Deep Learning for Detecting Building Defects

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***Abstract*— This review article identifies the deep learning methods for building defects detection, adapting an updated version of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure a rigorous and transparent review process. The review reveals that convolutional neural networks (CNNs) and their variations are the most popular in this field. By systematically identifying and categorizing the most relevant articles, we present a detailed taxonomy of the methods and applications. Additionally, the article explores current trends and discusses future directions, including advancements in real-time defect detection and the utilization of more diverse and comprehensive datasets.**

Keywords—artificial intelligence, deep learning, building defects.

I. Introduction

In the field of structrual engineering, building defects are defined as structural flaws that have the potential to affect a building's quality, operating condition, and its safety. As the structure gets older, it can develop defects like cracks, moulds, corrosion, and stains that lead to the degradation of structure. These types of building defects have the potential to degrade the structure and can lead to significant safety hazards. Investigation of such building defects and their causes is very important to maintain the building's stability and prevent them from collapsing. In order to find these defects, researchers are investigating deep learning methods to improve the identification of defects with high accuracy (Kim, K.W. et al., 2024). In the past, defect identification and its analysis have required manual inspection procedures that were less efficient. On the other hand, in today's world, deep learning algorithms are able to examine large amounts of image data gathered from building inspections (LeCun Y. et al., 2015). Deep learning, has emerged as a transformative technology in various fields, including defect detection. Deep learning is a method that use multiple hidden layers in a neural network (NN). These hidden layers are used to transform the input data into a representation. Adding more hidden layer helps to solve the complex problem more efficiently. This NN can handle very complex tasks by utilizing a large network and a large dataset. Deep learning becomes an effective method, especially for tasks like image recognition, delivering efficient results (Goodfellow I. et al, 2014). Deep learning has the ability to identify significant defects in building structures and predict the failure, which significantly improve the planning of projects, their safety, and engineering efficiency (Yang D, 2024). The application of deep learning in detecting building defects representing an important development in the construction industry, as explored in this study. The material composition, service life, and environmental factors contribute to the degradation of these structures. It becomes more complicated to predict the remaining service life (RSL) of such structures when they are made of different kinds of materials (Karimi, N. et al., 2023). In addition, defects such as voids, leaks, steel corrosion, and inner layer deformation can significantly affect the RSL of a structure. The RSL of buildings can be efficiently assessed and maintained using deep learning methods (Zhu H. et al., 2024). Hence, the use of deep learning with the required amount of data makes it possible to predict the RSL.

Inspection of such degradation and its treatment on time is a very important factor. Manual inspection can be less efficient and time-consuming, with a higher labor cost. While the implementation of deep learning techniques to identify different building defects makes it more efficient (Cumbajin, E. et al., 2024). Early detection of defects and their treatment in both existing and newly constructed buildings are very important for maintaining their safety and reliability, which helps reduce the risk of structural failure over time (Kuchipudi, S.T., & Ghosh, D., 2024). Considering the importance of historical structures, the effectiveness of structural health evaluations has increased recently due to developments in deep learning, computer vision, and digital image processing (Fu, X. & Angkawisittpan, N., 2024). These technologies provide a novel approach to defect identification, increasing efficiency and accuracy while reducing the need for material and labor. In most cases, deep learning utilizes a convolutional neural network (CNN), which has strong feature extraction abilities using large datasets and high-dimensional parameters. A classical representation of the CNN method for detecting building defects is presented in Fig. 1, which is adapted from (Perez H. et al., 2019).

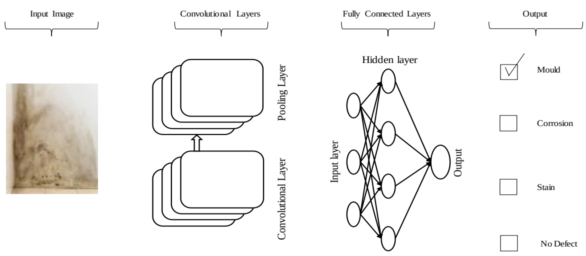

Fig. 1. Classic example of building defect detection using deep learning.

