DOI: 10.3217/978-3-99161-057-1-056

A novel approach to bridge repair using photogrammetry and additive manufacturing

Raguez Taha[1], Didem Ozevin[1]
[1] Department of Civil, Materials, and Environmental Engineering, University of Illinois Chicago,
842 W Taylor Street Chicago, IL USA
email: rtaha2@uic.edu, dozevin@uic.edu

ABSTRACT: Traditional inspections of aged steel bridges rely primarily on visual assessment, often depending on qualitative analysis and requiring expert engineering judgement. Additionally, these methods are often labor-intensive, time-consuming, and costly, limiting their feasibility for widespread implementation. Accurate condition assessment, due to corrosion loss, remains a challenging factor in structural inspection, complicating the evaluation of its impact on bridge performance. This paper presents a novel workflow that integrates smartphone-based photogrammetry and metal additive manufacturing (AM) to improve condition assessment and enable data-informed repairs. High-resolution 3D models of a corroded decommissioned steel beam retrieved from a Chicago Transit Authority bridge were generated using a photogrammetry pipeline optimized for image quality and overlap. These models allowed for precise quantification of section loss and the design of custom-fit repair parts. A proof-of-concept repair component was fabricated using metal 3D printing and designed to restore the original geometry of a corroded flange section. While mechanical validation of the repair part is ongoing, this workflow demonstrates the potential for scalable, low-cost integration of digital imaging and AM in bridge maintenance.

KEY WORDS: Photogrammetry, Additive manufacturing, Smartphone, Bridge inspection, SHM.

1 INTRODUCTION

In the United States, there are more than 617,000 bridges, and 42% of them are at least 50 years old. About 7.5% are in “poor” condition (or structurally deficient) [1]. Although these bridges are classified as being in poor condition, they are not considered unsafe. However, they require significant maintenance and rehabilitation and are at a higher risk of future closures and weight restrictions. Illinois has the third-largest bridge inventory in the U.S., with 2,405 bridges in poor condition, most of which are locally owned. This creates a significant maintenance backlog. To address this issue, the Illinois Department of Transportation has adopted a cost-effective, continuous maintenance strategy to prevent the need for major rehabilitation [2].

These maintenance strategies rely on visual inspection methods, which require expert engineers and are often subjective, depending on the engineer's expertise. While some nondestructive evaluation (NDE) methods are used, more accurate NDE techniques are often very expensive and require trained personnel to collect and process the data. As a result, they are not widely implemented. A major issue that steel bridges face is corrosion, and quantifying corrosion becomes difficult when relying solely on visual inspections. Additionally, the current repair technologies for corrosion loss are not effective in the long run. The most common repair method for corrosion is reinforcing the affected area with built-up shapes on both sides, which are either bolted or welded to the existing structure. While this 'sandwiching' method restores the cross-sectional area, it does not address the underlying corroded plate, which remains exposed. Corrosion damage can continue to grow, leading to earlier repair needs.

The absence of a cost-effective, easy-to-use method for accurately assessing corrosion loss in steel bridges highlights the need for a more effective approach to documenting and evaluating bridge conditions, as well as for implementing better repair strategies.

This study proposes a practical workflow that integrates smartphone-based photogrammetry and metal additive manufacturing (AM) to enhance the condition assessment and repair of corroded steel bridge components. By utilizing high-resolution 3D reconstructions generated from smartphone-based photogrammetry, this approach enables precise quantification of section loss, improved visualization of deterioration patterns, and more data-driven repair recommendations for aged steel bridges. Additionally, it uses metal additive manufacturing to produce custom repair parts based on the 3D reconstruction models generated from the photogrammetry analysis. By directly translating detailed digital models of the deteriorated sections into precise, tailored components, this approach not only ensures a perfect fit but also improves the overall quality and efficiency of repairs. It reduces material waste by using only the necessary amount of material, minimizes labor by automating the production of repair parts, and shortens repair times by streamlining the manufacturing process. The goal of this proof-of-concept study is to evaluate the feasibility of this workflow as a scalable, low-cost solution that can be incorporated into existing maintenance practices.

2 BACKGROUND

2.1 Photogrammetry in structural health monitoring

Photogrammetry has become a powerful tool in structural health monitoring (SHM), offering a non-contact, high-precision method for assessing and documenting structural conditions. In a study by Valença et.al, photogrammetry was shown to be a reliable alternative to LVDT methods for SHM,

DOI: 10.3217/978-3-99161-057-1-056

especially in inaccessible environments. They developed a methodology using photogrammetry to generate accurate 3D measurements on long-span beams and pedestrian bridges in Aveiro, Portugal. They were able to achieve an average accuracy in the displacement accuracy of 0.1 mm in steel connection tests, which focused on the 'strong beam/column/weak beam' connection [3].

