:

- INSPIRE application schemas
- spatial and temporal representations of spatial objects across different levels of detail
- spatial and temporal relationships between spatial objects
- unique object identifiers
- constraints
- reference to common spatial and temporal reference systems
- controlled vocabularies
- support for multilingual aspects

[125] In the INSPIRE Directive "Application schema" is defined as "conceptual schema for data required by one or more applications ".

[126] In INSPIRE "Data product specification" or "Data specification" is defined as "detailed description of a data set or data set series together with additional information that will enable it to be created, supplied to and used by another party [ISO 19131]"

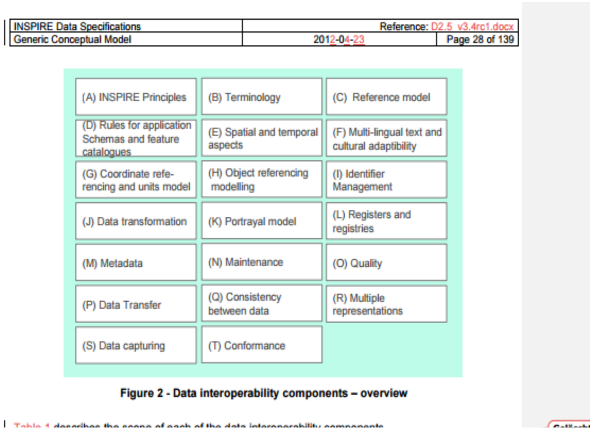


Fig. … Data interoperability components – overview (source: D2.5 INSPIRE document - "INSPIRE Generic Conceptual Model for INSPIRE")

An UML (Unified Modeling Language) diagram gives an overview on the main elements of the specifications and the relationships, while the definition of the spatial objects, attributes, and relationships are included in the so-called Feature Catalogue (where users can check if it contains the data necessary for the applications that they run). The use of a common conceptual schema[127] language such as UML allows for an automated processing of application schemas and the encoding, querying and updating of data based on the application schema – across different themes and different levels of detail.

[127] In INSPIRE a "Conceptual schema" is "a rigorous description of a conceptual model for some universe of discourse".

Appendix 5

Normative References on Road Transport (Italy)

(source: Giannattasio, 2005 http://www.dica.unict.it/users/dcafiso/Allegati/SIIV%20Relazioni/SIIV_CT_Giannattasio_%20normativa.pdf)

TOPIC	STANDARD
GEOMETRIC DESIGN	1978: Geometric Design Standards for Urban Road Design; CNR B.U. n. 60, 26 April 1978. 1980: Geometric Design Standards for Road Design; CNR B.U. n. 78, 28 July 1980. BU CNR n. 90 (4/15/83) - Rules on the geometric and traffic of urban road intersections. 2001: Functional and Geometric Design Standards for Road Design; DM November 5, 2001 Ministry of Infrastructure and Transport, Rome, Italy 2001. 2004: 22.04.2004, Ministry of Infrastructures and Transport; Modifiche al D.M. 05.11.2001; G.U. 25.06.2004, n. 147. 2006: D.M. Guidelines for the functional and geometric Design of Road Junction Ministry of Infrastructure and Transport, Rome, Italy, 2006. Circular no.3699/2001, "Guidelines for Road Safety Audit and Inspection", Ministry of Infrastructure and Transport, Rome, Italy, 2001. 11. Directive 2008/96/EC of the European Parliament and of the Council of 19 November 2008 on road infrastructure safety management, Official Journal of the European Union, 29.11.2008. Ministry of Infrastructures and Transports - document to pre-normative character, approved by the Commission Roads CNR, in September 2001, "Regulations on functional characteristics and geometric road intersections "and approved with amendments by the Board of Public Works in 2004. •" Intersections flush "- Ch. X of the standard CNR VU n. 31 (28/03/73) Ministry of Public Works - a character-normative document approved by the Commission Roads CNR, 2001" Functional and geometric parking areas, parking and service of highways and main roads extrarubane ".
GENERAL RULES	DL 285-92 - New RoadCode (OJ of 18/05/1992) DPR 495-92 - Implementing Regulation of the Road Code (GI of 12.28.92) as amended by Presidential Decree 610- 96 (see above) DPR 610-96 - Modification of Presidential Decree 495-92 - Regulations implementing the new Highway Code (OJ of 04/12/1996) CNR BU n. 77 (05/05/80) - Instructions for the preparation of road projects (Sost. BU no. 5-1967). CNR B.U. n. 91 (05/02/83) - Instructions for determining the profitability of road investment. CNR B.U. n. 125 (4/20/88) – Instructions on planning of road maintenance Ministry of Infrastructure and Transport document-character pre-normative, approved by the Commission Roads CNR, 2001 "Technical standards for the regulation of the construction and maintenance of road infrastructure "
CADASTRE AND CLASSIFICATIO N	2001: DM 1 June 2001 "How to up and updating the cadastre of roads in accordance with art. 13, paragraph 6, of the legislative decree 30 April 1992 n. 285, as amended "/ 2001: Guidelines for the Design and Update of Road Cadastre: Ministry of Infrastructure and Transport, Rome, Italy 2001 10.

	"Criteria for the classification of the network of existing roads in accordance with art. 13, paragraph 4 and 5 of the New Highway Code ", Study Report of the National Research Council, Committee for the rules relating to materials and road design, construction and maintenance of roads, to the Board of Public Works
ROAD SURFACE	1995: CNR B.U. n.178 – 1995 - "Catalogue of road surfaces"
UNDERGROUND UTILITIES	1998: UNI CEI 70030 - September 1998 - Technological plants underground - General criteria for installation. 1999: PCM 3.3.99 Underground Directive - Directive for the rational arrangement in the basement of the underground technological systems (Official Gazette of 11/03/1999) 1998: UNI CEI 70029 - September 1998 – multifunctional facilities for the coexistence of network services different - Design, construction, management, and use - General criteria and safety
SIGNAGE AND EQUIPMENT	1992: CNR BU n. 150 3/19/92 "Standard on furniture function of urban roads" Cap. 3 2000: Directive LL.PP. 24/10/2000 - Directive on correct and uniform application of the rules of the Road Code regarding signs and criteria for installation and maintenance (OJ 28/12/2000 n. 301) 2002: DM Ministry of Transport Infrastructure 07/10/2002 Road vehicle signs - Technical regulations concerning disclosure schemes, differentiated by category of road to be taken to the temporary signaling.
SAFETY BARRIERS	1992: D.M. February 18, 1992, # 223 "Regulations Technical Instructions for the design, approval and use of road safety barriers" 1995: CIRCULAR Ministry of Public Works June 9, 1995, n. 2595 "Road barriers of security. Ministerial Decree of 18 February 1992 n.223 " 1996: DM October 15, 1996 "Upgrading the Ministerial Decree of 18 February 1992 n.223, containing technical instructions for the design, approval and use of road safety barriers" 1998: DM June 3, 1998 "Further update of technical instructions for the design, approval and use of road safety barriers and technical requirements for testing for the purpose of" 1999: DM June 11, 1999 "Additions and amendments to the decree of 3 June 1998: Update of the Technical Instructions for the design, approval and use of road safety barriers" DM 2001: August 8, 2001 n.4785 - Extension of the terms' Art. 3 of DM June 11, 1999 2004: MD June 21, 2004 - "Update on Technical Instructions for the design, approval and use of road safety barriers and technical requirements for the testing of road safety barriers" 2004: CIRCULAR Ministry of Infrastructure and Transport, August 25, 2004, n. 3065 "Directive on the criteria for the design, installation, testing and maintenance of restraining devices in road construction
STREET LIGHTING	2003: UNI 11095: 2003 Light and lighting - Lighting of the galleries. 2001: UNI 10439: 2001 Lighting - Lighting requirements of motor traffic. 1999: UNI 10819: 1999 Light and lighting - Outdoor lighting installations - Requirements for

	limiting upward dispersion of light flow. UNI EN 13032 Road lighting - Forthcoming Traffic
TRAFFIC	CNR BU n. 150 (3/19/92 "Norma on furniture functional urban street - Cap. 2 Traffic lights" Minitero LL.PP. - Document approved by the Commission in pre-normative character of the road CNR, 2001 "traffic light control systems Traffic - Technical Standards " Ministero LL.PP. - Document approved by the Commission in pre-normative character of the road CNR, 2001" Information systems users - Guideline for the design " Ministero LL.PP. - Document to prenormative approved by the Commission road CNR, 2001 "Monitoring systems Traffic - Guidelines for the design"
ROAD SAFETY	2001: Circular no.3699/2001, "Guidelines for Road Safety Audit and Inspection", Ministry of Infrastructure and Transport, Rome, Italy, 2001. 2008: Directive 2008/96/EC of the European Parliament and of the Council of 19 November 2008 on road infrastructure safety management, Official Journal of the European Union, 29.11.2008.
AIR POLLUTION	1983: DPCM 28/5/83 – Inquinanti dell'aria. Limiti massimi di accettabilitàà nell'ambiente esterno (G.U. 28 maggio 1983, n. 145) 1988: DPR 203/88 – Norme in materia di qualità dell'aria 1994: DM Ambiente 15/4/94 – Inquinamento atmosferico. Norme tecniche sui livelli e stati di attenzione degli inquinanti nelle aree urbane (G.U. del 10/5/1994) 1998: DM Ambiente GU 3/8/98 – Piano per la tutela della qualità dell'aria. Mobilità sostenibile nelle aree urbane (G.U. del 3/8/1998)
NOISE POLLUTION	1991: DPCM 1/3/91 - Rumore. Limiti massimi di esposizione in ambiente abitativo e urbano 1995: Legge quadro sull'inquinamento acustico 26 ottobre 1995 n. 447 – Principi fondamentali in matiera di tutela dell'ambiente esterno e dell'ambiente abitativo dall'inquinamento acustico (Suppl. ord. G.U. 30/10/95 n. 254) 2004: DPR 30/3/2004 n. 142 – Disposizioni per il contenimento e la prevenzione dell'inquinamento acustico derivante dal traffico veicolare (G.U. 1/6/2004 n. 127) 2005: U20.00.114.0 – 2005 – Linee guida per la progettazione, esecuzione e collaudo di sisistemi antirumore per infrastrutture di trasporto via terra.

APPENDIX WITH Normative references (ISO/EN)

GEOGRAPHIC INFORMATION	EN ISO 19101:2005, Geographic information — Reference model ISO/TS 19103:2005, Geographic Information — Conceptual schema language 19107:2005, Geographic information — Spatial schema 19108:2005, Geographic information — Temporal schema 19109:2006, Geographic Information — Rules for application schemas 19110:2006, Geographic information — Methodology for feature cataloguing 19111:2007, Geographic Information — Spatial referencing by coordinates 19111-2:2009, Geographic Information — Spatial referencing by coordinates — Part 2: Extension for parametric value 19112:2005, Geographic information — Spatial referencing by geographic identifiers 19115:2005, Geographic information — Metadata EN ISO 19115:2005/AC:2008, Geographic information — Metadata — Technical Corrigendum 1 INSPIRE Data Specifications Reference: D2.5_v3.4rc1.docx Generic Conceptual Model 2012-04-23 Page 11 of 139 19123:2007, Geographic information — Schema for coverage geometry and functions OGC 06-103r3, Implementation Specification for Geographic Information - Simple feature access - Part 1: Common Architecture v1.2.0 NOTE This is an updated version of "EN ISO 19125-1:2006, Geographic information – Simple feature access – Part 1: Common architecture". A revision of the EN ISO standard has been proposed. 19126:2009, Geographic Information – Feature concept dictionary and registers 19131:2008, Geographic Information – Data Product Specification 19135:2007, Geographic information — Procedures for item registration 19136:2009, Geographic Information – Geography Markup Language ISO/TS 19139:2007, Geographic Information – Metadata – XML Schema implementation ISO 19156:2011, Geographic Information – Observation and Measurements UML 2.1.2, Unified Modelling Language (UML) Superstructure and Infrastructure, Version 2.1.2 Commission Regulation (EC) No

	1205/2008 of 3 December 2008 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards metadata D2.9 Guidelines for the use of Observations & Measurements and Sensor Web Enablement-related standards in INSPIRE Annex II and III data specification development, version 2.0 OGC 09-146r1, GML application schema – Coverages, version 1.0.

Appendix 5

Questionnaire 3D-Road inventory: status July 2015

This questionnaire is an activity of the GISLab (Department of Civil, Environmental, Aerospace and Materials Engineering) of the University of Palermo, Italy. The purpose of the survey is to catch information world-wide about road inventories (state of art, needs, constraints, and possibilities also in the perspective of a development towards a 3D road inventory). By sharing this information, it should be possible to improve cooperation, learn from each other and support future developments. The results will be made available on request. Please complete this questionnaire by July 30, 2015 and send it to susanna.gristina@unipa.it.

1. Questionnaire n.1 - Road Inventory

(Target: technicians from international highways agencies or involved in transport)

In Italy roads are classified and registered into an inventory called "Road Cadastre". Each institution, owner of public roads, has to build a road registry because government legislation requires it. The road inventory includes data related to the geometry and the features of roads (classified into administrative and technical / functional categories).

This part of the questionnaire refers to the road inventory of your country (needs, limitations, issues and improvement, possibilities…).

Name:……………………………...…… Surname:……………………...…………………

Organisation/company/institution:……………………………………………………………

Occupation/Role in the company:……………………………………………………………

Country:………………………………………………........................…………………..

1	Does a road inventory exist in your country?	☐ Yes ☐ No If yes, it is: ☐ Digitalised ☐ Not digitalised

2	What is the name of this road inventory?	🕴 Road registry 🕴 Road inventory 🕴 Road cadastre 🕴 Road asset management 🕴 Road archive 🕴 Road plan 🕴 Other (please, write the exact name): …………………....
3	Which is/are its main purpose/s?	🕴 Juridical 🕴 Ownership registration 🕴 Fiscal screening 🕴 Planning 🕴 Road management 🕴 Road maintenance screening 🕴 Road safety audits 🕴 Accident modelling 🕴 Road Protection Scoring 🕴 In-depth accidents analyses 🕴 Other: ...…………………………………………........
4	Is the road inventory managed by a public institution?	🕴 Yes 🕴 No

5	If yes, which institution / institutions manages / manage it?	🕴 State 🕴 Region 🕴 Municipality 🕴 Other: …………… Name/Type of the institution: 🕴 Minister of ………….……...…………................. 🕴 Department of.………………………………………… 🕴 Other): ..……………………..……................................
6	If not, is the road inventory managed by private institutions or companies?	🕴 Yes 🕴 No Name/Type of the private institution/company: ………………………………………………………………
7	Does your country use a road administrative classification?	🕴 Yes 🕴 No
8	If yes, how are roads classified in it? *(e.g. Motorways, Suburban primary roads, etc.)*	🕴 ……...……………… 🕴 ……………………....... 🕴 ……………………... 🕴 …………………….…. 🕴 ……………………... 🕴 …………………….…. 🕴 ……………………... 🕴 ……………………....….
9	Does your country	🕴 Yes 🕴 No

	use a road technical/functional classification?	
10	If yes, how are roads classified in it? *(e.g. Highways, National roads, Local roads, Military roads, etc.)*	🕴 ……...……………… 🕴 …………………………..... 🕴 ……………………... 🕴 …………………………..… 🕴 ……………………... 🕴 …………………………..… 🕴 ……………………... 🕴 ……………………….....…
11	Is the text of relevant laws or regulations about road inventory and road classifications available? If so, please, give references to relevant document(s). English language preferred if possible.	🕴 Yes 🕴 No References: ………………………………………………………… ………………………………………………………… ………………………………………………………… ………………………………………………………… ………………………………………………………… ………………………………………………………… ………………………………………………………… …………………………………………………………
12	What kind of information does the current road inventory in your country record?	🕴 Geometrical data (2D) 🕴 Geometrical data (3D) 🕴 Geographical data 🕴 Road components 🕴 Road signs 🕴 Pipes 🕴 Administrative data 🕴 Ownership 🕴 Others: ………………………………………………
13	What kind of information does the current road inventory provide to users?	🕴 Geometrical data (2D) 🕴 Geometrical data (3D) 🕴 Geographical data 🕴 Road components 🕴 Road signs 🕴 Pipes 🕴 Administrative data 🕴 Ownership 🕴 Others: ………………………………………………
14	Are data from the road inventory easily available?	🕴 Yes 🕴 No How available: 🕴 by WebGIS 🕴 by a web platform 🕴 by Geospatial Web Services 🕴 by a web database 🕴 by WebGL 🕴 Others: ………………
15	Are data from the road inventory shareable?	🕴 Yes 🕴 No How shareable:

		☐ by WebGIS ☐ by a web platform ☐ by Geospatial Web Services ☐ by a web database ☐ by WebGL ☐ Others: ………………
16	Would you implement any improvement about the current road inventory?	☐ Yes ☐ No Improvements: ……………………………………………………… ………………………………………………………
17	Do you know any software allowing users to collect and assess road data within a road inventory *(e.g. DB, GIS, etc.)?* If yes, please indicate: (a) the name of the software, (b) its main possibilities, (c) and its main constraints.	☐ Yes ☐ No The name of the software: ……………………………….... Its main possibilities: …………………………….......... Its main constraints: ……………………………............
18	According to you, what kind of software tools can provide for an effective method to inventory and monitor of roadside assets?	☐ 2D CAD ☐ 2D GIS ☐ 3D CAD ☐ 3D GIS ☐ BIM ☐ MySQL and similar DB ☐ Others: ...…………………………………………………
19	Please, supply the name, the address, the email and the phone numbers of people involved in road inventory implementation or project.	Name: ……………………………………………….… Company/Organisation: …………………………….......... Address: ……………………………………………….… E-mail: ……………………..………………………….... Phone numbers: ………………………………………...

