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1 **Smart technology applications for the optimal management of underground facilities**

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11

12 **Abstract:**

13 This study centers on the use of smart technology to improve the lifecycle management of  
14 underground facilities. It presents a comprehensive digital solution that addresses the  
15 challenges of underground facilities, particularly those related to the extensive use of  
16 underground space, as well as the requirements for safety, sustainability, and quality of  
17 services. The proposed solution emerged from discussions with experts, companies, and cities  
18 involved in the design, construction, and management of underground facilities. In this paper,  
19 we first discuss the major challenges of underground facilities, then, we present the  
20 development of a smart solution to address these challenges. This study demonstrates a  
21 promising perspective for the use of smart technology in the optimal management of  
22 underground facilities, and paves the way for its implementation.

23

24 **Keywords:** Artificial Intelligence; Lifecycle; Safety; Smart City; Maintenance; Smart  
25 Technology; Underground Facilities

26 **1 Introduction**

27 This study presents a smart solution for the lifecycle management of underground space,  
28 which plays a major role in urban areas (Nelson, 2016; Darroch et al., 2018). Underground  
29 space hosts vital urban infrastructures for water, energy, telecommunication, and

30 transportation services, as well as structures built to accommodate residential, industrial, and  
31 service purposes (Sterling et al., 2012; Broere, 2016). This space also plays a major  
32 environmental role as it reduces traffic jams and contributes to the reduction of energy  
33 consumption, as well as urban greenhouse gas emissions. Furthermore, it acts as an excellent  
34 thermal insulator for buried constructions, which leads to a high energy consumption  
35 economy. This space could be used as an energy source via geothermal energy. In large and  
36 crowded cities, underground space presents an effective alternative for the construction of  
37 new infrastructures or extensions of existing ones. It also presents a reliable driver for urban  
38 socio-economic development. However, owing to high population growth, rapid urbanization,  
39 and increasing concerns in sustainable and livable cities, underground space is subjected to  
40 increasing pressure and numerous challenges. It is already crowded with facilities,  
41 constructions, and objects that were built throughout the city's history with the principle of  
42 "first come, first served." In addition, this space is heavily exploited by several public and  
43 private stakeholders, who lack coordination, cooperation and a common sense of shared  
44 perspective and vision for its use and development. Underground space also faces a legal  
45 challenge concerning its ownership and maintenance. This issue raises several questions,  
46 including: who is responsible for the structure, equipment, indoor environment, surrounding  
47 soil, and security of underground space? To determine the responsibilities and roles of the  
48 authorities and companies involved in the management of underground space, these crucial  
49 questions should be addressed.

50 Underground space is also subjected to specific safety challenges (Eskesen et al., 2004;  
51 Hu & Huang, 2014), lifecycle management (Reilly & Brown, 2004), and sustainability  
52 (Sterling et al., 2012; NAS, 2013).

53 Because these challenges will be predictably increasing in the future, owing to the  
54 pressure of population growth, urbanization, and climate change, it is necessary to develop  
55 innovative solutions that improve the efficiency, safety, and quality of services related to  
56 underground space. Innovation is also required to monitor underground space and share data  
57 among the stakeholders of underground space.

58 Recent progress in the field of smart cities and related issues such as smart grids,

59 intelligent transport, and smart buildings, offers new opportunities for the development of  
 60 comprehensive solutions that improve the management of urban systems, including urban  
 61 infrastructure, services, and governance (Momoh, 2012; Lin et al., 2013; El-Hawary, 2014;  
 62 Anthopoulos, 2015; Shahrour et al., 2016; Tuballa & Abundo, 2016; Cheng et al., 2016;  
 63 Bagdadee & Zhang, 2019).

64 This study presents the application of smart technology to underground space. The  
 65 scientific novelty of this study is illustrated in Table 1, which shows the evolution of a  
 66 number of scientific records indexed by ISI-WEB in the last decade, based on the following  
 67 topics: (i) “smart city”, (ii) “underground space and urban tunnel”, and (iii) “underground  
 68 space and urban tunnel” and “smart city.” This table shows intense scientific activity in the  
 69 first two topics, including the recent emergence of the application of smart city solutions in  
 70 the field of urban underground space. The synthesis presented in this study is based on the  
 71 analysis of 58 references, which are given in the reference list.

