

1 Type of the Paper (Article, Review, Communication, etc.)

## 2 Cost And Time Analysis Of 3D printer In Potholes Repair

3 Esha Waris <sup>1\*</sup>, Sana Riaz <sup>1</sup>, Dawood Tahir Mayo <sup>1</sup>, Mutahir Abbas <sup>1</sup>, Malik Sarmad Riaz <sup>1</sup>

4 <sup>1</sup> Civil Engineering, National University of Technology, Islamabad, [Pakistan.sanariazf22@nutech.edu.pk](mailto:Pakistan.sanariazf22@nutech.edu.pk),  
5 [taseerabbasf23@nutech.edu.pk](mailto:taseerabbasf23@nutech.edu.pk), [dawoodtahirf21@nutech.edu.pk](mailto:dawoodtahirf21@nutech.edu.pk), [mutahir@nutech.edu.pk](mailto:mutahir@nutech.edu.pk), sarma-  
6 [driaz@nutech.edu.pk](mailto:driaz@nutech.edu.pk)

7 \* [eshawarisf21@nutech.edu.pk](mailto:eshawarisf21@nutech.edu.pk)

### 8 Abstract

9 The growing demand for sustainable, efficient and long-lasting road maintenance method  
10 has promoted the exploration of innovative technologies in infrastructure repair. This re-  
11 search examines the potential of the performance of 3D printer for repairing the pothole,  
12 focusing on its comparative cost and time performance against the traditional patching  
13 technique. A simulated case study in Rawalpindi compared both approach in term of cost,  
14 and time. The 3D printer utilized a modified asphalt mix incorporating treated face masks  
15 to enhance durability and reduce environmental impact. The analysis revealed that the  
16 cost of 3D printer is higher due to specialized equipment, it's significantly reducing labor  
17 input, material wastage and repair time. Additionally, the automation aspects allow for  
18 consistent repair quality and lower rework frequency. Despite the absence of field work  
19 and regional cost variation the need for further practical evaluation. This research sup-  
20 ports the smart infrastructure technologies aimed at improving road durability, reduce  
21 environmental impact, and optimizing public maintenance resources.

22 **Keywords:** Pothole repairing, 3D printer, Time analysis, Cost estimation.  
23

### 24 1. Introduction

25 Potholes are a global and pervasive problem in road infrastructure, causing damage  
26 to vehicles, traffic congestion, and high maintenance costs. Although potholes are a com-  
27 mon form of pavement distress, but traditional repair methods like cold patching, hot mix  
28 asphalt application, and manual repair are usually just temporary solution, these tradi-  
29 tional methods are inefficient, time consuming, also lead to uneven repair quality and  
30 need repetitive reapplications, particularly in regions with high traffic and unpredictable  
31 weather areas. To deal with such limitations, modern technologies like 3D printing, ro-  
32 botics, and artificial intelligence (AI) are used. They have emerged as the new standard of  
33 road maintenance and infrastructure management.

34 In the last decade, 3D printing has become important in construction industry as it is  
35 able to produce complex geometries, minimize material loss, and accelerate construction  
36 timelines. [1] Provided Basic knowledge and overview of 3D concrete printing, emphasiz-  
37 ing the affordability and can be applied in different types of structure. Using these meth-  
38 ods to a next level [1], Analyzed the feasibility of using waste materials in 3D concrete  
39 printing to make the built environment more sustainable. These results form the founda-  
40 tion for the development of using the 3D printing technologies in asphalt road repair as it  
41 requires the same level of precision, efficiency, and material quality. 3D printing for road