Recently, Unmanned Ariel Vehicle (UAV) photogrammetry has been utilized to create high precision 3D models for dam monitoring to enhance the damage detection and emergency inspection capabilities [4]. In this study, researchers successfully generated detailed 3D models, achieving a Root Mean Square Error (RMSE) of 3.00 cm and 3.95 cm in the horizontal and vertical directions, respectively, when compared to the Ground Control Points (GCPs) [4].

Backhaus et. al combined UAV photogrammetry and structured light scanning to enhance the structural health monitoring of concrete bridges. UAV data was used for crack detection, while SLS scanning was used to obtain detailed measurements. The study found that UAV could detect cracks as small as 0.05 mm [5].

These studies demonstrate that photogrammetry is a reliable method for SHM, enabling accurate damage detection and 3D reconstruction. Its application has shown to improve the effectiveness of structural assessments which would enhance the safety and maintenance planning in the future.

2.2 Additive manufacturing in civil engineering

Additive manufacturing is a process of joining materials layer by layer to create an object from a 3D model (ASTM Standard F2792-12a, 2012). Additive manufacturing enables greater geometric flexibility, allowing for the creation of complex shapes and structures [6-9]. In civil engineering, AM has been utilized in the optimization of connections such as the Nematox façade node [10] and lighting pole nodes [11]. Additionally, it has been utilized in the construction of steel and concrete bridges as well as houses and offices, more notably the MX3D metal pedestrian bridge, Castilla-La Mancha concrete bridge in Madrid, and Winsun houses and offices in Dubai [12-14].

Limited research has been conducted on utilizing AM as a repair technology except most recently in a study by Zhang et al, which investigated the effectiveness of laser additive manufacturing (LAM) for repairing corroded steel bridge beams. This study specifically focused on the mechanical properties and microstructural characteristics of the repaired materials were investigated [15]. The researcher found that the AM repair successful restored the mechanical properties of the defective specimen.

3 METHODOLOGY

This approach can be broken down into three main steps: image capturing, image reconstruction, and repair manufacturing. Further explanation of each of these steps is discussed next.

3.1 Image capturing

Capturing high-quality images if the foundation of reliable 3D reconstruction in photogrammetry. Several variables influence the accuracy and resolution of the resulting model. These variables include image resolution, image overlap percentage, and the camera setup. Image resolution depends on the camera specifications. For example, Agisoft Metashape—used in this study—recommends a minimum resolution of 5 megapixels to achieve suitable model detail. In this study, smartphone cameras were used to demonstrate a low-cost, accessible method for data collection. Another key factor is image overlap, which ensures that surface features are captured from multiple perspectives. A high overlap percentage allows the software to accurately identify and match common points between images. This is critical for generating a consistent and complete point cloud.

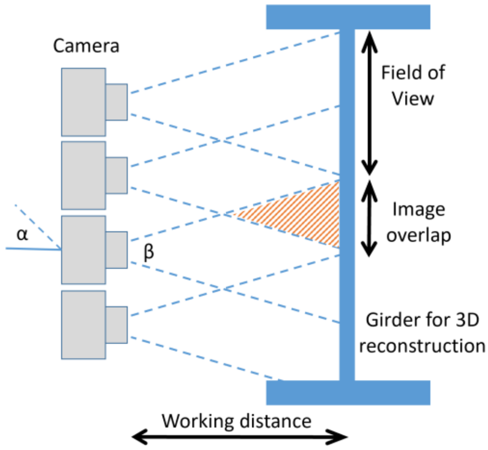

Figure 1. Photogrammetry variables and camera setup.

The overlap ratio is defined using the relationship between the field of view (β) and the camera rotation angle (α), as shown in Equation (1):

$$Overlap\ ratio\ (\%) = \frac{\beta-\alpha}{\beta} \quad (1)$$

In this equation, β represents the camera's field of view, and α is the angular increment between successive images. A smaller α (i.e., closer spacing between photos) leads to higher overlap and better reconstruction accuracy.

Camera orientation and distance to the object also influence data quality. For best results, the object should be captured from multiple angles (e.g., top, side, diagonal views), maintaining consistent lighting and focus. Figure 1 illustrates the recommended image acquisition setup and key photogrammetry variables.

3.2 Image reconstruction

Once images have been captured, the photogrammetric reconstruction process is caried out using Agisoft Metashape. The first step is to upload and review all images, removing any that are blurry or do not contribute additional information about the object. This pre-processing step helps optimize both processing time and model quality. Next, the alignment step generates a sparse point cloud to estimate the camera positions based on the common features detected across the image set. Following alignment, a dense point cloud is generated using depth maps. Using a higher accuracy setting during this step helps preserve finer details.