72 The remainder of this paper is organized as follows. First, the paper presents the  
 73 challenges of urban underground space to determine the requirements for an innovative  
 74 solution. Next, it presents the smart city concept and its application to underground space.  
 75 Finally, it provides some recommendations for the implementation of the “smart underground  
 76 space” solution.

77

78 Table 1. Scientific ISI-Web records for topics related to “smart underground space”

Topic year	Smart city	Urban underground space and tunnel	Underground space, urban tunnel and smart city
2010	74	335	0
2011	142	348	0
2012	225	425	1
2013	444	543	2
2014	778	431	1
2015	1388	557	2
2016	2073	743	8
2017	2897	653	6
2018	2998	806	6
2019	2409	734	3

79

## 80 **2 Methodology**

81 The methodology of this research is based on an extensive literature review as well as on  
82 discussions with companies and local authorities relevant to underground facilities and smart  
83 city solutions, including the academic and professional experience of authors in the field of  
84 underground space and smart cities (Shahrour et al., 2016; Farah & Shahrour, 2017; Abbas et  
85 al., 2017; Abou Rjeily et al., 2017; Shahrour et al., 2017; Xie et al., 2018; Saab et al., 2020;  
86 Shahrour & Zhang, 2020), and the results of a series of international conferences “Smart  
87 Underground Space” organized by the authors in 2017, 2018, and 2019 (SUS-Shanghai, 2017;  
88 SUS-Shanghai, 2018; SUS-Lille, 2019).

## 89 **3 Underground space challenges**

### 90 **3.1 Overview**

91 Underground space plays a vital role in urban areas because it hosts critical urban  
92 infrastructures such as utilities and facilities for transportation, water, energy, and  
93 telecommunication. However, this space is subjected to a multitude of challenges. It is  
94 exploited by several public and private stakeholders, with a general lack of coordination,  
95 cooperation, and a shared perspective and vision for the use and development of this space.  
96 Although some stakeholders, such as public authorities and owners, have long-term and  
97 holistic perspectives, others, such as operating and maintenance companies, usually have  
98 short- to medium-term perspectives with a focus on specific issues relating to this space.  
99 Owing to its high heterogeneity, density, foundations, constructions, utilities, and diversity of  
100 hosted facilities, underground space is very complex. In general, cities do not have a clear  
101 map for underground space, and this sometimes results in accidents that cause damage to  
102 some underground utilities owing to construction activities. Such damage can lead to  
103 significant disruptions both above and below the ground.

104 The following sections focus on two specific challenges of underground space. The first is  
105 related to safety, which is particularly essential for the underground space owing to the  
106 limited access to this space and the large economic and environmental consequences of severe  
107 incidents in it. The second challenge is related to the lifecycle management, which is  
108 particularly complex because of the long lifetime of underground infrastructures, such as  
109 tunnels and utilities, several stakeholders in this space, and the difficulty in conserving and  
110 transmitting data and information throughout the lifetime of underground projects.

### 111 **3.2 Safety of underground space**

112 Owing to its high vulnerability, as well as its vital role in providing urban services  
113 (transport, water, energy, communication, etc.), safety is considered a major challenge in  
114 underground space. Safety in this space is more critical than in the surface space because of  
115 the restricted access to it in the event of a severe accident. These accidents could cause  
116 structural instability, water infiltration, fire, electrical outage, and air contamination.  
117 Additionally, incidents such as floods or fires could cause a chain of events with severe  
118 damage to the structure of underground space, its equipment, and hosted services. In the  
119 metro tunnel, these damage could disrupt the traffic of both the metro system and other  
120 transport networks above the ground.

121 Guidelines have been established for risk management in tunnels and underground  
122 projects. The working group 2 of the International Tunneling Association published  
123 guidelines for tunneling risk management in 2004 (Eskesen et al., 2004). These guidelines  
124 provided owners and consultants with best practices for the risk assessment of tunnels, and  
125 described the process of risk management throughout the entire implementation of a tunnel  
126 project. According to these guidelines, risk management should be included as an integrated  
127 part of the planning and construction of any major underground project. In China, the first  
128 guideline for the risk management of tunnels and underground projects was issued in 2007. It  
129 was then updated as a national code for the risk management of underground projects in urban  
130 rail transit in 2012 (Hu & Huang, 2014).