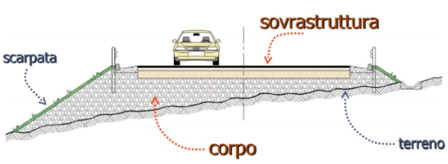
2. Questionnaire n.2 - Road Inventory and 3D data about roads

In Italy roads are classified and registered into an inventory called “Road Cadastre”. Each institution, owner of public roads, has to build a road registry because government legislation requires it.

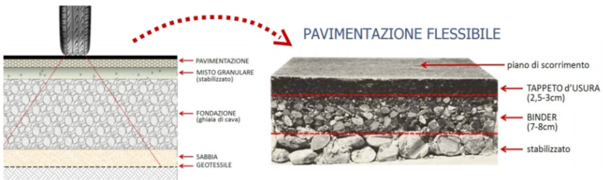
Currently, it does not register “**3d road situations**” (e.g. overlapping and interlocking road networks, pipes, tunnels, etc. as well as their 3D road parts and components and 3D environmental and urban contexts). This part of the questionnaire refers to the road inventory of your country (needs, limitations, issues and improvement, possibilities…). It aims at collecting your main needs related to the management of data on 3D road situations (both design, construction and maintenance of roads).

Name:………………………………… Surname:……………………………… I work: ☐ as a road designer ☐ for a road construction company ☐ for a road maintenance company ☐ for a highways mapping agency Organisation/company/institution:……………………………................................. Country: ..……………………………...		
1	Does a road inventory exist in your country? Please, fill in the box.	☐ Yes ☐ No If yes, it is: ☐ Digitalised ☐ Not digitalised Name of the road inventory: ………..…...........................…… Name/Type (public/private) of the institution managing the road inventory: ………………………………………..........
2	Do you use the road inventory? For what purpose/s?	☐ Yes ☐ No Purposes …………………………………………………
2	Do you consider the current road inventory a good tool for your purpose?	☐ Yes ☐ No
3	Would you implement any improvement about it? What?	☐ Yes ☐ No Improvement/s suggested …………………………………
4	Do you know of any	☐ Yes ☐ No

	successful software collecting and assessing data for road inventory? If yes, please indicate: (a) the name of the software, (b) its main possibilities, (c) and its main constraints.	Name of the software: ……………………………………....... Main possibilities: ………………………………….............. Main constraints: ……………………………………….......
5	Compared to the current road inventory data in your country, which further/different data would you need to design your road projects (or for road construction/maintenance)?	Useful additional data: …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… ……………………………………………………………
6	Do you consider a three dimensional road inventory useful? Why?	🕴 Yes 🕴 No A 3D road inventory might be useful to: ……………………………………………………................
7	Which **3D situations** among the ones below might be useful to record and describe about roads within an inventory *(e.g. pipes, tunnels, etc.)*? Please, check the box that best corresponds to your answer for each example below. Multiple answers allowed.	

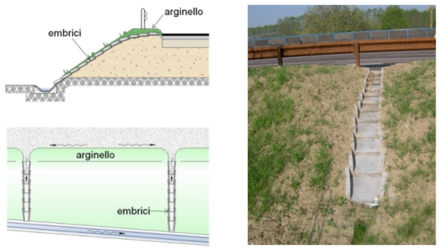


a)

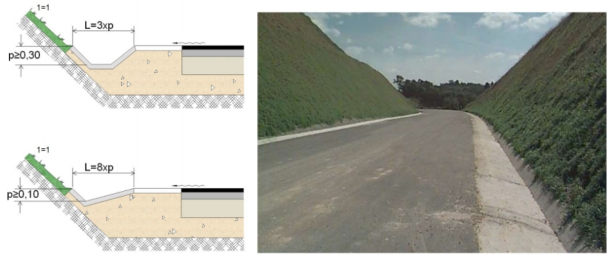


b)

c)



d)



e)

f)

g)

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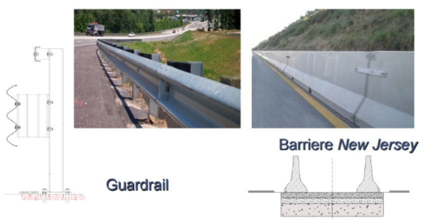

i)

l)

m) **No one**

n) **Others**: ……………………………………………………

8	For your purposes (road design/	⧫ Yes, 2D data integration is enough ⧫ Yes, possibly 3D data integration

	construction/ maintenance/ management), do you think useful integration between road projects' data and road inventory's data? Which data in particular? Why?	🕴 Yes, just raster files of 2D drawings about roads 🕴 No. No integration needed Data to be integrated……………………………………..… Because………………………………………………..…. …………………………………………………………… …………………………………………………………… …………………………………………………………… …
9	For your purposes (road design/ construction/ maintenance/ management), do you think useful integration between 3D road models and the road inventory? Why?	🕴 Yes 🕴 No Because…………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………… …………………………………………………………...
1 0	For your purposes (road design/construction/maintenance/management), do you think useful integration between 3D space and temporal representations of roads, into a single 4D space/time representation within the road inventory (e.g. to describe the infrastructure's life-cycle)?	🕴 Yes 🕴 No
1 1	Is there legislation (law and/or regulations) for 3D descriptions of roads? If so, please, mention law and article(s). English preferred if possible.	🕴 Yes 🕴 No References: …………………………………………………………..

1 2	Are there projects for 3D data registering of roads? If so please, mention them.	☐ Yes ☐ No Projects: …………………………………………………………………..
1 3	Is there a formal model for 3D roads (UML style)?	☐ Yes ☐ No Formal model for 3D roads: ……………………………………………………………………
1 4	Do you know any 3D GIS software about roads? Which one?	☐ Yes ☐ No Name of the 3D GIS software about roads: ………………………………………
1 5	The registration of 3D roads is done by:	☐ Mapping agencies ☐ Road registry institutions ☐ Others: …………………… ☐ Nobody
	Are 3D registrations handled by the same organisation that handles traditional (2D) road administration?	☐ Yes ☐ No
1 7	Please, supply the name, the address, the email and the phone numbers of people involved in road inventory project.	Name: …………………………………………………… Company/Organisation: ………………………………..….. Address: …………………………………………………..… E-mail: ………………………..… Phone numbers: ………
1 8	Please, supply the name and the contact information of any commercial vendor/system used for data collection of road inventory objects.	Name: …………………………………………………… Company/Organisation: ………………………………..….. Address: …………………………………………………..…… E-mail: ………………………..… Phone numbers: ……..

Appendix ...

Interviews

INTERVIEWS TO ROAD DESIGNERS

A number of semi-structured interviews were carried out with road stakeholders based in the same country of Italy (Sicily) and involved in road design: the CEO (individual interview) and three project managers and designers (triad interviews), an Italian engineering consulting company, and providing highly integrated specialised engineering services (planning, design, supervision of works and Project & Construction Management processes) in transportation infrastructure, water, environment, energy and main civil structures. It has a technical staff of about 600 people - about 100 of them working in Italy - and Regional branches also in Africa and Middle East. Over fifty years it has carried out more than 700 projects in Italy and abroad for a value of more than 100 billion US$.

INTERVIEW N. 1

July 13, 2015 - Interview with Respondent 1 (R1), CEO

R1: In Palermo I have always held an operative headquarter that deals mainly with Italy, but doing something also abroad. Rome is the general headquarter; in Milan there is another one. Then we have offices directly abroad; so our distribution is directly with locations abroad, that is, they do everything but with an interface with Italy ".

S.G.: *The Road Cadastre was established in 1992 and, in 2001, by the Act of June 1, 2001, the procedures for its establishment and updating have been established. However, still today many organizations have not provided for its implementation. What major difficulties were encountered for the construction of road cadastres? And how can they be resolved?*

R1: But I do not know what are the real technical problems. I think that perhaps administrations underestimated the problem of the knowledge of what is the real Road Cadastre. This is for me the problem. The law that established the Road Cadastre is a very important standard because it is fundamental to start from a correct understanding of what is not only the functionality of the road, but what are the physical characteristics of roads (especially going over what the history of our country has been and hence the story since the post-war - from the '60s onwards - when the primary roads have been developed and, in particular, when the roads of minor importance have been developed. So this belongs to a totally different story, to two different historical periods. Therefore, the Road Cadastre is important for knowledge. Though, this is definitely an early stage, primordial, because a Country that tends to develop in terms of the territory, and therefore in terms of the strategic and economic development, based on the knowledge of the physical state of the primary and secondary roads, must think about its own future. Thus, the infrastructure planning aimed at creating synergies models - and then interchange models - between transport infrastructure can arise only on the basis of knowledge. Hence, to me the Road Cadastre is an important activity, which was to be done by separating the primary from the secondary road system, also on the basis of the type of infrastructure, as they were not built with an identical principle, but by meeting different historical needs. After that, once known such historical needs, we must be aware of what we actually have and plan the future development, for sure, by new systems of design, project implementation and then planning and programming.

R1: *Do you make use of the Road Cadastre in your design work? Do you consult it before starting a project?*

A.B.: No, because the Road Cadastre definitely has started, but especially in some regions is totally non-existent. So, as regards the infrastructure - also important infrastructures - to date it is not an element of reference for road designers. When we talk of construction period it means not only the physical characteristics of roads, but also the structural characteristics, and the techniques used for building them; and then certainly it provides those bases that are more fundamental to road design.

S.G.: *If it was implemented, what information should be provide to a designer?*

R1: As I said, it is crucial because today the Road Cadastre should give the real knowledge not only physical of the road, but also the construction period. Construction period characteristics mean not only physical, but also structural, techniques that are within that building; and then certainly it gives those bases more fundamental to road design.

S.G.: *Hence geometry, features, materials...*

R1: Characteristics of materials, standards in accordance with whom the road was built (from the geometric standards to structural and geomechanical standards), period in which road infrastructures were built (that are historical periods). It is normal: in Sicily there are many roads that date back, as well as in Italy, to two centuries ago; then others dating back to before the post-war, i.e. before the '50s; and then all the primary infrastructure development which changes the concept of the vehicle with the consequence that from the '60s people discover the alternative to the railway line, which is precisely the road. And then the first primary roads begin to be built, but with different techniques - both geometric and structural and constructive. So the Road Cadastre should be just this connection as the road is not a line: the road is an element that lives within the territory, and then that interface with the territory and must live within the territory. We must move from an important concept: the road is a disturbing element, in general, of the territory; however, though it is a disturbing element, it may fit well and can become instead an element of development of the territory. So these steps are not theory, but reality and therefore things we must think about properly, when going to build a new infrastructure system. And it is clear that knowledge is essential. Such knowledge cannot only tied to the single project, as, whether tying to the individual project, knowledge may be very limited and local, whereas a knowledge linked to a Road Cadastre, which becomes more specific about the actual construction and geometric characteristics of the road, then surely has an important function for the development.

S.G.: *So do you think that, for example, a 3D model that is queryable, and hence is also a data model (i.e. a model not only for display), also allowing both studying the relationship with the context in which the road infrastructure is located and the time factor -*

because there is the possibility of course to record the "story" of the road in some way, i.e. to document the history of road infrastructure and its characteristics - can be a useful tool for road design?

R1: Absolutely. It will certainly be a complex tool, but an important one. Today we have daily evidence of the difficulties we meet. What does this mean? That as having no real knowledge of the context of the roads, in order to create development, it is very often believed that we can create growth by investments in new roads. Well, I believe that any country that has a conscience must first adjust all the existing infrastructure system, which is practically its asset, because if you go to a private company, what the asset of a private company is given by? By what is owned and which represents the asset for accounting purposes. So in our case in a country, an area, a region of a country, the asset is the presence of infrastructure on which it has invested in previous years. So having the ability of adapting this asset and make it truly an asset for the country, instead of a cause of inefficiency, it is crucial for development. Once you rearrange your asset, then you can certainly think of implementing it with further infrastructure.

S.G.: *Currently which software are used by road design company for designing roads?*

R1: Regarding technical details, as I am the managing director of a very large company that works mainly abroad, but also in Italy, I cannot tell the name of the software we use: it does not go out of my check. I will be able to direct you to those who can tell you what are reference software today - not only nationally, but also internationally. We can give you the right information as our turnover is 86.5% abroad, 13.5% Italy; so we have a pretty clear international vision of those which are the programs that actually are used in various fields, both roads and structures.

S.G.: *I see that there are designers working at a local level that are still stuck to the two-dimensional CAD or GIS.*

R1: No, this should not exist at all. But do you know what is the big problem? Unfortunately investments are required to build up an enterprise and today an engineering company must provide important services, as significant investments are needed and very often a local studio does not have the force and this must also understood. So, in my opinion, this is a cultural investment.

It is not correct: I can understand that we are an international company; we work worldwide and we are independent, but I think it is not fair that a local study, which rightly can make an important service to the territory, would be obliged to invest in software and technology. It would be more correct to do a focused investment on a framework of services that can be used by more studies, and then to create an office, a platform providing services to users for a month, two months, or three months: at that point it should be an appropriate level platform to meet those which are today international needs. So this is the concept. Any institution (e.g. the Region of Sicily) should create a technology platform available by its own offices, and also private - certainly in payment: the investment for a platform with a suitable software system would be a certainly farsighted investment. It is outside my personal view of things today, but if I had to make a criticism about the Sicily-Italy system, it would be this, because I know well the investments and objectively you can not think to not ask for a proper Road Cadastre, a three-dimensional design as it is normal to do, because you do not plan anything in CAD: because from the geometrical point of view today, the Act of 2001 imposes certain checks: road design, which certainly remains one of the most complex designs, is part of an iterative system of phases that require the re-verification of a project at least tens of times to achieve the appropriate final results. This has to be interconnected with the entire structural system to be able to give an output that can be read even in the future for the purpose of programming, planning and maintenance, and definitely imposes important investments. So, regardless, I consider that for a local service it would certainly be appropriate to create a platform available to more local studies that definitely have an important know-how from a theoretical point of view, but that may not have adequate means.

S.G.: *Saying this, you gave me a very important input as a motivation for my research work. In this picture, basically I can show you a little of what I would try to do, not necessarily by an on-screen use (virtual), but by logging on the Internet - let's image that this is a road infrastructure within its context – we would have the opportunity to query a large set of data.*
R1: Sure.

S.G.: *As you are the CEO of an international business company, on the basis of your knowledge and experience related to your role within your company, let's talk about European standards. You spoke about a platform that hopefully could somehow convey data not only local, but that - for those working internationally - may have characteristics compliant with data used in various countries (some of them will based on the same standards, whereas others on different ones).*
R1: They are different standards, so it is clear that they are not always the same by law; but that does not mean ... The country can be different, but the methodology should be the same. It is clear then that standards on structures, on roads, on visibility checks or on structural inspections are different from country to country; however, you can do this with programs and platforms that make you manage the same features with different standards, as we do usually. The important thing is certainly the know-how and how to interface in this world. I believe that at this time in Italy there are great difficulties due precisely to this lack.

S.G.: *Definitely one of the problems I faced in my work is to understand how technicians consider these standards: e.g. the INSPIRE Directive, CEN/TC 278 standards and all these European directives that from time to time we European countries should implement. Are they really helpful or are they only theoretical aspects that are the result of these Working Groups, but then operationally …*
R1: Well, operationally … zero today.

S.G.: *And in other European countries, for what it is in his knowledge?*
R1: No, not that. In our country, yes. Because I believe that from the point of view of infrastructure planning and investments scheduling we are very far behind other European countries. We still go forward to the change of governments to decide whether a stretch of a motorway has to be built or not. But how can be this the criterion for deciding if I do not say a highway but a simple stretch has to be built or not? Or if has to be built with priority 1 or priority 50? But how is it conceivable to determine if an infrastructure stretch should be done with priority 1 or priority 50 depending on the change of government? It's impossible. There is no other European country for which there is a so burdensome situation relating to infrastructure: either it is needed or is not. Is there an economic study about that to decide? And technical? And financial? Good. If that infrastructure has real motivations to be built from an economic, technical and financial point of view, and it is a priority for the economic development not only of the country and territory, but within a larger system, then that must have that priority. It can not changed because the individual Minister or the individual Prime Minister considers not to do it more or to do it before or afterwards.
So, we participate in European corridors ... And then? To do what? To get any funding. And then we can decide to do it or not do it. This can not be accepted as a model. I have to say, and, in general - I connect with what I said initially - we were a country well infrastructured than many other European countries: Spain in the '80s was not infrastructured; and so it was better to make new infrastructure with new loans. But for us that we had a major infrastructure, definitely it agreed first to "crank it up" and then really implement a suitable cadastre of roads; and then plan with intelligent planning model as it was a big help. Now the European Union rightly says: "I need this".

