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Cloud Point: An Innovative Approach for Solving Challenges in Engineering

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Abstract. Point cloud technology considered a breakthrough, in industries like engineering, architecture and construction deliver a three-dimensional depiction of objects and spaces. This georeferenced technology enables in depth visualization and comprehensive analysis of structures assisting in tasks ranging from architectural planning to the restoration of historical landmarks. Its usefulness extends to manufacturing and product design well providing a tool for modeling and simulation in virtual environments. In this research study, the utilization of a 3D laser scanner to generate a point cloud of the vessel "TEF" is examined. This detailed assessment aims to detect deformities and damages resulting from wear or collisions, offering an evaluation of the current condition of the vessel. The capability to capture details brings about opportunities for upkeep and repairs, underscoring the significance of this technology in maritime conservation and safety.

1 Introduction

The utilization of point clouds, which depict objects or spaces with georeferenced points, plays a pivotal role in fields such as reverse engineering. In these contexts, they are essential for reconstructing models of existing manufactured items through 3D scanning, aiding in the replication of designs and improving products. By employing technologies such as 3D laser scanners, which use infrared laser technology to swiftly capture information, alongside photogrammetry and other digital capture methods, the precision and efficiency of these reconstructions are significantly enhanced. These methods have been increasingly integrated into industrial workflows, not only for their accuracy but also for their ability to integrate with CAD software, providing a seamless transition from physical objects to digital models [1,2,3]. This integration is crucial in sectors where high fidelity replication of complex geometries is required, such as automotive and aerospace engineering, where precision is paramount [4,5]. Additionally, the advancement in software algorithms has greatly improved the processing times and quality of the point cloud data, further enhancing the utility of this technology in practical engineering applications [6,7].

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Historically, the adoption of point clouds began in earnest with the advent of laser scanners in the 1990s, facilitating faster and more accurate data capture [6]. Since then, advancements in scanning technology and increased processing capacity have broadened their applicability, making them indispensable tools for detailed visualization and analysis across various technical disciplines. This includes industries like engineering, architecture, and construction, where point clouds simplify design processes, facilitate detailed analysis, and enhance project planning. In the fields of preservation and heritage conservation, the meticulous documentation afforded by point clouds is critical for the successful restoration and preservation of historical structures [9, 10].

Furthermore, within civil engineering applications, this technology has transformed inspection and maintenance procedures for infrastructures such as bridges and tunnels. It provides precise measurements that help identify deformities or structural issues, enabling targeted repairs that enhance safety and longevity [11, 12]. In manufacturing and product design, point clouds support the development of prototypes that can be thoroughly examined and refined before physical production, significantly reducing both costs and time involved in bringing products to market [13].

This research study focuses on applying a 3D laser scanner to generate a point cloud of the vessel "TEF," with the aim of detecting deformities and damages resulting from wear or collisions. This assessment is crucial not only for evaluating the current condition of the vessel but also for planning maintenance and repair work, thus underscoring the significance of this technology in maritime conservation and safety.

The scientific contribution of this article is significant, as it provides a comprehensive analysis that can guide similar evaluations in other sectors where structural integrity and safety are of paramount importance. By detailing the methodologies used and the insights gained, this paper enhances our understanding of the practical applications of point cloud technology and its benefits in real-world settings. It contributes to the ongoing dialogue in the scientific community about the importance of technological advancements in maintaining and enhancing the safety and functionality of maritime and other infrastructures [14, 15].

2 Case of study

In this case study we delve into a real-world situation involving Bictum Industries as they investigate surface deformations, on a ship referred to as "TEF" for confidentiality reasons. These deformations could stem from collisions with reefs, regular wear and tear or other external factors. Detecting these issues early not ensures the safety of the crew and the ship. Also results in cost savings on maintenance and repairs. The goal is to utilize a 3D laser scanner to generate a detailed point cloud pinpoint any deformations document them create symmetry plans and offer recommendations, for preserving conditions.

2.1 Problem description

The ship named "TEF " as shown in Figure 2 needs an evaluation to determine the extent and nature of surface deformations that could affect its reliability. These deformations could be caused by collisions, with floating objects strain from weather conditions or regular wear and tear from prolonged use. Detecting these issues on is crucial to prevent serious structural failures.