131 Hu & Huang (2014) presented sophisticated risk management standards for tunnels and  
132 underground projects in China. They indicated that the risks in large projects were previously

133 managed by engineering decisions during the design and construction phases. This practice  
134 however resulted in a lack of a standard procedure for implementation and verification. For  
135 the implementation of risk management in tunnels, the key factors to consider are the  
136 identification of potential risk sources, elaboration of corresponding preventive measures, and  
137 preparation of an emergency rescue plan. Dynamic risk management should be established on  
138 construction-based information and site monitoring (Hu & Huang, 2014).

139 To address the safety issues of underground spaces, it is necessary to develop a  
140 comprehensive management system that includes historical and real-time data on the structure  
141 of underground space, its equipment, use, and adjacent environment.

### 142 **3.2 *Lifecycle management***

143 Underground space projects, especially the construction of tunnels, utilities, and large  
144 facilities, are very complex and expensive with a long lifecycle that includes four long stages:  
145 planning, design, construction, and exploitation. Each stage is operated by specific experts,  
146 who utilize and generate a high amount of data that are necessary for the management of the  
147 current stage and subsequent stages. These data are generally related to the physical  
148 components of underground space as well as its operating activities such as maintenance,  
149 usage, incidents, expenses, and performances. The management of existing underground  
150 facilities, legacy infrastructures in particular, involves the collection of construction and  
151 operating historical data, as well as their integration with the information system of the  
152 facility. One of the major challenges to the lifecycle management of large construction  
153 projects is the loss of data and information at the transition between subsequent stages. An  
154 international survey of several tunnel projects showed that it was difficult to obtain specific  
155 and relevant information on these projects because once they were completed, the data they  
156 generated were either archived or dispersed among the project stakeholders (Reilly & Brown,  
157 2004). Because data loss could result in severe problems in the management of underground  
158 space, which leads to substantial additional expenses, it is necessary to develop and apply  
159 digital tools in storing the data collected throughout the lifecycle of underground space.

160

## 161 **4 Smart City solution**

### 162 *4.1 Use of data for comprehensive and knowledge-based city management*

163 The smart city concept is based on the use of digital and social innovations to improve the  
164 efficiency and security of urban systems as well as the quality of life of its residents and their  
165 involvement in urban development. It also aims at creating a friendly urban environment that  
166 reduces the consumption of natural resources and pollution via emissions. This concept is  
167 based on an interdisciplinary approach of a city that utilizes technical, social, and  
168 environmental data to develop a knowledge-based management of the city (Anthopoulos &  
169 Fitsilis, 2013; Anthopoulos, 2015). Data were collected using the smart monitoring of urban  
170 systems, including its water, energy, and transportation infrastructure, as well as its urban  
171 environment and activities (Momoh, 2012; Buchholz & Styczynski, 2014; El-Hawary, 2014;  
172 Shahrour et al., 2016; Tuballa & Abundo, 2016). Smart monitoring is based on the use of  
173 smart sensors, social media, and authorized data to conduct a real-time survey of urban  
174 systems. Operating data are stored in large datasets, together with information on  
175 infrastructure assets and other useful data such as climate information, traffic, and user  
176 profiles. The data obtained include images, videos, and audios, resulting in the development  
177 of urban big data (Mayer-Schönberger & Cukier, 2013; Chen et al., 2014). The analyses of  
178 both real-time and historical data provide an enhanced understanding of the functioning and  
179 performance of urban infrastructure. It also allows the optimal management of urban systems  
180 by improving asset management and reducing the consumption of natural resources and the  
181 emission of greenhouse gases. Furthermore, the smart city concept is based on a sustained  
182 interaction with citizens. Today, social media offers the outstanding ability to establish  
183 two-way communication and cooperation between the city and its residents. It provides  
184 residents with pertinent information concerning urban services, including environmental and  
185 safety issues. In return, it enables city managers to receive feedback from residents.

