

Article

The Primacy of As-Built Drawings in the Management of Underground Utility Operations: A New Zealand Study

Sami Maree¹, Funmilayo Ebum Rotimi²  and James Olabode Bamidele Rotimi^{3,*} ¹ Hamilton City Council, Hamilton 3240, New Zealand; samimaree77@gmail.com² Built Environment Engineering, Auckland University of Technology, Auckland 1010, New Zealand; funmi.rotimi@aut.ac.nz³ School of Built Environment, Massey University, Auckland 0745, New Zealand

* Correspondence: j.rotimi@massey.ac.nz

Abstract: There are increasing incidences of damages to underground utilities and services during maintenance and construction works. These have posed significant challenges to utility owners regarding the magnitude and costs associated with remediation works. Therefore, this study investigates the management activities for underground utility maintenance works in New Zealand to establish the significance of as-built drawings as a mitigator of these challenges. Data for the analysis was obtained through a questionnaire survey of asset owners, consultants, and contractors based in three major city centres in New Zealand. The responses are analysed descriptively and inferentially for ease of understanding of the study findings. The findings established the challenges around the as-built records, which were significant to utility damages during construction operations in New Zealand. The study participants highlighted other factors such as poor project management, site records, communication, excavation operator competencies, and inadequate site inventory. Generally, more investment in asset documentation is recommended for asset owners. Innovative approaches to information capture, monitoring and updating of as-built drawings are also suggested to improve on current routine processes. Other solutions relate to skills acquisition and development in the management of underground utility maintenance projects.

Keywords: as-built drawings; excavation works; strikes; utility damages



Citation: Maree, S.; Rotimi, F.E.; Rotimi, J.O.B. The Primacy of As-Built Drawings in the Management of Underground Utility Operations: A New Zealand Study. *Buildings* **2021**, *11*, 399. <https://doi.org/10.3390/buildings11090399>

Academic Editor:
Jurgita Antucheviciene

Received: 30 July 2021
Accepted: 3 September 2021
Published: 7 September 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Urban centres around the world comprise a complex web of utilities that constitute the lifelines of those cities. These utilities can be located above or below ground depending on the type of utilities, the urban infrastructure model, costs, maintenance needs, and operational strategies. There is a general tendency to locate more services underground because of their aesthetic benefits, creating a more modern urban environment. In general, underground utilities comprise power, gas, telecommunication, water, drainage and sewage systems, and other buried services.

Unfortunately, these buried services are quite often damaged, sometimes avoidably and at other times unavoidably. Utility strikes/damages result in service losses and project delays, environmental damages, fatal and non-fatal injuries [1,2]. Ariaratnam and Proszek [3] have also explained that such damages lead to costly litigation and legal consequences that could be avoided through good construction practices. According to Zeiss [4] there were about 400 fatalities from damaged utilities during excavation works in the last two decades, which were in similar proportions as fatalities caused by commercial air crashes in the U.S. Zeiss argues further that, damages to underground utilities add unnecessary costs amounting to about USD 50–100 billion dollars to the US economy. Van Oort, Bregt and de Bruin [5] suggested that damages to underground services in advanced economies were significant, in the order of at least tens of millions of dollars per country per annum.

There are indications that incidences to utility damages are on the increase. CGA [6] reports a 16% rise in utility damages from 439,000 in 2017 to 509,000 in 2018, with excavation works cited as the most common root cause of utility damage. In New Zealand, Waka Kotahi [7] have also indicated that there are significant gaps that need addressing in the identification and protection of utilities during road works, in response to high incidences of damaged utilities. Waka Kotahi have suggested an industry-wide approach to tackling the problem by providing utility information to reduce the frequency of utility strikes/damages. It is evident that challenges around the high rate of damages to underground utilities deserve attention.

Therefore, this study seeks to establish the reasons for utility damages and strikes during construction activities in New Zealand. It further verifies the linkages between the frequency of strikes and the quality of as-built records held by utility owners. Correspondingly, the study questions in the context of underground utility operations in New Zealand are: (1) What are the reasons for utility damages and strikes in New Zealand? (2) Is there any connection between the quality of as-built records and the frequency of utility damages and strikes? In other words, the study investigates the management activities for underground utility maintenance works in New Zealand to establish the significance of as-built drawings as a mitigator. This paper begins by providing a brief review of the study area to expound on the magnitude of the issue. A description of the methods used in the study investigation is given, followed by the presentation of the results and, finally, the implications of the study findings and general conclusion.

2. Underground Utility Damages: A Review

2.1. The Nature of Underground Utility Damages

Al-Bayati and Panzer [1] have indicated that the incidences of damaged underground utilities are on the increase and have heightened the need for improving construction works and processes. Such incidences result from global population growth and technological advances that create a need for regular upgrades of old infrastructure and services. For instance, over half of the world 's population lives in cities, leading to increased capital investment for infrastructure and utility services [8]. Most utilities are buried underground in urban centres to present a visually pleasing built environment. However, damages to those underground utilities have become a common feature of most developed countries, where a significant percentage of utilities are buried [6,9]. Therefore, damages to underground utilities are not unique to New Zealand. It is imperative that stakeholders pay attention to the problem, because correctly planned and well-managed utility infrastructure projects could play a major role in urban sustainability. Trout and Blakeley [10] have linked damages in critical lifelines to poor infrastructure resilience.

As indicated in the introduction, damages to underground utilities can lead to accidents and injuries, production delays and costly service failure [8]. According to Al-Bayati and Panzer [1], disruption to infrastructure services projects occurs daily and on several projects. Identifying the key causes behind underground infrastructure damage provides a strong chance of mitigating future damages. Bilal et al. [11] explain that the different dense networks of buried utilities make construction-related excavation difficult. Especially where comprehensive and accurate documentation of the utilities' location is not available, the threat of damage to utilities resulting from construction works is increased. Subterranean penetration risks causing damage to underground utility operations Infrastructure occur because they have not been documented appropriately [12]. Thus, a well-organized network of services will reduce repair costs and the risk of strikes [13]. Al-Bayati and Panzer [1] conclude that the success of underground damage prevention efforts is dependent on the efficiency and effectiveness of key stakeholders such as: excavators, utility owners, and call centres.

