

1 **Augmented Reality for urban utility infrastructure: A UK**
2 **perspective**

3 Dr. Poorang Piroozfar^{1,2,3,4}, Mr. Alex Judd^{1,3}, Mr. Simon Boseley³, Mr. Amer Essa³,
4 Dr. Eric R. P. Farr^{2,3,4}

5 ¹ School of Environment and Technology, University of Brighton, Brighton, BN2 4GJ, UK

6 ² Digital Construction Lab, University of Brighton, Brighton, BN2 4GJ, UK

7 ³ MAVRiC Research and Enterprise Group, Shoreham-by-Sea, BN43 6AX, UK

8 ⁴NONAMES Design Research and Studies, 1249 F Street, San Diego, CA 92101, USA

9 A.E.Piroozfar@brighton.ac.uk

10 **Abstract.** Research on Augmented Reality (AR) in the architecture, engineering
11 and construction (AEC) industry is still new. As part of a comprehensive study on
12 the application of AR technologies for urban utility infrastructure, this paper sets
13 out to contribute to the state-of-the-art in this area by presenting the results of an
14 industry survey in the UK. The results of the survey conformed, in principles, to
15 majority of findings of the previous research in the field, but also revealed some
16 new or contradictory patterns. Geo-locationing and geo-tagging are still major
17 concerns and have not yet been completely resolved. Relying on global systems
18 does not look like the most reliable option and local systems are required to either
19 replace or jointly work with global systems. With respect to non-AR issues, it is
20 crucial that the quality and content of infrastructure and utilities data are improved
21 and ideally stored centrally in a nationally-procured database.

22 **Keywords:** Augmented Reality, Construction Industry, Handheld Devices, ICT
23 Application, Infrastructure, Urban Utilities.

24 **1 Introduction**

25 Research on Augmented Reality (AR) in the architecture, engineering and construction
26 (AEC) industry is still new and more so compared with Virtual Reality (VR). Therefore its
27 definitions are yet very much subject to different views and to some extent disagreement.
28 Milgram and Kishino's [1] definition places AR on a spectrum between actual and virtual
29 reality, taxonomizing it as a form of "Mixed Reality". It seems to be the most established
30 and widely referenced definition of AR ever since it was proposed.

31 As part of a comprehensive study on application of AR technologies for urban utility
32 infrastructure, this paper sets out to contribute to the state-of-the-art in in this area by
33 presenting the results of an industry survey in the UK. Firstly, a critical review of literature
34 on AR and its associated aspects and areas is carried out. The paper then reports on the
35 findings of a survey which was conducted after the participants partook in a hands-on trial
36 of the AR experiment primarily developed for this study. The experiment was intended to be
37 applicable to a variety of mobile devices. The results of the survey conformed, in principles,
38 to majority of findings of the previous research in the field, but also revealed some new or
39 contradictory patterns which are discussed in this paper. As a part of the comprehensive
40 study and once the questionnaire survey was concluded, a series of expert interviews were

41 carried out to enhance the depth of this study and increase validity and reliability of its
42 knowledge claims. The results of interviews are not presented in this paper due to restrictions
43 on paper length.

44 **2 Literature Review**

45 **2.1 Data Availability and Accuracy**

46 The key to handheld AR applications is geospatial data [2]. Asset owners and local
47 authorities are making their data more accessible [3], comparable to Google™ [4]. Lack of
48 [uniform] digital formats [5], inaccuracy of as-built information [6] and need for a shared
49 geospatial platform [2] to link with large quantities of BIM hosted information, streamlining
50 and simplifying its application [7] have been highlighted in previous research. Previous
51 research on AR for subsurface utilities has raised concerns about the accuracy of source data
52 [5, 6, 8, 9], with proportionate correlation to the level of complexity [10] and public safety
53 [9]. Accurate GPS would be required [11] which can facilitate data collection and storage
54 merger [6] signifying that AR could assist with refining the detail of a geospatial model on-
55 site, where live visual links to the back office allow for real-time attribute editing and
56 redlining [11]. Accuracy tolerances range from +/-150mm [12] to 300mm [2, 13] or even
57 500mm [8]. It is suggested that this variation may be the result of geo-locationing reducing
58 accuracy levels to 450mm [6] and possibly even more within street canyons [2, 9]. This has
59 also been attributed to limitation associated with ground penetrating radars (GPR) in
60 capturing data pertaining to new plastic pipes [5], low pressure gas and water pipes, and dead
61 power cables [3]. However, developing technologies such as pit photogrammetry and
62 gyroscopic mapping can provide accuracies well in succession of 150mm [14], or multiple
63 surveying methods to enable accurate data capture [6, 15]. The encapsulation of non-asset
64 data [15] and the lack of control of human errors and surveyors' skill [6] impose some
65 significant challenges. For AR to work in unprepared environments, it is important to have
66 accurate tracking information [5, 9]. This can be achieved by tracking the precise position
67 and orientation of the user and their relative position against the hardware plans [13, 16].

