# A Comprehensive Study of BIM for Infrastructural Crack Detection and the Vital Strategies

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*Abstract*—**Building information modelling is one of the emerging technologies in the construction industry and is relevant to its productivity and efficiency. Application which affects the product and process of the industry. An underdeveloped area with less attention is its adoption for crack detection and visualisation for infrastructural maintenance. This study provides a thorough perspective on BIM adoption for crack detection and visualisation. It also identified the different strategies that can aid in the adoption and use of BIM for infrastructural monitoring and maintenance in South Africa. The study adopted a quantitative approach, and questionnaires were distributed to industry professionals through an online platform. The collected data was analysed. The results indicate a need for incorporation of this aspect into the HEI curriculum and a teaching approach that is practical and experimental to be adopted.**

***Keyword—Developing country; emerging technology; facility management; visualisation; emerging technology; South Africa***

## I. Introduction

Structural and civil infrastructures lose performance and deteriorate over time; detecting and visualising defects such as cracks on infrastructures is critical to ensure proper maintenance and predict possible failures [1]. Several infrastructure failure accidents in South Africa are related to insufficient crack inspection and condition assessment. For example, a coal silo that collapsed at the Majuba power station in Mpumalanga due to cracking and poor maintenance contributed to excessive power cuts, which negatively impacted the country's economy [2; 3]. Crack detection is part of infrastructure maintenance plans carried out regularly to monitor the health of infrastructures. Visualisation is typically used to sort large images and video data visually to improve crack inspection [4]. Infrastructure cracks are the earliest indication of material deterioration and possible infrastructure failures [5]. Crack detection information can be used to diagnose and guide the appropriate maintenance methods and approaches to prevent catastrophic failures [6]. Crack detection using visual inspections is cumbersome, costly, and inefficient [7].

The traditional methods for crack detection are visual inspections, which are conducted utilising manual observations by maintenance inspectors and engineers. Over the years, several disadvantages have been noted from manual crack detection observations. The disadvantages include time-consuming, expensive, and inaccuracy due to irregular conditions and human errors. In most cases, the reliability and accuracy of the method depend on the specialist's knowledge and experience [5, 8]. Some cracks on engineering structures can only be detected at a microscopic level, which is difficult to detect with manual inspection methods. Therefore, as clearly stated by [6, 8], manual crack detection methods are not economical and have lower accuracy levels. With the increasingly complex engineering infrastructures being developed in South Africa, there is a need to adopt new automated crack detection methods.

Over the years, reliable surface crack detection methods have been developed to effectively detect cracks on infrastructure surfaces. Automated crack detection methods are fast and reliable; hence, they boost the productivity of detecting cracks in surface structures [6]. Automatic crack-detecting methods, such as image processing techniques, have gained popularity in recent years, where crack information is extracted from images for analysis. According to study [9], some of these image processing techniques also produce unsatisfying results, as the crack analysis by computer software depends on the quality of images and the characteristics of surfaces.

The adoption and implementation of BIM have gained popularity over the years, and it has been used for planning and design. However, in recent years, BIM applications have expanded to be used in clash detection, carbon capture, and asset management [10]. The study conducted by study [11] noted that it is an area that requires attention.

## II. Development of Cracks in South African Infrastructures

According to the South African Institution of Civil Engineering (SAICE) report, a significant portion of South Africa's infrastructure is in poor condition. Roads, bridges, healthcare facilities, and water management structures have surface cracks [12]. Streets and buildings across the country are cracking due to various factors, and there is no indication of proper maintenance systems and plans in place, as this problem of cracks on infrastructures has worsened over the years [13; 14; 15]. The research in study [4] assessed the adoption of computer vision-based models such as BIM to detect defects in infrastructure regularly as part of maintenance. It has been noted that cracks are the most common defects resulting in infrastructure deterioration. Therefore, adopting and implementing effective crack detection methods such as BIM is critical to visualising cracks and improving the state of infrastructures in South Africa.

One of the recent disasters caused by undetected surface cracks in South Africa involves an incident in one of the largest power stations operated by ESKOM in Mpumalanga. In November 2014, a concrete coal silo collapsed at the Majuba power station due to cracks that were not detected on the surface of the silo as part of regular maintenance of the power station. The power station at the time of the incident supplied about 10% of the country's electricity. Hence, the disaster contributed to the continued rolling blackouts of load shedding in South Africa. During the incident investigations, cracks were discovered on other silos resulting in the complete shutdown of the power station [16; 3]. Concrete silos are some of the most critical structures in the industrial sector; they are normally used to store bulk solids such as coal. Therefore, periodic inspections for signs of distress, such as cracks on these structures, are critical in their lifecycle [2]. However, concrete silos are high-rise structures with limited access to external surfaces. Therefore, it's not feasible to detect cracks on these structures using manual inspections. Hence, adopting advanced methods such as BIM for crack detection in the South African construction industry might be a solution to prevent disasters, such as using BIM applications to maintain infrastructures. BIM applications have the potential to detect and visualise cracks in infrastructures. Therefore, the current study assesses the adoption level of BIM for crack detection and visualisation within the South African construction industry as part of continuous progress toward full integration of BIM.