Furthermore, past experience, available project data, utility records, visual site markings, and buried services data held by national and local governments could significantly improve the situation [8]. Al-Bayati and Panzer [1] suggested a three-step process to re-

ducing damages caused to underground utilities. The first step is to require contractors (i.e., excavators) to contact notification centres that will in turn notify utility owners. The second step requires utility owners to mark their utilities. Finally, to require contractors to avoid damages by respecting the marks and exercising care within the tolerance zone established around marked utilities. Their three steps are the primary components of current damage prevention efforts in the United States. While the steps may seem unique to the United States, it has useful application in most developed countries such as New Zealand where a centralised database of buried services is held. In the next section, we provide a brief review of the root causes of underground utility damages to give a clearer understanding of the magnitude of the challenges required to be dealt with.

2.2. The Root Causes of Underground Utility Damages

Researchers have tried to identify reasons why utilities are being damaged during construction work to seek solutions to this nagging construction problem. Generally, the root cause of utility damages is linked to the quality of information held of the utilities before construction operations [14,15]. This information is very often non-existent, incomplete, or inaccurate; hence the probability of damage and strikes increases during construction works. Additionally, Metje et al. [9] describe situations where utilities have been abandoned and untraceable thus contributing to their poor locating accuracies. In addition, the quality of utility location may be hampered by congested services, size and composition of the utilities, and the limitations to the use of site instrumentation due to right-of-ways [14].

Another salient cause of underground utility damage is traceable to the human element. Here, poor data entries and documentation [12], along with stakeholder behaviours [16], are listed as contributory causes. Al-Bayati and Panzer [16] explain that stakeholder behaviours impact damage prevention processes by creating “system noise” through poor communication, excavator and locator behaviours, and poor operating conditions. Other human factor causes are lack of care around the services, rushed jobs and inadequate or poorly planned operations [9]. The primacy of adequate training and skilling-up of construction operatives cannot be overemphasised. This needs to be coupled with the implementation of standard operating procedures around damage prevention.

Jeong and Abrahams [14] have reported issues that are contingent on the use of technology in construction operations for underground utilities, such as causing damages to underground utilities. For example, the capital outlay required for site instrumentation (locators) may be prohibitive, increasing the probability of location inaccuracies. In addition, Jeong and Abrahams [14] suggest that regulatory restrictions can become impediments to the use of certain technologies in underground operations.

2.3. Issues Relating to Poor As-Built Drawings

According to van Oort, Bregt and Bruin [5], excavation works are the main reasons for underground utilities damage or strike. As was previously explained, a major cause is the quality of information or accuracy of spatial data. As-built drawings are the primary source of up-to-date location information for underground utilities, hence the detection period is highly dependent upon the level of details it provides [5]. Low-quality, as-built drawings can result in increased risks and consequently escalated operational costs. Son et al. [17] suggests that lack of as-built drawings quality leads to cost increases and productivity losses due to the need to verify the position of existing onsite utility assets continuously.

Complete and precise as-built drawings are more than simple documents created when a construction project is completed [18]. They are critical tools that provide essential system information in emergency and non-emergency situations (such as information on isolation valve(s) in unidirectional flushing) [18]. Unfortunately, there are instances where some minor alterations to installations may not be apparent. For example, there may have been a need to put a bend in a straight length of pipe during installation. As-built installations should reflect these actual utility changes [18]. Depth records, locations of utilities and

visual markers for utilities could significantly reduce damages during excavation and digging activities. Such accidents will be prevented if the excavator operator is aware of the location of the service in relation to the position of the machinery. Besides disruption to public services, underground strikes have led to the loss of many lives and extensive damage to property worldwide [18].

The inadequacies of as-builts information have been widely studied [19,20]. Incorrect as-built drawings frequently cause additional work, conflicts, and design changes [21]. Furthermore, Zeiss [4] found that low-quality as-built records of underground utilities in Singapore contributed to wrong decisions, lengthy and deceptive planning processes, unnecessary costs, more litigations, and overall impairment of construction success. Other consequences include increased time and costs, improper logistic support management and employee organisations, disruption to utility services, and injury and fatalities [22]. Zhang and Wu [23] estimated that a conservative estimate of public costs was as much as USD 1.5 billion, correlated with buried services' excavation losses in 2016. In their study, Zhang and Wu [23] analysed the reasons for poor as-built drawings to include: (1) overlooked or missing as-built drawings; (2) changes to physical site features; (3) limitations of technology; (4) lack of updates to as-built drawings; (5) errors and mistakes in digitalizing as-built drawings; and (6) changes to utility location without notification.

2.4. Minimising Utility Damages in New Zealand

An innovative approach that commenced in 2008 in New Zealand to provide a central repository of utilities information for 183 different utility services and asset stakeholders, is called "BeforeUdig" (<https://www.beforeudig.co.nz/nz/home> (accessed on 10 December 2020)). BeforeUdig provides as-built information of underground utilities in New Zealand such as locations, depths, and pipes diameters. The service is built for all, from landowners to civil contractors, drainage builders, plumbers, architects, developers, and various other users, where information on the location, hazards, and risks connected with buried services is required. The new system has effectively removed manual processes for most local councils by transforming and expediting the response to inquiries [24]. Australia has a similar service called Dial Before You Dig (DBYD) which enhances communication and collaboration in the form of a one-call service to all stakeholders. The USA has its "One Call" service that operates likewise. The regulations around their use allow a contractor to provide excavation notification, schedule the excavation to prevent hidden utility damages, and maintain clearance between any mechanical or manual digging operations and the service networks. Compliance is statutory and organisations involved in any excavation works are responsible for any damages to the asset owner and are deemed negligent under the law [3].

