

Identifying the Gaps between Research and Real-World Needs in Structural Inspection using Digital Tools

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Abstract

Europe faces significant challenges in maintaining its aging infrastructure due to extreme weather events, fluctuating groundwater levels, and rising sustainability demands. Ensuring the safety and longevity of infrastructure is a critical priority, especially for public organizations responsible for asset management. Digital technologies have the potential to facilitate the scaling and automation of infrastructure maintenance while enabling the development of a data-driven standardized inspection methodology. This extended abstract is the first phase of a study that examines current structural inspection methods and lifecycle monitoring activities of the Dutch public and private entities. The preliminary findings presented here indicate a preference for data-driven approaches, though challenges in data collection, processing, personnel resources and analysis remain. The future work will experiment integrating advanced tools, such as artificial intelligence supported visual inspection, on the existing inspection datasets of these authorities for quantifying their readiness levels to the fully automated digital inspections.

Introduction

A substantial portion of Europe's infrastructure is potentially in a critical condition, as many assets were constructed during the mid-20th century. The research by Del Grosso et al., (2002) shows that the majority of the infrastructure in developed world was built in the decades following the WWII, while Jonkman et al. (2018) presents a very similar picture specifically for the Netherlands. Ordinary engineering structures are typically designed for a 50-year service life, while some critical infrastructure is designed for a 100 year life expectancy. Given these design lifespans, much of the infrastructure of Europe is now approaching or exceeding its intended use. Consequently, there is a pressing need for a comprehensive evaluation to identify structures in critical condition and determine the appropriate measures for renovation or replacement.

The problem at hand has reached critical safety limits, as recent examples of structural collapse have been observed in Europe, such as the Morandi Bridge in Genova, Italy, which collapsed in 2018, and even more recently, the Carola Bridge in Dresden, Germany, which collapsed in 2024. Despite the infrastructure becoming older, the traffic loads are increasing on this infrastructure. Hanley et al. (2016) and Del Grosso et al. (2022) indicate an increase of 4-5% annually in the coming years.

On top of the increasing human activities on this aging infrastructure, the IPCC (2020) reports that climate change is increasing the frequency of extreme droughts and heavy rainfall. Droughts lead to soil subsidence, causing cracks and settling in infrastructure (Corti et al., 2009). Heavy rainfall saturates soil rapidly, resulting in runoff, flooding, and erosion, which can trigger mudslides or landslides (Vardon, 2014). These events damage infrastructure by eroding surfaces, washing away roads, and weakening foundations.

It is now widely recognized that existing infrastructure can no longer be maintained safely and efficiently using traditional methods, especially in the face of increasingly limited financial and human resources. The adoption of digital technologies is no longer optional but essential, a reality acknowledged across all sectors. However, a critical question remains: are institutions truly prepared for this digital transition, and to what extent? To explore this, a preliminary study was conducted involving visits to various Dutch institutions and participation in on-site structural inspections to gain firsthand insights. This study presents the results of this series of inspections.

Current Inspection Processes and Challenges

The work presented here focuses on current methods of structural inspection and lifecycle monitoring, with particular emphasis on assessing the extent to which Dutch institutions effectively utilize digital technologies in these processes. As part of this study, several inspections were carried out in collaboration with various Dutch public and private entities, including Water Authority Noorderzijlvest, Rijkswaterstaat (the Dutch Ministry of Infrastructure and Water Management), Province of Groningen, and Fugro. These organizations are actively engaged in conducting inspections and asset management activities for infrastructure assets such as dikes, storm surge barriers, roads, bridges, and viaducts. Images from these inspections, taken by the authors, are presented in Figure 1.

Public entities are responsible for a significant portion of infrastructure in the Netherlands. During inspections the authors have participated, it became clear that most stakeholders prefer a data-driven approach to inspection and management for obvious reasons. Stakeholders emphasized that assets such as roads and dikes, along with their pavements and coverings, face increasing risks due to subsidence, soil settlement, and heavier traffic loads, all of which have worsened the last years. Additionally, these assets cover vast inspection areas, such as kilometres of dikes, requiring optimization due to financial and personnel constraints. This also applies to high bridges or difficult-to-reach locations, such as underwater areas, where technologies like drones can aid in performing inspections.

Current climate policies mandate the use of innovative materials, such as bio-based or recycled materials, for both new pavements and repairs. One of the findings of this preliminary research, however, is that, experimentation with new pavement types (e.g., warm asphalt, recycled asphalt) is necessary by climate policies, but their lifespan remains uncertain, necessitating extensive field testing, which increases costs. Despite their potential merit in more sustainable construction, such experimental methods increase the workload of inspection of these authorities, bringing in several uncertainties into long term maintenance planning.