The CNN method is often used method because of its ability to identify defects using image data. It involves the collection of detailed information about building structure data. Once the data is collected, features like cracks, stains, and mould are extracted using a convolutional layer. After this, pooling layers are used to reduce the dimension and make a robust model with high efficiency. The fully connected layers are integrated to learn the features. During the training, each defect is labeled and classified based on its patterns. The output layer assigns each defect as per the classification and predicts the defect. In addition, the CNN model can be used to detect real-time defects. Perez H. et al., 2019). Similarly, (Yang D. 2024) utilized a deep learning-based CNN model for the image processing of a structure to identify and verify different types of defects with high accuracy. In a study by (Kim, K.W. et al., 2024), the you only look once (YOLO) model was utilized to identify micro cracks. Later, this model is integrated with the CNN to improve detection performance. Another study by (Karimi, N., et al., 2023), identifies defects in a historical bridge by categorizing different materials used in the bridge construction. They utilized different deep learning models with different materials and chose the ideal model that showed high accuracy. In order to make tunnel predictive monitoring more efficient, (Zhu H. et al., 2024) utilized the ground-penetrating radar (GPR)-based assessment method, which is integrated with building information modeling (BIM) and the CNN model. CNN's ability to identify defects with high accuracy makes it the most reliable deep learning method as compared to other traditional methods. It is also being utilized by (Cumbajin, E. et al., 2024) to identify small cracks in ceramic pots. From identifying various defects in large structures to detecting small cracks in ceramic pots, CNN has proven to be a more efficient method. Routine inspection plays an important role in ensuring the reliability and strength of the structures. In accordance with this, (Kuchipudi, S.T., and Ghosh, D., 2024) have proposed a CNN-based methodology that can automatically detect and categories the various defects with high accuracy. In a study by (Fu, X. & Angkawisittpan, N., 2024) utilized the deep convolutional neural network (DCNN) was utilized to identify and classify different types of defects, and then a YOLO-based image classification model was developed to achieve high accuracy. This study reviews significant deep learning methods for detecting building defects and predicting their RSL, aiming to identify the most efficient method for accurate defect detection. The structure of this study is as follows: Section 2. follows the research methodologies. Section 3. highlights the significant applications of deep learning in detecting building defects. The findings from this study along with future directions are concluded in Section 4.

II. Methodology

The research methodology used in this study was to make a comprehensive literature review based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The PRISMA method is a structured, four-phase process for performing systematic literature reviews. The four significant phases are identification, screening, eligibility, and inclusion. The main purpose of the PRISMA methodology is to help academics find the most relevant studies they are researching. In order to make sure the maximum quantity of related documents is being located, a thorough methodology was used with the help of different databases. This PRISMA methodology ensures that all selected documents are connected to each other and relevant to the topic. We chose Scopus as our primary search engine because of its extensive collection of peer-reviewed scientific literature and easy access to relevant papers in a variety of academic fields. In order to achieve this, the titles, abstracts, and keywords of the documents are continuously evaluated for the keywords of building defects, deep learning, CNN, recurrent neural networks (RNN), long short-term memory networks (LSTM), generative adversarial networks (GAN), transformer networks, auto-encoders (AE), deep belief networks (DBN), deep q-networks (DQN), graph neural networks (GNN), and defining NN. At the identification stage of the study, preliminary searches in the Scopus libraries showed up 448 publications, as shown in Fig. 2.

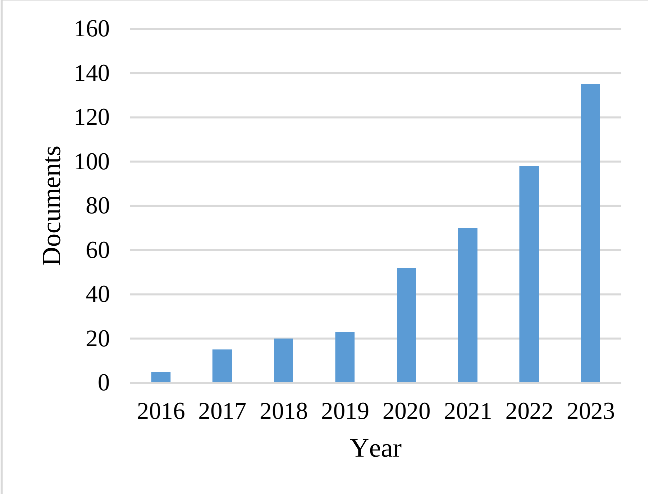

Fig. 2. A representation of the initial database having 448 articles from the period of 2016 to 2023