68 **2.2 Model Content and Platform**

69 Due to dynamic and high-risk environment of construction sites, mobile technologies are
70 favoured for hosting AR [4]. Mobile device benefits have been highlighted as: portability,
71 cost and availability [7], while their ability to convey more detailed information has been
72 picked up by others [4] with the possibility of pixel level accuracy [16]. Size and shape [6],
73 color and color compliance with company drawing protocols [13], while following utility
74 disciplines [2], being to scale and having a coherent colour coding schema [17], and
75 transparency [18], displaying data quality [5, 9] as meta-data [2] have been discussed as
76 content requirements of an augmented utility model. It has been suggested that the shape of
77 utilities should differ according to cross-section type [6]. Others have suggested a lower level
78 of detail [19] to improve the processing speed. Depth perception have been picked up [13],
79 with a 5mx5m virtual hole [16, 20] to enhance it [21], and prevent the virtual layer "floating"
80 on top of the real environments, especially in monocular displays [2]. It is suggested that as
81 well as the utility objects, the models also need to consider scene composition [13], or a
82 rendered 3D terrain [6]. Conversely, others point at cost implications [22] or increasing
83 chance of clashes with real-world features [9]. Although field workers may wish to see all
84 underground assets buried at one spot [2], this can be difficult due to large areas covered by
85 utilities [13]. Appropriately filtering the data [2] and simplifying the visualization can help

86 avoid misperceptions [19]. Occlusion has been picked up with relation to on-site safety [18]
87 and surrounding environment [5] and a semi-transparent visualization has been suggested to
88 address it [18]. As discussed previously, communicating the uncertainties associated with
89 visualization accuracy is an essential requirement for operators [6]. This, however, could
90 cause model over-complication. One suggested method is to use meta-information labelling
91 [2], permitting informed field decisions [6] and allowing for rapid cloud-enabled access to
92 data [4], including geophysical meta-data to inform excavation techniques [10]. Others have
93 found that informing field workers of extra tasks and tools provides little benefit [2]. As for
94 platform, ease of use and convenience have been discussed, with respect to platform
95 ergonomics [19] and daylight impact on user's experience [2, 16, 20]. A laptop or screen
96 cover can resolve these problems, but interactivity should be kept at minimum and the device
97 needs to be mounted to keep hands free [2]. Over a decade ago it was believed that 4-5
98 satellites would be able to enable accurate positioning [5]. However, registration is still
99 highlighted as a shortcoming for AR [9]. Using a simultaneous localization and mapping
100 (SLAM) system has been suggested to enable continuous data transmission [7], particularly
101 when combined with a magnetic orientation sensor [22]. Stable localization technologies [7]
102 need to effectively be associated with a grid for future data retrieval and analysis [6].