All institutions the authors joined in inspections use one or multiple sorts of digital tools. These tools include custom platforms, GIS-based tools, drones or simple image storage and

processing tools devised specifically for the purposes of the inspection. One common problem manifested by these visits is the handling of the data. The handling refers not only to storage, but also to efficient processing of these data. Some examples are,

- comparison of multiple images taken from the same (or almost the same) location at different times,
- clustering similar pictures, similarity laying either on the type of the problem or type of the structure (i.e. bring all photos of corrosion in the last period, filter all cracks photos observed on dikes in the last number of years, etc.)

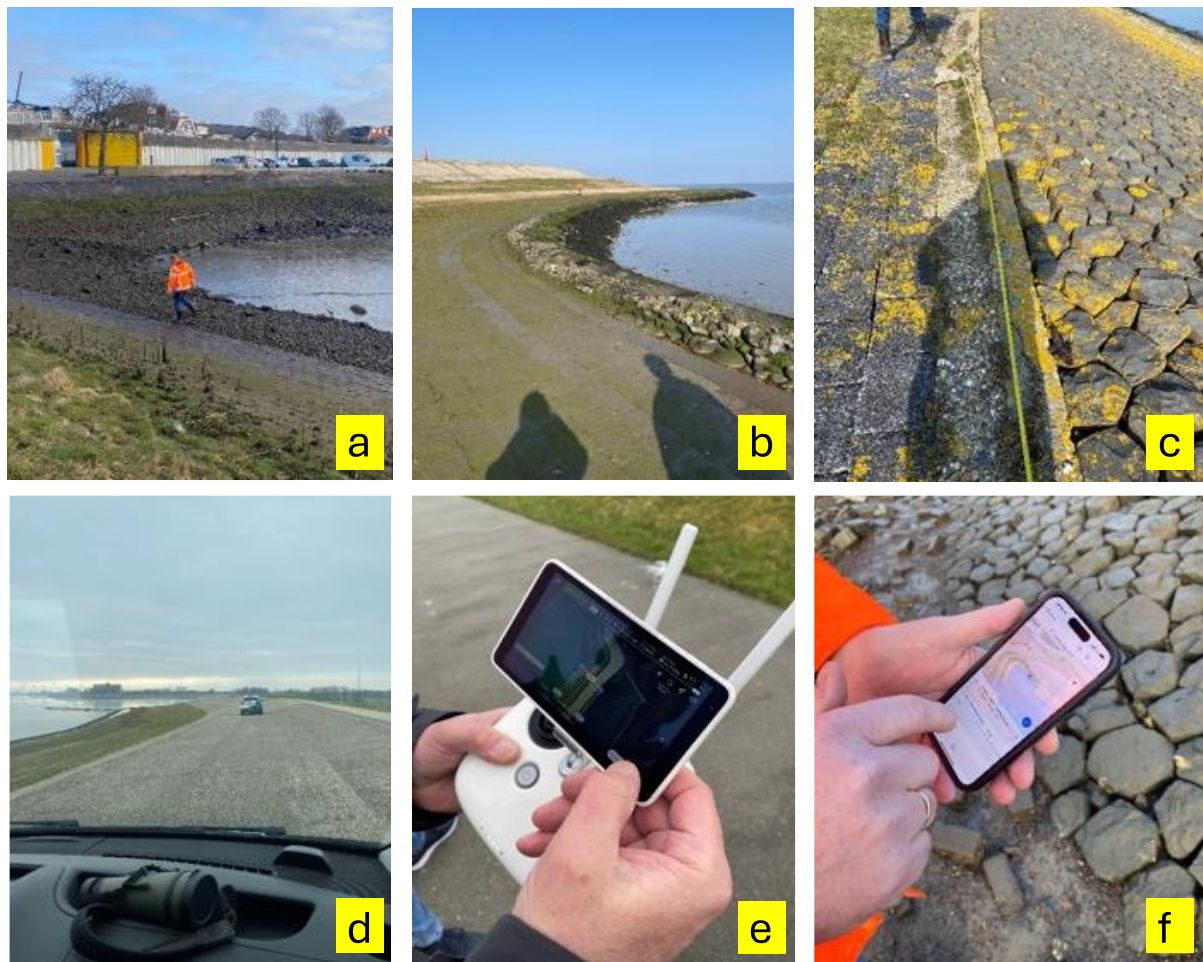


Figure 1. Performing an inspection of a dike, including pavements and coverings; photos taken by R. Veenstra, March 2025 – walk-through inspection of dike and coverings (a, b and c), drive-by inspection of the asphalt (d), use of drone (e) and GIS tools (f) for more efficient data collection.

The steps within a data-driven approach typically include stages such as data collection, processing, and analysis, among others. Public entities often contract private firms for inspections, primarily relying on technologies like drones and LiDAR for data collection. However, technological advancements vary across firms, with some innovating faster than others. While outsourcing data processing and analysis incurs high costs and limits knowledge retention within public organizations, discussions with stakeholders indicate that many still face challenges in these areas. One of the main barriers identified in this research is the uncertainty among institutions regarding which technologies they truly need. The abundance of solutions offered by technology providers does not necessarily align with the actual needs

of these institutions. As a result, a significant gap remains between what is available on the market and what is perceived as necessary on the ground.