These articles went through the screening stage to filter out duplicate and irrelevant articles. At this stage, 200 articles moved to the next eligibility phase after the 248 identical articles were removed during screening. These remaining 200 documents are again evaluated based on the importance of their abstracts, titles, and year of publication. Following the PRISMA guidelines and an expert review to exclude less relevant articles, the resources were reduced to 20.All of this study's conclusions are based on the inclusion of these 20 research papers. The work flow of this methodology as shown in Fig.3. and PRISMA methodology as shown in Fig. 4, has been adapted from (Ardabili, S. et al., 2023; Ardabili, S. et al., 2023; Mosavi, A. & Ardabili, S., 2023; Rituraj, R. et al., 2023; Mudabbir, M. & Mosavi, A., 2023; Ardabili, S. et al., 2023).

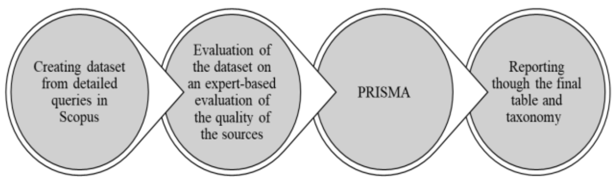

Fig. 3. Represent the work flow of the methodology

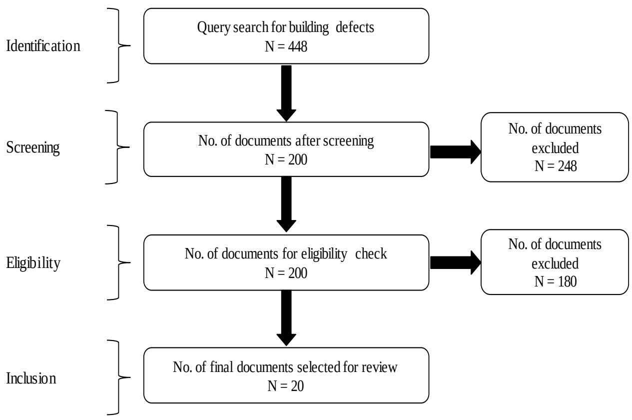

Fig. 4. Represent the most relevant literature after using PRISMA

For additional analysis, the 44 articles were arranged into a table having information about the author, publication year, concept, and used deep learning method. This gave an extensive summary of the concept and procedures used in the recent years. The methodology started with comprehensive searches in Scopus to create a dataset containing peer-reviewed studies. Experts evaluated the quality of each source based on their respective areas of expertise, following the PRISMA methodology. The final table summarized the findings and employed a taxonomy to categorize sources by their reliability and relevance. This comprehensive methodology ensured the accuracy of the study, which aims to present a systematic literature review of the most efficient deep learning methods used in detecting building defects. This review aims to support and guide future research on evaluating structural health and predicting the RSL. Such deep learning methods and their application in detecting building defects are detailed in Table 1. with a brief summary.

III. State of the Art Review

In this section the fundamental studies are reviewed.