103 **2.3 Planning and Analysis**

104 Institute of Civil Engineers (ICE) in collaboration with British Standard Institution (BSI)
105 developed PAS 128:2014 to ensure H&S for underground utility detection, verification and
106 locationing. According to PAS 128:2014, Table 1 [12] Quality Level A (QL-A) accuracy is
107 achieved through trial holes prior to which, QL-B data is reflected by painting on the road
108 surface. Previous research highlights issues with time consumption [20], disruption to the
109 public [5], error rates [9, 17] and the lack of persistent visual guidance once the markings are
110 destroyed [22]. AR has been suggested to be applied to assist with this scenario. The use of
111 a mirrored pre-captured environment with 2D surface lines associated with it has been
112 proposed, highlighting accuracy advantages in areas of non-flat topography [20].
113 Conversely, others have suggested that the main benefit of AR is its use in real world/time
114 and not a pre-capture [21]. Arguably, a system has been suggested to integrate interactive
115 scene modifications to update QL-D information to QL-C [20] arguing that the system works
116 well for virtual excavation methods [18]. For planning purposes, this 2D overlay system
117 could assist with standard surveying tasks where AR can be used to take measurements [2]
118 which could be more accurate than manual methods [9]. However, both systems focus on 2D
119 representation without 3D geometry which was a concern for some others [15].

120 **2.4 Excavation**

121 AR can increase the excavation teams' awareness of utilities [4], especially in 44% of works
122 in the UK that take place without a utility search [3]. Lack of persistent visual guidance [6]
123 and the undetermined distance of the excavator bucket to the pipe crown [22] have led to
124 debates around the process of imagination in excavation practices. The use of real time
125 kinematic algorithms to accurately calculate this distance as well as a combination of audio-
126 visual alerts for the operator [8] and proximity analysis [6] have been suggested to address
127 this. However, high-tech AR systems may give a false sense of accuracy [5], resulting in
128 negligence towards H&S in site operations. Even with the most robust AR systems, safety
129 concerns can occur due to personal behaviour and negative attitudes of the AR operators,
130 even if they are well trained [19]. To ensure that inexperienced or untrained workers are not
131 disadvantaged, visual literacy skills should be improved and more than one user should use
132 the platform to ensure safe procurement [19] where a supervisor can observe the AR

133 visualization [8]. While concerns have been raised as interactivity may deter the users'
134 attention from their tasks, [7], some researchers suggest that interactivity provides a more
135 meaningful overlay visualisation [21] and allows for better performance [6]. Either way the
136 excavator operators should have minimal interaction with AR technologies. Having a
137 reference screen within the excavator cabin [22] may be a way forward to reduce H&S risks.

138 **2.5 Socio-Economic Impact**

139 Jung [10] asserts that the use of subsurface utility engineering has potential savings of 10-
140 15% in the US and that the earlier this is implemented, the higher the benefits would be. AR
141 has shown the potential to eliminate the need for surface excavation, reducing environmental
142 damage and its associated costs [13]. Moreover, it shows potential in utility strike avoidance,
143 reinforcing the connections between people and objects through an intuitive mixed reality
144 [22], and reducing the need for interpretation and imagination [9], leading to less error-prone
145 decisions [21]. As a result, there are potential savings in project time and financial resources
146 [8]. It has been suggested that the ratio of indirect to direct cost of repair is 29:1, which does
147 not cover costs associated with back office time and plant costs [3]. Besides, there are other
148 dimensions associated with social implications of utility strikes which will always be
149 assumed as the asset owner's responsibility from the general public perception even if they
150 are not at fault [3]. AR helps contractors with discovery-based learning methods [22],
151 allowing their operators to understand how to avoid or deal with utility strikes if they occur,
152 essential for modern complex engineering projects [19].

153 **3 Research Design and Methodology**

154 This study investigates the applicability of AR technology and its associated tasks for urban
155 utilities and infrastructure in the UK, with an aim to gauge users' perceptions of benefits and
156 limitations of the concept and the technology. A literature review was carried out to build an
157 extensive knowledgebase associated with the application of AR especially for urban utilities
158 to then be used in the design of the research instrument for this study. A mixed-methodology
159 approach was used in primary research to overcome limitations which may have otherwise
160 been inevitable if a single-method approach were used. Quantitative and qualitative methods
161 were applied using a questionnaire survey after the participants took part in an experiment
162 developed for this study, followed by an expert interview to add depth to the study. Particular
163 care was taken to adapt primary research methods in the most appropriate manner in order
164 to avoid giving the impression that AR is a complex or confusing concept especially to those
165 who may have had limited exposure to the concept in its intended context of application. A
166 less considerate approach could have resulted in misrepresentation of, or at best case scenario
167 an unintended bias in, the findings. Pivotal to the data collection instrument of this study was
168 the experiment design which was developed following the break-down of the tasks and
169 intentions required to be fulfilled for the specific purpose of this study. Due to limitation of
170 the space, this paper only presents the questionnaire survey data. The findings of the expert
171 interviews will be presented separately.