But why? Because EU needs to know that all investments made within the European Union reflect the profitability canons: profitability towards the territory. It is not true that an infrastructure creates economy: an infrastructure may create diseconomies because you invest, spend money and do not have an economic return, and if I insert an infrastructure within a territory, the European Union will say: "Would you mind to explain if this actually creates economy or not, or if it is the most correct solution?". Today we are not able to do it. In general, in front of European committees, we tend to take them around, saying: "It is better this, it is better that." But, if we discover our cards and ay: "This is the state"... Who can tell whether this creates economy or not if we do not have a real vision of the infrastructure system today? That is the issue.

INTERVIEW N. 2

July 20, 2015 - Interview with Respondent 2 (R2) (Project Manager - Roads Sector Manager)

S.G.: *Your Company deals with road design.*

R2: I am a Project Manager - although born as a road designer - so I see road design also globally, that is, not only by the only road point of view, but also hydraulic, structural, etc. The first thing we need is the geometric three-dimensional survey of the road, precisely understood as the so-called "blacks package": i.e. all that is paved (the upper part paved with all the layers - they are called "the blacks" because of the first layers of bitumen - or however, the paved part, which is basically the roadway) and everything relating to the embankments and trenches escarpments in order to precisely define the geometrisation, i.e. straights, curves and everything relating with the road body. This can be done by means of aerial surveys. Today also we use the most modern tools such as drones to do this type of relief (they are still being tested, but cost very little; so they may be an option). Then, next to this, of course, a detailed relief (topographic relief on the ground) has to be made. First, the survey serves to complete the aerofotogrammetric relief through several checks, but it mainly serves to define those works that are not easily readable by a simple aaerofotogrammetric survey: for example, the relief of the tunnels or of some works such as viaducts, bridges, etc.

S.G.: *With respect to these structures, which data do you use, in addition to the geometric ones?*

R2: With regard to tunnels, basically we have two types of tunnels. Tunnels are divided into natural and artificial. The substantial difference is the way to build them, the geometry (although, in principle, artificial tunnels are always those rectangular, whereas the arched ones are natural, but it is not always so), and the way they are built, that deals just a little with the relief, but gives a little the idea of the construction difficulty: i.e. the natural tunnel is excavated as well as if it were a kind of hole in the mountain, whereas the artificial tunnel involves simply a dig – and you can do as you want -, then the structure is built, and backfilled. In principle, there are several methods, but in the end the problem is always the same. The difference, from the geometrical point of view, is to detect the internal details of the tunnel, that is, the shape, and all that is inside the tunnel, especially in terms of plant, for example. This relating to the geometry of tunnels. Then maybe we can talk about the signs a bit apart. Once detected the internal geometry, spaces, etc., I do not think other is needed. As regards the viaducts, instead what is needed is much more complex because interventions on viaducts are to be made in function of their degradation. It is something a bit more complex because in that case a good archive must contain more than a geometric survey of the structure: in this case, for example, the deck and the thicknesses of decks and slabs are also to be detected - a deck includes both slab and the main and secondary beams; the relief of the piles on which the deck rests and of pier caps, i.e. the elements of transition between the pile and the deck, up to the end to foundations (where it is a bit more complicated because we are underground and the relief can be done simply as an archive than what is the historical archive of the structure. This relates to the geometry of the viaduct. Next to this, a very important issue on viaducts concerns, in terms of maintenance, joints and supports. The joints are those elements of transition between the various slabs. Very often, the roadworks seen on the highway are aimed at replacing deteriorated, degraded or dilapidated joints. The supports are all those elements on which all the beams of the viaduct rest; in many cases, such as on the Palermo-Catania constructed almost entirely as a viaduct, after 30-35 years of course these elements gradually degrade over time and must be replaced. Next to this, there is an important element along the whole road that are the retaining elements for safety: the barriers. These are both in viaduct and in current section as we call that which is not a structure; while, as regards tunnels, these elements are not there, or there are the so-called "redirecting profiles", which are a kind of concrete element with a shape aimed at redirecting the vehicle, but are not exactly a real protective element. These are important elements as in Italy we have one of the most stringent standards in terms of safety barriers: in quotation marks, from this point of view our roads perhaps are the safest. However, road safety is all connected to regulations that are relatively new and start from 2004. Hence, you can see both barriers that are absolutely inadequate, because they were built thirty years ago, and the newest barriers today, perhaps even overly protective with respect to what happens in other European countries, for example. The relief of these elements allows monitoring over time what happens: i.e. usually impacts and accidents that break, for example, point features, but somehow affect the operation of the barrier. I have no idea how ANAS to do for example: if it makes constantly this type of survey at sight , i.e. there are menders going around that, when they see, they report, according a protocol...

S.G.: *But you also have to identify even what is the exact point, etc. So, I wonder, if that point element, geo-referenced can...*
R2: Absolutely. If the relief of all the road already exists and one goes there with the GPS, and says: "We are here", there is a point and he takes a photo, automatically the information can be loaded in this archive where it is said that that element is of course a point element, potentially dangerous and therefore requires an intervention there. Certainly it would be a very useful tool also for ANAS - which today is not provided with - especially for maintenance of: a) barriers, b) the pavement. That of pavement degradation is a complex issue - there are texts and texts that talk about it: it is a bit more complicated because you make a survey today and tomorrow the situation is completely different because the degradation is continuous; at the same time it is not so, because it is not from one day to another that the pavement degrades. Indeed, it takes time. However, in principle, it has always a pattern becoming faster over time, i.e. there is a trend of pavement degradation that is, first, a degradation perceived only visually through small lesions, etc. So that the check can be done only through a continuous monitoring by tools such as equipped cars continuously monitoring a road, for example, and that, depending on the type of degradation, then intervene or not. There are many theories about that. The thing that usually happens is the opposite: if this type of degradation is blocked at the beginning, then the cost of maintenance of a road is lowered considerably, but it is not so for several reasons: a) because there is never money for maintenance; then, with the few that is available, the intervention is made where the degradation has extended so much that that singular point of the road became dangerous. But it is the cat chasing its tail, because, as the degradation increases, there will be less and less money to intervene. Why do I say this? Because, initially, the first symptoms of the pavement degradation appear; then they begin to form traces in the pavement through subsidences (the causes may be

different, but basically the degradation is almost always the same); the trace then is travelled undergoing dynamic stresses and, the deeper it is, the greater the impact of the wheel is: the consequence is an acceleration of further degradation, until it forms a real hole and finally there is an intervention (also as a consequence of some accident). However that is a managerial problem, then surely ANAS will be more precise on this type of intervention.
Another type of degradation that occurs in certain areas regards for example the aspects more related to the geotechnical and geotechnical problems, that is, the movements of the ground around the road. What is currently happening for example on the Palermo-Catania highway with the collapse of these viaducts is not a collapse of the structure by itself: it is nothing more than a trigger of landslides quiescent over time that suddenly trigger and cause all these movements; therefore, the viaduct collapses due to these movements.
The continuous monitoring (especially of areas with landslides), which normally should take place, allows evaluating in time the danger that there may be. It is an aspect in itself, but a very technical aspect especially relating to geology, the geotechnical of soil in lands crossed by a road, especially in the most dangerous areas (i.e. the area identified by CAI - Italian Alpine Club - as landslide zones or high risk zones). Hence, potentially that could also be something interesting - but it goes a bit over what is the simple relief of the road – also trying to identify through a visual study what are the aerial photos of the areas crossed by the road itself (but I think this is beyond what you were prefixing as a goal).

S.G.: *I show you this, for example. I started from some hypotheses, but I ask you if there are cases in which a 3D documentation... a 3D model that is queryable...are useful. I will show you an example. We applied this in the field of Cultural Heritage on a building: it is a three-dimensional model that you can interact with. By clicking on certain parts of this model, you can have a variety of information (e.g. location, history, summary data, etc.). So my question is: if you could have - I also talked about this with Prof. Bevilacqua - a platform where you can have road segments, a network of road infrastructure, that you can see as a model...*
R2: A three-dimensional geometric model. Probably so, and it is not a complicated thing to do.

S.G.: *But in our case it is associated with a database and ...*
R2: Yes, a database with information on the location, dimensions ... yes, you can do it. The materials are a bit more complicated because often what is built also differs from the project. The road structure itself, for example, consists of material coming from embankments, in quotation marks, but we do not know what is inside. As you build a road ... Imagine a road of kilometres and kilometres whose project has provided the use of materials from embankments whereas in most cases materials are assembled on-site, directly, in situ,... it means that some materials maybe deriving from excavations are reused through lime stabilisation processes. In my opinion, it is complicated to make a database on actual component materials from embankments. It is easier to have the geometrisation: you might have the thickness of the pavement. Then the elements of the road body are always: the foundations of the road body (again, obtainable only from the projects, and whether projects correspond to what has been actually built), the real road body, various kinds of materials belonging to groups with features, but I think that we can go beyond that. Then there is the pavement, which is also very variable because there is always a project of the pavement and its real construction. Moreover, it depends on what we are talking about: i.e. if we are talking about recent roads or built 40 years ago. With regards to old roads, it is almost impossible to determine all of this, unless you make cores every few to determine through the carrot (sample) the material that is there. However, it is variable. For example, on the pavement there is a continuous charging of material: i.e. in the presence of old pavements, depending on the type of degradation, a recharge is made, and then you will find sections where the thickness is 50 cm, and others where it is 20 cm... therefore, it is almost impossible, in my opinion, to determine such a thing.

More details can be obtained with regard to the roads of new construction or recent, for which there is already a project and from the project you can derive certain values. But even that is not certain. Contrary to what happens for the structures, there is a building process that includes the reprocessing of drawings called "as-built", i.e. that represent things as they were built during the execution of the work. But these elaborate focus mainly on the structures and in a new construction you will always find all the as-built of viaducts, tunnels, walls, and reinforced lands... Other issue, for example, is the failure of reinforced lands on the Agrigento-Caltanissetta road: there was a failure of a embankment. It was said that it was a failure of the viaduct whereas it was a reinforced land to failure. Of these works there are always the "as built". With regard to the road, instead, this does not always occur, unless there are large variations.

Therefore, if during construction there are point variations, it is not sure that there are the "as built", because in this case the construction process is more general: even if it is applied point-to-point, however, is always spread. It is not a point structure that you can act on in a certain way; and also it has tolerance and variability margins relating to the minimum technical characteristics required by the project and that the road trunk has to keep, but it is not sure that it will necessarily be made of that kind of material: I can built an embankment with the material from quarries, having certain characteristics, but if at that time I am doing excavations and have materials from the same site with certain characteristics or processed in some way (i.e. stabilised with lime or cement), I could also use them. So in practice it is impossible to include in a database such data on kilometres of road on a continuous. Otherwise you can describing that section without defining the construction materials, but as "road embankments": that is, a single cross section point-to-point can be seen from the GIS, because cross sections are embankments, in which there is written "embankment body with materials of "x" type... which are those that have those features. Then they may come from excavations, but the type is that. Stop. Or pavements with an "x" value of thickness and those particular characteristics required by the project. This can be done, but again, only for recent projects.

S.G.: *Sure. And that is why also designers were included in this survey. Let's suppose to be able to have a model by which determine, for example, that there is a portion of the road under construction that has been made with some materials – relating to the nature of the soil - and another part instead realised differently. Might it be of interest? Or does it not care because the important thing is that materials are only similar to what was foreseen in the project? That is, if during construction it could be established that from x km to y km this layer is composed of ...*

R2: In practice, it already provides. In the executive phase of the project it is already so. I know I have to realise that road with materials from quarries from kilometer 1 to kilometer 100, and from kilometer 101 to kilometer 300 with other materials, etc. But what then is intended for "quarries" in reality during construction is not monitored in these terms: i.e. there is a continuous monitoring, there is a continuous control of what happens, but there is not a precisely processing of the "as built" for this type of things.

S.G.: *What if there was a chance to do it (because, for example, there is the site manager that can deals with it)?*

R2: Yes. You can also asks for it, but it is to be excluded that in some construction site there are also the "as built" of the road because it is so much changed. It is easier that there is when switching from an embankment to an embankment with structures, for example: i.e., first I had an embankment, then, for some reason, the embankment has become an embankment with reinforced land. At that point you will find the "as built" of the reinforced soil and then it will means automatically that that type of embankment is different, but because there is a structure. Difficult to find this kind of detail of the built into a simple embankment; and, in the end, I do not even know what it would serve for. So... If the goal is always road maintenance, the problem of maintenance is unfortunately very complex:

the factors that trigger the road degradation process are manifold, but the main one is a bad realisation of the embankment or subsidence of the subsoil or a bad design/execution of those that are the dreinage below the embankment, (not to mention the poor design or implementation of the pavement package, but that is the end because you have to think of the pavement as a long-term work. It is not a rigid element which can break: it is a flexible element that can last more or less time (but always from 10 years and over). Hence, when after 2 years a new road begins to yield at a point, it is not due to the pavement: it is mostly due to other factors. Therefore, it is not easy to go and verify these factors because there may be a failure of the substrate (it can always take place due to the hetero-geology for example, or to the infiltration of water for excessive rains that generate sagging below the pavement: that is the cause which produces the collapse of the whole).
It may be that the drainage is designed badly: perhaps it was necessary to make a deeper cleaning up. They are works that still yield over time; but these failures have to be designed within a range. If not, it is obvious that there is an excessive failure than expected.
Another factor, not least, is the realization of these embankments that must have certain characteristics of lift and therefore must be made and verified during the execution. However, as they occur on roads that are many kilometers long, often no one is able to say the cause between the bad check and bad realization... that is, if the embankment yields, when it yields, you make a coring and discover that the kind of embankment was made with unsuitable materials or has not been well compacted (there is also an element of significant compaction). Now, it is difficult to monitor all of these factors. What you can monitor is the effect, not the cause (that is what should be monitored over time if there are failures at one point). Then at that point you to consult the database and say: "There is a subsidence, let's see how to act". But then the intervention should be done always through the same system: i.e. through diagnostic surveys that are made later to understand where the problem is; but the problem does not arise a priori.

S.G.: *However, with regard to materials, I would already have the information before, rather than do the coring ex post ...*
R2: No, it has to be done in any case, because, even though I have all the information, the fact that there has been failure is an indication that something was wrong and I can not know if I do not a coring. If it is done in a workmanlike manner with the material that I can or cannot know, there should be no failure. Therefore, if there was a failure, there was a problem: what is it related? The surveys are critical to take action on the maintenance of a road. Otherwise, as often happens, there are failures, there is no money to make investigations nor the considerable renovation and then you do a recharge and go.
The failure comes from the substratum, continues to yield; another charging is done until this failure completely breaks the road; then it closes and an extraordinary maintenance work is done on that type of road. Unfortunately, about this, in my opinion, you should go to the ANAS maintenance department: there they will tell you that the problem is essentially an economic problem, in the sense that they fail to make a road maintenance program of they should do because they do not have the money available. When they have money, they intervene where there is an absolute need, giving priority and also assuming the responsibility, because then, when a car flies off a viaduct because the barrier is not up to standard, and you were not able to adjust it in accordance with standards as you do not have the money to do it, then they try all perpetrators. In essence, the culprit does not exist in this case.

S.G.: *Which software do you use?*
R2: The one used for road design is called PROST.

S.G.: *And what type is it? Is it a CAD? Is it a BIM?*
R2.: It is a kind of terrain modelling, of geometrical design of the ground. This software relates to design. Then there is a number of software concerning the structural part, checks and other... If you want, then we can make a list of the software. The road design is a 3D design, because just as the road is composed, it must be three-dimensional necessarily. It starts from a 3D survey of the ground: so the design of the survey is the first thing you need. From 3D survey then you proceed with a 3D design of everything. 3D design is this: for all this using PROST. The outputs instead are in CAD format. So then everything is processed in a CAD system, but two-dimensional, because then the outputs are: floor plans, profiles (often at 1:10 map scale, because the extension of a road is much larger than the difference in height) and cross-sections, i.e. sections made every 10 metres, or 20 metres, depending on the type of detail, the type of design. Hence, in fact, it is a full 3D design: it is not a GIS project because we do not need a GIS to design. It serves for other purposes.

S.G.: *Such as analysis, geolocation...*
R2: Yes, analysis... For example, we have used GIS as required by the administration for a railroad design, but actually it was the administration that needed GIS in order to have an instrument and say: "This is a project. Within this project here is this line. And then a whole series of data was dropped within this system", and that does not simply concern the road geometry or materials, but also a whole series of boundary instruments that could be relate to the constraints (as the whole design naturally interacts with the planning instruments of the countries that are crossed, and the environmental, landscape and archaeological constraints). The road design is the most complex design (in the sense of structured and multidisciplinary) that there may be because addresses and crosses different aspects. Often a road design involves even 20 specialists because there are 20 aspects that you have to deal with in a local area: so, there is an archaeologist, a hydraulic engineer, the hydrological, the geologist, the structural engineer, the road designer, the expert of signage, etc.