Conceptualising this sort of process as a control mechanism between participants in the infrastructure assets owners and contractors trying to excavate close to hidden networks has demonstrated the different ways entities could interpret the system and how it affects its use [25]. However, the systems are not fool-proof, existing as-built drawings are not accurate enough to locate utility lines correctly.

In summary, the benefits of maintaining accurate asset as-built records to minimize utility damages and strikes are well known and being proactively implemented. However, studies highlighting inaccurate as-built records and the issues associated with the inaccuracies have not been investigated in New Zealand. In the current study, we analyse the reasons for as-built drawing inaccuracies and investigate the requirements for solving some of the identified inaccuracies.

3. Materials and Methods

This research highlights the significance of as-built records by investigating utility damages and strikes in construction operations. Therefore, a quantitative research method was employed as the epistemology underlying the conduct of the research. Thus, patterns, possible forecasts, and a broader view of the results and their generalisation, could be

established [26]. Participants' responses and feedback were obtained using a questionnaire survey. The questionnaire was semi-structured with both open and closed-ended questions. This was adopted to enable accurate information to be obtained from the respondents. Rotimi [27] believes that the method of data collection depends on the nature of the information required for a research and other prevailing circumstances specific to the study area. The questionnaire survey was designed based on literature review and scholars that investigated similar objectives in other countries. It is noteworthy that, the best way to reach the study participants for this current research is through emails. The questionnaire was distributed among the selected industry stakeholders via emails. Before commencing this research project, the authors sought clearance from Massey University ethics committee since ethical considerations are fundamental in any research project.

This study targeted specific stakeholders (utility asset owners, infrastructure consultants, civil contractors, land surveyors and utility locator specialists). This approach can be regarded as a purposive sampling strategy. Tongco [28] explains that a purposive sampling technique is effective when a non-probability sampling is required to examine an explicit trend of phenomena with well-informed experts. The study participants were selected on the basis of a degree of homogeneity of their roles and experiences in large infrastructure construction operations. This ensures that the data collected was reliable and adequate [29]. The authors needed to ensure that the participants' email addresses were current and up to date, as industry members could leave their jobs and firms, which might affect the participants' contribution to the survey [30].

Due to the absence of annual damage reports through asset owners' websites in New Zealand, the questionnaire survey was sent through a digital word file by email to practitioners between April and July 2020 during the COVID-19 lockdown in New Zealand. The questionnaire survey was administered to 100 different participants in the field of infrastructure construction such as: utility asset owners, infrastructure consultants, civil contractors, land surveyors and utility locator specialists. However, the initial response was low for the first two months, but after email reminders, a total of 34 usable responses were collated for analysis, representing a 34% participation rate. The data collected was considered reliable because of the variety of specialist roles of the respondents, such as: asset owners, engineers, infrastructure consulting firms and contractor project managers, with the majority having at least 10 years of experience in the infrastructure construction field.

The survey consists of 24 questions, divided into two parts. The first part sought viewpoints on current as-built records and their accuracy in New Zealand based on five-point Likert scales. The second part of the survey captured historical records regarding utilities damages during the year 2019; the number of times as-built drawings were requested from asset owners; awareness of specialist locators availability in the market; and one-call (BeforeUdig) services providing utility as-built drawings. The last set of questions was designed to receive respondents' feedback regarding other factors that might affect utility damages on site and recommended solutions from different point of views. The survey covered five major cities in New Zealand, as indicated in Table 1. This study is one of the first undertakings to investigate utility damages and strikes in construction operations in New Zealand.

Analysis of the data was by both descriptive and inferential statistics. The descriptive analysis permits data exploration to be presented in tables, charts, and graphs, which show data distribution patterns that have emerged from a variety of statistical tests [31]. On the other hand, inferential statistics allow the study to draw conclusions that extend beyond the immediate data [32]. For all inferential statistical tests, the threshold was set as $p \leq 0.05$. To check group-wise variations in the population means, independent samples' t-test and one-way ANOVA were conducted. Additionally, the trending scatter with the best fit line was plotted to illustrate the relationship of the two quantitative variables (number of utility damages reported and number of jobs executed by contractors).

Table 1. Participants demographics.

Participants' Information	Responses	No.	%
Roles	Asset owner	6	18
	Consultant	7	20
	Contractor	21	62
Location in NZ	Auckland	15	44
	Wellington	5	15
	Waikato	7	20
	Bay of Plenty	2	6
	Northland	5	15
Respondents reported damages in 2019	Number reporting damages	15	44
	Number not reporting damages	19	56

4. Results

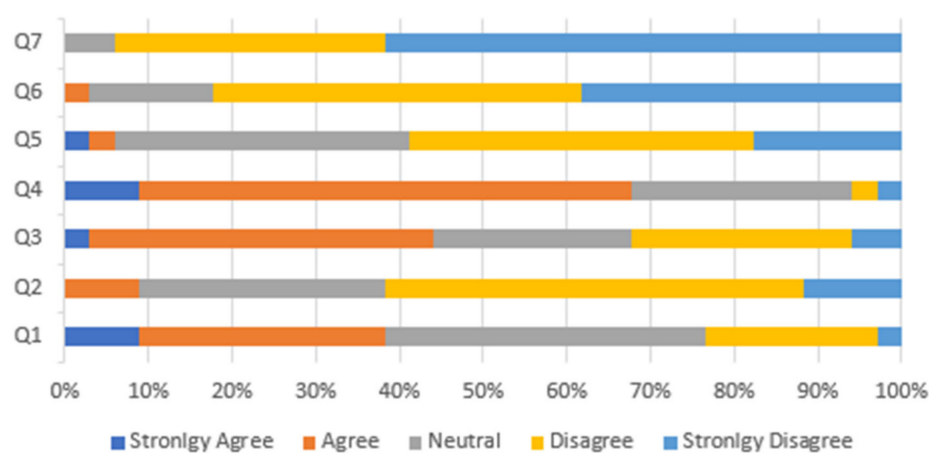
As indicated, the questionnaire had three parts on which the analysis was based. The first part covered the demography of the respondents, the second was on the accuracy of the as-built records and the third part focused on utility damage reports in New Zealand. The results from these aspects of the survey are described in the following subsections.