186 During natural or human-made hazards, smart monitoring allows authorities to collect  
187 data on the actual functioning and performance of urban systems, as well as the behavior of  
188 residents. Using advanced analysis tools, such as artificial intelligence, the analysis of these  
189 data provides an enhanced understanding on the actual reactions of technical and social



190 systems to urban hazards. Owing to the learning capacity of the smart city concept, the  
191 analyses of real-time and historical data permit the early detection and management of  
192 incidents, as well as the restriction of their extension to larger areas. Regarding large faults in  
193 urban systems, smart technology allows the efficient self-healing of complex urban systems.

194 In a smart city, sensors, data information systems, social media, and other emergent  
195 technologies work together to track, share, and analyze data concerning resources, demands,  
196 and urban-system performances at different scales and under various conditions. This allows  
197 urban stakeholders to develop and implement a comprehensive city management plan, which  
198 improves the efficiency and security of urban systems as well as the quality of life of its  
199 residents.

#### 200 ***4.2 Implementation of the smart city solution***

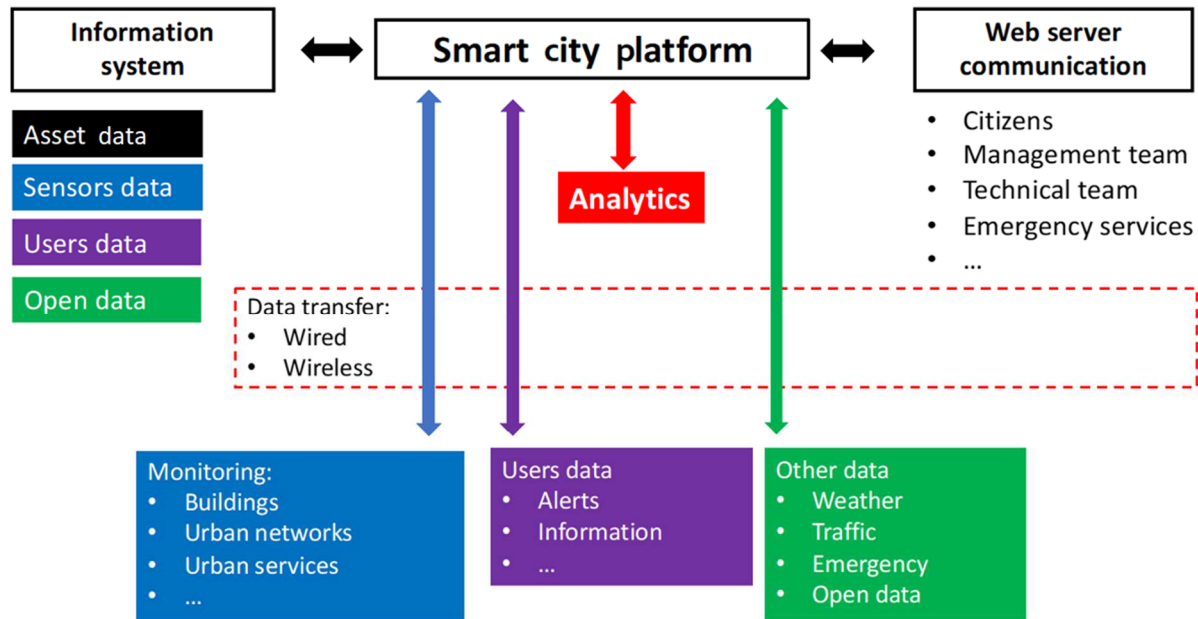
201 The implementation of the smart city solution requires the development of a smart  
202 platform that coordinates operations related to a smart city, such as data collection, data  
203 processing and analysis, system control, and interaction with city stakeholders (Shahrour et al.,  
204 2017). Figure 1 illustrates the architecture of this platform, which is connected via wired and  
205 wireless communication technologies to urban systems, urban infrastructure, users, and urban  
206 environment. By utilizing these connections, the platform collects data, ensures data integrity,  
207 and stores both raw and cleaned data in the information system. Additionally, the cleaned data  
208 include asset data obtained via the connection to digital modeling tools of urban systems, such  
209 as the geographic information system (GIS) and building information modeling (BIM).

210 The platform incorporates software for data analysis using both engineering and  
211 information technology tools, such as artificial intelligence, to convert real-time and historical  
212 data into operational data, which ensures the optimal and safe management of urban systems  
213 and a friendly environment for citizens.