S.G.: *So, there is this software that allows 3D modelling with CAD outputs. The GIS actually ...*
R2: The GIS is only used in presentations or because the administration needs to have a tool accessible to all (for example that it can share on its own website, so that everyone can access it). It is a kind of advertising, but is also a very useful tool as, by putting in a whole series of data, anyone can take all those basic data needed for a study, a design or any other use.

S.G.: *Is the data contained within the current Road Cadastre of your interest?*
R2: They do not fit in the design. Maybe for the accidents or something else it might be something useful, but there we are in a slightly different field, i.e. the field of transports, which is the basis for road design: I mean, usually the upgrading of a road comes from transport requirements: e.g. a road congested by traffic, so it is no longer suitable for that level of service. The service levels go down depending on the type of traffic on a certain type of road. When the service level is too low (according to the road congestion index), then a traffic study is conducted to understand how to adapt that type of road in order to have a road with a higher service level. Theoretically, the design should always follow these standards. It is not always the case, as usually the roads are political factors: first they build the Agrigento-Caltanissetta road and then they check if actually the traffic study justifies that type of road. However, usually road design starts from input data, which are precisely related to the traffic and also in part to the accidents. Then the study of road accidents is another thing.
There is also another quite particular field that could bring a big benefit to this kind of cadastre: in particular in my thesis I dale with road accidents study by systems called artificial neural networks. They were based precisely on a

set of input of constituent - and not only geometric - elements of roads: there it is important to have the geometry (that is, the radii of curvature, gradients, and all geometric elements that can be the cause of the accident, but that above all are related to the data on when the accident takes place: what has happened at the time when the accident occurs). It means, for example: rain, wet road, accident-related data that are very important for analysing both accident rate and then the causes. There, the GIS can be useful and could be increased with the data relating to traffic accidents, in which accidents are positioned: i.e. they can be determined in that position because GIS already contains all the geometric elements.

Traffic police reports could be contained into the "accident" element (to understand if it was a rainy day, if the road was wet or not, even through these that I do not know if are sensitive data: on this I have no idea, so I do not know if they are available; however, you might already understand whether the driver was drunk or not, that is, to then have a series of analytical inputs for an even more complex study of accidents. And further data that do not even come to mind: for example, even the barrier (if - at that point where the accident occurred - the barrier was in accordance with standard or not), the state of degradation of the road surface, all the surveys made when the accident occurs and that can then be all useful within a GIS. This is an important thing.

There are university studies that have been already carried on and hence can be imported. My degree thesis, with Eng. Junta as a supervisor, focused on artificial neural networks of road accidents: it started from a series of database and has been applied for example to the Sicilian motorways. Hence data that we have detected already exist and can be reported in a GIS for example.

INTERVIEW N. 3

July 20, 2015 - Interview with three technicians: Filippo Ragusa (R3 F.R.) (Project Manager - Roads Sector Manager), Giuseppe Alagna (R4 G.A.) (Project Manager - Head of Roads Sector), Antonio Miosi (R5 A.M.) (road designer)

S.G.: *The University of Palermo is carrying on a research as a part of a PhD in collaboration with the University College London. The topic is the implementation of a 3D road cadastre. Basically we are trying to gather information of what are needs and requirements of road agencies, designers and companies that carry out significant road construction and maintenance projects. What we would like to understand is how much the road cadastre is currently used in their area, what usefulness the current road cadastre has in your daily work (where it has already been implemented because not all regions have made it). We would also like to understand whether making a database of road infrastructure that is based on a queryable three-dimensional model can be useful to you in the design phase and during construction and maintenance, and what data can be more useful. Unless you do not tell us that you need just two-dimensional. We have prepared some examples that we think could be interesting to document three-dimensionally with respect to roads: hence, the roads in the relationship with the ground especially in the presence of slopes, etc., the layers of the road package composition, barriers, retaining walls, tunnels, viaducts, pipelines that are under the road structure. I will show you an example that relates to a monumental building we worked on: in your opinion, if we have a 3D model that is not only to be looked at, observed, but also queried, can it be a useful tool to give you the information and what in your respective fields?*

R4.: We have the most recent experience that it is precisely that of the 189 road. We are taking care of the preliminary design of the Palermo-Agrigento road in the Agrigento tract. The work has been commissioned and assigned by the Province of Agrigento, but we also have relationships with ANAS, that is the other owner of the infrastructure. They have provided us with documentation of their road cadastre and, as their website shows, the only information they gave us was the three-dimensional axis with the information related only to the placement

of structures. This is the only information that we have been given: a 3D polyline. As we are dealing with the preliminary stage of the project, and therefore a status quo analysis was required by contract, we would have liked to have some more information (at least relating to the platform in its three-dimensional composition, also to do some assessments and analysis on the current road status). So, for example, we would have liked if there was even only the platform including all its compositive elements, and the margins; additional information, for example, on the positioning of the related structures; a first analysis of the road, as we take care of road design: i.e. all related to a check of the current situation and then to a preliminary safety analysis of the road, considering the geometry, visibility issues, unobstructed view of the space as required by the regulation. Such information were already missing. If in addition to this it was possible to have a three-dimensional platform and hence with the possibility of checking roadsides in relation to the axis, (i.e. having precisely the trend of the cross-platform with side obstacles and then containment works, barriers, and so forth), it would be very useful for us, already in the requirement specification in which we found ourselves. Such information are lacking.
Also with regard to the presence of structures, we would have expected something easier and more manageable because, given that the tool that we had been given were shapefiles, i.e. files that are usually managed through a GIS, from this point of view we are not advanced users who use GIS habitually; and then, as usually we use AutoCAD and road design software, we have not been able to use this thing properly. About the other things you mentioned, even with respect to the road body/structure, if it was possible to have them, we would really like. If there had been even the possibility - I do not say, for example, also in detail, because I have seen in the documents that we have received from you a lot of detailed stuff related for example to bumps and other things – but if there had been even the possibility to have the element of embankments or the presence of containment works and correctly identified the major structures, surely more stuff we have, better it is... but I find it hard to think there is a chance to get information for example on the composition of the road surface; the underground seems more complicated... however, if there is availability... as, however, owners, managers and organisations should do this.

S.G.: *The hope would be that all roads that now are to be recorded, are documented since the design stage in such a way as to make life easier for those who will work on them.*
R3: For a road newly built, and hence recently designed, it is more simple. The only thing is that it is more complicated because during the construction phase, for example, the elements within the road body are not recorded. There are not the "as built" of the road, of the road design (not only of the roads already built, but also of those built very recently).
R4: There is no doubt. Because, moreover, information should fix a state of fact.
R3: Exactly, and which is evolving during construction.
R4: As they should correspond to what is built there, which is most complex; but, just at first glance, if I look at my needs as a designer, I like everything, I want the full package: if you can get this, all right.
R3: To have a good geometry of the road, all the structures, the survey of the structures both detectable by an aerophotogrammetric survey and by details of bridges, viaducts, tunnels, including the dimensions, would be already very useful for a good design.
R4: Moreover, within a GIS all this information should be querieable by connecting with other information; hence, if I click on a specific structure, for example, I could open pictures, have a number of things, or a summary table.
R3: For example, a summary table of viaducts.

S.G.: *We can say that the minimum goal could be having a three-dimensional model by clicking on which you can also open a pdf if you need the CAD... although the desirable and most advanced situation is that I can click on the individual element and know width, length, height, composition, and all kinds of information - also historical - on interventions.*
R3: But not only. A database of all the road elements would allow to make already the comparison, that is, "viaduct long "x", with these characteristics", or "how many bridges are on the way", and to have already a kind of database that can be used for many purposes.

S.G.: *For example for metric calculations.*
R4: I think that it serves also to the road manager - regardless of the needs of others - to schedule proper maintenance. If he must properly evaluate what the needs are, I think that it is the best to everyone that he has the most information on the infrastructures, especially on the *de facto* state, also being able to see how the infrastructure is constituted. The need we had was just this. The information that we received *(n.o.e. from ANAS)* was this simple polyline; therefore, as we had to go and check the state of art especially of structures and as it is a draft adaptation of an existing road, it is crucial to know how the infrastructures are geometrically, but also from a structural point of view. Hence, it is imperative to have information. As it always concerns infrastructures dating back to the '70s and '80s (at best), we can not have these things in an electronic format; therefore, you have to go for a relief ... but the owner of the road, in my opinion, has this need.
R3: Even of a photographic survey, for example, of the structures; even if the photographic survey leave things as they are in the sense that at that moment there is a situation that after two or three years could also change; however, it is monitoring: even a certain date is important to already start to prioritise.
R4: Yes, but I think that now we have the tools to have also a three-dimensional expeditious relief of the infrastructures by laser scanners and similar techniques, in addition to photographs.
R3: But, for example, now you can make an orthophoto of all infrastructures, go even from below, then detect the photographs by cheap tools.
R4: It is also important to know the conditions of the road surface and not only what is underneath that is more complex as they predominantly should know which are the possible crossings and concessions relating to the roads built: i.e. if any kind of cables passes, e.g. cables, power lines, gas pipelines and any crossings in addition to the hydraulic crossings. However, if there were important crossings with gas utility networks, electricity, fiber optic or any other thing, in my opinion, it is important that it is documented. Then within this list I did not see any reference with regard to lighting systems (that always the road manager deals with). If I am a road manager, I would like to know at any junctions how they are illuminated: i.e. the lighting systems. Or other things, such as tunnels: for example, there are important facilities. Also for safety purposes: for example, the localisation of the bys, the SOS stations... I think that whatever may be useful to frame these issues in such an instrument would be essential. With regard to the road surface it is more complicated, in my opinion, and even the composition of the road body seems to me a bit more difficult to be obtained; but I think that it is not something to be excluded, in the sense that it could be something that is growing, that is to be developed over time as if the administration makes interventions or projects not so much on the road structure that is complicated... but knowing how the road surface is... maybe yes. If they make specific interventions and have to rebuilt the road surface, it can be included.
R3: It might be useful to 360°, i.e. all maintenance interventions made on the roads may be registered within the GIS with all that they can detect. In this case it can be the road surface, that is, an intervention on the the road surface. They do a core drilling and record that composition and so forth. If they make an intervention on a barrier, they will do the same thing.

R4: According to me, the first things related to Sicily must be by force of things surveyed and recorded from the point of view of the most recent interventions: then, surely the road surfaces, surely the safety barriers. Moreover, to know presumably the latest interventions (not only to locate them, but also to find out if the latest interventions are consistent with the new standards) and the horizontal and vertical signs (if they have been redone or updated, placed, maintained or whatever).

S.G.: *Some of the things that you have mentioned could theoretically be identified two-dimensionally.*
R4: Absolutely yes.

S.G.: *This is the reason why I ask you if having the opportunity to document some of these things in three dimensions can be an added value or what two-dimensional data you will not forfeit.*
R4: According to me, the horizontal and vertical alignment of the road platform is the most indispensable. As a road designer, I need to accurately evaluate and immediately import it inside: even if I had to do a preliminary expeditious study, the tool that a road owner (such as a local authority or an owner of a road) possibly provides a designer should be the easiest to allow him to make evaluations. If I must do a safety analysis (even quickly), I need the horizontal and vertical alignment of the road: hence, the profile, the composition, which is the cross trend of the road, is fundamental to me.

S.G.: *And the data associated with it? I mean, if we would like to associate a database...*
R4: Why not? Sure.
R3: The gradient of the road, the side slopes, everything about the three-dimensional geometry of the current situation is important for any design basis, because when we start with a design - even just an adaptation - we are just doing a detailed survey of the road. If one already exists, it is obvious that all is faster: these are a big waste of time that we have.
R4: Absolutely. Other information that I think should also be present or available through a GIS as a query or as a representation are certainly all the accesses (speaking of secondary rural roads to go down, more or less).
R3: And then perhaps also the geological surveys, that is, over the years a number of reliefs, surveys, coring with campaigns in several years have been carried out on the roads for different reasons: they could represent in a GIS a very important database for the design.
R4: Of course.
R3: Which the managing body provides us somehow. They are data that they have available and that could be part of this tool.
R4: Another thing that I think is important in this information - even if I do not know if they are the purposes prescribed by the regulations, is the number of accidents on any type of road, to the vehicles, but also to people with damages or dead: I think it is important that it is recorded within this tool to do the analysis. As all the analysis we have developed - also to offer a wide range of things - start from an analysis of the accident and then, finding the possible causes of this accident, geometrical issues are addressed, or relating to the paving plan or signage or any else. I think these are the basics. Am I forgetting something?
R5: I can only think... as I believe that you want to match the geometry, even brought to 3D, with a 2D and a database, but what scale are we talking?

S.G.: *We can get to details.*

R4: He is right. He is the designer. With tolerances that are usually used we can have problems with the information that is transferred to us.

R5: Not only. The scale is important because we have maps at a scale of 1:10,000 and we are talking about a reference system. If we go to other scales, we move on to other reference systems. And if we go to the Land Registry and the expropriations, already we have another. And how will you do? You should convert them with the tolerances and deformation of each scale. It is not an easily solvable problem, because I know that the Land Registry has already attempted to convert the cadastral sheets in mapping systems, and not always with success. Therefore, address this.

R4: But is the starting system used the National Cartographic System?

R5: You should decide because, depending on the scale, you have a Gauss Boaga or Cassini Soldner, but are they 3 different ways.

R4: But I think that the purpose, for what I had seen, was always at UTM level.

R5: Indeed. If you speak of a basis for a preliminary project, I think that it is what the designer need in the first instance... because basically when we begin to plan, then we must do all the topographical and structural surveys, as I do not think that the road administration will be able to provide it the designer. But in the first instance, if the institution asks us for making some general projects, today we should incur considerable costs and then maybe throw it (because it should be an idea that the managing body says it likes, but the road costs 10 trillion that it does not have at the moment and it is not something feasible). Instead, if the institution gives us the input to study the feasibility, but at the same time gives us the means to be able to draw, i.e. a database with a 3D-mapping at a scale suitable already for the preliminary project, we would definitely comfortable.

R5: But within the Cadastre would information be accessible by users? Would they only regard the platform or there would also maps or other?

S.G.: *We can say that the main objective is the infrastructure.*

R3: It is an open tool that you can implement in one way and then continue working, implementing, adding data.

R5: Yes. But we imagine for example that ANAS does it....

R4: Other countries (Anglo-Saxons, Frenches...) do not have some problems. The Italian problems are due to the fact that the history of Italian cartography has had a very special labour because once you started with cadastral sheets that had practically a local representation, then it was assumed the geoid and the ellipsoid that instead other nations have adopted shortly after. So we found ourselves in bringing the history to the modern age. That was our problem. Or you should upgrade all of the past, which is not easily accomplished.

R4: But I think that that is the trend, i.e. to standardise all cartographic representations in a single system.

R5: They tried it as, when it was internationally with the UTM, theoretically that was the concept. There are several reference systems on Monte Mario, others in Greenwich.

R4: But the use of UTM allows to have a "conversational ease": for example, now we all use Google Earth and it is easier to have it in UTM and import it to Google rather than do it with another system.

R5: It should certainly be an international system.

R4: The idea should also be implemented also at Community level, at European Union level.

S.G.: *Actually another aspect of the research should also be compatible with those that are the European Directives as INSPIRE or standards such as CEN/TC 278, etc. which by the way you have to see, despite the study of all the Working Groups, if technicians consider them operationally viable or considered useless: that is all theory; but are they rules that serve or not serve... In theory, we should* *transpose slowly the fruit of this work. In theory, when we are going to create this conceptual model, also due to these interviews, we should implement small examples of road models with some case studies such as those I showed you and make a database with fields that are those with data reported/requested by you, and that are alphanumeric data, raster, cartography, etc.*

R5: I think that placing the safety elements is crucial, as well as recording the speed limit of a road, for example, so I can go to calculate travel points and then I can go to assess the levels of service depending on the traffic and then from this the need comes...

R3: I think we must make a big difference between roads newly built and old roads, because in a newly constructed road as the Agrigento-Caltanissetta road, if you implement the limits, the limits will have to be a result of a study.

R4: You have already "a photograph" of the situation of the state of art. If you develop an analysis of the state of fact, you realise for example if can improve the safety situation with minimal interventions by acting for example on signs or other aspects or with the imposition of speed limits or if the situation even worsens.

R5: I identify myself with the manager: ANAS, for example. On the Palermo-Catania stretch, typically I spend for example 3 hours. Now there is a problem related to the viaduct: if I have a similar database, and have the alternative route to avoid this viaduct, I know in real time how much it costs in terms of time and money to the driver to get from Palermo to Catania. If I break this database and I have the speed limits and the traffic data, I can determine the A, B, and C service levels. If I am a manager and instead I am not on the motorway but on the 113 National road, and I have available "x" money, I can focus on the points where the level of service is lower, and then I could already publish an advice for road interventions not over the whole length of the road, but only related to those that already at first emerge as needed.