TABLE I. DEEP LEARNING APPLICATION FOR DETECTING BUILDING DEFECTS

Authors	Source	Application	Methods
Yan Y. et al., 2017	Sensors	Building extraction	DL, SSAE
Perez H. and Tah. J.H.M., 2021	Structural Control and Health Monitoring	Enable real-time detection	CAHM, DL
Perez H. et al., 2019	Sensors	Precise detection and localization of building defects	CAM, CNN, TL
Oh B.K. et al., 2023	Integrated Computer-Aided Engineering	Estimating strain in building structures	CNN
Kung R.Y. et al., 2021	Advances in Civil Engineering	Defect detection using mobile devices and UAVs	CNN
Peng X. et al., 2021	Smart Structures and Systems	Detecting and measuring hidden defects	DL, ResNet, Center Net
Wang C. et al., 2021	Automation in Construction	Brick building recognition using street-view images	R-CNN
Hsu S.H. et al., 2023	Earthquake Engineering and Engineering Vibration	Real-Time damage identification in building	DL, YOLO
Zhang G. et al., 2022	Automation in Construction	Automated building exterior defect detection	DL, DAN, PSPNet, DETR
Lee K. et al., 2020	Sustainability	Monitoring system to identify exterior defects	DL, CNN
Jiang Y. et al., 2021	Journal of Performance of Constructed Facilities	Identifying defect from infrastructural facilities.	DL, U-Net, FCN
Jayaraju P. et al., 2022	Traitement du Signal	Identifies building cracks	CNN, RNN
Kalantar B. et al., 2020	Remote Sensing	Automated detection of damaged structures	CNN
Li Z. et al., 2023	Smart Structures and Systems	Automated post-earthquake structural assessment	ResNet, SPP, ASPP, FC
Garrido I. et al., 2021	Engineering Proceedings	Improving building defect detection	R-CNN,
Rodrigues F. et al., 2022	Applied Sciences	Building defect detection and categorization	R-CNN

Recent advancements in deep learning have revolutionized building defect detection. The extraction of buildings is very important for the planning and development of urban areas to build a smart city. In a study by (Yan Y. et al., 2017), the author proposed a building extraction method using a remote sensor using a stacked sparse auto encoder (SSAE). Aerial images are collected for the training. It has been further evaluated by comparing the model with a DBN and support vector machine (SVM). In terms of results, the SVM method is more effective than the others, but it consumes more time, whereas SSAE is also efficient in less time, whereas DBN shows the lowest accuracy amongst them. Another study by (Perez H. and Tah. J.H.M., 2021) explores effective methods for detecting building defects. A deep learning-based mobile application is being developed to identify building defects in real time. The defects are categorized as cracks, mould, deterioration, and stains. The proposed model showed the highest accuracy with the identification of stains and the lowest accuracy with the crack. This accuracy is mainly dependent on the resolution of the images. Hence, for better results in all categories, high-resolution images will be required. Similarly, (Perez H. et al., 2019) developed a deep learning model to detect defects by categorizing them as mould, stain, deterioration, or no defects. Transfer learning (TL) is used for data classification. The image augmentation technique is being utilized to improve the data quality. By integrating Class Activation Mapping (CAM), the defects are accurately identified. The proposed model achieved high accuracy in all categories. Defect optimization is a very fundamental aspect of structural health monitoring (SHM). For this, (Oh B.K. et al., 2023) developed the deep learning-based CNN model to measure different defects, specifically stain. This model was developed to measure the stain defect using correlation analysis.

Traditional building inspection methods are laborious, costly, and time-consuming. Hence, the use of an unnamed armed vehicle (UAV) makes it the most effective inspection method, with great mobility, high accuracy, and ensuring safety. In accordance with it, (Kung R.Y. et al., 2021) combined UAV technology with deep learning to automatically detect building defects. ResNet and Center Net is used to extract the desired output from images. The developed model is validated with high accuracy. In addition, (Peng X. et al. 2021) developed an UAV-based deep learning model with thermography to detect and measure the exterior defects of buildings. Fuzzy clustering methods are used to achieve high accuracy and reliability. This deep learning model shows an accuracy of over 90%. Despite the many advantages of using UAVs, there are also some limitations. It is challenging to obtain authorization for a UAV to fly over street traffic, and its utilization is unlikely due to its limited battery life. For this, (Wang C. et al., 2021) utilized street cameras to collect the building image for the training dataset instead of UAVs, considering the limitations of UAVs. The author developed an R-CNN model that can classify building structures and quickly identify defects in buildings. In addition to this, researchers also investigated how to improve real-time building inspection. For this, (Hsu S.H. et al., 2023) focused on using augmented reality (AR) technology. He developed a real-time defect detection method using the YOLOv5m model to identify common defects like cracks, paint degradation, and rebar deterioration. This proposed method is validated as an efficient method for building inspection. In a study by (Zhang G. et al., 2022), they developed a deep learning model and integrated it with three different networks, i.e., the Dual Attentional Network (DAN), the Pyramid Scene Parsing Network (PSPNet), and the Detection Transformer (DETR), for accurate and automatic detection of defects. The proposed model is validated with good reliability and stability. (Lee K., et al., 2020) developed a model that uses the R-CNN model integrated with the region proposal network (RPN) to track and recognize different types of defects in building exteriors. The RPN determined the images and proposed the defect region. (Jiang Y. et al., 2021) utilized a U-Net deep learning model with fully convolutional network (FCN) for high accuracy with less training data. This model has the potential for roadway assessment, building facade inspection, and solar panel inspection. (Jayaraju P. et al., 2022) used a deep learning model for detecting surface cracks in concrete structures. The effectiveness of smaller datasets using CNN is analyzed and compared with that of RNN. It is limited to binary classification. CNN detected cracks with 99% accuracy, while RNN had 50% accuracy.