The fact that institutions ‘seemingly’ use some sort of digital tool does not necessarily mean that they, and efficiently, involve these tools into their processes and get the planned return of investment of time and money. The research reported here yielded two reasons why this is happening:

- depending on the size and budget of the institution, the digital tools may be managed by a very limited number of rather “curious” personnel, while the majority of the personnel either prefer legacy methods, or stay distanced to these technologies because of lack of knowledge, or simply not believe their efficiency,
- the amount and versatility of the collected data become overwhelming, so the energy is mostly spent on collecting the data while processes for largely or fully automatizing the entire process is largely lacking.

Next Steps and Future Research

One aspect that became clear from the interactions with the institutions, as reported above, is that they collect and possess large databases. Furthermore, and in most cases, these datasets are annotated and labelled up to a certain degree. Following the initial study and based on this finding, the second phase of the research will focus on integrating advanced tools, such as AI, into the data analysis process using the existing databases. These databases often include tabular data, such as the reported structural problems, locations and decision made, a set of data very suitable for machine learning or simple regression algorithms to make projections and predictive maintenance activities. The overwhelming size of such data probably does not allow human experts to easily come up with patterns repeating themselves in such data. Furthermore, a vast database of images is also available in all cases. During the next phase of this research, key parameters like ravelling, cracks, and other factors affecting the infrastructure will be collected and analysed, considering climate impacts and other hazards influencing the built environment. One large link missing in these endeavours will be the labelling of the data, something that will need to be co-organized with the institutions owning the data since they do have the expertise in correct labelling. Labelling is crucial for developing effective tools and making use of the existing databases.

Finally, a methodology will be proposed to create a projection scheme for maintenance and planning, making use of the existing databases, which will form a key component of this approach. This comprehensive methodology aims to provide organizations with a deeper understanding of the lifecycle of their assets, enabling more efficient asset management strategies that reduce costs, minimize labour requirements, and streamline time-consuming processes.

One good example that will be used in the next phase is the detection of cracks on infrastructure. Cracks are often manifestations of structural problems, and their sequential and continuous monitoring is essential. Several studies on crack detection using artificial intelligence have primarily focused on identifying crack formation. To assess the efficiency and effectiveness of these approaches, various Convolutional Neural Network (CNN) techniques, including patch classification, boundary regression, and pixel-level segmentation, were tested (see Dais et al., 2021 for an example). Figure 2 presents a visual representation of the output of an automated AI algorithm used on a traditional inspection photo from a dike,

highlighting cracks in a covered dike surface. However, the tool currently struggles to accurately detect cracks in higher-resolution, noisier images, suggesting the need for further refinement. These kinds of tools can be enhanced through additional training with labelled data, an improvement that can benefit from the existing and very large databases the institutions have. Re-training such models on these existing databases will also help customizing such models, for instance, using it more efficiently on cracks on dikes rather than cracks on masonry walls.



Figure 2. Crack detection using an AI algorithm on a traditional dike inspection photo (photo taken by Veenstra, March 2025; the purple overlay, which is the pixel-wise prediction of location of cracks, is generated using a model trained via a CNN-based crack detection model¹).

In the subsequent phase, the focus will shift to rigorously testing and validating the models developed for structural inspection problems (crack detection concrete spalling, structural deterioration due to vegetation and water intrusion etc.), which involves comparing model outputs with real-world asset management case studies from the participating organizations to assess their accuracy and practical applicability. Through these phased studies, this study seeks for practical implementation of the available technologies to the existing issues, while identifying the gaps and the readiness levels of the institutions for a fully automated structural inspection work stream.

¹ Available on GitHub: <https://github.com/DavidHidde/CNN-masonry-crack-tasks>

Conclusions

This study highlights the challenges and opportunities in transitioning toward digital infrastructure inspections in the Netherlands. While there is growing interest in data-driven methods, several barriers limit effective implementation.

First findings from inspection participated by the authors in the above-mentioned institutions include:

- Institutions often lack clarity on which technologies they need, leading to a mismatch between market offerings and operational requirements.
- Digital tools are often in use, but sometimes managed by a small group of tech-savvy staff, limiting organization-wide adoption.
- Data collection is extensive, yet processing and analysis remain underdeveloped, reducing the value extracted from inspections.
- Many organizations already possess large, partially annotated datasets that are suitable for AI-based analysis and customization of the existing anomaly detection models, but lack standard labelling practices.

Future work will focus on integrating AI tools, such as crack detection and other anomaly finding algorithms, with existing inspection data to evaluate their performance and help quantify institutional readiness for automated workflows.

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