214 Finally, the platform adopts friendly graphic tools for its communication and interaction  
215 with city stakeholders, including its residents, socio-economic stakeholders, urban managers,  
216 and policy makers.

217

218



219

220

Fig 1. Architecture of the smart city platform.

## 221 5 Smart solution for underground facilities

### 222 5.1 Presentation

223 The development of a comprehensive smart solution for underground facilities is an  
 224 emerging topic. Previous works on smart tunnels mainly focused on the development of  
 225 advanced systems for monitoring the soil and structural displacements during tunnel  
 226 construction. Inexpensive sensors and optical fibers were used during the construction of a  
 227 tunnel in London to monitor soil movement during tunneling (Bennett et al., 2010). A “smart  
 228 tunnel” was constructed in Kuala Lumpur in Malaysia (Zaini et al., 2012). The smart  
 229 depiction of this tunnel involved its multi-usage for the reduction of both flood damage and  
 230 traffic jams. A smart solution for underground space aims at the construction of a  
 231 comprehensive system based on a comprehensive monitoring of this space and the use of  
 232 advanced data analysis tools to improve:

- 233 (1) the quality of life and services of residents;
- 234 (2) asset management, particularly the efficiency and maintenance of this space;
- 235 (3) safety and security in underground space, as well as in surrounding constructions and  
 236 environment.

237

238 The architecture of this smart underground solution is similar to that used in smart cities  
239 (Fig. 1). It is built around a platform that collects data from sensors, authorized sources, and  
240 social media, and transforms these data and algorithms via a software into operational data to  
241 operate the optimal and safe management of underground space and provide high-quality  
242 services to users. The performance of the smart underground solution depends on the quality  
243 of the collected data and their applications in the lifecycle management of underground space.  
244 The following sections discuss these issues while focusing on the underground information  
245 system and the use of data during the construction and operational stages of the underground  
246 space.

## 247 ***5.2 Underground information system***

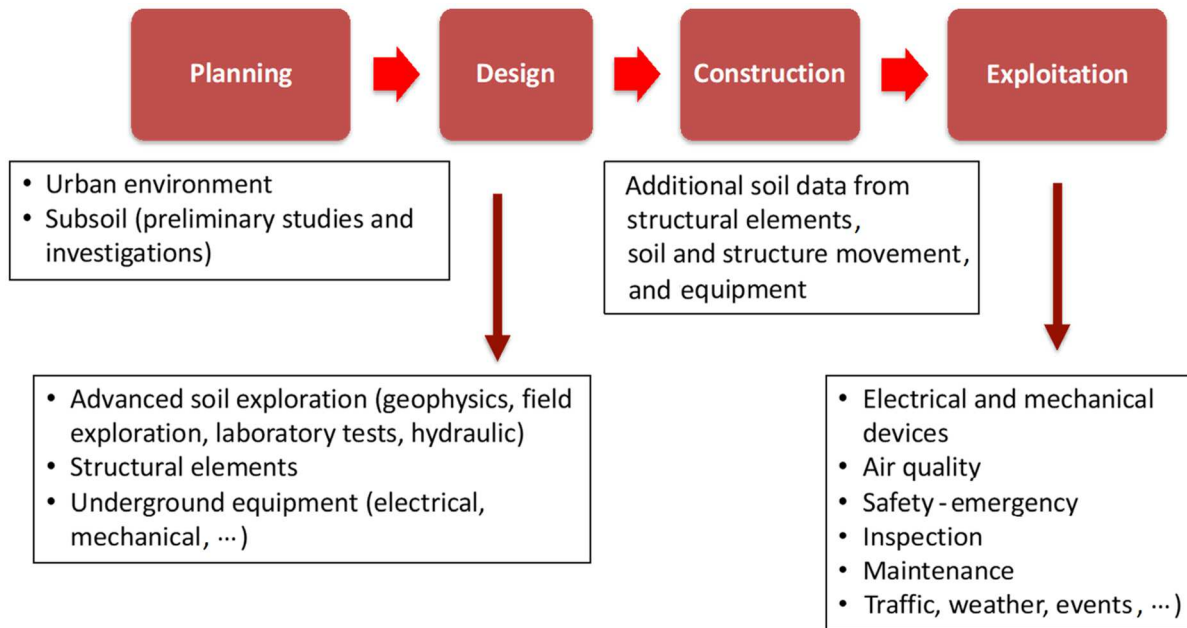
248 The underground information system includes data and information on underground space  
249 throughout its lifecycle. Figure 2 summarizes the collected and generated data at each stage of  
250 the underground space project. The collected data include data collected on the urban  
251 environment, subsoils, structural elements, surrounding buildings, and facilities.

