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Viability of 3D Utility Modeling for USACE Vertical Construction Projects

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Abstract

Federal construction organizations such as the U.S Army Corps of Engineers (USACE) have continued to use 3D modeling in the realm of Building Information Modeling (BIM) to assist in their construction operations. BIM capabilities have allowed for agile design and increased coordination during construction, and improved data management post completion for the facility. There is a distinct gap in capturing site utilities in 3D space within the BIM models. Site utility work, where miss aligned crossing, inaccurate data, and unknown site conditions can cause major expenses, or delays to the project. To fill this gap the industry has developed 3D utility modeling software to provide similar benefits to a jobsites' civil aspects as BIM does to the main facility. However, all too often these systems are not used in tandem to help inform the jobsite. This paper seeks to provide a preliminary exploration on whether the joint use of BIM and 3D utility modeling is a viable approach for government to produce more efficiently designed, constructed and managed facilities. A qualitative approach using semi-structured interviews with government officials was used in the conduct of this study. The results indicate that it may be too soon to implement this technology on USACE construction projects.

Keywords

Underground Utilities, Federal Construction, BIM, 3D Utility Modeling.

1. Introduction

Underground utility lines and connections are a vital component of public and private facilities which integrate them with local and national service providers. This has led to a highly complex and developed network of utility lines across the world. Unfortunately, due to decades upon decades of construction operations, the exact locations of utility lines are often vaguely known. Particularly underground utilities where the pipes, conduits, and cables are not visible from the surface. To address this issue and prevent costly change orders a new discipline of civil engineering known as Subsurface Utility Engineering (SUE) has been developed. Within the US, SUE typically follows the CI/ASCE 38-02 standard that assigns ratings to the confidence of the location of the utility line, as well as necessitates a deliverable of a drawing and or diagram that depicts the X, Y, & Z coordinates of all utility lines within a project 'Limits of Work' (L.O.W). Occasionally these deliverables take the form of a 3D utility model which can be updated and maintained throughout the life of the installation.

Studies have shown that 3D modeling, and subsurface utility engineering has yielded impressive benefits to construction (Pilia & Anspach, 2014). So much so that the Department of Transportation (DOT) within the U.S has made the involvement of a SUE firm mandatory for many construction projects. There is some agreement that SUE and 3D modeling for construction projects is generally beneficial for general infrastructure. However, data is unclear about SUE, and more specifically 3D utility modeling benefits to primarily vertical projects in the federal construction sector. This paper seeks to examine this ambiguity in data by qualitatively assessing current utility construction methods of those who do design, construction, or facility maintenance within the US federal government to evaluate the viability and usability of adding 3D utility modeling in large vertical construction projects. For these projects sitework is a large component of work and utility strikes or redesign change orders are all too common and costly. While organizations such as U.S Army Corps of Engineers (USACE) are currently implementing Building

Information Modeling (BIM) for large vertical projects, they typically do not implement the equivalent for facility site work. This is important because there is a distinct difference between BIM and 3D utility modeling as BIM is primarily known for building design assistance and less so the site utility location and layout development. In other words, it is not necessary that the use of BIM include a 3D model of site utilities, although it is possible for the design and construction team to do so in commercially available software.

2. Literature Review

It is important to understand how 3D utility modeling differs from standard geographical information systems (GIS). GIS is a computerized system for acquiring, controlling, and displaying data pertaining to the situation on the ground level (Shekargoftar et al. 2022). It primarily uses 2-D data points to provide information. Due to this reliance, it has been found that GIS offers poor tools for operations management during utility work (Lee. Et al. 2018). 3D utility modeling is in a sense a merger of Building Information Modeling (BIM) which has primarily been utilized in the architecture / engineering / construction (AEC) field and spatial 3D GIS. This provides a higher level of detail and a far more easily interpreted data model (Lee. et. al. 2018).