Earthquakes are destructive natural disasters that frequently come with little or no warning. It can cause big damage to buildings, infrastructure, and the environment. It can't be avoided, but it can be prevented. Regarding this, (Kalantar B. et al., 2020) developed and analyzed three CNN models, i.e., twin, fusion, and composite, to detect earthquake damages using remote sensing (RS) images of before and after earthquakes. The twin model is validated with high accuracy. Similarly, (Li Z. et al., 2023) developed a deep learning based CNN model integrated with Spatial Pyramid Pooling (SPP), Atrous Spatial Pyramid Pooling (ASPP) and Fully Connected (FC) layer to assess the building conditions after an earthquake. It can efficiently identify defects, monitor health of structural components, and estimate the damage state of buildings. (Garrido I. et al., 2021) provide a plan to improve the decision-making process for building preventative measures. It combines spatial and temporal deep learning models to analyze data from infrared thermography (IRT). It has shown an accuracy of 92.8% for the identification and classification of defects. (Rodrigues F. et al., 2022) developed an automated tool to detect and characterize building defects with the help of BIM structure. Deep learning based R-CNN model is used to detect the defects from images. The integration of BIM with R-CNN model makes the defect detection process more efficient. After outlining the most significant deep learning methods in detecting building defects are briefly summarized and taxonomy of this study is presented as in Fig. 5.