252 The information system also includes data on underground space equipment, such as the  
253 electrical grid (tension, frequency, consumption, etc.), water system (pressure, flow, quality),  
254 ventilation system, access control, air quality, safety, emergency equipment, and video  
255 protection. It also includes other useful data such as those related to traffic, weather, urban  
256 activities, events (sports, spectacles, etc.), and density of users, as well as information  
257 concerning the safety and security of users.

258 The information system could be connected to digital systems, such as GIS, BIM, and  
259 civil information modeling (CIM), which provide powerful management tools for buildings  
260 and facilities (Penttilä, 2006; Aji et al., 2013; Cheng et al., 2016).

261 To harness massive amounts of both structured (files, tables, sheets, etc.) and unstructured  
262 data (images, audios, and videos), researchers recommend the use of big data tools  
263 (Mayer-Schönberger & Cukier, 2013; Chen et al., 2014; Karimi, 2014; Breunig et al., 2020)  
264 and artificial intelligence methods (Bouayad & Emeriault, 2017; Vo Pham et al., 2018; Xu et  
265 al., 2019; Shreyas & Dey, 2019) for data storage, processing, and analysis.

266 The maintenance of underground information systems is vital because of the critical  
 267 feature of this space, as well as its complexity. This maintenance should be handled by a  
 268 committee of public and private stakeholders in underground space. The committee has the  
 269 responsibility of setting operation rules related to data collection, management, sharing,  
 270 access, protection, and valorization.



271  
 272 Fig. 2. Information system for the lifecycle management of underground space.

273 **5.3 Smart solution applications in the construction stage**

274 Underground space is subjected to various risks during the construction stage, such as  
 275 those related to:

- 276 (1) hazardous soils, owing to the eventual presence of utilities, blocks, cavities, ancient  
 277 deposits, and water;
- 278 (2) excessive deformation and soil settlement, which could result in the significant  
 279 collapse and interruption of construction works or/and severe damage to surrounding  
 280 constructions and facilities; and
- 281 (3) disruption of urban services such as transportation, water, energy, and  
 282 telecommunications services (Liu et al., 2005; Wu et al., 2015; Qian & Lin, 2016).

283 Over the last decade, an increasing trend in underground construction accidents has been  
 284 observed in China (Ou et al., 2008; Yoo & Lee, 2008). The smart underground solution

285 benefits from the significant progress made in the application of structural health monitoring  
286 (SHM) in underground construction works (Bhalla et al., 2005; Chai et al., 2011; Qian & Lin,  
287 2016). This technology allows the tracking of soil and structural deformations during tunnel  
288 deformation, and then adjusts the excavation process to limit induced deformation.

289 A recent review on the use of artificial intelligence and tunnel monitoring allowed the  
290 enhancement of TBM tunneling efficiency and safety (Shahrour & Zhang, 2020). Xie et al.  
291 (2018) demonstrated how the use of settlement monitoring, together with deep learning,  
292 provided a reduction in the soil settlement during the construction of a station of the Nanning  
293 metro in China.

294 Geo-risks related to the lack of data and information on the subsoil, incorporated utilities,  
295 and other objects also constitute a crucial safety challenge for the construction and  
296 operational stages. Smart technology could help address this challenge by incorporating and  
297 updating data on the soil and maintaining the utilities in the underground information system  
298 presented in section 5.2 (Alqadad et al., 2017). Another approach to addressing this challenge  
299 is by utilizing digital tools such as BIM, GIS, and mobile augmented reality applications for  
300 the 3D visualization of the subsoil during urban construction projects (Huston et al., 2017).