42 repair remains an emerging area and also has shown great potential [2]. Develop 3D-  
43 printed asphalt mixtures which is particularly designed for the maintenance of pavement,  
44 in addition to it, it is also able to dispose material layer-by-layer. Their research showed  
45 the potential for at a time repair with slight traffic disturbance [3]. Gives the idea of a novel  
46 method which is based on the combination of 3D-printing with LiDAR scanning for auto-  
47 mated pavement crack and pothole repair. This technique enables precise mapping and  
48 real-time modification of the material layers of 3D-printing. These initiatives were verified  
49 by [4], who also used a LiDAR-integrated system, focusing on its adaptability in changing  
50 urban environments. Other researches have been focusing on support systems and plat-  
51 forms that can facilitate autonomous use of such technologies. [5] Created a model of a  
52 machine-learning-based pothole repair, which utilizes image recognition and perfor-  
53 mance data to maximize repair timing and methods. In the same vein, [5] proposed a  
54 framework for combining AI with 3D printing infrastructure to attain high autonomy and  
55 efficiency in pothole repair. [6] Proposed a robotized Raspberry Pi-based system for real-  
56 time 3D reconstruction and mapping of potholes, providing a low-cost and scalable solu-  
57 tion appropriate for local governments. In order to guarantee the productivity and long-  
58 term use of 3D-printed repairs, material study is important. Research have done on which  
59 material can be compatible with 3D-printing system for road pavement repair, focusing  
60 on thermal behavior, adhesion, and time setting under natural conditions. These materials  
61 guarantee that 3D-printed patches can handle traffic loads and unpredictable weather in  
62 the long run [4].

63 Field applications and researches are now turning to the results of theoretical and  
64 experimental studies. The result of a 3D asphalt printing in practice and show that how it  
65 could fix pavement cracks in minutes. In his report he also noted the usability of the tech-  
66 nology in the field [7]. A lightweight.

67 robotic platform is designed for pothole repairs, able to cover urban highways, and  
68 moreover he also shows the adaptability of 3D printing solutions for use in various road-  
69 way conditions [5].

70 As a result, these researches suggest that uniting robotic automation, pothole diag-  
71 nosis, LiDAR scanning, and state-of-the-art material science, researchers and engineers  
72 are designing the next generation of infrastructure maintenance technologies that are  
73 more rapid, more precise, and far more environmentally friendly than previous ap-  
74 proaches. These developments not only minimize the expenditures of maintenance for the  
75 long term but also help in realizing the overall vision for smart cities and intelligent road  
76 infrastructure systems. Figure 1 shows the 3D printer which is used to repair a pothole.  
77



78  
79 **Figure 1.** First AI-Driven Pothole Repair Robot, a. Robot Performing pothole repair, and b. AI drone  
80 for potholes repairing

81 This study compares the time and cost-effectiveness of repairing potholes using the  
82 3D printer with traditional methods under simulated conditions. Material consumption,  
83 labor, and machinery accuracy are the main subjects of the study. The automation of the  
84 3D printer increases accuracy and decreases the manual labor involved. While repair  
85 speed and robotics efficiency are not directly acknowledged, the future role of AI also  
86 highlights the logistic and operational limitations and recommends future research on  
87 cost-effectiveness and real-world applicability.

## 88 2. Research Specification

- 89 1. Location – A Rawalpindi Road is selected for this case study.
- 90 2. Test case – A single pothole was repaired using 3D printer and patch machine.
- 91 3. Pothole specification: Length: 1'(0.3048 m), Width: 2'(0.6096 m), Depth: 0.3'(0.09144 m)
- 92 4. Traditional patching time estimates from: a) NHA repair log. b) PEC standards for  
93 maintenance of road.

## 94 3. Methodology 108

95 Cost effectiveness and time efficiency is analyzed in this case study by comparing 3D  
96 printer and patch machine for repairing potholes. Facemask is added in bitumen for 3D  
97 printer to increase its sustainability and durability. The size of the potholes is 1' (0.3048  
98 m) length, 2' (0.6096 m) width and 0.3' (0.09144 m) depth. The methodology is divided  
99 into two major section which is cost and time analysis.

### 100 3.1 Cost Analysis

101 This study's cost analysis aims to compare the overall expenses to repair potholes  
102 using the conventional method and a 3D printer. Material, labor, operational components,  
103 and equipment costs were among the important financial components that were analyzed  
104 step by step in this cost analysis. The material cost is the key component in this analysis.  
105 The price per unit volume of the pre-prepared bitumen mixture, which includes treated  
106 aggregates, is recorded and compared with the conventional asphalt used for repairing  
107 potholes. One of the key advantages of using a 3D printer is that it minimizes the wastage  
108 of material as compared to the traditional method and machine trowel filling method.  
109 Labor costs play a significant role in cost analysis, as the traditional method requires mul-  
110 tiple workers to repair a pothole. The cost analysis also includes the initial investment in  
111 the 3D printer, regular maintenance, and depreciation over time.

