11th International Conference (CITC-11)
September 9-11, 2019, London, UK

Augmented Reality for urban utility infrastructure: A UK perspective

Dr. Poorang Piroozfar[1,2,3,4], Mr. Alex Judd[1,3], Mr. Simon Boseley[3], Mr. Amer Essa[3], Dr. Eric R. P. Farr[2,3,4]

[1] School of Environment and Technology, University of Brighton, Brighton, BN2 4GJ, UK
[2] Digital Construction Lab, University of Brighton, Brighton, BN2 4GJ, UK
[3] MAVRiC Research and Enterprise Group, Shoreham-by-Sea, BN43 6AX, UK
[4]NONAMES Design Research and Studies, 1249 F Street, San Diego, CA 92101, USA
A.E.Piroozfar@brighton.ac.uk

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

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

1 Introduction

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

As part of a comprehensive study on application of AR technologies for urban utility infrastructure, this paper sets out to contribute to the state-of-the-art in in this area by presenting the results of an industry survey in the UK. Firstly, a critical review of literature on AR and its associated aspects and areas is carried out. The paper then reports on the findings of a survey which was conducted after the participants partook in a hands-on trial of the AR experiment primarily developed for this study. The experiment was intended to be applicable to a variety of mobile devices. The results of the survey conformed, in principles, to majority of findings of the previous research in the field, but also revealed some new or contradictory patterns which are discussed in this paper. As a part of the comprehensive study and once the questionnaire survey was concluded, a series of expert interviews were carried out to enhance the depth of this study and increase validity and reliability of its knowledge claims. The results of interviews are not presented in this paper due to restrictions on paper length.

2 Literature Review

2.1 Data Availability and Accuracy

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

2.2 Model Content and Platform

Due to dynamic and high-risk environment of construction sites, mobile technologies are favoured for hosting AR [4]. Mobile device benefits have been highlighted as: portability, cost and availability [7], while their ability to convey more detailed information has been picked up by others [4] with the possibility of pixel level accuracy [16]. Size and shape [6], color and color compliance with company drawing protocols [13], while following utility disciplines [2], being to scale and having a coherent colour coding schema [17], and transparency [18], displaying data quality [5, 9] as meta-data [2] have been discussed as content requirements of an augmented utility model. It has been suggested that the shape of utilities should differ according to cross-section type [6]. Others have suggested a lower level of detail [19] to improve the processing speed. Depth perception have been picked up [13], with a 5mx5m virtual hole [16, 20] to enhance it [21], and prevent the virtual layer "floating" on top of the real environments, especially in monocular displays [2]. It is suggested that as well as the utility objects, the models also need to consider scene composition [13], or a rendered 3D terrain [6]. Conversely, others point at cost implications [22] or increasing chance of clashes with real-world features [9]. Although field workers may wish to see all underground assets buried at one spot [2], this can be difficult due to large areas covered by utilities [13]. Appropriately filtering the data [2] and simplifying the visualization can help avoid misperceptions [19]. Occlusion has been picked up with relation to on-site safety [18] and surrounding environment [5] and a semi-transparent visualization has been suggested to address it [18]. As discussed previously, communicating the uncertainties associated with visualization accuracy is an essential requirement for operators [6]. This, however, could cause model over-complication. One suggested method is to use meta-information labelling [2], permitting informed field decisions [6] and allowing for rapid cloud-enabled access to data [4], including geophysical meta-data to inform excavation techniques [10]. Others have found that informing field workers of extra tasks and tools provides little benefit [2]. As for platform, ease of use and convenience have been discussed, with respect to platform ergonomics [19] and daylight impact on user's experience [2, 16, 20]. A laptop or screen cover can resolve these problems, but interactivity should be kept at minimum and the device needs to be mounted to keep hands free [2]. Over a decade ago it was believed that 4-5 satellites would be able to enable accurate positioning [5]. However, registration is still highlighted as a shortcoming for AR [9]. Using a simultaneous localization and mapping (SLAM) system has been suggested to enable continuous data transmission [7], particularly when combined with a magnetic orientation sensor [22]. Stable localization technologies [7] need to effectively be associated with a grid for future data retrieval and analysis [6].