Using a 3D laser scanner is essential for this assessment as it creates a point cloud that accurately captures the vessels shape. To start the process a 3D laser scanner is positioned to project laser beams onto the vessels surface. The sensors on the scanner capture the reflected light from these beams measuring the time it takes for the light to bounce back. These measurements are then used to calculate distances between points on the surface forming a comprehensive point cloud that forms the basis for examination.

Following scanning individual points in the point cloud undergo surface editing where they are processed and linked together to create a seamless surface mesh. This mesh faithfully represents the vessels geometry. Is vital, for analysis purposes. The 3D model generated from this mesh allows an evaluation of the vessel's integrity.

This thorough analysis helps in identifying areas where structural problems have emerged assessing their seriousness and determining the urgency of fixes. The 3D model acts as a tool for developing plans to restore symmetry during repairs and providing customized recommendations to maintain the vessels capabilities.

By making use of 3D scanning technology Bictum Industries can implement maintenance approaches that result in savings in costs and time for future extensive repairs. This does not improve safety. Prolongs the lifespan of the vessel but also optimizes resource management, within the company.

2.2 Methodology

The evaluation process for the ship "TEF," as depicted in Figure 1, incorporates a series of methodologically rigorous steps that ensure a comprehensive assessment leading to a detailed maintenance plan. The process begins with meticulous surface preparation, crucial for accurate data capture with 3D laser scanners, a step underscored in [16] for its importance in eliminating scan inaccuracies. The scanner setup, as detailed in [17], is optimized to capture all necessary details, which are then processed to remove noise and outliers, ensuring high-quality data for deformation analysis [18]. The generated surface mesh facilitates the visualization and analysis of the ship's physical deformations, with the analysis in [19] highlighting the critical role of such models in identifying structural issues.

Further, the deformation analysis pinpoints potential integrity threats, forming the basis for a targeted evaluation and diagnosis, which [20] notes as essential for effective maintenance planning. The subsequent steps of compiling reports and implementing maintenance strategies, supported in [20] and [21], respectively, ensure that findings are not only well-communicated but also actionably applied to enhance the vessel's operational safety and longevity. This methodical approach, grounded in established engineering principles and supported by contemporary research, exemplifies the integration of advanced technological tools and strategic planning in maritime engineering, demonstrating its significant value to the scientific community and industry practitioners alike.

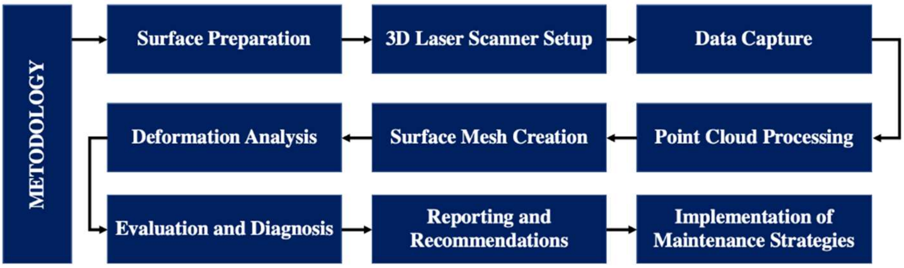

Fig. 1. Methodology flow chart.

Surface Preparation; Before starting the scanning procedure the surface of the ship "TEF" was cleaned meticulously to eliminate any debris, dirt or substances that could disrupt laser scanning. In this case the existing paint, on the ships surface did not cause any issues in creating a point cloud eliminating the need for treatments like applying matte spray or powder to reduce reflectivity.

3D Laser Scanner Setup: Positioning and calibrating the 3D laser scanner strategically to cover all areas of the ship is essential, for capturing data on its entire structure.

Data Capture: The scanner emits laser beams onto the ships surface and information collected from these reflections is utilized to generate an accurate point cloud representation of the ship's geometry.

Point Cloud Processing: After capturing the data, we work on cleaning up the point cloud information by removing any noise and outliers. This prepares a dataset that can be used to create a surface mesh.

