Feasibility of Utilizing Autonomous, Trenchless Tunneling Technology

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The construction industry as a whole has not increased its productivity level as much as other industries in the world. Professionals are constantly trying to think of new ideas and methods to improve the efficiency of construction through new technology. One area in which productivity needs improvement, is in land development. Trenching for underground utilities and services uses a lot of time in a project's schedule as well as costs which can be reduced with the use of autonomous, trenchless tunneling technology such as the "BADGER", (RoBot for Autonomous unDerGround trenchless opERations). This technology is being designed to use a combination of an accelerometer, a gyroscope, a magnetometer, and a GPS to dig a trench in the correct location and at accurate slopes while also utilizing 3D printing technology to create conduit to maintain the tunnel it just created. This concept seems to work in theory; however, it raises some concerns when put to practical use.

Keywords: Construction, Underground Utilities, Land Development, Efficiency

Introduction

Trenchless tunneling is the practice of creating a passageway without disturbing the surface above the excavation. It is a method used when installing or replacing pipes or utilities without the use of conventional open trench construction (Trenchless Tunneling, 2019). The open trench method presents many risks in both safety as well as delays in a project's schedule. Additionally, utilizing the open trench method adds more work and cost with the demolition and replacement of the surface. The added work results in a longer project time and items like general conditions that accrue over time such as traffic control will become more and more expensive. Therefore, any method able to consolidate the project schedule will in turn produce a less expensive project as a whole, given the absence of unforeseen circumstances. Trenchless tunneling is a relatively new technique used for such purposes like those mentioned, but current methods in place are very costly and prove to be unfeasible. Zhao and Rajani who are authors of *Construction and Rehabilitation Costs for Buried Pipe with a Focus on Trenchless Technologies* write, "The data indicate that, in general, costs of the trenchless methods increase with the increase in pipe size. Costs of emergency repairs are more than 3 times the normal repair average." However, the concept has been applied earlier as a way to create transportation tunnels through mountains and underwater bodies using tunnel boring machines (Mishra, 2017). Even though this concept has existed for these purposes, there are more variables to be taken into consideration when performing this method on streets of cities. Existing methods and machinery to perform trenchless tunneling include:

- Horizontal Directional Drilling – A pilot hole is drilled on the proposed line shown on plans with a drill bit that is equipped with a survey tool to monitor the progress of the borehole. A reamer is then used to enlarge the hole to meet the diameter of the required pipe size. Finally, the pipes are then pulled through the hole.

- Horizontal Auger Boring – A rotating cutting head drives a horizontal shaft from the drive to the reception shaft. The excavated material is then brought back to the drive shaft and then removed. As the bore continues on, a hydraulic jack pushes a casing into place.

- Pipe Ramming – Pushing casing or steel pipe into the ground with the force of repeated blows using a ramming tool that is powered by a hydraulic force, like water or fluid pressure. It is a method for both horizontal and directional pile driving.
- Impact Moling – This method involves using a pneumatic hammering tool in the installation of pipes or cables with small diameters. It is easy to operate, has a low cost, and requires little to no excavation for connection and termination pits. The downside to this method is that it is limited to small crossings less than 150 feet and the small diameters of pipes its capable of servicing.

(Mishra, 2017)

Additionally, methods for fixing or rehabilitating existing pipes include:

- Cured-in-Place Pipe – Installing a flexible liner which has been impregnated with thermosetting resins into the existing pipe. The liner must be installed very snuggly into the host pipe before the thermosetting resin is activated by hot water or steam and is allowed to cure and fully harden.
- Thermoformed Pipe – Pipe liners that deformed, flattened, or folded into a C, U or H shape at the time of coiling. The two main types of these pipe liners are polyethylene and polyvinyl chloride (PVC). This method is used in sewer, industrial, and storm pipe repairs. It is also possible to use this method for repairing potable water pipelines because it is non-toxic.
- Sliplining – Method of inserting new pipe by pulling or pushing it into the existing pipe and grouting the annular space. When it is in place, the pipe is grouted to hold the lining in place and for additional rigidity. This method is mostly used to seal leaks and in straight applications.
- Modified Sliplining – This is the same concept as sliplining however, this method utilizes a spiral wound panel or a formed-in-place pipe to reline and rehabilitate aging or damaged pipe.
- In-Line Replacement – The method is similar to pipe bursting. It is the process of installing or upgrading an old sewer line with a new pipeline on the same line. The new installation often has a higher load carrying capacity to improve the function of the sewer when there is a known increase in load. The use of directional drilling makes it possible to replace old pipes without having to dig up roads and driveways. This method is also used to replace old and cracked pipelines that cannot be restored.
- Mechanical Spot Repair – This method essentially aims to repair the insides of the pipe for fractures, cracks, breaks, collapsed pipe sections, infiltration, offset joints, etc. As opposed to replacing the entire pipe, spot repair is used to restore the structural integrity of the pipe. This method can be used in sewage and potable water pipes of all diameters and can be done in a short amount of time from a manhole.

(Mishra, 2017)

Autonomous, Trenchless Tunneling Technology

As mentioned before, the construction industry is constantly striving to find new ways and methods to increase productivity and become more efficient. That is where this concept of autonomous, trenchless tunneling is introduced. Currently, there are no finished and usable machines that are capable of this, however one machine named “BADGER” (roBot for Autonomous unDerGround trenchless opERations) is part of a three-year project led by Spain’s Universidad Carlos III de Madrid (Coxworth, 2017). The diagram shown in figure 1 illustrates the many parts and components that make up this machine. The front of the machine will have a drilling head, which will also use ultrasound to help break apart material that it is auguring into. Behind the drilling head, there are several segments that resemble a worm. These segments are covered with mechanisms that clamp against the inside walls of the tunnel. The rest of the segments then slide along forward relative to those mechanisms, allowing it to use peristaltic wavs to inch its way along. On the back of the machine will be a 3D printer which will deposit a layer of resin on the walls of the tunnel, reinforcing them and essentially turning the tunnel into a pipe. It will be connected to a control unit on the surface which connects to the machine by power and data cables. This control panel will be operated by crew members who can monitor the progress of the machine or possibly even take over and manually control it if necessary. In addition, at the rear will be a tubular appendage which will pump the dislodged soil up to the surface (Coxworth, 2017).