S.G.: *May 3d be of interest to this type of problem?*

R3: The level of service relates many factors from geometry to road traffic; hence, there is also an aspect related to vehicular traffic.

R5: The service levels derive both from a planimetric study and elevation. If you do not know the altitude, you can not determine it. So necessarily by 3D, although not "pushed." In fact according to me it is a very valid idea, however, to facilitate the designers in a preliminary feasibility study: I would not use a 3D for example for a mapping at a map scale of 1:1000, 1: 2000, 1:500 because as a designer I I would have great concerns to take these databases and make a project on these databases.

R4: Up to the level of the preliminary project, yes.

R3: Unless you exploit these new systems ...

R5: Yes, but practically it is unmanageable. Now starting from scratch and making this would be the best, but I think there would be many difficulties to push between the map scales of 1:10,000 and 1:5,000.

R4: With the resolutions and tolerances ...

R5: Yes, but also because...

R3: If we want to make a 3D survey of the road, however, the only way is make a flight and a representation with a map scale of 1:5000 of all that is there, then to spend a certain amount of money to have a 3D survey of the road or by tools that cost less (like drones that allow to use a little higher map scales).

S.G.: *With regard to safety barriers and signage, for example, MMS are also used: the vehicle passes ...*

R3: Yes, sure. The vehicle passes... there are many tools that can be used; however, then it is up to see what is more usable by an economic point of view...

S.G.: *For new constructions of roads we thought that the scale of detail could be useful to identify specific elements that should be replaced, for example, and then to have the "picture" of what is the life cycle of an item that is part of the road or if there have been some inefficiencies (e.g. the safety barrier a part of which must be replaced) or to know that it - or a part of it - was replaced in the "x" year; also to build three-dimensionally all that is also modular, in some way, or made of many parts (rather than modular), and to be able to highlight which part has been replaced ...*

R3.: It is an important thing because, for example, there are regulations relating to barriers that require certain barriers made in accordance with standards, crash tested and that only certain companies can install. However, with regard to maintenance a strange thing happens: everybody can make point elements instead, as long as they have the same geometric characteristics they had before. Hence, the element that you replace, as a point incident happened there, do not have to be necessarily the same barrier provided by the Fracasso company... It may be a guy who makes barriers, also in his own home, but with those elements that, after you have intervened in several places, at the end you do no longer have the real barrier you designed, but you have a series of patches made within a certain stretch. Hence, to have the database can also be useful in this also to understand...

R4: You have to understand, however, if the road institution is obliged to update this information, that is all these things that possibly should be present in this tool, because if then there is a point intervention and nobody makes peremptory...

R3: But the tool is also useful for the institution, I mean, to know to have planned and intervened in those points is already important to understand how to act...

R4: We are in the real world... to force somebody... A structure is needed, some staff doing all these things and properly trained. To update such an instrument is not immediate.

R5: The designer or the company or the construction manager, as having already a base, is obliged to update it.

R3: In an ideal world it would be great, but probably it should be thought in several stages: a first stage as a first road geometry through the tools whose degree of tolerance and scale they will set, and then, gradually, they will begin to enter a series of data.

R5: The more you add, the more beautiful it is.

R3: The more you add, the better it is, the more usable it is; then it depends... maybe the manager realizes that its program of interventions can be improved by that tool; then he will be the first to update those data to try later to have a more useful programming.

S.G.: *Surely research pushes us always ahead in the world of ideas. Then the realization will be a percentage...*

R3: It will depend on numbers: of money, cost, people...

R4: ANAS is doing the same thing more or less, that is, it did the three dimensional aspect: it did the 3D axes and the positioning of structures (i.e. they tell you the start and end of the structure, or...

R5: But do they correspond?

R4: Enough.

S.G.: *What was that rich road cadastre you were talking about?*

R4: The ANAS road cadastre. If you see - also looking for "ANAS Road cadastre" on Google, there is a page that explains exactly what the content of their road cadastre are (which is what we had been provided with regard to the 189 road: a 3D polyline with the positioning of the structures).

S.G.: *Which country do you mainly deal with?*

R4: Italy.

S.G.: *In other countries where you work, there will be some differences ...*

R4: Yes. I personally have no experience of other countries; however, we did not have experience with other bodies because, for example, I do not even know if at provincial level information exists and a road cadastre has been set up... hence, I would not know what to say. I have no experience of other countries.

R5: This is a problem: all that is theoretically beautiful, but we risk making a product that becomes garbage because, if in five years you do not appoint somebody to update these data, in the sixth year I will take everything and throw it.

S.G.: *Of course. It would be obsolete...*

R5: Because I'm going to get mixed up in trouble...

R3: Beyond those elements that are rigid and remain the same as the geometry - except that I do an adjustment and therefore I have to adapt (but it is an exceptional case already, then if all the other dynamic data are not made in a way... and not are continuously updated, they do not even make sense.

S.G.: *We can say that, if there was a willingness, this tool would allow a technical director to photograph the situation and be able to upgrade the platform in real time in theory.*

R3: But this system has to be managed. If it is a tool managed by ANAS, I make the project, give it to them and the body implements it or gives me permission to implement it, but there must be someone who manages it.

R4: You asked about tools and software that eventually should be used.

S.G.: *Yes. Eng. Ragusa told me about PROST.*

R3: Yes. She asked me what tools we use to design and I said that we use PROST for road design with outputs in CAD…

S.G.: *Because we are indeed asking if you use CAD, if you use BIM, if you use GIS, 3D...*

R3: Not GIS.

R4: GIS, yes. Now we start to use it: QGIS or Map regarding the use of cartographic information or for converting shapefiles to other formats compatible with AutoCAD, that is easier for all. But I think that shapefile can be used in PROST instead.

R5: I have never tried/done the test...

R4: Geometric information yes, graphic information yes.

S.G.: *But PROST, regarding textual parts, contents... or uploading regulations, raster ...*

R5: No.

R4: No. No. Raster yes, but this is not its purpose. It is like an advanced CAD.

S.G.: *Thank you. I ask you about your role in the Company.*

R3: I am involved in road design. I am a project manager.

R4: So do I.

R5: I am a road designer.

S.G.: *Does the Company deal mainly with construction of new roads?*

R3: With infrastructure.

R4: Even railway, harbour...

S.G.: *The CEO told me that you have also worked on a 3D GIS for the railways ...*

R3: Yes, we have. For the Circumetnea *(n.o.e. the Circumetnea railway is a narrow-gauge railway that connects Catania with Riposto, completing the circumnavigation of Etna and through different centers).* However we have been working with an external consultant who was in charge of managing all the data that we have, to be implemented within the 3D GIS.

R4: Here we mainly use PROST...

R3: From PROST you can export a 3D model - I do not know at what level of definition - where you can see the terrain model and the road. We can make a 3D output of the project. It makes the 3D output in AutoCAD.

http://www.sierrasoft.com/it/products/prost.asp

INTERVIEWS TO ROAD MANAGERS

INTERVIEW N. 4

November 2, 2015 - Interview with Respondent 6 (R6), ANAS Road Cadastre in Sicily.

S.G.: *We are conducting a research work with the Faculty of Engineering of the University of Palermo and the University College London. The theme is the road cadastre. We're trying to figure out how to imagine a road cadastre also based on a three-dimensional model and using the GIS functionality. Hence, georeferencing and possibilities of both visualising roads three-dimensionally and also querying this model to acquire information, but that should be useful.*

R6: The world of 3D is a world that we discovered a bit of time ago and we are using it very much; however when you talk about 3D, perhaps you mean something different than...

S.G.: *We have seen the drawings relating to the Catania-Ragusa road project. The Company provided the designs of this track that derived from a 3D polyline and on which we began to build a model as a sample starting from road sections between consecutive sections and we split the whole road package into its components (eg. the wear layer, the binder layer, the base layer, foundations, underpinning, etc.). Hence, the 3d model that you mean...*

R6: Let's start from the beginning: the Road Cadastre was established by ministerial act; therefore, initially ANAS do everything that the decree describes. We were among the first of its kind in Italy to implement this decree because many other roads managers (such as provinces, municipalities) have not equipped themselves or, however, whether equipped, they have started and then left things a little in half. Since the beginning ANAS has a Road Cadastre Operational Unit that has always worked and that for a certain time did everything that the decree provides. We have implemented a GIS system that allows us to manage the graph and update it constantly and we made cards that allow us to periodically update everything that happens on the roads. Here in Sicily we have 4,000 km of roads, and every day something changes; hence, effectively, therefore any number of employees the Road Cadastre Operational Unit has, it will never be enough because every day something happens.

We can barely follow significant developments. It may happen that a roundabout is built in Ragusa and I do not know because maybe it is not a work developed in ANAS, I mean it is not an ANAS contract, but rather it is the object of a protocol that ANAS has signed with the Municipality, the Municipality realized without informing me and it has nothing to do with me, I realize at some point that a roundabout was built and I have to go and update the graph. Then, to implement what the act requires is already difficult. Implementing it with anything else might be interesting but I think we should think about really important structures within institutions. I do not know if other bodies may do it. For us it is already difficult; for a municipality I think it could be something really difficult. But coming back to the 3D issue, we went beyond the ministerial act: we have equipped ourselves with very efficient high-performance instruments including one whose cost was nearly 2 million Euros that allows us to make acquisitions through a series of cameras and laser scanners which allow us to model the territory.

S.G.: *Not every user knows how to manage the data acquired by the laser scanner...*
R6: From this point of view, by talking with my colleagues in provinces and municipalities, I understand that we are definitely a little ahead of them, even though, like them, we are always in trouble because the primary task of ANAS has always been to build roads and then the objective is to build a road and to manage it. However, between the the construction phase and the management phase it has always been preferred to work more on the construction because the construction of a new route is very much more interesting from the point of view of the media. Hence, the Road Cadastre serves more to manage that to build. Now with the new management of ANAS probably orientation is changing.

S.G.: *Then currently does ANAS have an its own road cadastre?*
R6.: Yes. ANAS has its own road cadastre.

S.G.: *Does it refers to all that regards the regional territory? How it is divided?*
R6: Yes. Each compartment has its own regional Road Cadastre Operational Unit, working exclusively within the regional area.

S.G.: *So in reality it is fragmented. Is it by compartment ?*
R6: It is fragmented, but everything is managed by the General Directorate based in Rome, which has jurisdiction throughout the region and is responsible for its coordination. So we say that it is fragmented, but reduced to coordination. This one, for example, is a piece of highway that was detected by laser scanner and allows us to have more than that required by the ministerial act: the opportunity to do the analysis of what is visible from the roadway. So, for example, I can see the wall, measure the size, for example, have the size in this case of this tunnel, measure the curbs, so all that is visible at the plan level. Besides this, always going beyond what is required by ministerial act, ANAS has made contracts with external for the survey of all that is not visible on the road surface, and then we found all underpasses, all manholes, all walls scarp, and sized all the works by filling in cards. These cards were compiled by the survey teams and then they have been loaded into a computer system of ANAS named as SOAWE

S.G.: *Are these only the data of the Road Cadastre or is there something more?*
R6: No, there is much more than the Road Cadastre. There is much more. We went far beyond what the ministerial act provides. Hence, for every infrastructure we detected all that can be detected.

S.G.: *We are studying on a hypothesis improving the current road cadastre. We are interested in learning your needs from the point of view of each operator dealing with building or maintenance or underground utilities, but also of the archaeologists of the Superintendences which must make an assessment of the archaeological potential, etc. So would it be possible to have examples of these* *cards to be able to evaluate how it is currently the Road Cadastre, and how might it be?*

R6: Yes. Also these cards are in a phase of evolution now because from a paper ballot that is scanned and inserted into a computer system (that one, which is called SOAWE) we moved since very little to a computerized card: that of the ART project, which stands for "ANAS Rileva il Territorio" *(n.o.e. ANAS Detects the Territory)*, and recently our operators attended a course because we are practically loading all cards on a tablet, and this system allows us to have real-time updating of our software. The purpose of that is to capture the geometric information, but, once you have acquired - and that there, theoretically, less than collapses, no longer change - mostly the aim is to monitor all variations, then monitor the defects, the evolution of the defect, and for this reason we periodically send our operators throughout the territory to see if there was a a variation of the defects.

S.G.: *And do you take pictures of it? Or videos?*

R6: We take a photo of it and we write the defect not random, but using a manual of defects that we have developed in my office and it works very very well. This one is the Handbook of the defects used for the training of our operators and we basically cataloged all possible defects on the infrastructures. For each defect we associate the photo, a description, the possible evolution of the defect and an assessment on gravity that are variable through votes from 1 to 7 depending on the severity that can reach; so our operators must also give an assessment of the defect, as well as photograph it, and tell us exactly what it is. So, they do not have to invent anything. They go around with these photos and tell me, "I have seen a injury x cm long".

S.G.: *They remind m the UNI standards on degradations and instability for the restoration of buildings.*

R6: Yes. So the purpose here is very noble: it is to identify the defects and especially to train the staff ANAS on identifying defects. And all is always loaded into the same computer system that, once implemented for a number of years, should give us the opportunity to feedback also on the extraordinary maintenance to be activated.

S.G.: *Might these votes serve to establish the facts beyond political priorities for interventions?*

R6: Exactly. The purpose is precisely that.

S.G.: *That is to make a hierarchy.*

R6: The aim is to directly query the system and not to intervene because a politician reported: "Repair for me that particular bridge because I am stronger than the others", but allow the General Directorate to identify digitally - and hence non subjectively, but objectively - the areas in which to intervene before and those in which interventios can be carried on later.

S.G.: *And are these assessments made for road segment?*

R6: These assessments must be made to rule every three months and submitted every 6 months. We now have had difficulties because to send people running around with the paper ballot ... then we have equipped all of a tablet; we have made a remarkable investment. So if people go around with a tablet, they work much faster than with paper ballot; then there is the photo to download in the office and to be associated; in the meantime you have forgotten which photo you took... then however you use the camera, the piece of paper... you always loose something... Now we use the tablet, but we started recently.

S.G.: *But do they also have GPS to understand where they are exactly?*

R6: Once we detected precisely the structures by the differential GPS; then we know exactly where they are. The tablet is equipped with its own "only code" GPS that does not have centimetric accuracy but now I do not need it as I know exactly where the infrastructure is. I just have to know now where the operator is set more or less to take the photograph. Even because, when he takes the photo, he has to communicate it to me. He says: "I am photographing the deck number 5, the edge beam"; so I do not need to know exactly the centimeter where it is.

***S.G.:** When the operators go and give such votes, how many kilometres, how many hundred of metres of a road trunk do they know that they have to check?*
R6: This is another thing that we solved. I define ANAS as an elephant that must move uphill. All that from outside may seem easy for us indeed can be a complication. Initially the project consisted of assigning these tasks to a single team, i.e. the Road Cadastre Office, and periodically making these assessments, this patrol around as evaluations were made in sample regions to sample compartments that run 200-300 km of roads so it is feasible. As we manage 4,000 km of roads, I have overcome this personal battle and I said: "We are divided into maintenance centres and units. A maintenance centre manages an average of 500 km of roads and within each centre there are the units managing on average 100 km of roads". We managed to convince the General Directorate for choking these competencies and then assigning this competence on the survey of significant defects' evolutions and the compilation of cards to each manager - who manages his own 100 km and who is called Head Unit and is always a surveyor or engineer. This have been occuring for a short time; therefore, I think a year from now we will see results.

***S.G.:** So the minimum stretch is 100 km of analysis?*
R6: Yes. A hundred kilometers. And I think it's very much easier because a surveyor, who has to analyze 100 km, within such road lenght will find, at worst 20 important structures, 5-6 at best. It depends on the area. Generally, the most difficult structure to detect is the viaduct, then the manhole and the walls are quite simple.

***S.G.:** How do you detect it? By laser scanning?*
R6: It depends on the need. We have launched a survey campaign of all the major structures by laser scanning. Currently we have surveyed 30% of the structures. We manage about 1,500 viaducts.

***S.G.:** And how long have you use it?*
R6: We use the laser scanner from 2011. However, the laser scanner actually serves for the geometry of structures. There is also another experimental project. There is a colleague in Rome which is particularly skilled. He has invented a software for the analysis of bridges. By doing more laser scanning surveys of the same structure, repeated over years, this software is able to identify the geometric anomalies and colour anomalies. Then, when it detects a geometric anomaly, there is a series of defects associated: the abnormality of colour can be for example a water stain, or a detachment of the concrete, because if I compare a wet part to 6 months ago, the laser scanner is able to identify it, as it has an acquisition system based on reflectance. I think it is very complicated. There is a very full description. In fact it works like this: you have to unpack the structure in thousands of parts. For example, this is a beam: when doing the survey, I must unpack this part of the structure that is already a small part of it and I have to unpack it into 7 parts. Then, when I will have unpacked all the structure in these parts, the software will be able to tell me that the top of the lower surface on the right side, if compared to six months ago, has a defect of colour or has a defect of geometry. It draws it and should be able to help me to make the assessments.