4.1. Demography of Respondents

Table 1 provides a breakdown of the study participants regarding their roles, location and whether they reported utilities damages within their roles. The demographic information shows that over 70% of the participants work with contractors, and with more than 50% based in the largest regional area of Auckland. Contractors are at the coalface of construction activities involving buried utilities and services. Hence their larger percentage is significant to the reliability of this study's findings. Furthermore, about half of the participants have indicated that they reported utility damages within the last year of their responses to show how prevalent and topical the issue is.

4.2. Accuracy of As-Built Records

The second part of the questionnaire survey consists of seven questions on the accuracy of as-built records and the availability and accessibility of as-builts records in New Zealand. This section employed a five-point Likert scale (Strongly Agree, Agree, Neutral, Disagree, and Strongly Disagree) to permit data analysis. The summary of the response is presented in a stacked bar chart in Figure 1 that summarises the satisfaction levels of respondents to as-built drawings in New Zealand.

**Figure 1.** Satisfaction levels to as-built drawings.

The first question Q1 required respondents to indicate the availability of as-built drawings in New Zealand. The response was mixed, but about 38% agreed that these were available regardless of their levels of accuracy. The second question Q2 was more revealing on the accuracy of available as-built records. Only 38% indicated that they were satisfied with the accuracy of as-built records, 50% were neutral and 12% disagreed. The majority of respondents were unsatisfied with the accuracy of as-built records in New Zealand. Furthermore, the third question Q3 required respondents to indicate their opinions about access to as-built records through asset owners directly. Only 44% of respondents agreed that these were accessible, with 32% disagreeing.

To ascertain satisfaction levels with BeforeUdig services, the fourth question Q4 required respondents to indicate how accessible as-built records were through the service. A total of 68% agree that information on as-builts were easy to find through BeforeUdig services, with only 6% disagreeing. The follow-on question Q5 was desired to determine the accuracy of as-builts received through BeforeUdig. Altogether, 59% disagreed with the statement about the accuracy levels of information received through BeforeUdig. In the sixth question Q6, 82% disagreed with the statement that as-built drawings obtained through BeforeUdig services can be relied upon before commencing excavation works on site.

The last question Q7 wanted to confirm with respondents if as-built drawings were not necessary before excavation works. By disagreeing (94%) with the statement, it meant that respondents saw the relevance of as-built drawings in New Zealand. This also suggests high-level awareness of the importance of as-built records in civil and construction works.

4.3. Analysis of Utilities Damage Records

This section of the survey presents figures provided by the respondents on utilities damages in 2019 (refer Figure 2). The first question Q8, sought to know the number of times they requested as-built drawings from the asset owners, while the second Q9, sought the number of times requests were made through BeforeUdig services. The responses show that in 2019, as-built drawings were requested 488 times from owners, while as-built drawings were requested 508 times from BeforeUdig services. This indicates a high level of awareness about the importance of the BeforeUdig service as a single point of contact to provide assets' as-built records in New Zealand. As a follow-on, respondents were asked Q10 to provide the number of times they requested the services of specialist locating contractors before excavation works. The response was 250 times. On one hand, this reflects the awareness for reducing utility strikes and damages by using specialist utility locators. On the other hand, the use of specialist utility locators, suggest inaccuracies in the information obtained through BeforeUdig services or through the asset owners directly.

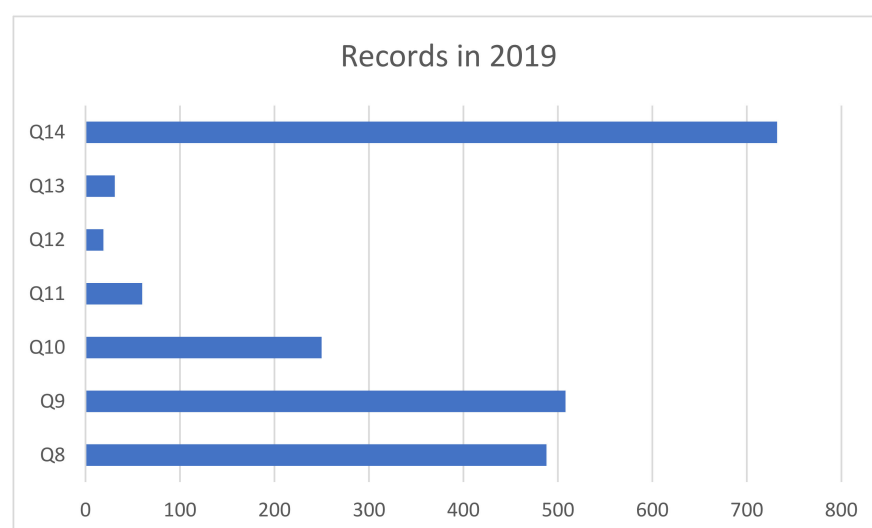


Figure 2. Survey responses to Q8–Q14.

Q11 of the questionnaire was on the number of utility damages reported by the respondents due to absence of, or inaccurate as-built drawings in 2019. The result shows there were 60 incidents of utility damage reported by 44% of the respondents within the period.

In the next questions Q12 and Q13, respondents were to provide the number of utility damages reported without the need for specialist locator services and after the use of specialist locator services. The responses show that 50 damages were reported for other reasons like, site management issues, incompetent operators, miscommunication, and limited accuracy of specialist utility locators. These damage reports are less than the damages resulting from poor as-built drawings of 10 damage reports in 2019. The total number of projects carried out by the 34 participants during 2019 is 732 projects as captured from Q14, noting that the (asset owners) participants are not considered.