172 **4 Data Collection and Analysis**

173 The questionnaire survey was distributed by email using a mixture of two-tiered non-random
174 sampling: purposive and snowball, to ensure that the AEC industry professionals with the
175 most relevant experience are included in the survey. The potential participants were

176 approached through the professional network of the researchers' and were asked to forward
 177 the request to those relevant professionals in their own network. Professionals with less than
 178 1 year experience, students who were undergraduates with no experience in the AEC industry
 179 and those that had no work experience in the AEC industry were deemed ineligible, hence
 180 excluded. Of total 115 survey questionnaires which were issued (23 professionals, 14
 181 colleagues, 5 academics, 11 peers, 28 social media and 34 through snowball sampling), 29
 182 responses were returned (25.22% response rate) of which one was considered invalid due to
 183 mismatched criteria, hence excluded. The questionnaire started with general questions about
 184 the age (with 18-24yr: 21%, 25-34yr: 14%, 35-44yr: 14%, 45-54yr: 25%, 55-64yr: 25%, and
 185 +65yr: 0%), gender (F/M: 21%/78%) and the years of relevant industry experience (1-5yr:
 186 25%, 5-10yr: 17%, 10-15yr: 12.5%, 15-20yr: 12.5%, 20-25yr: 8% and More than 25yr:
 187 25%). There were 4 mature students between respondents with some relevant industry
 188 experience including placement year. Those were excluded from the count of years of
 189 relevant industry experience but were included in the rest of this research. When asked if
 190 they use CAD software packages, out of 28, 11 answered no and the rest indicated use of
 191 AutoCAD (N=14), Revit (N=9), SketchUp (N=8), Civil 3D (N=6), ArchiCAD (N=20),
 192 Bentley Microstation (N=1), Vectorworks (N=1) and others (N=4).

193 Next question concentrates on the existing knowledge of AR between the participants
 194 where 64% stated that they had previous knowledge of AR in gaming such as PokémonGo
 195 (N=5), professional applications (N=4), general (N=4), reading about the subject (N=2) with
 196 media, education and phone applications (N=1, each). Of the participants, 12 stated that they
 197 had some knowledge of PAS128 of whom most were expert users in their professional
 198 practice. The participants then were shown a short video and asked to express their opinion
 199 about the positive and negative aspects of AR for urban utilities. Many highlighted benefits
 200 in relation to visualization aspects, suggesting that a 3D overlay gives a "clear picture of
 201 underground services", with some suggesting that this can "de-risk" an area. Other themes
 202 included convenience and simplicity of the model proposing that this method can sufficiently
 203 identify "hidden" utilities with ease. Some underlining themes included its aspects around
 204 safety and planning, suggesting that this could "prevent service strikes" through its use at a
 205 pre-construction/planning stage as an advisory measure. The least appealing aspect was the
 206 accuracy of visualization, with some suggesting that this was due to GPS, hardware
 207 registration and real time rendering. Others suggest these inaccuracies can occur due to an
 208 individual's interpretation of original utility records. Next question aimed at gauging users'
 209 perception about importance of the meta-data attributions to be included in the AR tool using
 210 a Likert scale (with 1=Not Important to 5=Exceptionally Important). The results indicated
 211 that positional aspects (i.e. accuracy, coordinates and grids) were ranked the highest while
 212 the contact details were perceived as the least important (figure 1).