### 112 3.2 Material

113 The cost of the material can be calculated per unit volume. Materials include bitumen,  
114 aggregates, and treated additives/mastic, which are mixed in asphalt to increase the sus-  
115 tainability and durability of asphalt. The ratio of additives in asphalt is 0-2% of the aggre-  
116 gates [8]. The material used in the 3D printer is less than that of the conventional method  
117 as the 3D printer analyzes and scans the shape and size of the pothole and prints accord-  
118 ingly.

### 119 3.3 Methodology

120 This study aims at the analysis of cost estimation for the 3D printer. Since there is no  
121 field trial, so the estimation is based on the literature review, rental market rates to simu-  
122 late the repair of potholes, electricity, operational and maintenance cost. The rental price

of 3D printer includes PPKR/hour (likely PKR/hour) with the nozzle diameter of 50 mm/min. The cost of the 3D printer is 5000 [units, possibly PKR or similar].

$$\text{Total cost} = \text{rate per hour} \times \text{total time} \quad (1)$$

As the operational value is already included in the rented value, so we do not calculate these values.

For the traditional method, machinery is not required as the potholes are filled manually, but some semi-mechanized machinery is used by the contractors. The semi machinery includes: asphalt hot box which is used to keep asphalt hot while transporting, vibratory roller to compact asphalt, air compressor to blow out the debris from potholes, and tack coat sprayer to apply adhesive before patching.

### 3.4 Labor

The estimation of the labor is analyzed by simulated conditions and assumed labor wages as there is no field trial for both traditional method and 3D printer.

For the 3D printer, only one technically skilled labor is required for operating and maintenance.

$$\text{Labor cost} = \text{wage rate per hour} \times \text{total hour} \quad (2)$$

For traditional method, a larger crew is required, typically including an operator, material handling, and level handling. A total of two laborers are required for the patch machine.

$$\text{Labor cost} = \text{wage rate} \times \text{total workers} \times \text{total time} \quad (3)$$

### 3.5 Time analysis

The time analysis of this study is based on simulated conditions using machine estimated rates, operational efficiency, and pothole volume. It compares the efficiency, labor involvement, material usage, and total time required between traditional pothole repair methods and an automated 3D printing approach.

The aim is to analyze the total time required to repair a pothole by both 3D printer and patch machine. Since field trials are not conducted, the methodology relies on:

Local municipal repair log - Rawalpindi.

Pakistan specific standards - (National Highway Authority NHA).

### 3.6 Traditional method

The time of the traditional method is calculated by using simulated method and NHA requirement. The time for the traditional method includes 5-10 min for site clearance which also includes traffic clearance from the road and it is done manually while ensuring the safety of the labor. This is followed by clearing the debris and cleaning the pothole which is done manually and often takes 10-15 minutes. Once the clearance is finished, it takes 15-20 min to fill the pothole by asphalt layers which is dependent on its volume and site conditions. After...

(Note: The text appears to be cut off at the end with "After the placement of the asphalt, the compaction is performed, usually done by a single compactor roller and takes additional 10 minutes. When the process is completed, the curing process is accomplished within 2-3 hours to gain strength and durability for permanent repair.

### 3.7 3D Printer Case

In the 3D printer case, the machine is configured with a nozzle diameter of 50 mm and the printer speed is 300 mm/min. The automated system first scans and analyzes the

shape of the pothole and then extrudes the material without the need for external manual labor. The time of the 3D printer depends on the temperature and environmental conditions and takes 2.5-3.5 hours, which is faster than the traditional method. Time calculations are given as follows:

$$\text{Time calculation for traditional} = T_{\text{setup}} + T_{\text{clean}} + T_{\text{fill}} + T_{\text{compact}} + T_{\text{cure}} \tag{4}$$

$$\text{Time required for 3D printer} = T_{\text{scan}} + \frac{V_{\text{potholes}}}{(V_{\text{print}} \times A_{\text{nozzle}})} \times N_{\text{layer}} + T_{\text{cure}} \tag{5}$$

This analysis provides a time-based performance comparison of both the 3D printer and the traditional method. The 3D printer is much faster than the traditional method and requires less labor than the traditional method. The wastage of material is also less as the 3D printer first analyzes the size of the pothole, scans the pothole, and then prints accordingly. This helps in understanding equipment productivity and planning logistics for large pothole repair production.