4.4. Mitigation of Utility Damage Incidents

This aspect of the questionnaire contained binary responses (Yes/No) to eight questions desired to capture respondents' viewpoints on how utility damage incidents could be mitigated in New Zealand. Table 2 gives a breakdown of the responses. Generally, respondents recommended the use of the services of both BeforeUdig and specialist locators in New Zealand. There was also a consensus that enhanced communication among project parties, proper record keeping, and improved knowledge base and site inventory could reduce utility damage incidents in NZ (Q17–19). Lastly (Q21,22), respondents felt that the human element through operators and their supervising managers significantly influenced utility damage incidents.

Table 2. Breakdown of binary responses.

No.	Questions	Yes	No
Q15	Do you recommend the services of (BeforeUdig)?	33	
Q16	Do you recommend the services of utility locating?	34	
Q17	Do you think enhanced communication amongst construction might reduce utility damage incidents?	26	1
Q18	Do you think keeping better records might reduce utility damage incidents?	26	
Q19	Do you think improved information on knowledge-based might reduce utility damage	26	1
Q20	Do you think a better site inventory might reduce utility damage incidents?	26	
Q21	Do you think lack of experience of Project Managers might increase utility damage incidents?	23	3
Q22	Do you think lack of competency of digging/excavation operators might increase utility damage incidents?	24	2

4.5. Analysis of Open-Ended Responses

Respondents were provided an opportunity to express their views freely on (a) the factors responsible for utility damages and (b) recommendations for improving utility damages in New Zealand.

Respondents' views on the factors responsible for utility damages in New Zealand were grouped under three categories with their corresponding frequency counts as shown in Table 3. The three categories were: technical; management; and standard factors that contribute towards the incidences of utility damages in NZ.

Table 3. Factors causing utility damage.

Main Grouping	No.	Factors	%
Technical	T1	Lack or absence of accurate as-built drawings	18
	M1	Lack of following (BeforeUdig) procedures (locating utilities, preventing damages)	9
Management	M2	Incompetent management and lack of communications, carelessness	24
	M3	Incompetent excavator operators' skills	6
	M4	Pressure on jobs	9
	S1	Absence of adopting standards to specify as-built drawing specifications and inspection	3
Standards	S2	Absence of strikes mitigation standards	3
	S3	Absence of liability against asset owner who own/produced poor as-built drawings	3
	S4	Insufficient allocated resources/budget to improve or produce as-built drawings quality	9

Regarding recommendations for improving utility damages in NZ, the respondents' viewpoints concerning this open-ended question were captured and grouped. The frequency counts for each respective viewpoint are presented in Table 4.

Table 4. Recommendation for improving as-built records.

No.	Respondents Recommendation	%
R1	Asset owner must invest to update existing as-built drawings, relocating services and produce new records	47
R2	Asset owners to address liability/penalties against providing inaccurate as-built drawings	9
R3	Use hydro-excavation instead of excavators where possible	21
R4	Apply mandatory as-built improved standards for all utility services and specify them as part of contract deliverables	18
R5	Apply mandatory utilities surveying during construction by third party surveyors	9
R6	Improve workers skills regarding site safety, excavation and (BeforeUdig) procedures	32
R7	Digitalizing, updating, and transforming all assets drawings into GIS system	15
R8	Consultant must take place in reviewing and approving as-built drawings deliverables	3
R9	Improve assets safe clearance requirements and locating requirements	9
R10	Employ specialist utility service locators before excavation	6

4.6. Further Comparative Analysis

Further analysis was carried out to permit more understanding of the respondents' viewpoints and actions. Tables 5–8 provide tabulations of the descriptive and inferential statistics performed on the data set. Firstly, the data on the number of utility damage reported and the projects carried out in 2019 was represented on a scatter plot (see Figure 3). The scatter plot shows a trending linear relationship meaning that the higher the number of projects handled the more the damages reported.

Furthermore, a t-test statistic was performed to compare the utility damage report and total projects carried out in 2019. The results presented in Table 5 are based on the positive responses from 20 out of the 34 respondents. The results confirmed (see Table 5) that there was larger number of projects carried out (mean = 10.35, SD = 21.98) than for utility damage reported (mean = 2.1, SD = 3.05). Comparing the two, the t-test found that this difference is not significant, $t(19) = 1.81, p < 0.05$. This suggests that as the number of projects increases, so does the number of reported damages, supporting the hypothesis that the total number of projects is a predictor of utility damages reported.

Table 5. Descriptive and inferential statistics result.

Statistic	Measures	Damage Reports in 2019	No of Jobs in 2019
Descriptive Statistic	Mean	2.1	10.35
	Standard Error	0.684028316	4.914679944
	Median	1	4.5
	Mode	0	0
	Standard Deviation	3.059067625	21.97911688
	Sample Variance	9.357894737	483.0815789
	Kurtosis	3.081911542	16.48910653
	Skewness	1.905244401	3.920983482
	Range	10	100
	Minimum	0	0
	Maximum	10	100
	Sum	42	207
	Count	20	20
Inferential Statistic	Pearson Correlation		0.591243756
	Hypothesized Mean		0
	df		19
	t Stat		1.815634867
	P(T ≤ t) one-tail		0.042621295
	t Critical one-tail		1.729132812
	P(T ≤ t) two-tail		0.08524259
t Critical two-tail		2.093024054	

Table 6. Regression analyses.

Measures	Regression Statistics
Multiple R	0.579023494
R Square	0.335268206
Adjusted R Square	0.314495338
Standard Error	2.530522123
Observations	34

Table 7. ANOVA analyses.

Measures	df	SS	MS	F	Significance F
Regression	1	103.3513549	103.3514	16.13972	0.000333489
Residual	32	204.9133509	6.403542		
Total	33	308.2647059			

Table 8. *p*-Value analyses.