Surface Mesh Creation: Using the refined point cloud data, we build a seamless surface mesh that accurately represents the ship's structure. This detailed model is crucial, for analysing any deformations that may occur.

Deformation Analysis: We compare the surface mesh with design models or previous scans to identify any deviations that could indicate issues or deformities.

Evaluation and Diagnosis: In this stage we evaluate the seriousness of any deformations discovered and decide on the urgency of repairs or adjustments needed.

Reporting and Recommendations: A detailed report is compiled, outlining all observations, analyses, and specific suggestions for repairing or maintaining the ship in the future.

Implementation of Maintenance Strategies: Based on the insights from the report we. Put into action maintenance plans focused on rectifying identified deformations and enhancing reliability and safety of the vessel known as "TEF".

Each phase outlined in Figure 1 plays a vital role, in conducting a thorough assessment process. These steps enable Bictum Industries to make informed decisions to uphold the integrity and operational efficiency of their vessel.

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3 Results

The results were obtained following the previous described methodology. Using a FARO Focus 5 scanner as depicted in Figure 2 to obtain a detailed point cloud. This scanner is known for its precision and ability to capture data in three dimensional settings. With an accuracy of, up to 1 mm and a range of up to 70 meters it allows for data collection in engineering scenarios.

The gathered point clouds were then imported into Autodesk Recap Pro software for image processing. Recap Pro serves as a tool that aids in handling analysing and visualizing sets of point cloud data offering a solid foundation, for interpreting data effectively.

Fig. 2. Illustration of Faro Laser Scanner 3D

A total of 46 scans were carried out from angles to ensure coverage and accurate point readings. Two perspectives, shown in Figures 3 and 4 depict the scan locations. Each gray circle, in the figures represents where the scanner was positioned during data collection. The additional perspectives can be. Accessed on https://github.com/jbvilleg/BuqueTef/ for an examination of the methodology and results.

These data are crucial for creating 3D models that aid in planning and assessing engineering projects providing a tool for tackling and resolving complex challenges, in the field.

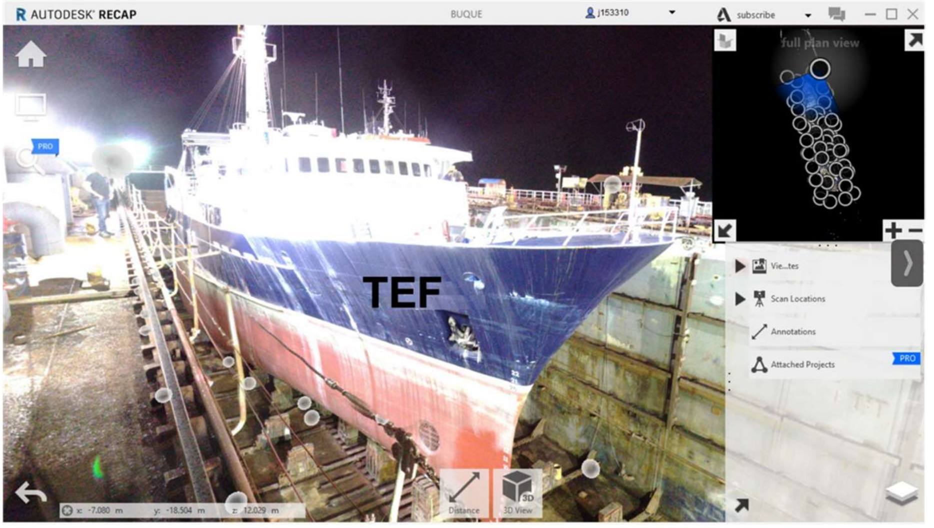


Fig. 3. TEF Vessel, left front view.