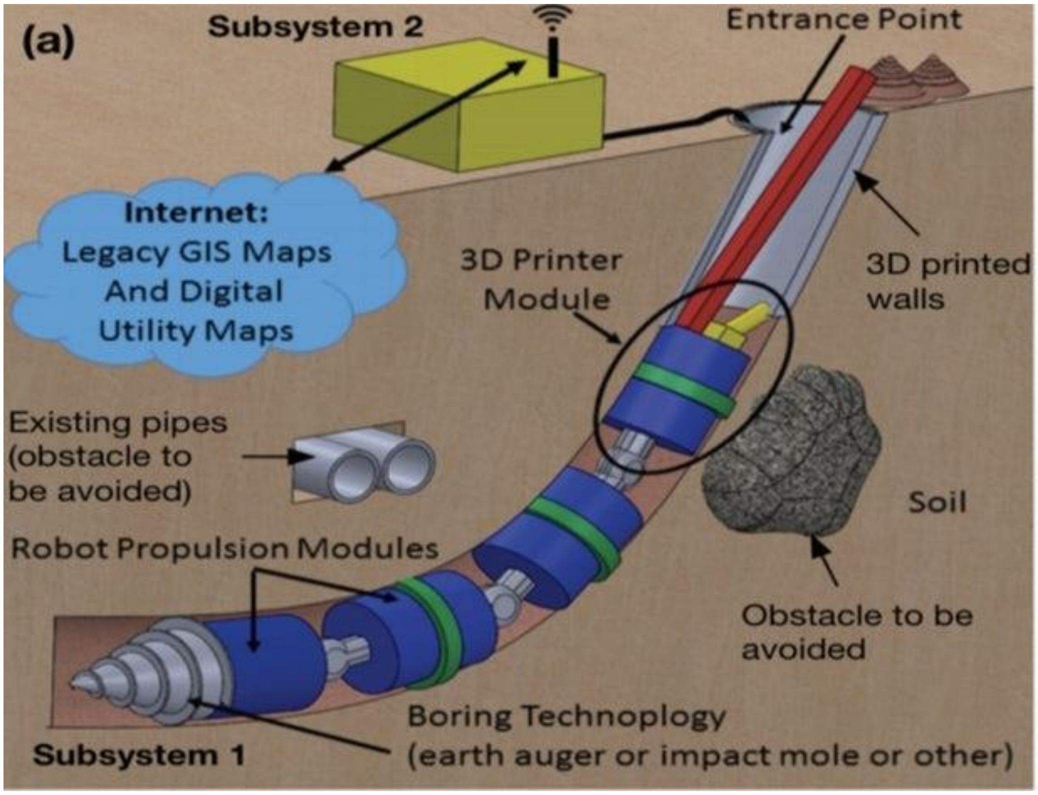

Figure1: “BADGER” Diagram

Source of Information: https://newatlas.com/”BADGER”-tunnelling-robot/50149/

Regarding the technology equipped within the machine, “BADGER” will utilize an inertial measurement unit, which is a combination of an accelerometer, a gyroscope, and a magnetometer. This technology will allow “BADGER” to gauge its relative location within the ground. In addition, it will detect and avoid obstacles in the ground like large rocks and existing pipelines in its path with the use of ground-penetrating radar. However, the path should be relatively clear, or any obstacles should have been already identified by the initial plot of the course of the tunnel done so by the use of a surface-located, ground-penetrating radar unit (Coxworth, 2017).

The use of this technology is best summed up by Professor Carlos Balaguer who is a member of the RoboticsLab at Charles III University of Madrid; “Let’s imagine that we want to connect two buildings standing on opposite sides of a main street in a modern city with a communication cable. In this case, making a trench would be the most common solution applied, [but this] would lead to traffic congestion, pedestrian inconvenience, and environmental pollution. The “BADGER” robot, however, will avoid all these problems through trenchless technology that will make a small hole in the ground, where the cable will be placed. Using its onboard sensors and an intelligent control algorithm, the robot will autonomously navigate from the basement of one building to the other, avoiding collisions with gas and water pipes, metro tunnels [and] big rocks” (Dormehl, 2017). The essence of the purpose behind this innovative technology is illustrated in figure 2. The absence of disturbance to the surface above the trench will prove to enhance the experience for the public during times of underground utility installation in an urban environment as well as provide many benefits to the contractors preforming the work.