Measures	Coefficients	Standard Error	t Stat	<i>p</i> -Value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	0.753123016	0.513113078	1.467753	0.151933	−0.292054123	1.798300154	−0.292054123	1.798300154
X Variable 1	0.076626675	0.019073572	4.017427	0.000333	0.03777508	0.11547827	0.03777508	0.11547827

To verify the reliability of this relation, a model regression test was conducted. Table 6 presents the model summary to determine the correlation coefficient (R) and coefficient of determination (R^2). The results show a value of 0.579 for (R) and 0.335 for (R^2), which are close to 1.0, meaning the dependent and independent sample variances seem to be reliable and fit a regression line. Table 7 shows the result of ANOVA analyses. The results indicate a low value of (*p*-value) as the two compared groups are significantly different (Sig. is less than 0.05). However, the ANOVA regression test shows one of the *p*-values as more than 0.05, while the other value shows less than 0.05, as seen in Table 8. The parameters of possibly liner relation are calculated as 0.73 and 0.077 for an initial relation between the number of conducted jobs and the number of expected utility damages, as

seen in Equation (1) below. Furthermore, (Figure 3) shows a best fit line for the possible linear relation of trending scatter points:

$$Y = 0.73 + 0.077X \quad (1)$$

where:

X is the number of jobs carried out, and Y is the number of utility damages that can be projected to happen under current operating circumstances.

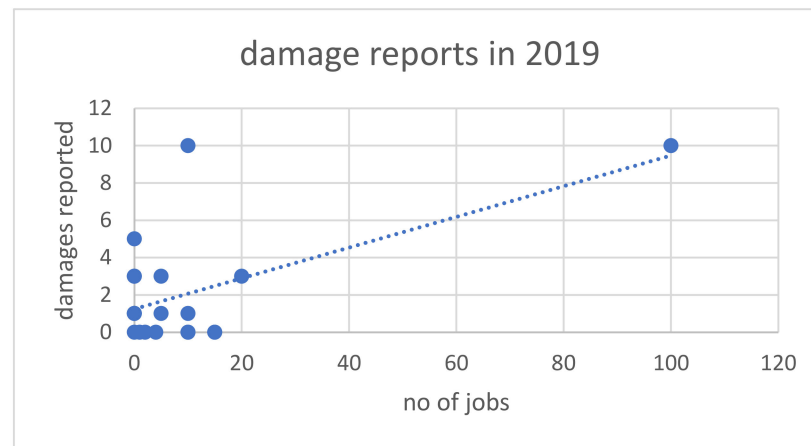


Figure 3. Scatter plot and linear relation graph between reported utility damages and carried out jobs by contractors in 2019.

5. Discussion

This study sought to establish the reasons for utility damages and strikes during construction activities in New Zealand. It verified the linkages between the frequency of strikes and the quality of as-built records held by utility owners so that the significance of as-built drawings could be made more apparent. The findings provided the opportunity, through both descriptive and inferential statistics, to draw insightful conclusions. Generally, there is more room to improve the quality of as-built records that are needed to curb incessant utility strikes and damages in New Zealand.

The reliability of as-built drawings and records are in doubt, considering the study findings on the number of reported utility damage incidents and the number of conducted jobs by construction contractors in New Zealand during 2019. The results show a possible linear regression relation for the tested samples where an initial relation has been created as: $(Y = 0.73 + 0.077X)$, where X: no. of conducted jobs and Y: no. of expected utility damages. For every 100 excavations, one can expect about 8 to 9 utility strikes across the country. This statistic does not appear to be good enough.

According to respondents, the reasons for utility damages in New Zealand have been divided into three categories viz: technical, management and standard issues, with a total of nine factors that cause utility damages. Additionally, 10 solutions were proposed by respondents in order to maintain and improve the quality of as-built records in New Zealand. We discuss the top three solutions briefly.

Larger responsibility was placed on the asset owners themselves, who will need to invest more in gathering, monitoring and updating their existing as-built drawings, use of relocating services and producing new records. In this context, utility asset owners and stakeholders will require standard operating procedures for collecting data during utility construction; as-built drawing specifications; and standard clauses within contract documents to cover strike mitigation prevention and management [33]. The use of innovative Ground Penetrating Radar (GPR) and Electromagnetic Locate (EML) detection tools that are based on Geographic Information Systems (GIS) should become standard in New Zealand. These should complement as-built records obtained through BeforeUdig

services or specialist locators, considering the challenges surrounding accuracy reported in this study.

Furthermore, accuracy in utility location will benefit from investments in other digital technologies. For example, Building Information Modelling (BIM) can enhance geometrical data storage and smart archiving that could facilitate information sharing amongst stakeholders with ease. BIM creates possibilities for rapid updates to as-built records as it lends itself to cloud-based document management systems. In combination with GIS, BIM could deliver convenient visualisations and interoperability in excavation works. [34]

Following the responsibility of asset owners is the training and education of operators, so that the mitigation of utility strikes can become real and achievable. This is the human element in utility damage as a result of operator, and often times supervisor, mistakes. In the literature, Taba et al. [12] refer to poor data entries and documentation by work administrators. While Al-Bayati and Panzer [16] suggest the human element is often at work in adverse stakeholder behaviours on construction projects. The construction industry is the engine of every national economy. With the latest surge in building and infrastructure developments, it has never been more important to invest in training experienced personnel [35]. Whichever way this is perceived, training and education in work requirements can reduce incidents significantly. A substantial number of the respondents recommend hydro-excavation. This technology is gaining popularity in New Zealand as a safer and faster means to uncover utility lines, cable and pipes without damaging them in the process.