S.G.: *And how do you unpack it?*

R6: The unpacking is done at the first survey. On the first survey I have to manage some functions within the software. I have to separate. I am not thrilled about this; however, it is a way: it is a good experiment. The software works in this way: once the structure has been unpacked, it puts on level plan the whole part and tells me what is the change that has been found in terms of percentage compared to before. It may well be that in the end I will be proven wrong. It is able to identify the anomaly and tells me what is the variation compared to before.

S.G.: *From the research point of view it is very interesting. What from a practical point of view?*

R6: In fact, it is what I suggested, saying to involve a university and helpful people under contract in the form of research grants in order to check a series of structures that have actually important defects and see how it works. But asking the single compartment to enable that kind of activity, in my opinion, is expensive because I am at 30% in the first survey of our structures; therefore it is really impossible to think that we can do at least two surveys per year for all the structures that we manage.

S.G.: *Okay. Call us. We also do these things.*

R6: In fact, we sometimes run very quickly, much more of our ability.

S.G.: *I am pleasantly surprised because I did not expect all this activity.*

R6: From this point of view, yes.

S.G.: *Probably all of these activities that ANAS carries out should also be notified because they are very appreciable.*

R6: This we do not do, it is true. We do not communicate much with the outside and actually this might be of interest to someone maybe. Certain projects, such as this, start very well and then, slowly, go a little to wane because they cannot find the support in the compartments. Because unfortunately in a compartment you have to run for a thousand things. You see it on the news, right? When the Himera bridge collapsed, I came back home after five days. I came from home because I was called and said that there was a problem and I had to go straight to the Himera bridge as we had to do the analysis to figure out what was going on. I told my wife: "I'm coming back"... and then I came back home on the fifth day. And then in order to handle some things you need some people who can do just that and nothing else; even for long periods. And, in my opinion, only a university researcher or a student can devote so much time to the project. We can not do it. Assuming that I would find 3-4 days to stay in the office, which is unthinkable.

S.G.: *But under your supervision surely there may be things you can do. The agreements also serve to this.*

R6: This is something that we are starting to do. Currently we have agreements: we have one with the Kore University of Enna and we had one with the University of Venice, very interesting. Some are able to take it forward.

S.G.: *So we can do even a quite interesting one with the Universities of Palermo and London.*

R6: We tried some time ago. I came to my mind ... there was a guy in Palermo, who was collaborating with the University of London and he contacted us for a search on the pavements ... he has tried in every way to have contact with us to make an agreement, but at that time he failed to achieve it.

S.G.: *It is interesting because, for example, before I deal with roads I have dealt with archaeology and similarly we I was thinking about laser scanning, that is, if I get the point cloud of a trabeated system, for example, the software is able to identify that that piece is the stem of the column, that other piece is the capital, that other one is the entablature, etc.? They are different things, but somehow related.*
R6: The software already exists. A colleague of mine, a computer scientist, implemented it, with funding through a company. It is still experimental, but they say it will soon begin to work. Definitely it works. The problem, then, is to be able to use it. This, however, is an example of our GIS. Through an agreement with the De Agostini publisher we have acquired the De Agostini digital maps. We then made our road graph that is continually updated and recalibrated in accordance with the specifications of the ministerial act. Then we have an agreement with the Military Geographical Institute: the agreement has been signed just in Sicily because other colleagues were not able to have it and by the Military Geographical Institute we were able to load all the IGM maps *(n.o.e.: IGM means Military Geographical Institute)*. This is an activity that we need more than anything else to understand the evolution of roads because there are roads that we "young people" do not know: for example, this is the old route of a road that now passes from here and then through this system we are able to identify what are the wrecks of our roads and what are our old competencies/responsibilities that maybe we have never given to others. We have gained orthophotos of the entire road network through ad hoc flights.

S.G.: *It is only for your exclusive use or is it accessible through the Internet?*
R6: No. This is just for our use. Doing various levels of zooms I can see and analyse the road in more detail and then, having done so, we have the different layers, such as our bridges on state roads, and for each of these structures I have a series of information which are those we need to do a quick analysis and I have a part of the information contained in the SOAWE software. So as for the bridges we have the layers for each type of structure: therefore, walls, manholes and everything that can be useful.

S.G.: *But are there any information provided by the legal Road Cadastre, which really you do not need?*
R6: Some things, indeed, may be not very useful: for example, the data on the pavements, right? Because data on pavements vary too quickly. Or barriers: the road barriers, once detected, should be detected then probably every day because every day in Sicily I think dozens of accidents happen. The barriers are damaged, destroyed, replaced, and then there are some information about the barriers that it is almost impossible to keep up to date because the decree provides a range of information relating to the construction…

S.G.: *Is it due to the updating difficulty primarily?*
R6: More than anything else it is due to the difficulty of updating as the data, once acquired, in some way is also used after a long time; hence, in my opinion, today it is not possible to say: "It never will be useful to me".

S.G.: *Because it is a very complex dataset. Then you even have added other things than that.*
R6: Yes. We have added so much compared to what was expected. Sometimes, while we are making surveys, at that time we wonder why we must acquire certain data and if we will ever need; however, I have to say that, if the data is there, sooner or later you need it; and then no one can lean so much and say: "It never will be useful to me."

S.G.: *Scrolling the fields provided by the Act, we find that are required: quality, sources, geodetic, projections, grids, geoid, magnetic, etc.*

R6: This is the geomatics that is a fundamental part and therefore certainly serves as envisaged by European Directives and therefore it must be absolutely adopted. Geomatics is the part that, in my opinion, is the bases, the fundamental one to do all the rest. Therefore, using the projections of the geoid, using the correct map projections - that in this case are latitude and longitude... That is crucial.

S.G.: *Among the themes we also reads about layers, geometries, edges...*
R6: Yes, these are all those parts relating to geometrisation that absolutely must be taken.

S.G.: *And that you have in your system.*
R6: Yes.

S.G.: *Therefore you have all that is required by law and in addition you have added...*
R6: Our additions are additional information for the survey of structures: this is something that the Act has not provided, and instead we have included because they are data that can be used for maintenance more than anything else, but regarding the creation of the graph, the geometry and the whole geomatics part, that has been adhered at 100%.

S.G.: *But does the National Archive of the Roads really exist?*
R6: The National Archive of Roads ?

S.G.: *The data of the single Road Cadastres should feed into a National Archive of Roads at the Ministry...*
R6: ...the Ministry of Infrastructure.

S.G.: *But have they already done it? Because not every Italian regions and every operator have developed their own road cadastre…*
R6: I really do not know, because I have always been at the Road Cadastre Unit: I was hired in Road Cadastre Unit by ANAS in 2005, so I have only ever dealt with that. We have contacts with the Ministry through our Head Office and then I do not know exactly which information exchanges the Ministry and the General Directorate have. I learned that since a few months there have been a greater level of attention by the Ministry toward us and that it will make some sort of monitoring on the activities of the ANAS Road Cadastre. I did not understand if accordingly to an agreement or a directive. Just a couple of weeks ago I received an email about it that says: it says that the road cadastre will be increasingly important and activities will be monitored by the Ministry also with direct inspections. It seems there is a willingness by the Ministry to increase the monitoring activities. I do not know if it refers only to us, or if it refers to all the bodies managing roads. Honestly, if this Archive exists and if is continually updated or not, is a question I can not answer.

S.G.: *While reading in the act that the information of each Road Catastre will converge into the National Roads Archive, I wondered: "How is it done? Does it exist?" Because the same road cadastre is not still implemented by everybody...*
R6: I think that it exists. Maybe, it is not fully operational, but it exists, because, for example, when I need to declassify a stretch of road or classify it, I can not do independently, but I have to write to the Ministry and to wait for a response from the Ministry. And, hence, the fact that there is this constraint to give a road a name (i.e. passing by the Ministry) makes me think that in fact they have an orderly archive and not allow any manager to have his own

way, i.e. to give a name than another. For example, to classify the "Catania-Siracusa" road (the last highway that was built), we had to wait for quite a while: the Ministry did not respond and that is a highway without number. I do not know if you have noticed: that is a highway which is called "A Catania-Syracuse" and not like the others that have a number and are the "A19", the "A20", the "A18".

S.G.: *So in the Road Cadastre it is registered "by name and surname"...*
R6: In the Road Cadastre it is registered as "A Catania-Siracusa" because the Ministry has not yet assigned a number to the road.

S.G.: *So it is established by the Ministry.*
R6: Yes. We do only a proposal. So I think that this archive exists: because otherwise they would have told us to name it as we wanted.

S.G.: *Well. After this first interesting overview, I would like to answer these questions that I have already sent you. So, about the fact that these Road Cadastres have not yet been developed by those who should have already done it, in your opinion what are the difficulties that managers are facing throughout Italy to implement it?*
R6: I guess for other bodies managing roads the difficulties may be purely an economic issue because in ANAS the implementation of the Road Cadastre was a considerable financial commitment. The mere detection of the graph in Sicily has costed nearly 2 million Euros. It is not a low cost activity; so I think for provinces and municipalities it has been a purely economic problem.

S.G.: *What is the most useful of the Road Cadastre in your opinion? Or the most useful utility.*
R6: The most useful to me is the ability to plan and manage our extraordinary maintenance to be performed on road infrastructures; and then, if the cadastre is implemented continuously and continuously updated, it gives the possibility to program all the interventions because you know the evolution of defects in any part including road surfaces.

S.G.: *Speaking of evolution, I thought, the time factor is also important. In fact, you are also analysing the variations. I In Road Cadastre this thing seems to me that is not addressed by the Decree. I would not like to remember bad.*
R6: I do not think so.

S.G.: *Indeed. For example, I do not think that are the Road Cadastre includes dates of maintenance or construction periods.*
R6: No. In ANAS we have our teams, our maintenance service units, I mean technicians who deal with the maintenance of stretches of about 100 km, quarterly and half-yearly - depending on the type of works - fill out the cards and require technical managers to draw up the expert reports to intervene. And then the ANAS organization is this: the technician goes on a quarterly basis to do a monitoring of the structure; if he detects something special, he writes an expert report and then the appraisal is financed or not depending on the importance of the defect or intervention to achieve: this goes beyond the Road Cadastre because the Road Cadastre intervenes only in case of modification, that is, if the maintenance centre indeed intervenes on the infrastructure, then it notifies the Road Cadastre Unit that records the change, but at this stage we do not say that the nucleus has to intervene. It works in reverse.

S.G.: *We were wondering if, on the basis of your experience, you have verified that the legal Road Cadastre met some needs and I think so because all the implementation that you did in addition. So having the opportunity to compare the minimum data provided by the decree with what ANAS needed to implement in addition, I think that the criticality of the system comes out. For us it would be very interesting if ANAS give us the opportunity to make this comparison. So then you will tell us how to make a request to have this list of data or a card as a sample to be able to compare and insert in the research work.*
R6: Sure.

S.G.: *Regarding the documentation of road infrastructure we wondered what importance you give to CAD and GIS systems.*
R6: We use GIS daily.

S.G.: *We found instead that the design studies meet some difficulties with this tool because they usually use CAD and hence, when they receive the shapefile from the road institutions, sometimes do not know how to handle them.*
R6: This depends on how they are sent. I have regular contact with several design firms. For example, I converted for them some information about a certain road as we had GIS data that they did not read in their CAD. The transformation from CAD to GIS is very simple, but we must do it with a certain criterion, because otherwise they can never overlay because the big problem is the geo-referencing. We, for example, in the case of the SS189 road we sent many data extracted from our Cadastre and that were very useful to them.

S.G.: *And have you sent them the data as a CAD or even text?*
C.S.: We sent tables because the great advantage of GIS is to be able to manage geographic information in the form of tables and graphics at the same time; and therefore from there then we unpacked all in tables (which they read in Excel) and graphs (which they read in AutoCAD).

S.G.: *So, if I were a road designer approaching to deal with a road project, I would call you, searching for data. What do you send me?*
R6: We send GIS data unpacked in tables and graphs.

S.G.: *And these tables and graphs are on...*
R6: It starts from the simple 3D geometry of the road axes.

S.G.: *Is it a 3D polyline?*
R6: It is a 3D polyline, which initially designers sometimes do not appreciate, but then they realize its usefulness. And then we provide a whole series of tabular information relating for example to the cross slope, the longitudinal slope, to the elevation of individual points on the road axis, to information relating to the geometry of curves and straights, in addition to a whole range of information (which, however, depend on the date of acquisition) relating for example to the state of pavement wear, the geographical position of the elements (for example manholes, beginning and end of major structures, the walls...).

S.G.: *All of this is in 2D GIS. Do you have them in Excel or in 2D GIS? I speak of manholes, etc ...*
R6: We have everything in GIS and then everything in .dbf (i.e. Microsoft Access). Then from there we manage the Excel.

S.G.: *And if they were in 3D?*
R6: Well ... now you have to clearly define what 3D is for you.

S.G.: *A three-dimensional model, first: therefore I can see a road as a 3D model, which is geo-referenced. So, I, if I have the so-called multiple z, therefore I see all projected onto a surface; however, things have their depth. But even if I had a multilevel intersection etc., if I look at them from above, projected onto the plan, I will have apparently coincident points, but they actually belong to different objects at different elevations. So actually I can do the operations I could do by a 2D GIS while working on a three-dimensional model.*
R6: Of course it is interesting to think about the management of a 3D GIS. Basically, it would allow us to make much more detailed analysis of each structure and directly from the GIS.

S.G.: *As you know the GIS unlike some road designers I interviewed and who were not very experienced, I can speak about the new functions that the three-dimensional GIS now allows. PostGIS has new 3D functions and now I would like to study them in order to understand what might be useful. Indeed, maybe later I will ask you if there are things of interest among those that I will find. But if at the moment, despite not having examined the subject, you were to come to mind, what would you expect that a 3D GIS could be useful for your work?*
R6: It depends on what you want to do, because, for example, the 3D GIS can be useful if you have to design a variant as you can immediately see what is the morphology of the area, the geometry of your existing infrastructure, and you can see how you that geometry may be varied. That definitely. With regard to the maintenance, for example the management of the pavement may be interesting because in a portion, in a stretch of road, I want to know which road package I have, and then instead of query and read the card... Here there is a card of a road package. Even these cards will be computerised soon.

S.G.: *Ah, because they are printed at the moment.*
R6: Yes, it took us a bit. In this card we can see that this is the information that I acquire every time and... they are changed... the technician gives me any thickness, length and everything I need. Currently the only way I have to know what is the package along a road segment from kilometre to kilometre is to go and look, though I do not have the ability to click and see actually what is, as I did for the bridge or for other structures.

S.G.: *So this would avoid a step because if I zoom in on the model, I take a section and within the 3D I have this information that I see drawn on this card because I have already modelled them ...*
R6: Sure. This can be very interesting. As it can be interesting for example making GIS more accessible to all because the big problem now is that we are a few and the one who manages GIS is the surveyor in charge of maintenance and who does not have in fact ... I mean, ArcGIS is overly complicated. Then to give everyone the chance to use a GIS with fewer functions, lightened, just only to be able to query the system.

S.G.: *By the way we would like to make the system accessible via the Internet, using a WebGL platform. Some technicians told me that considering the size or composition of the layers has no effetc because they say that they often do refills. Moreover, as they use for example retrieved lands they meet, then maybe the road composition at the execution stage is not exactly the same of the project provisions. I thought even more that to be able to know what material they used can be useful to them.*
R6: They should not say this because I consider the explanations of the accounting elaborate and I must have this road section that the accounting elaborate reports.

S.G.: *So actually you think it is useful.*

R6: I think it is useful. The only problem is to make easy the updating because they have no right to say that they use terrain materials that they find there because..., when you pay, pay that and then you must have that. Of course, there may be variations from the project, because maybe they found a rock and then they could not do…

S.G.: *But a fortiori you record it.*

R6: Yes. You record it and the only problem regards the refills because, if I have a collapse tonight, I have to make a refill at 5 am and I do not have time to call the surveyor or someone with the tablet to do the survey. So the update system is the major operational problem.

S.G.: *But could the updating be done by the company that goes for the operational service?*

R6: Currently it works as follows: the company must fill out the form. Often the company did not give us the form, then we tried to force the company telling them that if they did not give us the compiled form, they would not have been paid. Small companies have agreed to complete the form; instead, whereas other companies that I define a little more "educated" said that the Code of Public Works does not allow us to do this, but that they would have done the work and we would have to be payed. We should deliver a service order, they would have filled the card, as a result of the service order, and if they had decided not to fill the card for any reason, they would have made a reserve and were expected to be paid more. And so we have now these two types of situations: the small company or the willing company that accepts, and the litigious company that does not fill out the form because actually it is right.

S.G.: *It would not be an obligation.*

R6: And therefore the big problem is the update. This is a cadastral card. This is a company that sends us the card that we require on paper because it has to be signed. Photos are attached. Here they have made just the wear layer therefore the card shows the measure of 3 cm; here there are the information on the progressive kilometres (from ... to ...). As here we had interventions on intermittent traits they have compiled more cards because every card refers to a stretch. Even here they have made only a refill 3 cm deep. If I can always have this computerised information - and therefore paperless - to be captured in the system, but directly computerised and easy to make, then I might have a lot more data. In this way, here, in my opinion, many things escape.