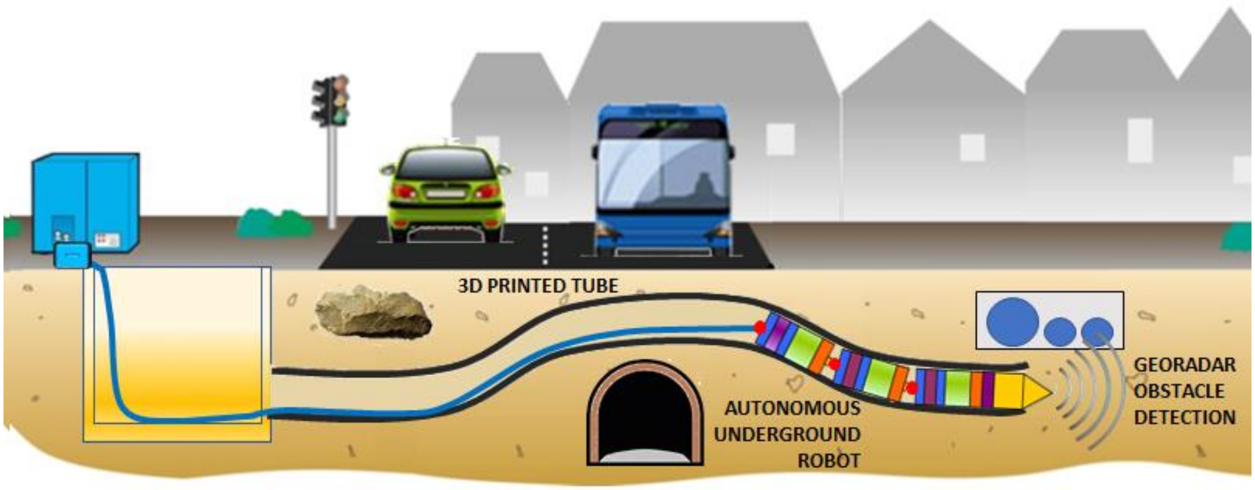

Figure 2: "BADGER" Utilization

Source of Information: https://spectrum.ieee.org/automaton/robotics/industrial-robots/eu-developing-robot-"BADGER"s-for-underground-excavation

Methodology

The objectives of this case study are as follows:

- To identify possible areas of usage in the United States.
- To highlight the advantages of using this technology in underground utility installation projects.
- To highlight the disadvantages of using this technology in underground utility installation projects.
- To determine if using this technology would be feasible for an underground utility contractor in the United States.

The methodology chosen to preform this study was primarily qualitative. The qualitative study was done through interviews of knowledgeable individuals with experience in land development, each with different points of view on such projects. The interviews focused specifically on "BADGER". I asked them what they thought about the concept, about what different situations this technology can be used in, advantages and disadvantages to using it, and if it would be feasible for an underground contractor to own and use in the United States. The feedback from the interviews were then analyzed and summarized in order to identify similarities and differences between the interviewees in order to come to conclusions. From this analyzation, the information gathered was categorized into the following groupings: different situations of usage, advantages, and disadvantages. The organized information was then utilized to conclude whether or not it is feasible to use this autonomous, trenchless tunneling technology on projects in the United States.

Results and Discussion

The following information was gathered through interviews of experienced individuals in the construction industry. The first individual is a superintendent for a heavy civil construction company, the second is a land developer for a local residential homebuilding company, and lastly, the third is a superintendent from an underground utility contractor. The goal of these interviews was to extract information about this technology based on their experience and where they see it most useful, as well as where it may not be practical to use.

Different Situations of Usage

One common topic that was discussed between all three interviews was the different types of projects that this technology would be useful for. The following situations were discussed on whether they would be able to utilize this type of equipment, and if not, then where the issue is with using it:

1. Installing Utilities Across/Along a Road or Body of Water: This was discussed in all three interviews as the most obvious and effective situation to use “BADGER” in because of the fact that it does not disturb the surface above the tunnel. In the case of a road, the pavement above the tunnel will not have to be demolished and repaved in order to complete the work. One catch with using this technology in this situation is that the conduit printed from the back of the machine may not be approved for all types of utilities that are needed to be installed. Therefore, if one of the utilities needed is not approved, then it would not make sense to use this machine for some utilities and then utilize another method to install the others.

2. Moving Overhead Powerlines Underground: There are many projects where a proposed building or development is interrupted by existing powerlines which need to be removed and replaced underground. In this instance, the use of “BADGER” would be beneficial given that the assumption that the rate that it can work is faster than traditional methods of either open-trenched or other trenchless approaches.

3. New Development: Projects in which there are not any existing utilities or development dedicate a lot of time and money trenching and shoring after grading of the site it completed. There are many opportunities in projects like these for the use of this technology for installing sewage, storm water drainage, electrical and communications conduit, water, etc. Using “BADGER” would be able to shrink the schedule immensely which would in turn save money. However, like previously mentioned, some utilities require specific piping material which would mean “BADGER” would have to be capable of printing such material.

4. Wineries: Wineries require a lot of drainage which is done by utilizing natural grades in the land as well as drain lines to direct runoff into drains. These drain lines do not typically need a specific type of pipe which makes this an appropriate situation for “BADGER”.