Finally, respondents to this study were unequivocal about enlisting external service providers for locating buried infrastructure. In New Zealand, both BeforeUdig and specialist locators were strongly advocated for. Further, the mandatory requirement for using certified/licensed third-party surveyors for specific categories of construction operations could be explored in New Zealand. The study found a consensus on enhanced communication among project parties, proper record keeping, and improved knowledge base and site inventory as the means through which utility damage incidents can be reduced in New Zealand.

6. Conclusions

This study sought to establish the reasons for utility damages and strikes during construction activities in New Zealand. It also determined from practitioners the solutions to these challenges. The study objectives were largely met and the findings were insightful on the improvement required by construction operations that involve underground/buried utilities.

The damages to utilities are significant and in the region of 8 to 9 incidents per 100 excavations in New Zealand. There is need to curb these incidences through better investments in as-built drawings and records. Asset owners should be proactive in their investments in the documentation of as-built records. Innovative Ground Penetrating Radar (GPR) and Electromagnetic Locate (EML) detection tools that are based on GIS systems are suggested in this study. We contend that these should become standardised in every construction operation in New Zealand. When utility strikes occur, asset owners invariably bear the burden of unmet project deliverables. Thus, their commitment to ensuring proper as-built records cannot be overemphasised. The construction industry's investment in BeforeUdig services needs sustaining so that more accurate and up to date information on the location of buried services and other utility assets in and around any proposed excavation sites is realisable.

This study suggests improved training and education of operators and their supervisors, so that the proper mitigation of utility strikes can become achievable. Furthermore, more collaborative approaches between all stakeholders are encouraged. Thus, the increasing uptake of BIM in New Zealand is acknowledged. This has been a game-changer to generating, processing, managing, and sharing project information amongst project stakeholders. Three-dimensional (3D) functionalities afforded by BIM could assist with

locating buried utilities and services and update them more easily to facilitate tracking of as-built conditions. Therefore, BIM has significant benefits to communication between all stakeholders so that there is a more open and committed approach to planning for excavation operations in New Zealand. Finally, this study recommends mandatory requirement for using certified/licensed third-party surveyors for specific categories of construction operations. This requirement could be incorporated into quality control documentation for critical projects.

The study findings provide helpful insight into the understanding into the management of underground utilities in New Zealand. The New Zealand literature surrounding this subject area is thin, and thus, this study portends a good resource for future studies. Future studies could explore technological products and solutions that could improve excavation works for buried utilities. The current research has focused on the improvement of as-built records from a process perspective.

Finally, this study is limited by its sample size because the survey was undertaken during COVID-19 lockdowns. Hence, more empirical studies are encouraged across New Zealand projects to extend the current findings. For example, financial considerations in future studies may help to buttress the primacy of as-built records as a cost-saving measure in underground utility operations.

Author Contributions: Conceptualization, S.M.; methodology, S.M. and J.O.B.R.; validation, S.M.; formal analysis, S.M.; investigation, S.M.; data curation, F.E.R. and J.O.B.R.; writing—original draft preparation, S.M., F.E.R. and J.O.B.R.; writing—review and editing, S.M., F.E.R. and J.O.B.R.; visualization, S.M., F.E.R. and J.O.B.R.; supervision, J.O.B.R.; project administration, F.E.R.; funding acquisition, J.O.B.R. All authors have read and agreed to the published version of the manuscript.

Funding: The APC was funded by the Productivity in Built Environment research group, School of Built Environment, Massey University, New Zealand.

Institutional Review Board Statement: The study was conducted according to the guidelines and approval provided by the Human Ethics Committee of Massey University (notification number 4000022572).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Al-Bayati, A.J.; Panzer, L. Reducing Damage to Underground Utilities: Lessons Learned from Damage Data and Excavators in North Carolina. *J. Constr. Eng. Manag.* **2019**, *145*, 04019078. [CrossRef]
2. Metje, N.; Atkins, P.R.; Brennan, M.J.; Chapman, D.N.; Lim, H.M.; Machell, J.; Thomas, A.M. Mapping the underworld—state-of-the-art review. *Tunn. Undergr. Space Technol.* **2007**, *22*, 568–586. [CrossRef]
3. Ariaratnam, S.T.; Proszek, J.J. Legal Consequences of Damages to Underground Facilities by Horizontal Directional Drilling. *J. Prof. Issues Eng. Educ. Pract.* **2006**, *132*, 342–354. [CrossRef]
4. Zeiss. Reducing Damage to Underground Utility Infrastructure during Excavation: Costs, Benefits, Technical Advances, Case Studies, and Recommendations. 2020. Available online: <https://www.linkedin.com/pulse/reducing-damage-underground-utility-infrastructure-during-geoff-zeiss/> (accessed on 16 May 2020).
5. Oort, P.A.J.V.; Bregt, A.K.; De Bruin, S. Detection and Risk for Digging Activities around Underground Cables and Pipelines: Implications for Spatial Data Quality. *Trans. GIS* **2007**, *11*, 131–149. [CrossRef]
6. CGA. *Damage Information Reporting Tool (DIRT): Analysis & Recommendations*; Common Ground Alliance: Alexandria, VA, USA, 2018.
7. Waka Kotahi NZ Transport Agency. *State Highway Control Manual SM012 Part 18*; New Zealand Transport Agency: Wellington, New Zealand, 2020.
8. Tanoli, W.A.; Sharafat, A.; Park, J.; Seo, J.W. Damage Prevention for underground utilities using machine guidance. *Autom. Constr.* **2019**, *107*, 102893. [CrossRef]
9. Metje, N.; Ahmad, B.; Crossland, S.M. Causes, impacts and costs of strikes on buried utility assets. *Proc. Inst. Civ. Eng.-Munic. Eng.* **2015**, *168*, 165–174. [CrossRef]