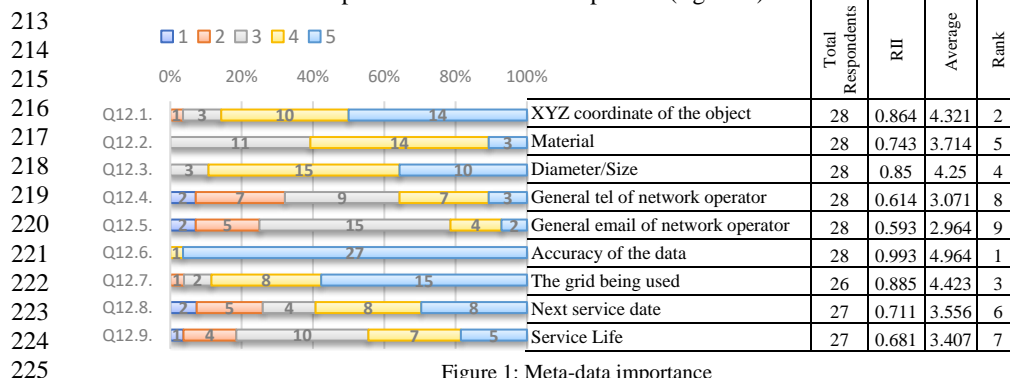


Figure 1: Meta-data importance

226 54% of respondents said they would add to this list with the majority alluding to the date
 227 of the source data being required. Others suggested that the ground conditions (water tables,
 228 foundations, etc.), survey types (PAS:128 Quality Levels) and safety zones should also be
 229 reflected to better advise the user of the data. Some minor accentuations alluded to positional
 230 data in terms of GPS coordination and referring to highways chainage nodes. Next question
 231 asked about participants' perception about the type of projects where AR technology for
 232 infrastructure and utility was deemed most suitable with tunnelling, urban regeneration,
 233 highways, new build and finally agriculture ranking from the most to least suitable.

234 Scenario suitability was the next feature which was gauged. 'Planning new utility
 235 networks', 'training' and 'planning buildings/structures around assets' were the three highest
 236 ranks while 'excavation of the utility asset' was ranked at the bottom of the list of seven
 237 scenarios (figure 2).

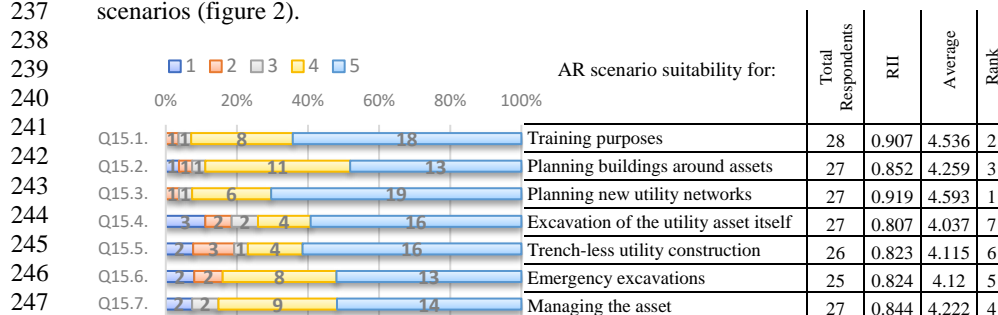


Figure 2: Scenario Suitability

250 Next question was intended to measure users' perception of how application of AR may
 251 affect the existing practice in urban infrastructure and utility sector using a 1-5 Likert scale
 252 (with 1=Strongly Disagree to 5=Strongly Agree). 10 questions were formulated to
 253 investigate this aspect around time, health and safety, incurred costs as well as effectiveness
 254 and ease of use of the technology. There seemed to be a consensus about using AR to help
 255 people better understand location of underground utilities which ranked the first with 96%
 256 agreeing or completely agreeing to it. This followed by AR's role in meeting QA standards
 257 and improving site H&S. The least favourable aspects were those associated with cost and
 258 time (figure 3).