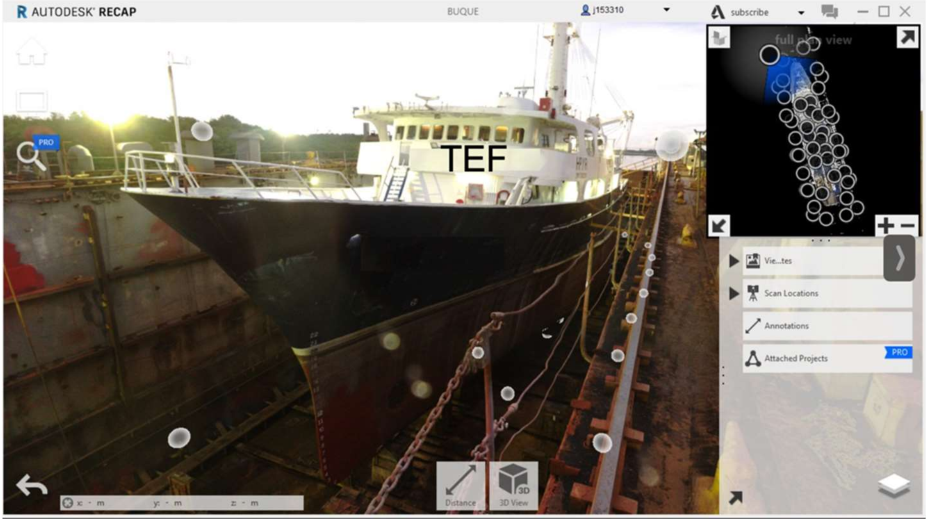


Fig. 4. TEF Vessel, right front view.

The point cloud data gathered allows for visualization of the ship, enabling structural evaluations to be conducted. Figure 5a displays an authentic image of the ship, while Figure 4b presents the point cloud representation, facilitating a comparison between the ship's current state and its digital model.

a) Real ship view

b). Visualization of point cloud generated by the 3D Laser Scanner

Fig. 5. View of the ship "TEF".

Through an exhaustive visual inspection of the point cloud, it was possible to verify the existence of noticeable deformations on the lower part of the vessel. The most notable deformations are marked on the white rectangles of Figure 6. This finding is crucial for assessing the structural integrity of the vessel and planning the necessary repairs.

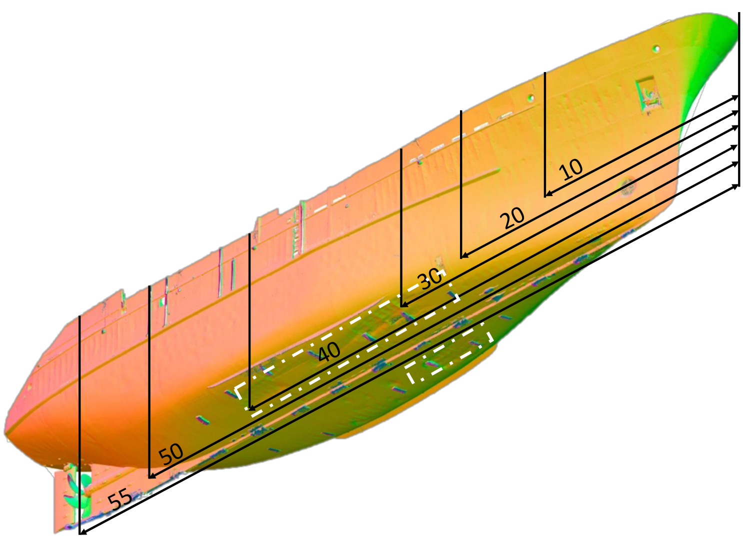
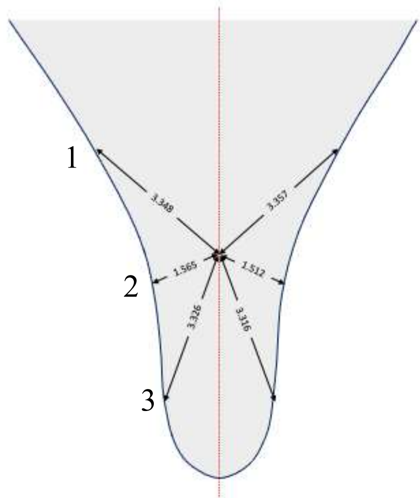