10. Trout, E.; Blakeley, R. *Auckland Fuel Supply Disruption Inquiry Report*; Department of Internal Affairs: Wellington, New Zealand, 2019. Available online: <https://www.dia.govt.nz/Auckland-Fuel-Line---Final-Report#Contents> (accessed on 12 March 2020).
11. Bilal, M.; Khan, W.; Muggleton, J.; Rustighi, E.; Jenks, H.; Pennock, S.; Atkins, P.R.; Cohn, A. Inferring the most probable maps of underground utilities using Bayesian mapping model. *J. Appl. Geophys.* **2018**, *150*, 52–66. [[CrossRef](#)]
12. Taba, S.T.; Zekavat, P.R.; Esgandani, G.A.; Wang, X.; Bernold, L. A Multidimensional Analytical Approach for Identifying and Locating Large Utility Pipes in Underground Infrastructure. *Int. J. Distrib. Sens. Netw.* **2015**, *11*. [[CrossRef](#)]
13. Hong Kong Institute of Utility Specialists. *Guide to Hong Kong Utility Data Management*; Utility Training Institute: Hong Kong, China, 2011.
14. Jeong, H.S.; Abraham, D.M. A decision tool for the selection of imaging technologies to detect underground infrastructure. *Tunn. Undergr. Space Technol.* **2004**, *19*, 175–191. [[CrossRef](#)]
15. Kamat, T. Real-time hybrid virtuality for prevention of excavation related utility strikes. *J. Comput. Civ. Eng.* **2014**, *28*, 04014001. [[CrossRef](#)]
16. Al-Bayati, A.J.; Panzer, L. Reducing Damages to Underground Utilities: Importance of Stakeholders' Behaviors. *J. Constr. Eng. Manag.* **2020**, *146*, 04020107. [[CrossRef](#)]
17. Van Son, R.; Jaw, S.W.; Yan, J.; Khoo, V.; Loo, R.; Teo, S.; Schrotter, G. A framework for reliable three-dimensional underground utility mapping for urban planning. *ISPRS-Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2018**, *42*, 209–214. [[CrossRef](#)]
18. Angers, J. As-built Drawings: As Good as Gold. *J.-Am. Water Work. Assoc.* **2001**, *93*, 46–48. [[CrossRef](#)]
19. Adams, G.A. GIS—An Alternative to As-built Drawings. *J.-Am. Water Work. Assoc.* **2002**, *94*, 50–55. [[CrossRef](#)]
20. Adam, M.N.; Ahmad, S.F. Causes of project delay: A case study on Clifton (sewage) pumping station. *Civ. Environ. Res.* **2019**, *11*, 1–5. [[CrossRef](#)]
21. Jeong, H.; Abraham, D.M.; Anspach, J.H.; Zemballis, N.M.; Lew, J.; Halpin, D. *Identification of Buried Utilities Using Subsurface Utility Engineering (SUE)*; North American Society of Trenchless Technology: Montreal, QC, Canada, 2002.
22. Osman, H.; El-Diraby, T.E. *Subsurface Utility Engineering in Ontario: Challenges and Opportunities*; University of Toronto: Toronto, ON, Canada, 2005.
23. Zhang, X.; Wu, D. Analysis of the Major Causes of Poor Quality As-built Records of Underground Utilities. *Int. J. Arch. Eng. Constr.* **2017**, *6*, 59–67. [[CrossRef](#)]
24. Hayes, I. Rotorua Lakes Council Improve Accessibility of Information. Available online: <https://www.beforeudig.co.nz/nz/news-events/case-studies/35-rotorua-lakes-council-improve-accessibility-of-information> (accessed on 20 February 2021).
25. Hayes, J.; McDermott, V. Working in the crowded underground: One call services as a boundary object. *Saf. Sci.* **2018**, *110*, 69–79. [[CrossRef](#)]
26. Bhandari, P. What Is Quantitative Research? | Definition, Uses and Methods. Scribbr. 12 August 2020. Available online: <https://www.scribbr.com/methodology/quantitative-research/> (accessed on 20 February 2021).
27. Rotimi, F.E. An Evaluative Framework for Defects in New Residential Buildings: The New Zealand Case. Ph.D. Thesis, Auckland University of Technology, Auckland, New Zealand, 2013.
28. Tongco, M.D.C. Purposive Sampling as a Tool for Informant Selection. *Ethnobot. Res. Appl.* **2007**, *5*. [[CrossRef](#)]
29. Alreck, P.L.; Settle, R.B. *The Survey Research Handbook*, 2nd ed.; Irwin: Chicago, IL, USA, 1995.
30. McPeake, J.; Bateson, M.; O'Neill, A. Electronic surveys: How to maximise success. *Nurse Res.* **2014**, *21*, 24–26. Available online: <https://pdfs.semanticscholar.org/7ec2/ed3bfae1f36616fb1d83d3dfc38887cbaa1d.pdf> (accessed on 20 February 2021). [[CrossRef](#)]
31. Blaxter, L.; Hughes, C.; Tight, M. *How to Research*, 4th ed.; Open University Press-McGraw-Hill Education: London, UK, 2010.
32. O'Leary, Z. *The Essential Guide to Doing Your Research Project*, 3rd ed.; Sage Publications Ltd.: London, UK, 2017.
33. Maree, S. *How Can We Minimize Underground Utility Damages by Improving as-Built Drawings Quality? Master of Construction (Construction Project Management) Research Report*; Massey University: Palmerston North, New Zealand, 2020.
34. Lee, P.-C.; Wang, Y.; Lo, T.-P.; Long, D. An integrated system framework of building information modelling and geographical information system for utility tunnel maintenance management. *Tunn. Undergr. Space Technol.* **2018**, *79*, 263–273. [[CrossRef](#)]
35. Chaparro, D.A.; Ying, F.J.; Rotimi, F.E.; Egbelakin, T. Commute and labour productivity: Investigation of inner city construction sites. *J. Eng. Des. Technol.* **2020**, *18*, 1305–1319. [[CrossRef](#)]

The primacy of as-built drawings in the management of underground utility operations: A New Zealand study

Maree S

2021