Advantages

“BADGER” provides the following advantages as according to the interviewed industry professionals:

1. Safety: The biggest advantage to using this trenchless technology is the decreased risk of danger on a job site created from trenching. A large amount of injuries and deaths on job sites have occurred due to trenches caving in. The number one priority for every contractor on every site should be safety which would be greatly increased by the use of this machine and eliminating the digging of trenches.

2. Cost Efficient: Without cost information available from the project team for this machine, it is hard to say if using it will be more cost efficient or not depending on the initial costs, repair costs, and maintenance costs. However, digging deep trenches requires heavy machinery which is not cheap to rent or own with the additional cost of operation. In addition, shoring is another added cost which would be avoided.

3. Time Efficient: Additionally, without information from the project team about how fast this machine can operate, it is difficult to come up with a definitive answer of its effectiveness on a project's schedule, however utilizing "BADGER" means time is saved from the absence of trenching, mobilization and installation of shoring, compaction, demolition, repaving, etc. Taking those activities out of the equation would leave a lot of room for the machine to operate very slowly and still be more time efficient than traditional methods.

4. Crossing Existing Pipes: The precision of drilling across or alongside existing pipes is crucial as to not damage them and cause problems to other utilities. The technology used in "BADGER" allows for it to have this precision which can be more reliable than a crew controlling the dig. Its detection capabilities can also help in preventing damage to the equipment in the case that a large object was on the proposed line of the trench.

Disadvantages/Concerns

"BADGER" provides the following disadvantages and concerns as according to the interviewed industry professionals:

1. Printed Conduit Not Being Approved for all Utilities: The machine is currently limited to projects which allow for the use of the certain material that is created from the 3D printer. Therefore, the material would have to be approved first in order for the machine to be useful. In addition, if some of the pipes needing to be replaced or installed are approved for the machines usage and the others are not, then it would be ineffective to use multiple methods.

2. Trenchless Tunnels Do Not Allow for Inspections for Public Agencies: Inspections of the installation would be difficult to perform because of the fact that there would be no open trench to visibly see the installation. A specific example would be installing electrical lines. The power providing company will need to inspect the installation and approve of it before allowing for the it to be connected.

3. Cost of Resin Material: One major component of the cost of operation for "BADGER" would be the cost of the resin material that is printed to produce the pipe. For this equipment to be considered cost efficient, the resin has to be very cheap compared to the cost of pipe itself. If that material is similarly priced to other pipe options, then it may not be worth it to change methods to utilize this machine.

4. Different Sized Tunnels: Another point of concern that was brought up in the interviews was how "BADGER" could create tunnels of different sizes. Pipes come in many different diameters depending on the required capacity of the utility. Therefore, there must be an ability to drill a variety of different sizes.

5. Compaction Testing: In a conventional trenching method, once the installation is done and the trench has been backfilled, there is compaction testing done prior to repaving or procurement of the finished top surface. Since there would not be disturbance to the surface then it is questionable as how or if compaction testing would be done to complete the project to test the integrity of the tunnel and disturbed ground.

Conclusion

"BADGER" is introducing a new avenue of trenchless tunneling technology to the world that can vastly increase productivity in the construction industry, more specifically in underground installation services. However, looking at the idea conceptually and with the guidance from experienced industry professionals, it raises too many concerns and drawbacks to be feasible at this time. However, as the project team continues to make strides in the prototype and specifications are made available, the technology may catch the attention of contractors willing to take a chance on this advancement in the construction industry.

Further Research

The research done for this project has been very preliminary because at this time, the prototype is not yet complete. This feasibility study has been executed with a conceptual point of view of this technology. Therefore, it would be very useful to repeat this study once there is a functioning prototype and specific specs of the machine are made available. Some important information to strengthen a future study would include:

- the rate of which the machine operates,
- the initial cost,
- operating and maintenance costs,
- how long the machine will last,
- and warranties.

Once this information is made available, then cost and schedule analysis can be performed to establish if this method or other previously used methods would be most effective for different underground utility projects across the United States.

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