Fig. 6. Layout of the General Section Plan

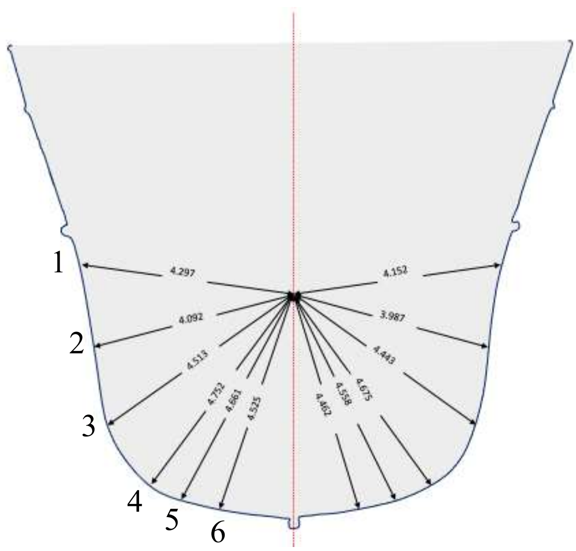
To conduct a depth examination of the deformities we made 17 crosswise cuts throughout the vessel. These specific segments enable us to assess symmetry concerning the axis of the vessel. We assessed symmetry by comparing the distances between points at heights on sides of the vessel. In Figure 7, six out of the 17 symmetry planes are defined, positioned at intervals of 10, 20 30 40, 50 and 55 meters. Figures 7 through 12 illustrate the symmetry analysis for these sections. For details on the remaining segments please refer to the repository at https://github.com/jbvilleg/BuqueTef/.

These evaluations are crucial for identifying the impacted areas and potential causes of deformations. They establish a foundation for maintenance or structural adjustments, on the vessel.



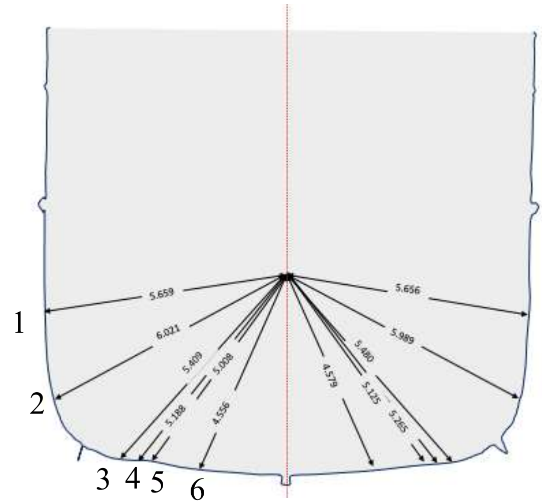
Ref.	Left point [m]	Right point [m]	Absolute difference [m]
1	3.348	3.357	0.009
2	1.565	1.512	0.053
3	3.326	3.316	0.01
Average			**0.072**

Fig. 7. Symmetry analysis for the transverse section located at 10 meters.



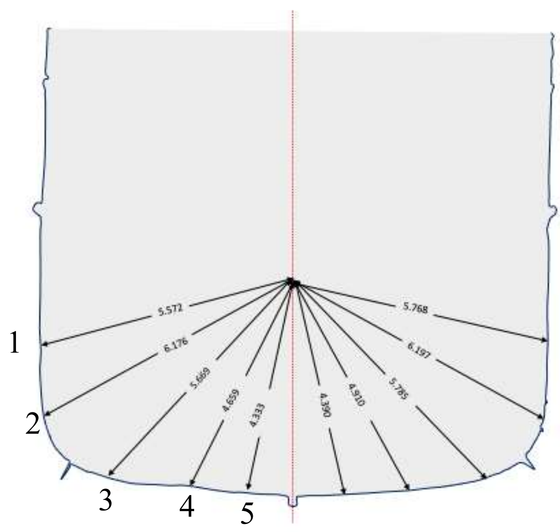
Ref.	Left point [m]	Right point [m]	Absolute difference [m]
1	4.297	4.152	0.145
2	4.092	3.987	0.105
3	4.513	4.443	0.070
4	4.752	4.675	0.077
5	4.661	4.558	0.103
6	4.525	4.462	0.063
Average			**0.094**

Fig. 8. Symmetry analysis for the transverse section located at 20 meters.