Like the multiple advances in BIM, 3D utility modeling has seen an increase in quality and usability. A growing number of DOTs' have been integrating and using 3D utility modeling (Pilia & Anspach. 2014). These departments have seen noticeable benefits from the implementation of this method. Part of the key components of this modeling method is utilizing a subsurface utility engineering (SUE) firm, is a relatively new discipline of Civil Engineering that focuses on design and construction of subsurface utilities. The primary standard they conduct subsurface site evaluation is ASCE Standard 32-02. This establishes the quality confidence levels of each subsurface utility on site. Once all known utilities on a site have been evaluated and assigned a quality level, the firm will then turn over an end of construction deliverable. Traditionally these deliverables come back as 2-D drawings in form of CADD drawings (Al-Bayati and Kinter, 2022). However, due to the nature of their evaluations they are fully capable of creating and or providing data for the creation of a 3D utility model.

The standard application of 3D utility modeling and their attached SUE firms has traditionally been on horizontal projects, where there are long runs of subsurface utilities with a multitude of crossing points, or infrastructure projects (Meis et al. 2021, Al-Bayati & Kinter, 2022). As one of the largest government construction management organizations the U.S Army Corps of Engineers (USACE) does have the capability to manage projects that utilize 3D modeling. The standards they follow are the Unified Facility Code (UFC) and the Unified Facility Guide Specs (UFGS) which can be found on the Whole Building Design Guide Website (UFGS | WBDG, 2023). 3D utility modeling already has a spec in place to cover how they are to be delivered to the end user. While some horizontal projects may receiver 3D utility modeling in the form Civil Information Modeling (CIM) packages, vertical projects tend to only use BIM without subsurface utilities included. This means there is rarely any real integration of 3D utility modeling on vertical projects leading to reliance upon the traditional 2-D data. SUE can provide immense benefits to the jobsite. The U.S DOT's Federal Highway Administration (FHWA) provided several case study results of projects that have implemented SUE and received noticeable benefits (2017). This is further corroborated by studies such as Coffin et. al. (2022) which demonstrated the importance of proper SUE on utility projects.

As discussed by Zembillas (2012a) the Federal Highway Administration (FHWA), reported that for every dollar spent on SUE they received a savings of $4.62. As described by Zembillas, (2012b), SUE utilizes advanced technologies to accurately identify, characterize, and map underground utilities. Its key activities include designating, locating, and managing data. Combining these activities provides a comprehensive 3D map of utility systems. To do this the subsurface utility engineer must investigate the site and assign each known and discovered subsurface object one of four SUE quality levels (Murphy & Borsack 2020). The SUE level describes how confident the engineer is about the location of the underground utility or object. Using ASCE 38-02 'Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data' the four quality levels are the following.

- Utility Quality Level D- "Information derived from existing records or oral recollections." This is the lowest level of quality for underground utilities and is not a desired rating for any utility on site.
- Utility Quality Level C- "Information obtained by surveying and plotting visible above-ground utility features and by using professional judgment in correlating this information to quality level D information." This quality level is typically seen as the minimal level required for any area of interest within a project site. To achieve this the Engineer or individuals working for the firm must visit the site and perform a survey.

- Utility Quality Level B- “Information obtained through the application of appropriate surface geophysical methods to determine the existence and approximate horizontal position of subsurface utilities. Quality level B data should be reproducible by surface geophysics at any point of their depiction. This information is surveyed to applicable tolerances defined by the project and reduced onto plan documents.” Quality level B is essential for providing highly detailed and accurate data on a utility location when developing a 3D model (Murphy & Borsack 2020).
- Utility Quality Level A- “Precise horizontal and vertical location of utilities obtained by the actual exposure (or verification of previously exposed and surveyed utilities) and subsequent measurement of subsurface utilities, usually at a specific point. Minimally intrusive excavation equipment is typically used to minimize the potential for utility damage. A precise horizontal and vertical location, as well as other utility attributes, is shown on plan documents. Accuracy is typically set to 15-mm vertical and to applicable horizontal survey and mapping accuracy as defined or expected by the project owner.” This represents the highest level of certainty that a professional can provide as the utility has been physically located and verified by the engineer. Often to do this it is necessary to use minimally intrusive excavation methods such as vacuum excavation (Sterling et. Al. 2012). As the cost of achieving a Quality Level of A can be four times as much as achieving a quality level of B it is typically not feasible or prudent to bring every utility up to that quality level (Al-Bayati et al, 2023).