301 Furthermore, the smart solution could benefit from tracking technologies used in  
302 underground projects such as radio frequency identification (RFID), global positioning  
303 system (GPS), wireless local area network (WLAN or Wi-Fi), ZigBee, and indoor  
304 localization (Ergen et al., 2007; Behzadan et al., 2008; Khoury & Kamat, 2009; Tu et al.,  
305 2009; Rao & Chandran, 2013; Jiang et al., 2015). In addition, the smart solution could be  
306 enhanced by recent developments in the early-warning decision support system (Lin et al.,  
307 2013; Jiang et al., 2015; Qian & Lin, 2016). Recent developments in the applications of  
308 augmented reality offer functional capacities to visualize buried utilities and objects, and  
309 consequently to avoid damage during construction (Ortega et al., 2019).

310

#### 311 ***5.4 Smart solution applications in the operational stage***

312 The operational stage involves the management of both the assets and equipment of  
313 underground space, such as:

- 314 (1) the electrical system, including the electrical grid, substations, transformers, lighting,  
315 and generators;
- 316 (2) the water system, including storm water, drinking water, and sanitation;
- 317 (3) the ventilation system, including air quality control, pumping equipment, air  
318 distribution system, and air treatment;
- 319 (4) the heating/cooling system, generally associated with the ventilation system;
- 320 (5) fire protection system;
- 321 (6) access control and emergency exit.

322

323 In this stage, each system requires specific monitoring. The electrical system benefits  
324 from the substantial experience in the field of smart grids, smart public lighting, and smart  
325 buildings (Bagdadee & Zhang, 2019; Verma et al., 2019). The technology in these areas is  
326 mature and currently widely used. Smart technology provides substantial improvement in the  
327 security of operations by confining local faults via the smart monitoring of electrical  
328 substations and appliances.

329 The management of the water system could also benefit from smart water technology via  
330 the smart monitoring of water flow, water pressure, and water quality (Abbas et al., 2017;  
331 Abou Rjeily et al., 2017; Farah & Shahrour, 2017; Saab et al., 2020). This system allows the  
332 rapid detection of water leak, accidental water contamination, and flood risk.

333 The management of the ventilation system is vital for the safety and comfort of users. It  
334 requires the monitoring of ventilation equipment, airflow, air quality, and comfort conditions  
335 (temperature, humidity, etc.). In addition to improved safety and comfort, the smart system  
336 allows essential energy savings.

337 Safety is a crucial issue in the management of underground space. Smart technology is  
338 particularly necessary for the early detection of incidents, which could be related to fire, air  
339 contamination, water infiltration, flood, structure collapse, and malicious actions (Singh et al.,  
340 2018). This early alert system includes sensors and video surveillance equipment. According  
341 to the type of incident, the system allows the user to transmit data and information  
342 instantaneously between services and authorities relevant to the event, take appropriate

343 measurement and actions via control devices (switches, valves, pumps, etc.) to confine the  
344 incident and trigger emergency actions, share data during emergency actions, and  
345 post-analyze collected data to enhance the resilience of underground space.

346 Inspection and maintenance are crucial for the safety and performance of underground  
347 space. Figure 3 illustrates how smart technology could help improve the quality of the  
348 inspection and maintenance of underground space. Besides digital identification and the  
349 localization of underground components, each component could be equipped with inspection  
350 and maintenance RFID tags that are connected to the smart platform via mobile application.  
351 These tags provide access to the inspection procedure, documents, and historical data. The  
352 system enables specific protocols to ensure inspection quality control and online reporting,  
353 which is automatically transmitted to the relevant staff with alerts in case of a need for urgent  
354 intervention. Maintenance RFID tags are used in the same way as inspection tags to improve  
355 efficiency and control the quality of the maintenance. Robots equipped with sensors and  
356 cameras could also be used for the inspection of limited access areas.

357 The availability of massive amounts of digital data on underground inspection and  
358 maintenance allows the use of digital tools, such as artificial intelligence, to categorize and  
359 explore the type, frequency, localization, and causes of component faults or degradation, as  
360 well as establish a predictive strategy for underground space inspection and maintenance  
361 (Tang et al., 2019; Wei et al., 2020).