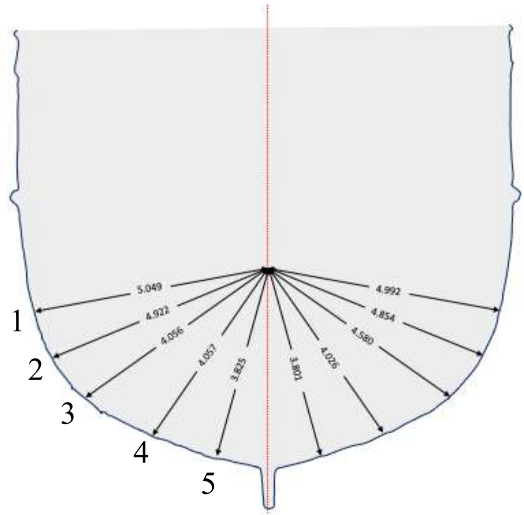
Ref.	Left point [m]	Right point [m]	Absolute difference [m]
1	5.659	5.656	0.003
2	6.021	5.989	0.032
3	5.409	5.480	0.071
4	5.188	5.265	0.077
5	5.008	5.125	0.117
6	4.556	4.579	0.023
Average			**0.054**

Fig. 9. Symmetry analysis for the transverse section located at 30 meters.



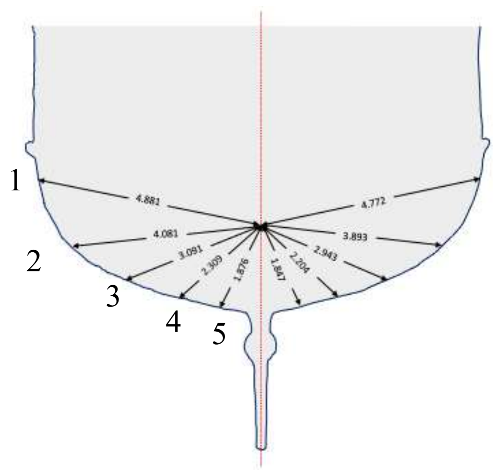
Ref.	Left point [m]	Right point [m]	Absolute difference [m]
1	5.572	5.768	0.196
2	6.176	6.197	0.021
3	5.669	5.785	0.116
4	4.659	4.910	0.251
5	4.333	4.390	0.057
Average			**0.128**

Fig. 10. Symmetry analysis for the transverse section located at 40 meters.



Ref.	Left point [m]	Right point [m]	Absolute difference [m]
1	5.049	4.992	0.057
2	4.922	4.854	0.138
3	4.056	4.580	0.524
4	4.057	4.026	0.031
5	3.825	3.801	0.024
Average			**0.155**

Fig. 11. Symmetry analysis for the transverse section located at 50 meters.



Ref.	Left point [m]	Right point [m]	Absolute difference [m]
1	4.881	4.772	0.109
2	4.081	3.893	0.188
3	3.091	2.943	0.148
4	2.309	2.204	0.105
5	1.876	1.847	0.029
Average			**0.116**

Fig. 12. Symmetry analysis for the transverse section located at 55 meters.

The examination of distortions using data gathered from the point cloud revealed size discrepancies across the cross sections of the vessel 'TEF.' These discrepancies ranged from 0.54 cm to 15.5 cm. The average discrepancy observed was 8.09 cm. This level of variation is noteworthy. Indicates areas that need careful attention for future repair or structural reinforcement measures.

The visuals produced from the scans offer a depiction of the condition of the vessel and its distortions. The red rectangles highlighted in the images point out areas, with the irregularities enabling an efficient visual evaluation of the structural deformities.

By implementing crosswise incisions and examining symmetry in sections of the vessel, a deeper comprehension of the changes was achieved. While the vessel remains operational addressing these distortions is essential to prevent repair expenses and ensure long term safety.