The SUE professional will continue to collect data throughout the process of design and construction constantly updating utility quality levels (U.S Department of transportation, 2022). Upon completion of construction, the SUE firm will provide a deliverable displaying all quality levels within the area of interest. A basic form of this would be a 2-D CADD file that provides the vertical data for the utility line but does not directly depict it. Advances in 3D modeling, however, have increased the capabilities and prevalence of 3D utility modeling being submitted as a deliverable (Pilia & Anspach, 2014).

3. Methodology

A qualitative data collection using semi-structured interview process was adopted in the conduct of this study. This paper seeks to get a holistic view of the potential benefits of 3D utility modeling within the life cycle of a facility, specifically on government projects. Data contained within a 3D utility model is highly focused on the design and construction side of the building life cycle yet integrating BIM modeling with O&M functions have shown great promise. A qualitative analysis will allow for a better examination of the general perceptions and understandings of the potential and limitations for 3D utility modeling integration for O&M functions. A profile of the eight interview participants in presented in Table 1. All interview participants had worked for more than 15 years for the government and had an average experience of 22 years.

Table 1. Interview Participant Profile

Number	Current Position	Years in Current Position	Years with Government
Participant 1	Government, Engineer	24	28
Participant 2	Government, Engineer	3	28
Participant 3	Government, Construction Manager	6	16
Participant 4	Government, Facility Manager	2	19
Participant 5	Government, Construction Manager	6	20
Participant 6	Government, Construction Manager	7	24
Participant 7	Government, Construction Manager	1	16
Participant 8	Government, Construction Manager	13	25

4. Results

A qualitative content analysis methodology was used to analyze open coded interview data. In performance of the qualitative content analysis, it was discovered that 4 overarching themes persisted across all discussions. Those themes were cost, implementation, government capability, and coordination, as shown in Figure 1. The image shows main themes as well as the 3 sub themes attached to each theme. These themes and their sub themes help categorize, compare, and understand the participants’ responses to the questions as a whole. For general clarity and awareness, this paper will discuss each theme and subtheme to understand participant perspectives. Each theme and sub-theme are discussed in the sections below.

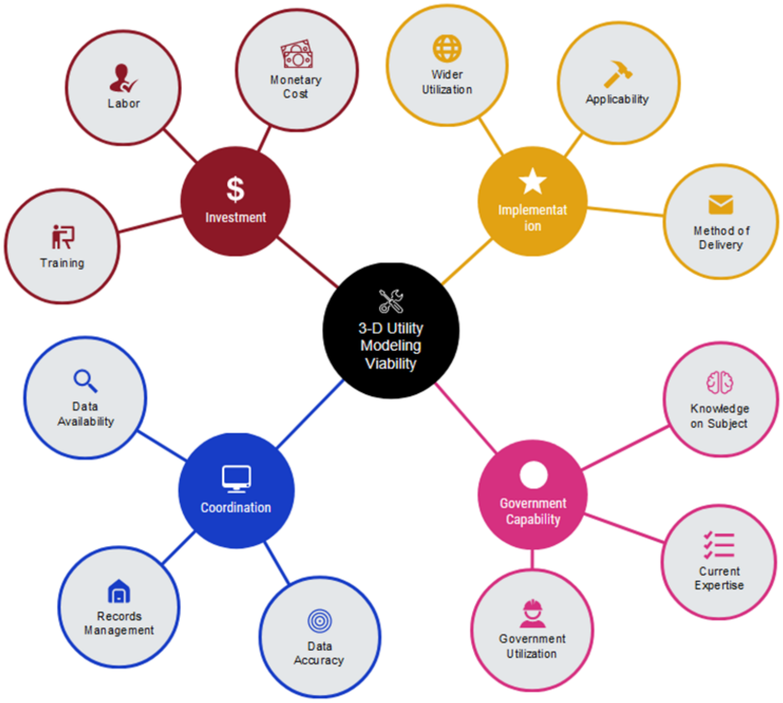

Fig. 1: Qualitative Content Data Analysis

4.1 Cost

The main theme of cost can be broken down into the 3 subcategories depicted, in essence this theme revolves around the commitments that the government must make to facilitate 3D utility modeling for a government facility. Through the nature of the questions asked to each participant, it was universally pointed out that there would be some form of investment required by the government to implement 3D utility modeling. Through the reviewing of the responses the commitment the government must make cannot be one off exchange. There is ongoing labor, monetary, and training costs that must be programmed.