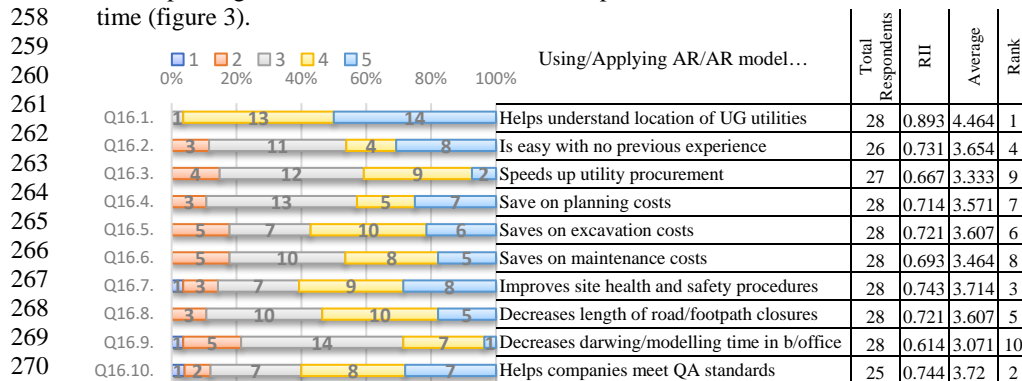


Figure 3: AR impact on existing urban utilities professional

273 Next question was a free-text question and asked about potential barriers the participants
 274 perceived on the way of wider implementation of AR in utility sector where the majority of
 275 respondents pointed towards accuracy of data. They associated this with the source data and

276 its reliability from desktop searches through to trial hole information. Other underlined
277 trends were associated tolerances, signal, software updates, and data management. Users also
278 highlighted their training requirements, site behaviours, resistance to change, detachment
279 from reality as well as legal and liability issues. To conclude the questionnaire, respondents
280 were asked if they would have liked to add any further comments. 35% of participants
281 completed this section. Suitability for the intended project or activity was amongst the raised
282 issues while some participants commented positively on promising future for AR in the
283 sector. In addition to some further concerns surrounding accuracy, one response highlighted
284 nausea and dizziness while watching the video.

285 **5 Discussion of Findings and Conclusion**

286 The findings of this study corroborate those of previous studies such as accuracy and
287 reliability of the source data [5, 6, 8, 9], and the need to include additional information as
288 meta-data [2, 10]. Model content and platform have been picked up by many researchers
289 before (e.g. [2, 4, 6, 7, 12, 13, 18-20]) and the fact that the majority of users in this study did
290 not have any major concerns regarding the experiment, confirms that the platform and model
291 content were successful in achieving the aim of this study. Issues associated with skill
292 shortage [6] did not seem to be a serious concern for the participants of this study as it was
293 believed to be easy for someone with no previous AR experience to become skilful at it.
294 Participants believed that having an AR model would improve site H&S procedures. This
295 may be true as carrying out AR-assisted tasks will reduce H&S risks. It may however, trigger
296 false impressions of safety given by AR; professional negligence; confusion between virtual
297 and actual environment; and finally increased distraction as a result of use of unfamiliar
298 technologies. Some of our findings did not seem to concur with previous reports and
299 researches. This was chiefly associated with cost. While previous research suggests – directly
300 or indirectly – that the use of AR technology for subsurface utility engineering has potential
301 to reduce the direct financial [8, 10] or indirect social [3] and environmental [13] costs, for
302 our participants cost-related issues were not the most positively impactful factors of AR for
303 urban utility. In conclusion, development of new affordable, user-friendly and open-source
304 applications, has made the level of R&D performed in this study possible; something which
305 was not even imaginable a decade ago. Despite being an overall success, the developed
306 experiment for assessing the AR technologies in urban utility infrastructure proved to be a
307 challenge in regards to app development and interoperability. Geo-locationing and geo-
308 tagging are still major concerns and despite long-term promises and hopeful expectations
309 have not yet been completely realized. Therefore, relying on global systems (including
310 cloud-based services and GPS) does not look like the most reliable option and more R&D is
311 necessary to develop local systems to either replace or jointly work with global systems to
312 enhance the accuracy and reliability of AR. As expected, raising awareness, education and
313 training need to improve. These are key to facilitate a major leap forward in exploiting the
314 full benefits such technologies have to offer to the AEC industry and to subsurface utility
315 engineering. With respect to non-AR issues underpinned by this study, it is crucial that the
316 quality and content of infrastructure and utility data are improved and ideally stored centrally
317 in a nationally-procured database.

318 **References**

- 319 1. Milgram, P. and F. Kishino, *A taxonomy of mixed reality visual displays*. IEICE
320 TRANSACTIONS on Information and Systems, 1994. **E77-D**(12): p. 1321-1329.