4 Discussion

The thorough examination of the symmetry of the 'Teff' vessel using point cloud technology has revealed a deviation of 8.09 cm across the hull's cross-section. While this deviation doesn't immediately impact the vessel's functionality, it does affect its stability, particularly concerning the transverse metacentre, and consequently, the ship's ability to maintain balance in challenging maritime conditions. Various factors could lead to alterations in hull symmetry, such as collisions with reefs, wear-and-tear, or encounters with floating objects.

These findings underscore the importance of targeted interventions, such as realigning structural components and reinforcing weak points, aimed at correcting identified deformities and enhancing the vessel's integrity. This ensures its long-term robustness and operational safety. Future endeavours suggest broadening the application of point cloud data to create detailed models. These models would enable simulations, utilizing the finite element method, to comprehensively assess hull stresses under diverse operational scenarios. This approach supports proactive and predictive strategies for maintenance and repair, thereby enhancing the vessel's durability and performance.

Furthermore, adopting this technology benefits not only engineering but also has the potential for widespread application across various engineering disciplines. In areas where precise simulations and detailed structural analyses are critical, it enhances design optimization and strengthens structural integrity management.

Using these technologies integrates innovation with conventional engineering methods, representing progress in predicting and addressing structural concerns. This advancement enhances the safety and efficiency of both marine and land-based structures.

5 Conclusions

The research carried out in partnership, with Bictum Industries focusing on the vessel "TEF " has shown the effectiveness of utilizing 3D laser scanning technology to identify and document surface changes. By following a process that involved preparing the surface using laser scanners, filtering data points, and creating symmetry plans a detailed representation of the ship's framework was achieved.

The analysis of the point cloud data and the resulting plans has allowed for the identification of deviations related to the axis indicating stresses affecting the integrity of the "TEF" vessel. While these deviations do not currently impede the ships operation, they point out damages that could result in repair costs if not dealt with proactively.

Addressing these deformations based on the gathered data will enable actions to be taken. This proactive step will ensure navigation at sea. Help reduce long term maintenance expenses. Moreover, maintaining records on the ships condition will serve as an asset, for inspections and maintenance tasks.

Furthermore, this case study highlights how 3D laser scanning technology can be applied in sectors of engineering and architecture where precise deformation detection and assessment of structural soundness are crucial. This technology can be applied to bridges, old buildings and important infrastructure projects expanding the advantages of this technology to sectors.

References

1. Abreu, N., Pinto, A., Matos, A., Pires, M. Procedural Point Cloud Modelling in Scan-to-BIM and Scan-vs-BIM Applications: A Review. ISPRS Int. J. Geo-Inf. **12**, 260 (2023) https://doi.org/10.3390/ijgi12070260
2. Mudit B., Sukhdeep S. D. "3D Scanning for Reverse Engineering- Technological Advancements, Process Overview, Accuracy Inspection, Challenges and Remedies". International Journal of Emerging Technologies in Engineering Research (IJETER). Vol. 5. (2017). https://www.ijeter.everscience.org/Manuscripts/Volume-5/Issue-10/Vol-5-issue-10-M-07.pdf
3. Valerga, A. P, Jimenez, R. A., Fernandez S., Fernandez, S. "Photogrammetry as an Engineering Design Tool". In book: Product Design. BY **3.0**. (2020). https://doi.org.10.5772/intechopen.92998
4. Javaid, M., Haleen, A., Pratap R., Suman, R. "Industrial Perspectives of 3D scanning: Features, Roles and it's Analytical Applications". Sensors International 2. (2021). https://10.1016/j.sintl.2021.100114
5. Abid H., Mohd J., Ravi P. S., Shanay R., Rajiv S., Lalit K., Ibrahim H. K. "Exploring the potential of 3D scanning in Industry 4.0: An overview". International Journal of Cognitive Computing in Engineering. Vol 3. (2022). https://doi.org/10.1016/j.ijcce.2022.08.003
6. Lang Z., Guoxing S., Yong L., Weiqing L. "Point cloud denoising review: from classical to deep learning-based approaches". Graphical Models 12. Vol 5. (2022). https://www.researchgate.net/publication/360326425_Point_cloud_denoising_review_from_classical_to_deep_learning-based_approaches
7. Zahra A., Qureshi, R., Sajjad, M., Sadak, F., Nawaz, M, Ahmad Khan, H., Uzair, M. "Current advances in imaging spectroscopy and its state-of-the-art applications". Expert Systems with Applications. Vol **238**. https://doi.org/10.1016/j.eswa.2023.122172
8. Spencer, B.F., Hoskere, V., & Narazaki, Y. Advances in Computer Vision-Based Civil Infrastructure Inspection and Monitoring. Engineering, 5(2), **199-222** (2019) https://doi.org/10.1016/j.eng.2018.11.030
9. Andriasyan, M., Moyano, J., Nieto-Julián, J.E., Antón, D. From Point Cloud Data to Building Information Modelling: An Automatic Parametric Workflow for Heritage. Remote Sens. **12**, 1094 (2020) https://doi.org/10.3390/rs12071094
10. Catbas, F.N., Cano, J.A., Luleci, F., Walters, L.C., Michlowitz, R. On the Generation of Digital Data and Models from Point Clouds: Application to a Pedestrian Bridge Structure. Infrastructures **9**, 6 (2024) https://doi.org/10.3390/infrastructures9010006
11. Al Shaini, I., Blanco, A.C.T. Bridge deck surface damage assessment using point cloud data. ABEN **4**, 31 (2023). https://doi.org/10.1186/s43251-023-00110-4
12. Pan, N.-H., Isnaeni, N.N. Integration of Augmented Reality and Building Information Modeling for Enhanced Construction Inspection - A Case Study. Buildings **14**, 612 (2024) https://doi.org/10.3390/buildings14030612
13. S. Chen, B. Liu, C. Feng, C. Vallespi-Gonzalez, C. Wellington, "3D Point Cloud Processing and Learning for Autonomous Driving: Impacting Map Creation,