4.1.1 Monetary Cost

The sub-theme of monetary cost revolves around the cost and funding required for the creation and implementation of a 3D utility model. Participants generally listed the monetary cost, of purchasing the model, developer, the cost of gathering accurate data, and the unique funding situation for each individual project. Participant 3 summarized the sentiment best when they stated "...you kind of have to look at everything including total cost of the job". There is a direct cost associated with obtaining highly accurate and reliable utility data, one that must be weighed with the needs of the project. A large multi-million-dollar project does not necessarily provide additional funding towards creation of a 3D utility model. Projects are often programmed with limited contingency funding for construction. The inclusion of a 3D utility model may very well reduce that contingency, which may be an overall deterrent to successful facility delivery.

4.1.2 Labor

The sub-theme of labor revolves around personnel commitments for the government should a 3D utility model be created. When it came to construction and design, participants generally believed that the delivery of a 3D model would best be handled by the general contractor or specialty firm, alleviating the need for continued staffing as part of the building life cycle. Some were concerned however about the requirements for the facility to operate and maintain the 3D utility model. Participant 4 provided the most concise fashion, "We are limited in resources, limited in staff and we have tons of programs that we're already using. Throwing this on to a workforce that's already really trying to manage a super old facility, you know, where does this line up in the overall priority". These models are not self-sufficient and will require periodic updates to remain current and accurate like any other utility data system. That may necessitate the need for specialized personnel to operate and manage the model data. Failure to do so may negate any benefits to having a model.

4.1.3 Training

The last sub-theme related to cost is training. Most participants described 3D Modeling software as complex to operate. For the most part they believe some form of basic familiarization training is required to simply navigate the system. Editing and modeling in the software may take longer which participant 1, described as potential years' worth of additive training to maintain proficiency. The theme was not all negative, as participant 5 found it simple to extract data, while participant 3 described a flattening learning curve as technology improves. This may suggest, as the technology continues to progress, the work force will be able to operate the 3D model with little training commitment by the government.

4.2 Implementation

This theme revolves around what can be gained or lost by implementation of the technology, as well as value determinations of its applicability. The subthemes that emerged from the analysis include applicability, current utilization, and delivery requirements for 3D modeling software, be it for 3D utility modeling and our how it relates to BIM.

4.2.1 Wider Utilization

This sub-theme is about how 3D utility modeling is currently being implemented and developed within the wider industry. First off it is abundantly clear from the data collected that private industry is far more capable of creating and operating 3D utility models. More specifics will be discussed later within this chapter regarding government capabilities, however numerous participants discussed increased integration of 3D modeling software by general contractors. While focused upon sphere of BIM, participants were generally proficient in operating the 3D modeling software for clash detections, and coordination. Participant 3 even stated that "Contractors are going ahead with 3D modeling because it's in their best interest"

4.2.2 Applicability

This-sub-theme is primarily focused on the perceptions of applicability for a 3D utility model in vertical construction. While a large portion of USACE construction jobs contain a vertical component, the vast majority found that 3D utility modeling benefits were not universal, for all primarily vertical projects. Generally, they believed that virgin land, and or small spaced location would not see sufficient benefit of the 3D utility model if they were vertical. With some going as far to say they'd prefer to receive a BIM model only. A potential reason for this is that a 3D utility model could be a standalone system that does may not directly communicate with the BIM model, as such need to be coordinated via a third software, such as Navisworks. That was not to say they didn't see an application. Most in fact stated they saw a sizable benefit for large projects and in particular campus programs where there are vast areas to be developed, and or highly congested utilities. This allows for a greater return on investment, via clash detections, and improved visualization which a majority found as a clear benefit of 3D utility modeling.

4.2.3 Methods of Delivery

This theme is focused upon how and when it is best for the government to receive and begin development of a 3D utility model. As a basic analysis, there are two components to the creation of 3D utility model. The data gathering phase, and its actual creation. Generally speaking, most participants found that subsurface utility data should be gathered as soon as possible, to help facilitate design. That would necessitate the A/E firm to develop the model, however due to the nature of construction they may not have a direct contract with the general contractor. This would mean there could be general liability concerns with what data contained within the model.