## III. Role of BIM in Infrastructure Maintenance

BIM is a technology that holds immense significance in construction projects and infrastructure maintenance. Its benefits range from better communication and collaboration to enhanced efficiency and reduced errors. Despite these advantages, many countries have yet to adopt BIM for post-construction maintenance fully. By leveraging BIM technology, stakeholders can ensure seamless infrastructure maintenance and upkeep, promoting safe infrastructure maintenance practices [4]. The critical role of BIM in infrastructure maintenance lies in the visualisation of geometrics and the integration of infrastructure information into 3D objects. Hence, defects such as cracks can be detected effectively and accurately, and the damage caused can be assessed.

Detection of cracks in infrastructure such as buildings, roads, and bridges is crucial for monitoring their structural integrity and health [6]. A crack is a fracture wherein the components or parts are not entirely separated [17]. It has been noted in the studies by [5; 6] that cracks on most infrastructures are early indications of deterioration. Cracks create access to the harmful and corrosive chemical that penetrates infrastructures, causing damage to their integrity, strength, and durability [18]. Considerable research has been undertaken into detecting cracks to address the issue of infrastructures developing cracks and to monitor their physical and functional conditions [6]. Incorporating crack detection into maintenance plans is a crucial aspect of the construction industry, particularly before infrastructure upgrades, reconstructions, or repairs. Doing so can help ensure the infrastructure's longevity and safety while mitigating the risk of more extensive and costly repairs down the line. As such, it is highly recommended that those involved in the construction industry prioritize crack detection as part of their overall maintenance strategy.

According to study [19], civil infrastructure must be regularly checked for structural integrity as it nears the end of its lifespan. The most critical checks are for crack detection, which uses various approaches and models. The methods and models for crack detection are regularly improved and updated to ensure accuracy and performance in the construction industry. Digital technologies and the 4th industrial revolution have developed computer-based models for crack detection. Most of these models are Computer-based models developed using digital technologies for crack detection, many of which rely on computer vision-based techniques [5]. It has been highlighted by [19] that computer vision-based models improve the accuracy of crack detection with an average precision of 95%. As such, there is an increasing trend of adopting computer vision-based models to boost the productivity of detecting cracks in structures [4]. Therefore, the South African construction industry stakeholders need to adopt computer-based models for crack detection to improve the country's infrastructure maintenance and state.

## IV. Benefits of Adopting BIM for Crack Detection and Visualisation

Building Information Modeling (BIM) has become an increasingly popular tool for infrastructure

Projects, particularly in detecting and measuring cracks. This approach offers a comprehensive and sophisticated solution that considers all aspects of the cracks, including their length, width, and depth [5]. BIM also generates 3D images that allow engineers and stakeholders to visualize the patterns of the cracks, which is extremely helpful in determining the most effective repair strategies [18]. BIM enables easier detection of structural cracks, thus facilitating the prediction of future conditions and determining necessary maintenance plans. As highlighted by [20], this technology also effectively allocates repair resources. By harnessing the power of BIM, organizations can optimize their maintenance strategies and ensure the longevity and safety of their buildings. Another significant advantage of employing BIM is accurately estimating the costs involved in repairing the cracks. Considering all relevant factors, such as materials, labour, and equipment costs, BIM can provide a detailed and reliable estimate of the expenses involved in repairing the cracks [21]. This information is crucial for project managers and stakeholders, allowing them to budget effectively and plan accordingly. Furthermore, BIM can aid in the formulation of effective infrastructure maintenance plans. By identifying the locations and severity of cracks, engineers can prioritize repairs and maintenance activities, ensuring that critical infrastructure is well-maintained and safe for use [22].

## V. Case Studies on BIM Implementation for Crack Detection and Visualisation

In this section, studies related to adopting BIM for crack detection are reviewed and discussed to assess the potential of implementing BIM for crack detection in South Africa.