2.3 Planning and Analysis

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

2.4 Excavation

AR can increase the excavation teams' awareness of utilities [4], especially in 44% of works in the UK that take place without a utility search [3]. Lack of persistent visual guidance [6] and the undetermined distance of the excavator bucket to the pipe crown [22] have led to debates around the process of imagination in excavation practices. The use of real time kinematic algorithms to accurately calculate this distance as well as a combination of audio-visual alerts for the operator [8] and proximity analysis [6] have been suggested to address this. However, high-tech AR systems may give a false sense of accuracy [5], resulting in negligence towards H&S in site operations. Even with the most robust AR systems, safety concerns can occur due to personal behaviour and negative attitudes of the AR operators, even if they are well trained [19]. To ensure that inexperienced or untrained workers are not disadvantaged, visual literacy skills should be improved and more than one user should use the platform to ensure safe procurement [19] where a supervisor can observe the AR visualization [8]. While concerns have been raised as interactivity may deter the users' attention from their tasks, [7], some researchers suggest that interactivity provides a more meaningful overlay visualisation [21] and allows for better performance [6]. Either way the excavator operators should have minimal interaction with AR technologies. Having a reference screen within the excavator cabin [22] may be a way forward to reduce H&S risks.

2.5 Socio-Economic Impact

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

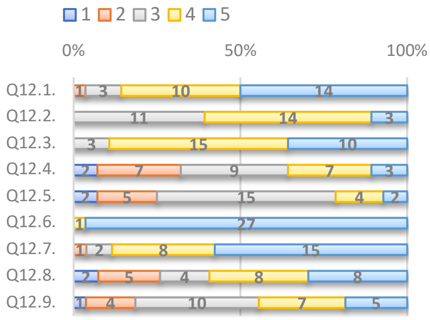
3 Research Design and Methodology

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

4 Data Collection and Analysis

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

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

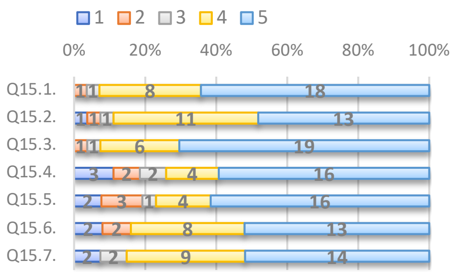


	Total Respondents	RII	Average	Rank
XYZ coordinate of the object	28	0.864	4.321	2
Material	28	0.743	3.714	5
Diameter/Size	28	0.85	4.25	4
General tel of network operator	28	0.614	3.071	8
General email of network operator	28	0.593	2.964	9
Accuracy of the data	28	0.993	4.964	1
The grid being used	26	0.885	4.423	3
Next service date	27	0.711	3.556	6
Service Life	27	0.681	3.407	7

Figure 1: Meta-data Importance

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

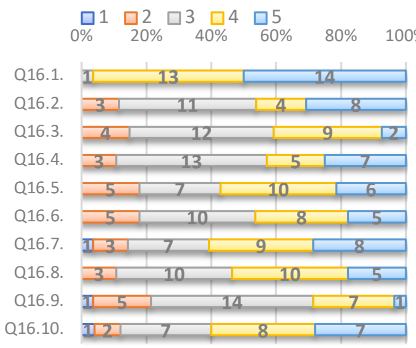
Scenario suitability was the next feature which was gauged. 'Planning new utility networks', 'training' and 'planning buildings/structures around assets' were the three highest ranks while 'excavation of the utility asset' was ranked at the bottom of the list of seven scenarios (figure 2).



AR scenario suitability for:	Total Respondents	RII	Average	Rank
Training purposes	28	0.907	4.536	2
Planning buildings around assets	27	0.852	4.259	3
Planning new utility networks	27	0.919	4.593	1
Excavation of the utility asset itself	27	0.807	4.037	7
Trench-less utility construction	26	0.823	4.115	6
Emergency excavations	25	0.824	4.12	5
Managing the asset	27	0.844	4.222	4

Figure 2: Scenario Suitability

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



Using/Applying AR/AR model…	Total Respondents	RII	Average	Rank
Helps understand location of UG utilities	28	0.893	4.464	1
Is easy with no previous experience	26	0.731	3.654	4
Speeds up utility procurement	27	0.667	3.333	9
Save on planning costs	28	0.714	3.571	7
Saves on excavation costs	28	0.721	3.607	6
Saves on maintenance costs	28	0.693	3.464	8
Improves site health and safety procedures	28	0.743	3.714	3
Decreases length of road/footpath closures	28	0.721	3.607	5
Decreases darwing/modelling time in b/office	28	0.614	3.071	10
Helps companies meet QA standards	25	0.744	3.72	2

Figure 3: AR impact oon existing urban utilities professional

Next question was a free-text question and asked about potential barriers the participants perceived on the way of wider implementation of AR in utility sector where the majority of respondents pointed towards accuracy of data. They associated this with the source data and its reliability from desktop searches through to trial hole information. Other underlined trends were associated tolerances, signal, software updates, and data management. Users also highlighted their training requirements, site behaviours, resistance to change, detachment from reality as well as legal and liability issues. To conclude the questionnaire, respondents were asked if they would have liked to add any further comments. 35% of participants completed this section. Suitability for the intended project or activity was amongst the raised issues while some participants commented positively on promising future for AR in the sector. In addition to some further concerns surrounding accuracy, one response highlighted nausea and dizziness while watching the video.