The question was raised wither an overarching firm such as SUE would be beneficial in facilitating its creation, however viability of their service during construction operations was generally considered doubtful. Participant 5 described the situation as follows. "…extra service on top of what either the installation will provide or what the contractor would provide you know to be quite honest, I'm not quite sure if we would see an immediate benefit out of that…" In short, USACE in particular already has multiple levels of data verifications and checks which may make an overarching entity redundant. Most felt it was best to receive the 3D model from the contractor at the end of construction in a similar fashion to a standard BIM model.

4.3 Government Capability

The overarching theme of Government capability is focused upon the participants' assessment of the government's ability to leverage the technology of 3D utility modeling. The central thought line is that participants expressed a limitation of the capabilities of the government to utilize 3D modeling in general, be it for BIM or utilities.

4.3.1 Knowledge on Subject

Knowledge on subject was an evaluation of how aware individuals were of the aspects associated with traditional 3D utility modeling development. This is not a determination of skill within the government, and more so an evaluation of what the participant was aware of, and what they or perhaps others were not generally aware of. This is being evaluated as it may help determine what additional information must be gathered and distributed to the field to allow for effective implementation.

Overall, the only area a sizable number of participants were not directly aware of was the role of Subsurface Utility Engineering. This is not unexpected, as indicated by Al-Bayati et al. (2023), SUE is largely unknown within the construction industry in which most participants reside. Anticipating this, and in an effort avoid potential confusion, the terminology of utility locating firm was used for the question, which was universally understood. One subject that participants seemed to mention is the lack of stakeholder awareness or buy in for 3D modeling capabilities. "I honestly think they're taking the BIM model that we send them and they're probably downloading them onto some shared drive somewhere and they're forgetting about it." Regardless of how good a model is when created if it is not used, it results in a wasted effort.

4.3.2 Current Expertise

The subtheme of current expertise is primarily focused on what the government employees can do regarding 3D utility modeling. While the government does possess some knowledge in modeling and creation of creation of 3D utility models, they are highly limited in number. For the most part participants believed the government lacked the expertise to create, manage and operate a 3D model. Participant 8 expressed how the government lacked the field personnel with "the software and the training to be able to successfully use it". This has led to a heavy reliance upon the contractor to produce and quality control the model, raising quality assurance concerns. What's more the participants expressed poor resources of the government to manage and update a model post construction completion. All this may indicate the necessity to conduct a programmed investment to fully utilize the software, be it 3D utility modeling or BIM.

4.3.3 Government Utilization

This subtheme is focused on how the government currently manages and operates 3D models. Vertical projects typically consist of a BIM model only, all though participant 2 described how a 3D subsurface utility was successfully implemented for a naval shipyard. What's more 3D utility modeling, is indeed present within engineering design shops, however as stated earlier, their interest is primarily horizontal construction projects. As mentioned, numerous times within this theme and by participants, the government typically relies upon an A/E firm, contractor, to deliver a usable 3D model. That 3D model is then used by the stakeholder for their record management.

4.4 Coordination

This overarching theme revolves around utility information on a job site, how it's communicated between parties and what data is required for the 3D utility model to be successful used. The participants' opinions were mixed on this theme. Generally, speaking, most felt that the overall quality of facility utility records were improving over time as facilities are updated, allowing for easier coordination yet there was a high variability to the quality. Historic records are harder to track and validate because some records may have been lost, forgotten and or never recorded at all. This makes 3D utility model creation reliant upon new data generated during construction and design which may or not be universally obtainable.

4.4.1 Data Availability

The subtheme of data availability revolves around how easy or hard it is to obtain data for any given site. As referenced earlier participants generally found that data was not always available for a site. Many participants talked about unknown or forgotten utility lines that have been abandoned in place. For older facilities, these records were simply not created thus they cannot be identified in the field without subsurface scanning. This is what creates the situation where differing site conditions can occur. The primary distributors of subsurface utility information are the facility manager and their stakeholders, according to the participants. It is the stakeholders' records that USACE uses to initiate design, inform construction, and update through as-builts. These are not universally well kept or maintained, especially for older facilities. It is perhaps for this reason participant 3 mentioned the utilization of experienced personnel for data collection. Those individuals who are close to retirement can function as a back up to the large amount of knowledge typically unmarked or forgotten in old facilities. Some gaps in information may be filled with that of experienced personnel, neighboring agencies, or private industry.