### 4 Results

This paper illustrates the detailed analysis between 3D printer and traditional methods of pothole repairing. The analysis is for a single pothole case study in Rawalpindi, Pakistan. The data is collected from literature review and by online sources as there is no field trial.

#### 4.1 Time analysis

The estimated time for 3D printer with the nozzle of 50mm diameter and print speed 300mm/sec is 2.5 -3.5 but with the time will reduced if the speed is increased. The analysis for traditional method is done by using NHA specification which include site clearance, debris removal, compaction and curing. The following table shows the time required for the traditional method to repair pothole. Table 1 shows the analysis and difference between the time of 3D printer and traditional method.

**Table 1.** Time analysis of 3D printer and traditional method

Parameter	Traditional method	3D printing (facemask)	Notes
Active labor time	1.5 hours (3 workers)	1 hour	3D printing reduces labor by 50%
Total repair time	2-3 hours	2.5-3.5	Faster curing with polymers

#### 4.2 Cost analysis

Cost estimation of 3D printer and traditional method is also done by theoretical method. 3D printer uses the mixture of bitumen, aggregate and facemask. The cost of 3D printer is 18% higher than the traditional method due to its higher initial cost. But this cost compensates in the long term as it reduced re repair as it gives high strength and durability as compare to the traditional method. Table 2 provide the detail analysis of cost for traditional method and 3D printer.

203

**Table 2.** cost estimation of 3D printer and traditional method

Parameter	Traditional method	3D printer	Notes
Materials	35100 (asphalt + tack coat)	48800	Material cost is high in 3D printer due to fibers i.e., facemask
labor	5550 (2 workers)	4000(1 technician)	Higher wages for skilled labor
Equipment	6500	8000	
Total cost	55670	68300	

204

4.3 Key takeaways

205

The key takeaways of the time estimation are given below:

206

4.3.1 Time estimation

207

1 3D printer is 2X faster than the traditional method. 230

208

2 Active labor reduced by 50%.

209

4.3.2 Cost estimation

210

3D printer is 18% more expensive than the traditional method and it is more expensive when use other fiber rather than the facemask. Long term savings:3D printing avoids frequent re-repairs.

211

212

213

214

215

216

217

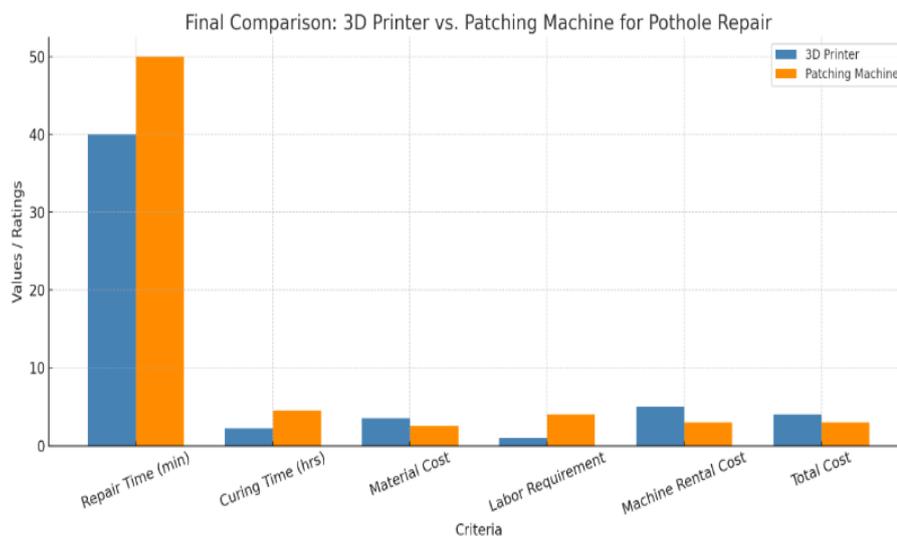
218

219

220

221

The results shows that the 3D printer is more expensive than the traditional method as its initial value is very high but it compensates with the long-term durability as the requirement for re-repair is less than the traditional method. The material wastage in the 3D printer is also less than the traditional method as it scans and analyze the geometry and then fill the pothole. 3D printer is faster than the traditional method in the aspect of time, the more the printer speed increase the less the time will be required In Figure 2the comparison of 3D printer and traditional method is highlighted and provide a difference between repair times, curing time, material cost, labor requirement, machine cost and total cost.