5 Discussion of Findings and Conclusion

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

References

1. Milgram, P. and F. Kishino, *A taxonomy of mixed reality visual displays.* IEICE TRANSACTIONS on Information and Systems, 1994. **E77-D**(12): p. 1321-1329.
2. Schall, G., et al., *Handheld augmented reality for underground infrastructure visualization.* Personal and ubiquitous computing, 13(4), 2009: p. 281-291.
3. LSBUD, *Digging Up Britain: How Vulnerable is our Utility Infrastructure?* 2017, LinesearchbeforeUdig: London, UK.
4. Fenais, A., et al. *Meta-Analysis of Augmented Reality Challenges in the Underground Utility Construction Industry*. in *Construction Research Congress 2018*. 2018. Tempe, Arizona.
5. Roberts, G., et al. *The location and positioning of buried pipes and cables in built up areas*. in *Proceedings of XXIII Fig Congress: Shaping the Change*. 2006. Munich, Germany: XXIII FIG Congress.
6. Talmaki, S., V.R. Kamat, and H. Cai, *Geometric modeling of geospatial data for visualization-assisted excavation.* Advanced Engineering Informatics 27, 2013: p. 283-298.
7. Chi, H.-L., S.-C. Kang, and X. Wang, *Research trends and opportunities of augmented reality applications in architecture, engineering, and construction.* Automation in Construction, 2013: p. 116-122.
8. Behzadan, A.H., S. Dong, and V.R. Kamat, *Augmented reality visualization: A review of civil infrastructure system applications.* Advanced Engineering Informatics, 2015: p. 252-267.
9. Côté, S. and A. Mercier. *Augmentation of Road Surfaces with Subsurface Utility Model Projections*. in *IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. 2018. Reutlingen, Germany: IEEE.
10. Jung, Y.J., *Evaluation of subsurface utility engineering for highway projects: Benefit–cost analysis.* Tunnelling and underground space technology, 27(1), 2012: p. 111-122.
11. Nicholls, G. and I.S.T. Powertech, *Using augmented reality as an extension to utility GIS.* IST Powertech journal, 2013: p. 62-64.
12. BSI, *PAS128: Specification for underground utility detection, verification and location*. 2014, British Standards Institute: London.
13. Schall, G., S. Zollmann, and G. Reitmayr, *Smart Vidente: advances in mobile augmented reality for interactive visualization of underground infrastructure.* Personal and ubiquitous computing, 17(7), 2013: p. 1533-1549.

14. Van Son, R., et al., *A framework for reliable 3-D underground utility mapping for urban planning* International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences., 2018.
15. Yan, J., et al., *THREE-DIMENSIONAL DATA MODELLING FOR UNDERGROUND UTILITY NETWORK MAPPING.* nternational Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences., 2018.
16. Roberts, G.W., et al., *The use of augmented reality, GPS and INS for subsurface data visualization.* FIG XXII International Congress, 2002: p. 1-12.
17. Meehan, B., *NJ Utility on Forefront with New Mixed Reality Application*, in *ESRI*. 2017.
18. Côté, S. and G.-V. Antoine. *Accurate OnSite Georeferenced Subsurface Utility Model Visualisation*. in *International Conference on Augmented and Virtual Reality*. 2015. Springer, Cham.
19. Li, X., et al., *A critical review of virtual and augmented reality (VR/AR) applications in construction safety.* Automation in Construction, 2018: p. 150-162.
20. Côté, S., I. Létourneau, and J. Marcoux-Ouellet. *Augmentation of Live Excavation Work for Subsurface Utilities Engineering*. in *ISMAR International Symposium on Mixed and Augmented Reality*. 2014. Munich, Germany: IEEE.
21. Junghanns, S., G. Schall, and D. Schmalstieg, *Employing location-aware handheld Augmented Reality to assist Utilities Field Personnel*. 2008, Springer.
22. Behzadan, A.H. and V.R. Kamat. *Interactive Augmented Reality Visualization for Improved Damage Prevention and Maintenance of Underground Infrastructure*. in *Construction Research Congress 2009: Building a Sustainable Future*. 2009.