Some participants spoke about the large amount of control private interties have on federal facilities. As mentioned by participant 6, the government relies upon private services such as local electric and gas companies to provide utility services to government installations. These service providers hold a large amount of authority when it comes to data availability. When the one-call is used to identify utilities, it is their locators who are brought in to identify the line. This means they in effect have control of the timeframe that information will be distributed to the government or the contractor. In addition, participant 3 stated that private entities may not always successfully transfer utility line information to them when they are working on their own lines. Understanding this, the government appears to push the bulk of the responsibility for field verification on to the contractor, to mitigate this uncertainty.

4.4.2 Data Accuracy

The sub-theme of data accuracy revolves around the reliability of the data provided to the designer, contractor, or government construction personnel. Overall, participants held the sentiment that data is improving and is highly accurate for facilities that have been constructed and or heavily renovated within the past 20 years. Facilities that are older tend to have gaps in data or unmarked locations as maintenance operations are not properly reported, and abandoned lines are not marked in as-builts. When it comes to the lines that are currently depicted few had words to add besides participant 1 who spoke upon the accuracy of XY coordinates, with Z coordinates usually only being depicted as part of gravity systems. As described by participant 5 "most of our contracts that build in utility locating requirement as part of the onus of our contractors" which currently leads to the contractor to verify the Z coordinates in the field.

As for the 3D model itself, participants generally expressed the need for the 3D utility model to be accurate to be useful. Participants described editing 3D models as being highly time consuming, and potentially costly. This means that failure to collect accurate data would potentially negate any benefit the software might have. The need for accuracy however must be weighed with the cost of construction. Thus, the most accurate forms of utility location such as test pits, must be done only in areas of necessity. The action of designating priority appears best handled by the A/E.

4.4.3 Records Management

The sub-theme of records management revolves around how that data is stored and distributed to the parties of action. Keeping with the overall trend, participants expressed how data was being managed more efficiently for newer facilities. Part of this appears to be due to digital transfer, post contract completion. When it comes to the 3D model, participants generally found that a 3D utility model would allow for the centralization of data and facilitate easy transfer of information. So long as it is accurate, they can pull material data, maintenance history, and crossing depths from it. As mentioned earlier, however, participants raised concerns that installations were not properly managing the files provided, in addition models that were being produced were not properly being inspected in the field. What's more the actual transfer of the model can potentially be contentious as liability and overall ownership of the data for the model. Multiple entities may have interest in the lines running through the property and those entities may restrict the data input, due to lack of action or security concerns.

When it comes to the communication of data between the 3D utility model, and the BIM model that is traditionally used for vertical construction, participant 1, described how the two systems do not communicate. 3D utility models typically only go to 5 ft. of the building line. At that point they become a part of the building system and are modeled in BIM. This means that any facility that receives a 3D model will in effect have two distinct systems with their own updating requirements. This is likely the reason most participants believed its use best focused on campus programs or large projects, as a single entity can expand the use of the 3D utility model to multiple sites and locations, creating a centralized bank of data.

5. Conclusions

The purpose of this paper was to assess the viability of 3D utility modeling for government installations, with a specific focus on vertical construction. Interviewees spoken to have a high level of experience working within the government, particularly and evaluating government construction, design, and maintenance requirements. Two main conclusions were drawn from the conduct of this research.

- The federal government has been implementing SUE into construction operation however it is markedly different from those utilized by DOT, and other primarily horizontal construction firms. USACE, which handles a large portion of military construction utilizes SUE/locating firms during design and RFP creation yet does not extend their services into construction. Part of the reason appears to be finance and coordination as the firm would require an additional contract held by the government and not the contractor who is operating the site. This would likely lead to questions on controlling the data on site, potentially creating a myriad of conflicts.
- The applicability of additional 3D utility modeling for vertical construction seems highly restricted to very large projects and campus programs where there is a large quantity of subsurface utilities. It does not appear that the government has the resources and capability to effectively leverage 3D utility modeling on a wide scale even though all interview participants saw benefits to the approach.

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