Localization, and Perception," in IEEE Signal Processing Magazine, vol. **38**, no. 1, pp. 68-86, Jan (2021), https://doi.org/10.1109/MSP.2020.2984780

14. Kiziltas, S., *et al*. "Enhanced Structural Analysis through High-Density Point Clouds: Techniques and Case Studies." Journal of Structural Integrity and Maintenance". International Journal of Building Pathology and Adaptation. Vol. **345.** Jun (2021), https://www.emerald.com/insight/2398-4708.htm
15. Ying, Z, Zhao, S., Bhuyan, S., Mishra, C. S., Kandemir, M. T., Das, C. R. "Pushing Point Cloud Compression to the Edge". International Symposium on Microarchitecture (MICRO). Pg **282**. (2022). https://doi.org/10.1109/MICRO56248.2022.0003
16. Minsuk, C., Minhyeok, K., Gwanyoung, K, Sera, K. "3D scanning technique for obtaining road surface and its applications". International Journal of Precision Engineering and Manufacturing. Vol **18**. (2017). https://10.1007/s12541-017-0044-1
17. Xóchiti, M., G., Oleg, S., Vera, T., Lopez, M. "Optimization of 3D laser scanning speed by use of combined variable step". Optics and Lasers in Engineering. Vol **50**. (2014). https://10.1016/j.optlaseng.2013.08.011
18. Burcu, G., E., Jerome, F., H. "Data Processing of Point Clouds for Object Detection for Structural Engineering Applications". Computer-Aided Civil and Infrastructure Engineering. Vol **28(7**). https://10.1111/mice.12016
19. Jawor, J., Luft, M., Łukasik, Z., Szychta, E. "Integration of Cloud Computing and Reverse Engineering 3D Scanning for marine applications". Portal Komunikacji Naukowej. Vol **30 (102)**. (2012). ISSN : 1733-8670
20. S.G. Rahul, Rajnikant Kushwaha. "Smart structural health monitoring system using IoT and wireless technology". Recent Advancement of IoT Devices in Pollution Control and Health Applications. 2023.
21. Karatuğ, Ç. Arslanoğlu, Yasin, Guedes, S., C. "Review of maintenance strategies for ship machinery systems. Journal of Marine Engineering & Technology". Vol. **22**. (2023) https://10.1080/20464177.2023.2180831