DOI: 10.3217/978-3-99161-057-1-056

After generating the dense cloud, Metashape constructs a 3D mesh that interpolates the point cloud data into a continuous surface. A confidence map is also produced, indicating the software's certainty in reconstructing each part of the model. Areas with low confidence may correspond to regions with poor image coverage or lighting inconsistencies and should be reviewed to assess the need for additional images.

Finally, a texture layer is applied to the model, projecting the original image data onto the 3D surface to create a realistic visual representation. At this point, the model can be exported for further analysis or used to design a custom repair part.

3.3 Repair manufacturing

After the 3D model is finalized in Agisoft Metashape, it is exported to Autodesk Fusion for design of the repair component. The goal is to digitally reconstruct the missing or deteriorated geometry based on the scanned surface.

To begin, a solid rectangular block is positioned over the corroded area in Fusion. This block is finely meshed to capture the geometry of the underlying surface with high resolution. The Modify → Intersect tool is then used to trim the repair block to match the corroded profile of the scanned model. The result is a 3D repair component that conforms precisely to the section loss, as illustrated in Figure 2.

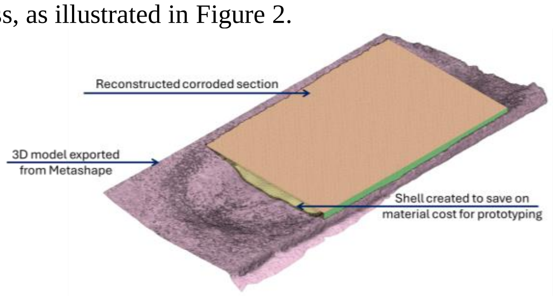

Figure 2. Reconstructed section of 3D model corroded section exported from Autodesk Fusion software.

Once the repair part has been reconstructed, a model is create which can then be sent to an appropriate 3D metal printing system to print the part. After which, this part can be fixed to the corroded section using epoxy and welding. Epoxy will be used to bond the corroded section to the repaired part and fill any gaps that were not captured during the printing process. Welding will be applied around the edge of the part, to ensure the repair part and the existing structure act as one system and it reducing the likelihood of the repair part detaching under flexural loading.

4 RESULTS AND DISCUSSION

To evaluate the proposed workflow, a section of the bottom flange from a naturally aged steel beam—retrieved from a decommissioned bridge in Chicago—was selected for reconstruction. This section exhibited visible corrosion, making it a suitable test case for photogrammetry-based defect capture. Various configurations were investigated to determine the optimal case for on-site inspections. The linear configuration, which focuses on a localized section, proved to be the most feasible option given the limitation of the existing structures on site.

This method was applied to a girder measuring approximately 1675 mm (5'-6") in length. The bottom flange of the girder was because visible corrosion was detectable. The initial test used 6 images, and a test used 108 images. This model was also used to create the repair part, as shown in Figure 2. From these two tests, it is evident that the number of images impact the confidence of the Metashape software in accurately reconstructing the features with the given images. As shown in Figure 3, with 6 images, the confidence level in the middle of the section increases as the overlap increases.

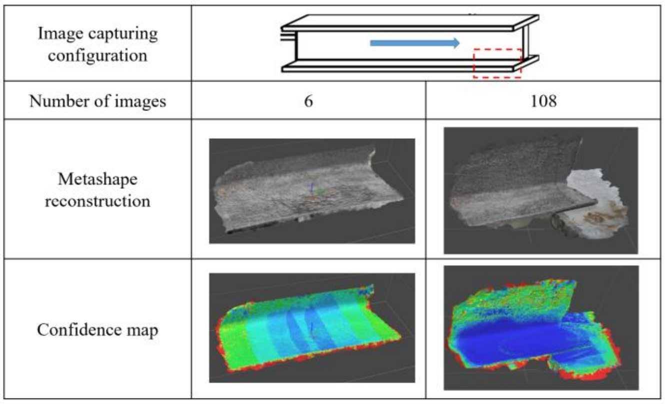

Figure 3. Reconstruction of bottom flange of aged steel beam using different number of images.

To further validate the workflow, a prototype repair part was fabricated using PLA plastic, based on the 3D model generated from the 108-image dataset. The purpose of this prototype was to assess the feasibility of capturing fine geometric details required for accurate fitment during future metal printing. The PLA part aligned well with the corroded geometry, suggesting that the photogrammetric model is suitable for generating repair components, as illustrated in Figure 4.

Figure 4. Reconstruction of bottom flange of aged steel beam using different number of images.

While this prototype was not intended for mechanical testing, it serves as a low-cost validation of the model-to-manufacture transition. Future work will include metal AM fabrication and mechanical testing to assess structural performance and long-term durability of the printed repair.