222

223

**Figure 2.** Comparison graph of 3D printer and traditional method

## 5. Discussion:

The comparative analysis of 3D printing and conventional pothole repair approaches proves that 3D printing has obvious benefits concerning time, labor and precision of the repairs, although its initial cost is greater. The 3D printer greatly saves on active participation in work and reduces material waste with automated scanning and the deposition of each layer, achieving a more uniform quality of the repair process and ensuring operational readiness in the shortest possible time, in comparison with conventional patching, which involves a significant amount of manual labor, a multi-step sequence of actions, and a long period of curing. The overall cost of the additive manufacturing technique is estimated as being 18 percent more expensive, due to specialized equipment and special asphalt, laced with modified fiber face mask fibers, but it is worth the result, since durability is increased, the rate of re-repair is decreased, and the aspect of utilizing the waste material is more sustainable. Traditional solutions, in contrast, are not permanent solutions and may need to be maintained every time, which makes them more expensive in the long run and more disruptive to traffic. Although the data are simulated and estimated cost-wise, the results are highly encouraging in that 3D printing can be a highly efficient and sustainable option in repairing the potholes in the city especially when we look at the long-term performance and life-cycle cost of the repair, as opposed to the initial cost of repair.

### 5.1 Limitations

This study provides a comprehensive analysis of cost and time, but there are some limitations as there is no field trial and the analysis is fully based on theoretical studies, simulated conditions, and assumptions. Field conditions vary widely due to temperature changes, traffic density, and labor availability.

Secondly, the cost analysis is based on specific market rates and it may vary with the region and availability of the equipment and project scale. In reality, there are hidden charges that include delivery of the equipment, project scale, operational charges, and others which are not considered in this simplified model.

Another limitation is that the productivity rate of the 3D printer is calculated using theoretical studies and literature, which may not fully reflect the variability in actual operational efficiency due to human involvement and site-specific conditions. Variations in the geometry and shape of real potholes will increase the real scenario time which ultimately affects the cost and time, filament/material usage, etc.

## 6. Conclusion

The study concludes that the 3D printer has a promising effect on pothole repair by utilizing the mastic/additives in the asphalt. While the 3D printer is much faster than the traditional method (reduced repair time up to 50%), the cost of the 3D printer method is slightly higher due to the equipment cost.

The researcher acknowledges the limitations of the theoretical method. Future research should focus on conducting field trials, improving cost-effectiveness, and making the technology acceptable in the real world, including exploring ways to enhance manufacturing resources and establish commercial capabilities.

## References

- [1] Wu, X., et al., *Investigation on interface fracture properties and nonlinear fracture model between ECC and concrete subjected to salt freeze-thaw cycles*. Construction and Building Materials, 2020. 259: p. 119785.

- 270 [2] Tu, H., et al., *Recent advancements and future trends in 3D concrete printing using waste materials*. Developments in the Built  
271 Environment, 2023. 16: p. 100187.
- 272 [3] Soliman-Junior, J., et al., *Automated compliance checking in healthcare building design*. Automation in construction, 2021. 129:  
273 p. 103822.
- 274 [4] Phan, T.M., et al., *Automated repair of asphalt pavement cracks and potholes utilizing 3D printing and LiDAR scanning*. Construc-  
275 tion and Building Materials, 2024. 450: p. 138748.
- 276 [5] Awuah, F.K., A. Garcia-Hernandez, and N. Thom, *Automating the repair of potholes using machine techniques and digitally*  
277 *crafted asphalt cartridges*. Construction Robotics, 2024. 8(1): p. 1.
- 278 [6] Gong, F., et al., *A review on the application of 3D printing technology in pavement maintenance*. Sustainability, 2023. 15(7): p. 6237.
- 279 [7] Bruno, S., et al., *A Small Robot to Repair Asphalt Road Potholes*. Infrastructures, 2024. 9(11): p. 210.
- 280 [8] Yalcin, E., et al., *Influence of pandemic waste face mask on rheological, physical and chemical properties of bitumen*. Construction  
281 and Building Materials, 2022. 337: p. 127576.