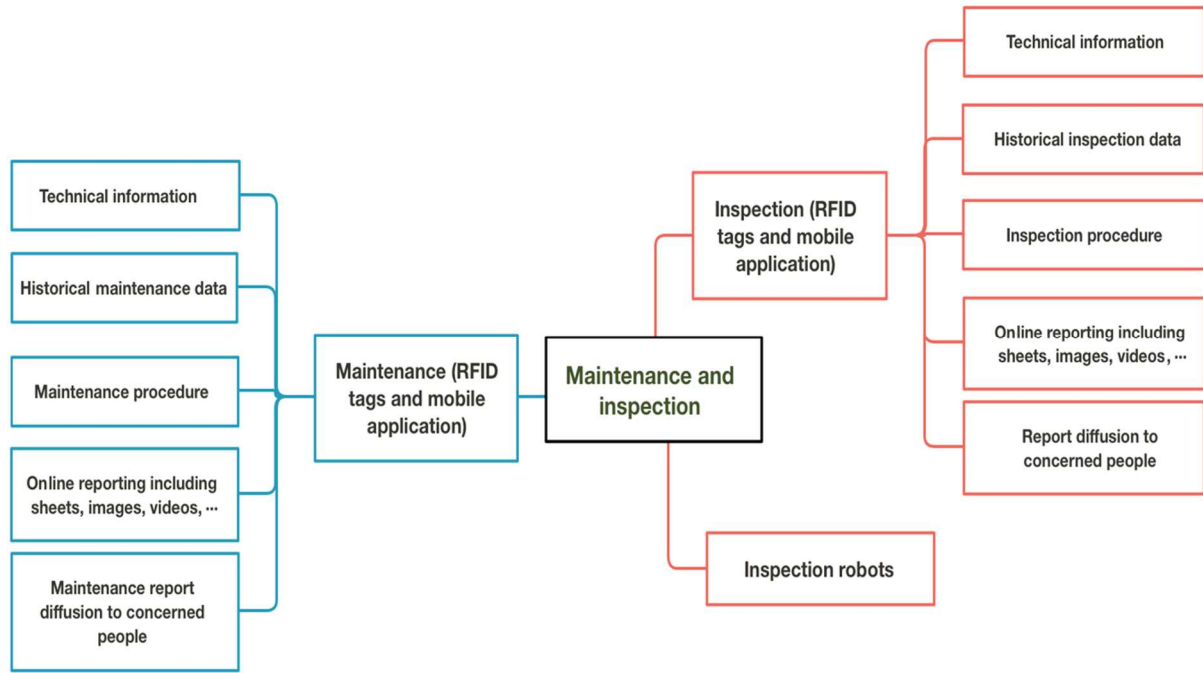


Fig. 3. Inspection and maintenance data of tunnels and hosted utilities.

## 6 Conclusion

Underground space plays a vital role in urban areas. It hosts urban infrastructure such as those related to water, energy, telecommunication, and transport. Owing to urban densification, underground facilities will play an increasing role in the future. Regarding surface structures, the management of underground facilities is subjected to specific challenges. Safety is considered the most important factor because of the critical role these facilities play and the limited access to them. A serious incident in underground space could lead to substantial economic and social losses. The lifecycle management of underground facilities also constitutes a significant challenge owing to the activities of several stakeholders and the difficulties related to each stage of the lifecycle management of these complex facilities.

Recent developments in the use of smart technology in urban areas such as smart grids, smart water, smart district heating, smart building, and smart city provide powerful tools for the optimal management of urban systems. Analysis of real-time and historical data enables an enhanced understanding of the behavior of these systems and their interaction with the environment.



380 The application of smart technology to underground spaces allows the construction of a  
381 comprehensive system that utilizes digital technology and data collected throughout the  
382 lifecycle of the underground facilities for their optimal and safe management. It also  
383 reinforces the involvement of different stakeholders in the optimal management of  
384 underground facilities. Furthermore, it presents a promising perspective that assures an  
385 optimal “continuity” in the management of underground facilities from the planning stage to  
386 the operational stage.

387

388

### 389 **Declaration-of-competing-interests**

390 The authors declare that they have no known competing financial interests or personal  
391 relationships that could have appeared to influence the work reported in this paper.

392

393

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