DOI: 10.3217/978-3-99161-057-1-056

5 CONCLUSION

This study presented a proof-of-concept workflow that integrates smartphone-based photogrammetry and additive manufacturing (AM) for the inspection and repair of corroded steel bridge components. The results demonstrate that high-resolution 3D models can be generated from smartphone images, even under field-like conditions, and used to design repair components that closely match the original geometry.

Initial tests using a naturally aged steel beam confirmed that image overlap and quantity significantly affect reconstruction quality. A prototype repair part was successfully fabricated in PLA based on the photogrammetry-derived model, supporting the feasibility of transitioning from image capture to repair part fabrication.

While promising, this workflow is still in its early stages. Future efforts will focus on transitioning from proof-of-concept to full-scale implementation. This includes fabricating repair components using metal additive manufacturing processes and performing mechanical tests—such as tensile and flexural loading—to evaluate the structural integrity of the repaired sections. Additional research will assess the scalability of the workflow for larger or more complex bridge components, ensuring it can be applied to diverse geometries and field conditions. The impact of environmental factors on photogrammetric accuracy, such as lighting variability, surface reflectivity, and site accessibility, will also be explored. Finally, a quantitative comparison between this workflow and traditional repair methods will be conducted, evaluating differences in cost, material efficiency, labor requirements, and repair duration to better understand the practical advantages and trade-offs of the proposed approach.

With further development, this approach has the potential to provide a cost-effective, accurate, and scalable tool for condition assessment and customized repair in routine steel bridge maintenance.

ACKNOWLEDGMENTS

This work was partially supported by the GAANN program for the project EXTending Civil Infrastructure REsiliency for Multihazards and Extreme Events (EXTREME), the Chancellor's Undergraduate Research Award, and the Chicago Transit Authority for the donation of aged steel beams and girders. We would also like to express our sincere thanks to Stephanie Bonilla, Undergraduate Research Assistant, for her contributions to image capturing.

REFERENCES

[1] ASCE (2021). "2021 Report Card for America's Infrastructure," *Reston, VA: American Society of Civil Engineers*. (2021). Available at: https://infrastructurereportcard.org.
[2] ASCE. (2022). "2022 Report Card for Illinois' Infrastructure". Accessed January 10, 2025. Available at: https://infrastructurereportcard.org/state-item/illinois/
[3] Valença, J., Júlio, E., & Araújo, H. (2008, June). Application of photogrammetry to bridge monitoring. In *Structural Faults & Repair, 12th International Conference* (pp. 10-12).
[4] Zhao, S., Kang, F., Li, J., & Ma, C. (2021). Structural health monitoring and inspection of dams based on UAV photogrammetry with image 3D reconstruction. *Automation in Construction*, *130*, 103832.
[5] Backhaus, J., Lopez, V. D. A., Maboudi, M., Bestmann, U., & Gerke, M. (2024). Combining UAV-based photogrammetry and structured light scanning to support the structural health monitoring of concrete structures. *Journal of Nondestructive Testing*, *29*(7).
[6] Berman, B. (2013). 3D printing: the new industrial revolution. *IEEE Engineering Management Review*, *41*(4), 72-80.
[7] Perkins, I., & Skitmore, M. (2015). Three-dimensional printing in the construction industry: A review. *International Journal of Construction Management*, *15*(1), 1-9.
[8] Tay, Y. W. D., Panda, B., Paul, S. C., Noor Mohamed, N. A., Tan, M. J., & Leong, K. F. (2017). 3D printing trends in building and construction industry: a review. *Virtual and physical prototyping*, *12*(3), 261-276.
[9] Gardner, L. (2005). The use of stainless steel in structures. *Progress in Structural Engineering and Materials*, *7*(2), 45-55.
[10] Strauss, H., AG, E. P. P., & Knaack, U. (2015). Additive Manufacturing for Future Facades: The potential of 3D printed parts for the building envelope. *Journal of Facade Design and Engineering*, *3*(3-4), 225-235.
[11] Arup. 3D makeover for hyper-efficient metalwork. Arup News; 2015.[accessed February 23, 2025].
[12] Parkes, J. (2021, July 19). *MX3D unveils world's first 3D-printed stainless steel bridge in Amsterdam*. Dezeen. https://www.dezeen.com/2021/07/19/mx3d-3d-printed-bridge-stainless-steel-amsterdam/
[13] Institute for Advanced Architecture of Catalonia. (2017). 3D printed bridge. IAAC. https://iaac.net/project/3d-printed-bridge/
[14] World Economic Forum. (2016). Winsun – Demonstrating the viability of 3D printing at construction scale. World Economic Forum.
[15] Zhang, S., Hou, P., Kang, J., Li, T., Mooraj, S., Ren, Y., ... & Chen, W. (2023). Laser additive manufacturing for infrastructure repair: A case study of a deteriorated steel bridge beam. *Journal of Materials Science & Technology*, *154*, 149-158.