### A. *Automated Concrete Defect Detection Using Building Information Model in Hong Kong*

The study by [23] adopted BIM for automated concrete defect detection. The 3D model was developed to detect the position and geometries of the concrete defect to guide subsequent maintenance stages. BIM implementation in this study was to overcome the disadvantage of manual inspection methods and assess high-rise buildings with limited access to external structures. The approach that was used in the study involved using a drone to take aerial photographs of a 10-story residential building near the University of Hong Kong. The 3D reconstruction was conducted to generate a defect point cloud (DPC) visualised in BIM to detect defects. The results from the study indicated that defect detection errors from the manual visualisation method had been reduced by up to 14%.

It is evident from this study that BIM adoption for crack detection improves the reliability of defect detection results; hence, proper maintenance planning can be done on the building. The whole process is much faster than the manual visual inspection of cracks. However, the process could be more precise; hence, proper training and understanding of BIM are needed before undertaking crack detection procedures.

### B. *Adoption of BIM for the Inspection of Monte da Virgem Telecommunications Tower in Portugal*

The research in [24] also explored the potential of BIM applications in crack detection by studying detecting cracks on a telecommunications tower that is 177m high in Portugal. In the study, a remote inspection of reinforced concrete was conducted using Unmanned Aerial Vehicles (UAVs), referred to as drones, to capture tower images from different angles and integrate these images into the building information modelling (BIM).

The photographs of the tower were collected in a photographic scan from the bottom of the tower to the top, capturing concrete surface conditions. Captured photographs were then processed and reconstructed into 3D modelling, which was integrated into BIM. The biological colonies are indications of cracks, a BIM-generated model that detects cracks in the tower.

Cracks on structures such as telecommunications towers with poor accessibility to external structures are not easily detected using manual visual inspection methods due to their long heights; as such, only automated technological methods such as BIM can detect cracks on their surfaces. The BIM model has provided efficient and reliable results for cracks in the tower. Hence, informed decisions can be made on the maintenance of the tower. This is a good case study that can be related to the case of a coal silo that collapsed at the Majuba power station in Mpumalanga, South Africa, due to cracking, which may be resulted from limited access to the coal silo to detect surface cracks on the structure. The new technology of detecting cracks improves infrastructure maintenance; hence, South Africa needs to adopt it.

## VI. Methodology

A quantitative approach was adopted to identify the strategies required to implement BIM adoption for crack detection in the South African construction industry. A total of 77 responses were retrieved and adopted for the study. The research instrument was randomly distributed online to professionals in the South African construction industry via Google Forms. The Cronbach alpha coefficient has been utilised to evaluate the quality and consistency of the data obtained from the study. This statistical method is widely used in research to measure the internal consistency of a set of variables. The coefficient's value ranges from 0 to 1, with 1 signifying perfect internal consistency and 0 indicating no consistency. The higher the coefficient, the more reliable the data. A Cronbach alpha coefficient of 0.85, which is a higher value, indicates that the data collected is consistent and, hence, reliable to be adopted to improve the adoption of BIM for crack detection. The adopted methodology has been used by studies in the construction industry [25, 26].

### A. *Background Information of Respondents*

The study's findings revealed that most respondents held a bachelor’s degree, the typical entry-level degree (see Table I). Many respondents possessed a master’s degree, while only a few held a doctoral degree. This suggests that most South African construction industry professionals do not pursue education beyond the entry-level degree. Many might have professional degrees, which were not requested in this study. Therefore, there may be a need for greater emphasis on continuing education and professional development to ensure professionals remain current with trends and best practices. The study involved eight professional categories with distinct affiliations. Most respondents belonged to the engineering and construction project management categories, while fewer participants were from the construction health and safety category. The findings indicate that engineers and construction project managers in the South African construction industry are highly interested in staying updated with advancements and technologies in infrastructure maintenance, actively seeking ways to improve their knowledge and skills. The years of experience is crucial in determining industry knowledge and exposure. The study revealed that most respondents have six to 10 years of experience, with fewer having over 20 years. This suggests the industry is dominated by professionals with moderate experience, with relatively few highly experienced professionals. However, it is expected that more experienced professionals are less inclined to adopt new technologies, such as BIM, for crack detection and visualization, compared with young professionals who are technology enthusiasts. The data also shows that many respondents are employed in the government and consultancy sectors.