S.G.: *Let me show you what we are doing. The model comes from a roadway provided by a Company, putting sections straddling the road: then so we took sections made at a constant distance of metres from each other and starting from the projection were mounted on the track as the basis of modelling. Here we have a number of layers corresponding to 3d solids so I can turn the wear layer off or the bump or turn them on etc. What it is our idea? I have this on my GIS, I click on one part and I get the information I need, and all is georeferenced. So now our challenge is that with all the difficulties that we have in understanding what the PostGIS software records, because at the moment we are doing tests. Does it accept meshes? No. And 3d solids? Perhaps, but we must see how it writes them. Or shall we build each block as 3D faces? So we are studying at the moment the aspect of modelling aimed at recording data. Then, as a technician, do you think that such a tool, which could link drawings, cards, raster…*

R6: Yes. I think it can be very useful both for road surface and for a whole series of minor works, the walls... Knowing the information and being able to directly interrogate in 3D can be very useful. I do not know if it is achievable for all road elements because to handle a 3D that is so large and especially to update it... You have to find a system that allows you to update it in a very simple way, i.e. that can be updated directly, by extracting data directly from a table that is always digitally compiled by the technician.

S.G.: *I used sections to build it, i.e. two-dimensional drawings straddling the track and then modelled: it was not an extrusion, but another command; however, they have been linked to be able to have the 3d solid of each part. And then here we would have all that is above, from the barriers to the signs, etc. Moreover, we have a question. Now GIS has another function related to the line of sight. So also this: to have the 3D to be able to control precisely the visibility, road safety, etc...*

R6: Yes. This is very useful also because now from this point of view I think there are many, many possibilities. We have made some recent experiments with a company. They collaborate a lot with the Universities of Ferrara, of Venice, they have spin off.... Here it is: an experiment for detecting by kinematic [...] laser scanning of urban corridors. Basically we mounted a laser scanner on a machine with a […] and tested the ability to detect some elements directly on kinematic, and it is working very well. Hence, for example, you can extrapolate the platform in 3D very quickly with a modelling software. It can be an excellent starting point below which to add all the layers that you need as you do not start from a centreline polyline or a road section designed as that is a project, but you have to start from the existing situation.

S.G.: *Sure. In fact there is also this issue. We were struggling to address two areas: already existing and new construction.*

R6: Because the new construction will never be like the project. So, in my opinion, that is the starting point. By it we are doing low cost experiments and they are working very well, but ANAS has adopted recently a tool called Cartesio. Basically this has two profilometres, GPS, inertial platform and then a very very interesting system: it captures images, has an option inside, a software, that automatically recognizes a number of road elements. And therefore automatically it recognizes the margin lines, the roadway, a series of road signs; it automatically recognizes the barriers, and then will be able to make a 3D restitution of a whole series of elements after the relief phase. This has been an investment, if I am not wrong, of about 800,000 Euros. The photo shows the vehicle equipped with all those systems, here the two lasers... the two 2d profilometres and then below there are the bars that make the relief of the rutting of road surface, the profilometre, a series of cameras. This is the vehicle. As we are the first Italian contracting and the major road manager at the national level, we must have the best means. We try to have the high efficiency of everything because we can no longer send the little man on the roads with GPS to do surveys. This is one of the recent projects. It has been placed on the road in late August. So it is not a product that has been used much yet.

S.G.: *So what shall we include within 3D GIS ? What cannot miss?*

R6: I see it very well for the management of the road surface.

S.G.: *And in detail?*

R6: In detail, the description of the layers of the road package, but, before implementing the 3D GIS, I would study systems for updating data in a very productive way as if, in order to implement a 3D GIS, I need 5-6 people working there, I risk never having the information or having it so late that in the meantime another change occurred. This is my big problem. I am sitting here today: somewhere someone is modifying roads and right now I do not have any information about it. So, who is changing the road should also capture the change and send it to me - and therefore anyone (architect, surveyor, operator, whoever...) should be able to do it. Otherwise I risk knowing it in six months, and when I go for the survey someone will tell me that they have already changed it twice and then...

S.G.: *A system like that of the tablet that you are trying to do.*
R6: Yes. Something like that.

S.G.: *It is succeeding?*
R6: It is succeeding because everyone has the tablet, the software inside is very simple and we have also given the menders. Because first it was thought that only the surveyor should handle it, whereas, no, all have to use it, even the menders, because the detection method has to be so simple that anyone should be able to use it, after a training.

S.G.: *With regard to the existing roads, I believe that, in addition to what is already visible, you can capture data only by maintenance, because or you do coring or you can not know. For example, if a road design firm was obliged to deliver you a 3D model in accordance with certain criteria, may it already be a base to work upon? Because if I must have a number of operators who must draw roads from scratch... if we looked to the future, we should have already delivered a model as well as now we technicians will use BIM for building in accordance with European standards, i.e. just the 3D model with the data in order to present projects. To be compelled in any way to deliver something to an authority means to take away a great deal about a job that would most likely be onerous.*
R6: This for road design.

S.G.: *Yes, for road design. For the existing…*
R6: I do not would link it to the design very much, but to the as-built by those who made the project because I need the project, but it is shown that it changes daily, because there are problems, expert reports/assessments are made, variants are made, and therefore from the concept to the realization too many changes are involved. The implementer must give me an as-built developed in 3D; but, beware, the implementer is no longer who has an office full of engineers and surveyors: sometimes he has an important technical staff, sometimes not. There a big problem arises.

S.G.: *I was told by the road designers of a design firm that they typically do as-built of structures, but not of normal road sections.*
R6: Yes, they do as built of structures.

S.G.: *According to you, would the as built also of the road trunk make sense?*
R6: The as-built of the road trunk is easier to achieve. It is not done because it is believed that ANAS does it or the Municipality does it, because it involves detecting the elevation of the road surface or of the section, but it is much simpler than the structure.

S.G.: *And, if there are any changes, how have the variations on a project of a road trunk been represented up to now?*
R6: It depends on the phase of the contract. For example, let's take the simplest case: ANAS makes a detailed design and contracts it. The entrepreneur, during the construction, realizes that there is a new fact (for example an excavation in rock was expected and instead there is another material and then the foundations of the manhole must be modified as they can not be more direct, but with poles. Then ANAS does a service order to the company saying that redesigns the structure and that the variant, once accepted by the Construction Manager, is realized. If I work in

the project from the beginning and I do not follow all these stages, I risk losing some parts because maybe in order to realize the different foundation, they lengthen or shorten the structure: that is something I must know.

***S.G.:** A little while ago you mentioned the European Directives. A chapter of this research should cover the standard: from CEN/TC 278 to the INSPIRE Directive, etc. I hear from most, however, that between saying and doing ... in short, these standards exist, are the result of this research of these working groups, but maybe at the end they are a bit disconnected...*
R6: In my opinion, they serve. They serve, however, to give indications on a general level, in the sense that for example the fact that they managed very well the part relating to geomatics was very useful. Now for example if we talk about a cartographic representation, now using a UTM representation and there are more difficulties related to the fact that someone works in Gauss-Boaga, someone in UTM, someone locally. And so it was very useful to me the fact that we have given directives of a general level.

***S.G.:** Why?*
R6: Because we, as a body, have set internal directives that actually exceeded the European one and I have never needed to go and see if what the General Directorate suggested me to do corresponds to the European Directive or not. Probably they did at the General Directorate at the beginning, when they generated the Road Cadastre, but then no one has never talked about it. For this reason I say that, with regard to the general aspects, it is fine. Then, in detail, everyone has their own needs.

***S.G.:** So you have to sew it on as the tailor does ...*
R6: Yes. You never go to see if more or less what you do or not is in accordance with the Directive x or the Directive y.

***S.G.:** So is your Road Cadastre that we saw a while ago?*
R6: Yes.

***S.G.:** And that is made through Arcmap?*
R6: Through Arcmap. Yes. Through ArcGIS. I have recovered a very important text. We have the Research Centre in Cesano, which is a centre that works very well and where they wrote the Guidelines of the Road Cadastre. This is our Gospel.

***S.G.:** That, compared with the Ministerial Act, is done by you.*
R6: This is done by us always with reference to the Ministerial Act, but there are all the standards that we have used for generating the Road Cadastre.

***S.G.:** And what do you mean, in this case, as standards?*
R6: All levels for the generation of the graph or the management of structures.

***S.G.:** How are the level 0, level 1 and level 2 managed here?*
R6: We do not manage it directly, in the sense that it is managed for the construction and then it is not touched anymore. I do not manage...

S.G.: *It is done once...*

R6: Yes.

S.G.: *And how shall the different levels be consulted? Are they represented each time in a different way?*

R6: Here is described very well. This is all that we have done, such further developments, the graph at level 2... It should be consulted because it contains everything that has been done.

S.G.: *When was this publication published?*

R6: This is quite old.

S.G.: *When was this publication published?*

R6: This is quite old.

S.G.: *But have there been progresses apart the cards?*

R6: Yes. Except the cards. This is even a summary report and there is also a CD that contains the printable version with examples: 178 pages, the presentation of the guidelines and software that I does not know what it is, the guide to the examples... The presentation is interesting.

S.G.: *But might it make sense to do two types of road cadastre? One for the existing and one for new construction? Or one large container where, however, there are two strands because however I think different aspects are addressed.*

R6: I think that the current road cadastre is working very well. If you eliminate the big problem associated with updating (mostly at the speed of updates), hence the more slender you make it better it is, and works very well especially with regard to the extraordinary maintenance phase. Regarding the design, I consider it a little less interesting because the designer needs always new data; so, for example, a road designer wanted our data on the SS 189 road: I think he has used it in the preliminary phase of the project, but then he needed to make an aero-photogrammetric flight, to use a topographer in the field, and then at the design stage it becomes a useful element but only for a small phase of the project. With regard to maintenance instead, it is very much more useful because it allows you to manage the entire process of planning, financing and management of works.

S.G.: *So in the end for new projects is always the as-built that matters.*

R6: Yes. Always the as-built.

S.G.: *And by the way what might be of interest to a designer? The existing road that is already built. So always things already mainly made.*

R6: Yes. Because then, when you built a new road segment, the as-built is useful as a zero relief where then put above everything will be the defect-change of the structure.

S.G.: *Have you also added orthophotos in your road cadastre?*

R6: Yes. We have added orthophotos. We have also created an application called GEOANAS. GEOANAS is an application for which even we were rewarded by the owners of Google Map (I do not know under what event).

GEOANAS is a GIS that probably in a few years will be accessible via the Internet. Currently not, because in Rome they said that there are problems related to the speed connection. GEOANAS is what you have seen in ArcGIS, but while there I have data only regarding my region, here I have the data of the cadastres of all the regions, there are all themes and I can query any element, for example in this case I can see all bridges, tunnels, overpasses, and analyse and verify everything. You spoke of orthophotos. Here we have the images in "real view", Google Map, Google satellite images and the relief images and above all - something that is very useful for us users - from here in my GIS system I have the ability to open Street View and then see at the date of the relief which is the... Beware: this is Street View. We also have our video capture system. Once a year about, we do a tour of the streets and we have a video capture and a mapping of the entire roadway. So this is the evolution of what you see in ArcGIS now, but that is currently accessible only from us. So it is interesting in part because it is not accessible to external users.

S.G.: *But do you participate in conferences with these applications?*
R6: Yes, but few of us. The conferences are reserved only to a few experts of the General Directorate. More than anything else people who work in Cesano participate. There there are informatics, managers of that system, those who know much more than us. For example, I found GEOANAS already created. I have not participated in its realisation, nor someone asked me what I would include within it. We are the executors of the Road Cadastre. The thinkers are all in Rome. Now they are realising that you have to consult workers in the area because many times you invent things that are beautiful from the theoretical point of view, but then almost impossible to achieve because, for example, to think of unpacking in millions of parts a viaduct like what you see there (a viaduct with 250 spans, decks... each deck has 6 beams…), to think of unpacking all that work in millions of parts to be able to do the analysis indeed I think it is almost impossible (or, however, if you realise, it actually takes so much time that when you have done you no longer need. There are applications developed from the base: the request to switch from paper forms to computer systems came from us who made a specific request to the General Management. Since the request of a year ago, they called several times to ask us for opinions and suggestions, also as a result of recent events.

S.G.: *Would it be helpful to have a cadastre for each categoriy of road?*
R6: No, in the road cadastre we differentiate roads in relation to regulations and therefore every road is treated differently.

S.G.: *To record the date of construction of the barriers or the date of a maintenance intervention... do you think that they are not very useful because they are so many?*
R6: They are too many.

S.G.: *Theoretically, it would be helpful... even to calculate costs in real time...*
R6: Any data can be useful. The problem is to do it because if I have to detect the date of construction of a barrier when the barrier is still at the laboratory under construction, it is one thing; if I have to do it on the road, it becomes much more complex because a highway barrier, for example, which is almost 2.5 m high, has the construction date written on the back and then detecting that element once the barrier is installed is not a simple thing. So, who you will send back? There is a high-performance system that allows you to do so. If you send people, you will have

safety management costs that are impressive. So they are data that we are not detecting. Each card is composed of several sections.

INTERVIEWS TO UNDERGROUND UTILITIES MANAGERS

INTERVIEW N. 5

As part of a survey of utilities that a 3D GIS data model relating to roads can offer to companies engaged in construction and maintenance of underground utilities, semi-structureed interviews to some A.M.A.P. technicians were conducted. A.M.A.P. (Municipal Company Aqueduct of Palermo) was founded in 1956. In 1993 it was entrusted by the Municipality of Palermo with the maintenance of the drainage system; in 1996 it begins the management in own of the sewage treatment plant; in 1999 it is turned into a Special Company and then transformed into a S.p.A. (Joint Stock Company) in 2001.

July 29, 2015 - Interview with Respondent 7 (Sewer Service both of Black and Rain Water and of Lifting Sewage) and with Respondent 8 (Management and Maintenance of Drains). A report of the interview follows here.

The AMAP is responsible for:

1. integrated water services;
2. disposal service of rainwater including cleaning of drains.

As well as Telecom Italy (the main Italian telecommunication company), Enel (the largest multinational company that produce and distribute electricity and gas in Italy), AMG Energia (company dealing with the activity of natural gas distribution for domestic and industrial uses in the municipality of Palermo and that manages the public lighting systems of the city of Palermo, undertaking the design, installation and management of technologically advanced equipment, doing both routine and scheduled and preventive maintenance), they must interface with the manager of the roads that in turn must interface with the owner.

What are the main issues?

1. Currently, an excavation is not used to check where to put the underground utilities, but where is the softer ground where to dig, and hence to accelerate the timing of the intervention at lower cost.
2. There is a not collaboration among bodies!!! For this reason, AMAP had to buy the Cable Detection.
3. A new road is not the result of the work of a single designer. Therefore, the road owner should oblige the various operators to provide the details related to their own work.
4. An appropriate differentiation between existing road and new road constructions, but it is obvious that to document the subsurface in the case of existing roads is impossible. Data integration can obviously take place thanks to interventions from time to time carried out (as the SITAR - Archaeological Territorial Information System of Rome does in order to detect the archaeological potential of the areas).

There are some companies that build viable underground passages that contain underground utilities IDROX is one of them and is headquartered in San Cataldo (Province of Caltanissetta).

It might be interesting know about underground utilities such as electric cable pipes, fiber-optic, water, drain, as the drain enters into the tunnel... if they are made of polyethylene, id underground utilities are correctly positioned, with information about minimum distances and depths. If I can not connect with existing networks, I will make manholes (but they are of a different nature). And in a city where underground situations exist from 1500 onwards?
A so-called 150,000 (electric cable "oil") is coated with metal. In order to find them underneath, they use the cables detector (as cables are envelopped with metal nets). If they are coated with polyethylene, things are more difficult. Regarding water pipes, they are blue with the words "water pipe" written on it, and a small net 15 cm wide with a small metal net built-in. Fiber optic and telephone cables walk underground but near the surface. All service branches have different diametres.
For each water outlet there is a blue card with the white cross and two numbers (which indicate respectively the distance of the outlet from the wall and the depth of the tube). If there isone number only, it indicates the distance from the wall to the main line (from which the bleeding takes place).
Employees handle data in EXCEL format updated by the operators (and especially by the responsibles of gully sucker interventions): e.g. the road where the intervention was carried out, the claim number, the date of intervention, the type of intervention.
GESCA software (i.e. GEstione SCAvi, which means excavations management) records: who, when, what size (important for claims). It is not easy to identify the point of the excavation (as they do not use GPS. They come back in the office and try to reconstruct the exact location of the intervention on the map...). AMAP performs provisional restorations with cold asphalt, while a company hired by them makes permanent restorations and final works. For this reason and for reasons of responsibility for them it is important to also record the date on which there is the handover from AMAP to the company contracted by them.
Palermo Environment S.p.A. was in charge of the relief of the drains of the city.