- 321 2. Schall, G., et al., *Handheld augmented reality for underground infrastructure visualization*.
322 Personal and ubiquitous computing, 13(4), 2009: p. 281-291.
- 323 3. LSBUD, *Digging Up Britain: How Vulnerable is our Utility Infrastructure?* 2017,
324 LinesearchbeforeUdig: London, UK.
- 325 4. Fenais, A., et al. *Meta-Analysis of Augmented Reality Challenges in the Underground Utility*
326 *Construction Industry*. in *Construction Research Congress 2018*. 2018. Tempe, Arizona.
- 327 5. Roberts, G., et al. *The location and positioning of buried pipes and cables in built up areas*.
328 in *Proceedings of XXIII Fig Congress: Shaping the Change*. 2006. Munich, Germany: XXIII
329 FIG Congress.
- 330 6. Talmaki, S., V.R. Kamat, and H. Cai, *Geometric modeling of geospatial data for*
331 *visualization-assisted excavation*. Advanced Engineering Informatics 27, 2013: p. 283-298.
- 332 7. Chi, H.-L., S.-C. Kang, and X. Wang, *Research trends and opportunities of augmented reality*
333 *applications in architecture, engineering, and construction*. Automation in Construction,
334 2013: p. 116-122.
- 335 8. Behzadan, A.H., S. Dong, and V.R. Kamat, *Augmented reality visualization: A review of civil*
336 *infrastructure system applications*. Advanced Engineering Informatics, 2015: p. 252-267.
- 337 9. Côté, S. and A. Mercier. *Augmentation of Road Surfaces with Subsurface Utility Model*
338 *Projections*. in *IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. 2018.
339 Reutlingen, Germany: IEEE.
- 340 10. Jung, Y.J., *Evaluation of subsurface utility engineering for highway projects: Benefit-cost*
341 *analysis*. Tunnelling and underground space technology, 27(1), 2012: p. 111-122.
- 342 11. Nicholls, G. and I.S.T. Powertech, *Using augmented reality as an extension to utility GIS*. IST
343 Powertech journal, 2013: p. 62-64.
- 344 12. BSI, *PAS128: Specification for underground utility detection, verification and location*. 2014,
345 British Standards Institute: London.
- 346 13. Schall, G., S. Zollmann, and G. Reitmayr, *Smart Vidente: advances in mobile augmented*
347 *reality for interactive visualization of underground infrastructure*. Personal and ubiquitous
348 computing, 17(7), 2013: p. 1533-1549.
- 349 14. Van Son, R., et al., *A framework for reliable 3-D underground utility mapping for urban*
350 *planning* International Archives of the Photogrammetry, Remote Sensing & Spatial
351 Information Sciences., 2018.
- 352 15. Yan, J., et al., *THREE-DIMENSIONAL DATA MODELLING FOR UNDERGROUND*
353 *UTILITY NETWORK MAPPING*. International Archives of the Photogrammetry, Remote
354 Sensing & Spatial Information Sciences., 2018.
- 355 16. Roberts, G.W., et al., *The use of augmented reality, GPS and INS for subsurface data*
356 *visualization*. FIG XXII International Congress, 2002: p. 1-12.
- 357 17. Meehan, B., *NJ Utility on Forefront with New Mixed Reality Application*, in ESRI. 2017.
- 358 18. Côté, S. and G.-V. Antoine. *Accurate OnSite Georeferenced Subsurface Utility Model*
359 *Visualisation*. in *International Conference on Augmented and Virtual Reality*. 2015. Springer,
360 Cham.
- 361 19. Li, X., et al., *A critical review of virtual and augmented reality (VR/AR) applications in*
362 *construction safety*. Automation in Construction, 2018: p. 150-162.
- 363 20. Côté, S., I. Létourneau, and J. Marcoux-Ouellet. *Augmentation of Live Excavation Work for*
364 *Subsurface Utilities Engineering*. in *ISMAR International Symposium on Mixed and*
365 *Augmented Reality*. 2014. Munich, Germany: IEEE.
- 366 21. Junghanns, S., G. Schall, and D. Schmalstieg, *Employing location-aware handheld*
367 *Augmented Reality to assist Utilities Field Personnel*. 2008, Springer.
- 368 22. Behzadan, A.H. and V.R. Kamat. *Interactive Augmented Reality Visualization for Improved*
369 *Damage Prevention and Maintenance of Underground Infrastructure*. in *Construction*
370 *Research Congress 2009: Building a Sustainable Future*. 2009.