TABLE I. RESPONDENTS BACKGROUND INFORMATION

| Category | Subcategory | Percentage (%) |
|---|---|---|
| Educational Qualification | Bachelor's Degree | 53.2 |
| | Master's Degree | 22.1 |
| | Diploma | 18.2 |
| | Doctoral Degree | 6.5 |
| Professional Affiliation | Civil Engineer | 29.9 |
| | Construction Project Manager | 22 |
| | BIM Professional | 13 |
| | Quantity Surveyor | 11.7 |
| | Construction Manager | 10.4 |
| | Architect | 6.5 |
| | Construction Supervisor | 3.9 |
| | Construction Health and Safety Officer | 2.6 |
| Years of Experience | 1-5 years | 10.5 |
| | 6-10 years | 31.2 |
| | 11-15 years | 26 |
| | 16-20 years | 16.9 |
| | Over 20 years | 1.2 |
| | Under 1 year | 14.2 |

## VII. FINDINGS

The study result is presented in this section

### A. *Strategies for the Adoption of BIM for Crack Detection*

The findings from the descriptive analysis indicate that several strategies could help successfully adopt and implement BIM for crack detection in the SACI. The most effective strategy in the SACI context includes universities teaching BIM tools and applications to students interested in pursuing a career in the construction industry. By incorporating BIM into the curriculum, students will gain an in-depth understanding of its benefits and grow their skills in utilizing BIM to detect cracks. Secondly, raising awareness about the benefits of using BIM for detecting cracks in the construction industry could encourage stakeholders to adopt this technology. This approach could involve creating informative materials or hosting workshops to educate professionals and decision-makers on the potential of BIM in detecting cracks. Thirdly, promoting BIM research for crack detection could help advance the technology and improve its effectiveness in detecting cracks. This could involve funding research projects exploring the construction industry's latest BIM applications and tools. Training professionals in BIM crack detection tools is crucial for successfully implementing this technology. By providing hands-on training and support, professionals will be equipped with the necessary skills and knowledge to apply BIM in detecting cracks in the construction industry. The effectiveness of this strategy has been highlighted in different studies, which include [25, 27]. The study suggests that the adoption and implementation of BIM for crack detection in the SACI requires a multifaceted approach that involves teaching BIM tools and applications at universities, raising awareness of the benefits of BIM for detecting cracks, promoting BIM research for crack detection, and training professionals in BIM crack detection tools. Strategies for BIM is shown in Table II.

TABLE II. STRATEGIES

| Strategies | Mean | Std. Deviation | Rank |
|---|---|---|---|
| Teaching BIM tools and applications used to detect cracks in the University | 4.45 | 0.770 | 1 |
| Raise awareness of the benefits of detecting cracks using BIM | 4.43 | 0.637 | 2 |
| Promoting research on adopting BIM for crack detection and visualisation | 4.41 | 0.807 | 3 |
| Promoting wider BIM adoption in infrastructure maintenance | 4.40 | 0.658 | 4 |
| Training and development of construction and maintenance professionals on BIM crack detection tools | 4.38 | 0.673 | 5 |
| Implementation of BIM throughout the lifecycle of government facilities | 4.29 | 0.830 | 6 |
| Acquiring of BIM crack detection software and tools by construction organisations | 4.26 | 0.755 | 7 |
| Development of national standards for local implementation of BIM for crack detection | 4.23 | 0.809 | 8 |
| Mandatory adoption of BIM for crack detection on government projects | 4.06 | 0.978 | 9 |
| Construction organisations top management formally approving the use of BIM for crack detection | 4.01 | 0.993 | 10 |
| Tax relief to motivate adoption among construction stakeholders | 3.65 | 1.295 | 11 |
| Financial incentives to fund the implementation of BIM for crack detection | 3.62 | 1.257 | 12 |
| Organisations utilizing BIM for crack detection to receive tax breaks | 3.55 | 1.341 | 13 |

## VIII. Conclusion

The study's findings on BIM adoption strategies have significant implications for the South African construction industry (SACI). BIM implementation is a complex process involving multiple stages and requiring careful consideration of various factors. Its success depends on a well-planned and structured approach that addresses the country's unique infrastructure requirements. This involves a thorough analysis of infrastructure defects, particularly cracks. Effective training is crucial for successful BIM implementation, enabling SACI professionals to acquire the necessary skills and knowledge to use the technology effectively. BIM adoption can lead to improved infrastructure maintenance, enhanced collaboration, and more sustainable and efficient crack defect repair practices if implemented correctly. BIM is an emerging technology with great potential in the construction industry for various applications, including crack detection. Many countries have proposed and implemented strategies to adopt BIM, as highlighted in the reviewed literature. However, the effectiveness of these strategies varies due to the unique requirements and demands of each country's construction industry. In the South African context, the analyzed data revealed that the most effective strategies for BIM adoption for crack detection are training and education. By investing in training and educating construction professionals on BIM applications, companies can ensure that employees have the necessary skills to implement this technology effectively. This can lead to improved efficiency, reduced costs, and increased safety in construction projects. Further studies can be conducted to evaluate the effectiveness of various BIM training programs and their impact on professionals' proficiency and project success. Also, researchers should explore the integration of BIM with other emerging technologies like AI and IoT for enhanced crack detection and infrastructure maintenance.

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