INTERVIEWS TO ARCHAEOLOGISTS

INTERVIEW N. 6

July 19, 2016 - Interview with Respondent 9 (R9) – Archaeologist at Ministry of Heritage and Culture - Superintendence for Archaeological Heritage of Rome, SITAR - (Archaeological Territorial Information System of Rome) Office

S.G.: *Do you use data from the Road Cadastre?*
R9: We use the Cadastre in general. Is it the same thing or is it something different?

S.G.: *The Cadastre relates to Land Cadastre and Buildings Cadastre. The Road Cadastre is a list, a register that has a database, where all roads (national, regional, provincial, military) are registered.*
R9: We use the Cadastre as a reference portal for a better referencing of archaeological findings, located both under the buildings and the ground, and the roads... even those that are statements of constraint and – we can say – previous archaeological elements are all resting on the Cadastre and then this is the usefulness of using that as a basis for better referencing. But I do not think that we use specifically the Road Cadastre. From a practical point of views he interfaced with ANAS technicians.

S.G.:* so t*he operational part is developed ...

R9: I do not deal with the operational part. I know the whole history of the Cadastre. We have made several agreements with the Municipality and currently we are using at this time a cadastre updated to 2006 if I am not wrong and unfortunately the representatives of the Municipality have changed over time. Basically, on the basis of this convention that we had done, as the Municipality must update every year the Cadastre (to update name of places and properties), the Municipality reversed the cadastral updates, multiplied them and put them on maps to give us the constant updating: however, that has not taken place because the manager changed, therefore at the moment we have this Cadastre updated to 2006 as the basis for referencing.

S.G.: *But do you deal with ANAS technicians?*

R9: Yes and no. We can say that there is a distinction between the historical centre of the rebuilt city where roads are in renovation and restoration, and instead stations in the suburbs. We deal with all those, who do underground work, including ANAS. Regarding road installation, every day we follow the telephone cables, high voltage cables, gas cables, all the services that daily are changed must have the prior authorization of the Superintendency of Rome and consequently there is the preventive excavation of these cables that are made in the roadways.

S.G.: *What kind of data do you require?*

R9: If you go on our website (www.archeositarproject.it), there are the standards relating to the delivery of the documentation (i.e. how georeferencing must be made and how the material should be delivered). You are interested in the graphic material, as I think that photos describing archaeological data are not of your interest; but in any case you can find the standards on the website: it contains the whole history of the project, who did it, the whole team, standards, conventions, access to wi-fi as a public user, and then there are the news that you find on the right including for example a nice thing: a guide for the access on the web eyes for the deaf community: i.e. the sign language or LIS.

S.G.: *Beautiful, this is also very interesting, beautiful. Then we asked technicians to find out if they preferred using CAD or 2D GIS for this data, and we discovered that there is a discrepancy: designers essentially have no literacy in terms of GIS, as they use CAD, while ANAS provides them GIS data or at least must then extract and transform data tables because designers cannot read and interpret them; so we have issues of format. Then, in question 4, for example, you see these images that we provided in the form of questionnaire to ask technicians which of these cases might be interesting for them to have a documentation of roads in 3D: this relationship of the road with slopes, or the various layers of the road surface, walls, supports, culverts, bridges; in short, this is all case studies that we presented to figure where it can be most helpful to document in 3d and in which cases.*

R9: For us, you know, the underground aspect is always of main interest. So for example one thing... with regard to underpasses and cables as shown in the figure an underpass should be made through the push tube: we do not authorise it, because, whether there were archaeological remains, it would be gutted in a short; so it is clear that in such types of roads for archaeological needs we like those who are inside and not those that are dug. However, relating to the possible archaeological presence below, if it were in 3D, it would be ideal to us.

S.G.: *Then your wish also in relation to the work of SITAR... you have also given us your analysis studies of the archaeological potential etc. in fact...*

R9: If there was a 3D, at least, not being able to make a 3D GIS, as you know better than I do. What we do is a pseudo 2.5D GIS in the sense that CAD files contains the elevations? I need to know if the archaeological system, just as we say the archaeological sediment thickness, should be at an elevation of -10 or -50; then generally if we want include the presence of archaeology between two elevations, the minimum and the maximum, it is a volume beyond the details relating to what is inside: so archaeometry is crucial.

S.G.: *Then, in your opinion, if a road designer had the opportunity to consult a Road Cadastre connected to a system like the one that you have implemented and there were reciprocal links between these systems...*

R9: It would be essential. Something that for example in Rome was always tried to do but never did, was to create relationships from the point of view of a GIS shared with all those who make underground utilities in the roads. Everyone who comes to Rome has always difficulties as there is a road segment closed for works of underground utilities which are right continuous and constant even in the same road. Today ACEA digs, tomorrow Italgas digs, the day after tomorrow Telecom digs... but I am not exaggerating, of course, not always and not in all the roads. Then if they simply would be coordinated, they could make a single excavation, a single recovery, and do all three maintenance, then if we add to this also the archaeological knowledge that we are slowly developing at SITAR, if you know that in that road you have already dug at least 3 metres of depth and the excavation that they have to do arrives to 2 metres of depth, we do not need to do the archaeological monitoring because the work occurs in a ground without archaeological findings. But everyone does things on his own. Even in Rome the Municipality, which is the only Municipality that has the dual responsibility of protection, there is the Superintendent Capitoline which also controls the cables and hence there is no connection also between us and them. Obviously this is the typical Italian madness.

S.G.: *Hence the lack of coordination... Even other stakeholders have spoken of the great difficulties of data updates.*

R9: Yes, we say, as there is no upstream connection, automatically everyone has their own of updating but a general update does not exist. In my opinion, as there is no coordination, the update also lacks. Even our case is not up to speed because we would need a Superintendent who requires the release of digital data and then, as the data is made, it is delivered to us, so we know in real time which are all excavations in progress on all roads, but, in general, in our case throughout the area. At that point, if you have a web tool that any data that you put is seen from the outside, the update is continuous and constant, but if, as it often happens, proprietary systems that are on the computer of the various agencies are used instead, it is clear that even though data has been updated, all the others cannot see it.

S.G.: *Then, if there was a 3D model of a road that you could query – I refer to question 6 – being able to obtain the data through a single click, in your opinion, and considering its interrelation or potential interference that could highlight if compared to the archaeological pre-existences, would it make sense to model a road infrastructure and at the same time shaping an archaeological scene in 3D?*

R9: As I said, it would be essential and you might have two levels: one in general, where - as I said before - may be only the thickness of the archaeological ground (hence, what depth archaeological findings begins and also end). Undoubtedly, it is a given variable; it does not continue permanently or over long distances, so you might have over a km of a road: archaeological findings within 50 cm up to 3 metres of depth for the first 100 metres of length of the road; no archaeological findings in the middle of the road; at the end of the road archaeological findings under 4 metres, maybe because the road is placed on a slope and later the ground was settled. So having this three-dimensional volume to understand how and at what level are archaeology findings would be a crucial first data for everything related to the design; this could be what we call general archaeological potential. After that, if you have the definition of the findings that are below the road surface, it is undoubtedly all earned. But even the only data regarding where archaeological findings begin and where they end at every point of the road, I think it would be an extraordinary data.

S.G.: *Ok, so they might be, for example, some volumes... they might also have a different colour...*
R9: In the stratigraphy of the road a red colour, then a red wave, a band, which tells you where there is the archaeological find and avoids a number of unnecessary excavations or designs that must then be modified, would be crucial. It would be crucial for the knowledge because then if you put that data, if detailed, in relation to other data on the archaeological knowledge that lie outside of roads, on the right and the left of roads...

S.G.: *What are the major difficulties met in combining the protection of the archaeological pre-existing structures with new designs? In addition to the issues on coordination, other critical issues may be highlighted?*
R9: There is a strong political will that does not want that there is a coordination, primarily related to spatial landscape plans that have not yet been adopted in most Italian regions, except for Tuscany, Apulia, Friuli and few other, and this had to be 7/8 years ago and has not happened, and of course the realization of a landscape plan within the region is already an extraordinary way of protection, integration and knowledge sharing among bodies. Moreover, there are no communications among different actors involved in planning, and each body has its own system. In our case the ours is open to the public at its disposal, so that, even if I do not have any direct interaction with the builder, the builder opens the website and sees at least for the areas already mapped what is and what there is not there. But this is a subject that should be taken into account, as in the realization of plans, all the professionals sitting around the table, who study and see the characteristics of territories and as a result decide what should be done in urban design and how Cultural Heritage should be enhanced in each territory and how it does not: in this case, structures that interfere with the heritage existing or discovered during the work might be constructed and cover, overlay, relocate any archaeological remains. I think it is just a matter of general policy will, because these are regional and even national tables that must establish the mode and can not be left to free initiative and the individual good will of the staff on duty.

S.G.: *But do you know if there are some good practices at European level in this regard, with respect to us?*
R9: At European level I do not know. I can say that the Apulian landscape plan is really an example, done taking into account all a number of characteristics that are related to the the ease of access to paperworks from the point of view of citizens, to the creation of a level collecting Cultural Heritage, to the relationship among Cultural Heritage and any new infrastructure. At the European level really I do not know.

S.G.: *At SITAR is also referred to the INSPIRE Directive, as it relates to the environment. Is it consulted or taken in account, or as it is a Directive regarding the environmental policy, it has no influence on the archaeological field?*
R9: We had taken into account all those that are European standards and also specifications from the point of view of the implementation of numerical maps etc, not only but in particular with our last two projects. Our former database has been translated in this European language called... We say that it is the translation of European standards of archaeological language while by the Memorandum of Understanding done with the University of Verona they took the full system used for Rome, called SITAR, that has become precisely SITAVR, they made a translation of language in GML, and uses languages that are more or less common throughout Europe.

S.G.: *I do not remember if in the SITAR database - surely I will be able to see again on the website – you have also recorded the type of road or the progressive kilometric where there are archaeological pre-existence...*
R9: I have recorded what?

S.G.: *The kilometre, the progressive milestones where there might be a certain archaeological pre-existence or type...*
R9.: No, no. In SITAR currently they do not exist, as we never designed the level of the archaeological potential... so it is theoretical but not practical. When it is determined that the archaeological heritage is there, in the card, where there was specified in the original documents... however you can find it from the placement i.e. the mileage of the road.

S.G.: *Are these data on the Internet?*
R9: On the Internet you can see all the cards - on both source information, and archaeological partition, and archaeological units – and all the plans that are on the web eyes. The only thing that is not open to everyone is the accompanying documentation, i.e. photographs, drawings and scientific reports that must be requested with permission. But all cartographic and shorthand parts are free.

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M.S.: No, no. In SITAR currently they do not exist, as we never designed the level of the archaeological potential... so it is theoretical but not practical. When it is determined that the archaeological heritage is there, in the card, where there was specified in the original documents... however you can find it from the placement i.e. the mileage of the road.

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M.S.: On the Internet you can see all the cards - on both source information, and archaeological partition, and archaeological units – and all the plans that are on the web eyes. The only thing that is not open to everyone is the accompanying documentation, i.e. photographs, drawings and scientific reports that must be requested with permission. But all cartographic and shorthand parts are free.

S.G.: *Thank you for such valuable information, in particular for the purposes of the model. I will treasure this suggestion while modelling layers.*

Appendix 8

SQL Code used

Code for project creation for Lacuna by SQL:

```
create table projectMetadata
(id serial, projectName varchar(250), tableName varchar(250),idColumnName varchar(250),
geometryColumnName varchar(250),,,,, , ....., .....  )

insert into projectMetadata (projectName,tableName, idColumnName, geometryColumnName)
values ('design','3Dcunetta','id3Dcunetta','geom');

insert into projectMetadata (projectName,tableName, idColumnName, geometryColumnName)
values ('design','3Dstrato_di_base','id3Dstrato_di_base','geom');

insert into projectMetadata (projectName,tableName, idColumnName, geometryColumnName)
values ('design','3Dbarrier','id3Dbarrier','geom');
alter table projectmetadata add primary key(id)
alter table projectmetadata add constraint "uniquetables" unique(tablename, projectname)
```

Hence the procedure provides to create a table to hold a list of layers to display for each project. For each table we need to know:

- the name,
- the id column (as we can't assume this is always 'id'),
- the geometry column.

For each table there must be an id column, as follows here making an example with the table "3Dstrato_di_base" relating to one of the road layers :

```
ALTER TABLE "3DSTRATO-DI-BASE"
ADD COLUMN id serial;
```

For each table, a row must be inserted into the projectmetadata table as follow:

```
Insert into projectmetadata (id, projectname, tablename, idcolumnname, geometrycolumnname)
Values
(6, 'design','3DSTRATO-DI-BASE','id','geom');
```

SQL Code for creating table

```
Create table feature
(id serial,
name character varying (100));

ALTER TABLE feature
ADD CONSTRAINT feature_pk PRIMARY KEY (id);


Create table user_lookup
(id serial,
user_group character varying (100));

ALTER TABLE user_lookup
ADD CONSTRAINT user_lookup_pk PRIMARY KEY (id);

Create table user_features
(user_group_id int,
feature_id int);

ALTER TABLE user_features
ADD CONSTRAINT user_features_pk PRIMARY KEY (user_group_id, feature_id);

ALTER TABLE user_features
ADD CONSTRAINT feature_fk FOREIGN KEY (feature_id) REFERENCES feature (id)
ON UPDATE NO ACTION ON DELETE NO ACTION;
CREATE INDEX fki_feature_fk
ON user_features(feature_id);

ALTER TABLE user_features
ADD CONSTRAINT users_fk FOREIGN KEY (user_group_id) REFERENCES user_lookup (id)
ON UPDATE NO ACTION ON DELETE NO ACTION;

Drop table representation;
create table representation
(id serial,
representation_type character varying (100));


create table feature_representation
(feature_id int,
representation_id int);

ALTER TABLE feature_representation
ADD CONSTRAINT feature_representation_pk PRIMARY KEY (representation_id, feature_id);

ALTER TABLE representation
```

```
ADD CONSTRAINT representation_pk PRIMARY KEY (id);

ALTER TABLE feature_representation
ADD CONSTRAINT feature_rep_fk FOREIGN KEY (feature_id) REFERENCES feature (id)
ON UPDATE NO ACTION ON DELETE NO ACTION;
CREATE INDEX fki_feature_rep_fk
ON feature_representation(feature_id);

ALTER TABLE feature_representation
ADD CONSTRAINT rep_fk FOREIGN KEY (representation_id) REFERENCES representation (id)
ON UPDATE NO ACTION ON DELETE NO ACTION;

CREATE VIEW feature_representation_types as
select d.name, e.representation_type from (select a.name, c.representation_id from
feature_type a inner join feature_representation c
on a.id = c.feature_id ) d inner join representation e
on d.representation_id = e.id;

Select * from feature_representation_types where representation_type = 'photo';
```

The general approach, hence, is the following:

1. to join 2 tables

```
select a.name, c.representation_id from
feature_type a inner join feature_representation c
on a.id = c.feature_id
```

2. to put brackets around them and give them a letter to refer to the result

```
(select a.name, c.representation_id from
feature_type a inner join feature_representation c
on a.id = c.feature_id ) d
```

3. then to add another table

```
select d.name, e.representation_type from (select a.name, c.representation_id from
feature_type a inner join feature_representation c
on a.id = c.feature_id ) d inner join representation e
on d.representation_id = e.id
```

With regard to the code for the physical implementation:

```
Insert into representation (geom, type)
Values (
st_geomfromtext('GEOMETRYCOLLECTION Z (POLYHEDRALSURFACE Z (((532927.527868419 181052.797338803 0,532931.345134153 181064.804039756 0,532934.873091355 181063.449696981 0,532930.966211646 181051.418393227 0,532927.527868419 181052.797338803 0))),POLYHEDRALSURFACE Z (((532931.345134153 181064.804039756 0,532927.527868419 181052.797338803 0,532927.527868419 181052.797338803 18.8794652406417,532931.345134153 181064.804039756 18.8794652406417,532931.345134153 181064.804039756 0))),POLYHEDRALSURFACE Z
```

(((532934.873091355 181063.449696981 0,532931.345134153 181064.804039756 0,532931.345134153 181064.804039756 18.8794652406417,532934.873091355 181063.449696981 18.8794652406417,532934.873091355 181063.449696981 0))),POLYHEDRALSURFACE Z (((532930.966211646 181051.418393227 0,532934.873091355 181063.449696981 0,532934.873091355 181063.449696981 18.8794652406417,532930.966211646 181051.418393227 18.8794652406417,532930.966211646 181051.418393227 0))),POLYHEDRALSURFACE Z (((532927.527868419 181052.797338803 0,532930.966211646 181051.418393227 0,532930.966211646 181051.418393227 18.8794652406417,532927.527868419 181052.797338803 18.8794652406417,532927.527868419 181052.797338803 0))),POLYHEDRALSURFACE Z (((532927.527868419 181052.797338803 18.8794652406417,532930.966211646 181051.418393227 18.8794652406417,532934.873091355 181063.449696981 18.8794652406417,532931.345134153 181064.804039756 18.8794652406417,532927.527868419 181052.797338803 18.8794652406417))))'),'geometry');