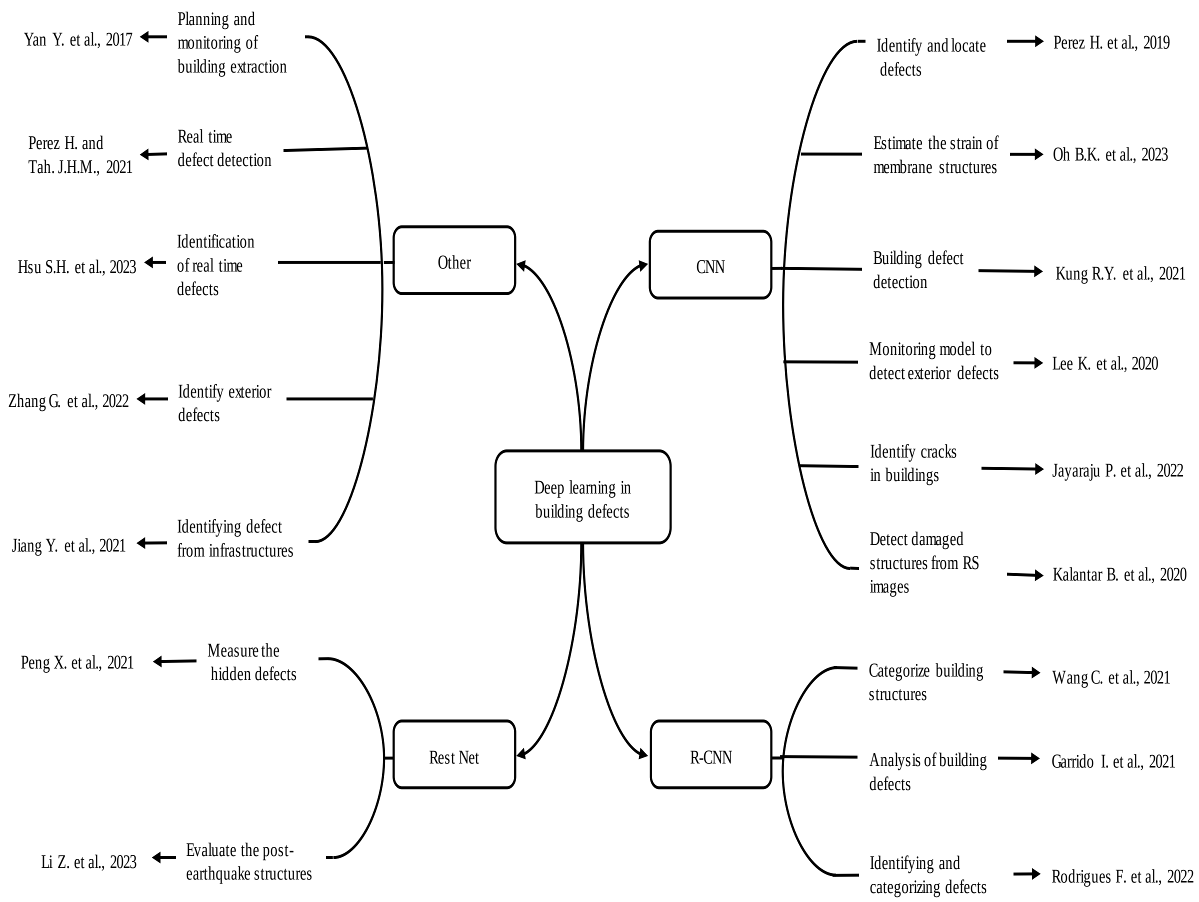

Fig. 5. Taxonomy of building defects with deep learning methods.

This taxonomy will help to understand the recent trend of deep learning in building defects. It categorizes the important deep learning-based methods such as CNN, R-CNN, and its variants to detect building defects. It has been noticed that the majority of the research on building defects is done using the CNN methodology because of its effectiveness. In addition to that, some research studies integrate CNN variants like R-CNN with other methods to improve the detection accuracy. Some of the research studies utilized Rest Net to improve the optimization of building structures with high accuracy. The other methods are based on UAVs and IRT, which are widely used to inspect and monitor building conditions. The method's applicability depends on its requirements and various conditions. Over all, CNN has dominated building defect research, and other methods like R-CNN, Rest Net, UAVs, and IRT play an important role in improving detection accuracy.

IV. CONCLUSIONS

Deep learning has been widely used in a variety of fields and shown potential in the field of structural engineering, especially in the area of building defect detection. It has proven its ability to automatically learn and recognize complex structures using large amounts of image and sensor data. This work aimed to provide a methodology for identifying research conducted using deep learning to detect building defects. The most significant deep learning methods for detecting building defects are reviewed, and a comprehensive literature review is presented using PRISMA methodology. The most recent peer-reviewed studies are included in this work. This methodology advances the inclusion on most significant research carried out in this field. The methodology, databases, and performance rates of used deep learning methods are compared and evaluated. Our finding reveals that, deep learning based CNN, R-CNN model and image processing methods integrated with UAVs shows the promising results. Deep learning-based models have proven to be the optimal method for detecting building defects and monitoring structural health. In conclusion, this study highlights the significant potential of deep learning in detecting building defects and predicting the RSL of structures. Image based defect detection method is a growing field presents various challenges. Further research aims to provide a YOLO model to identify and categorize the building defects and address the challenges associated with applying this method in real-world scenarios. For future research it is expected that further deep learning methods, e.g., Sarnovský et al., (2022).

ABBREVIATION

Abbreviation	Definition	Abbreviation	Definition
DL	Deep Learning	UAV	Unmanned Aerial Vehicle
NN	Neural Network	R-CNN	Region-based Convolutional Neural Network
RSL	Remaining Service Life	Res Net	residual neural network
CNN	Convolutional Neural Network	Center Net	Center Net Network
YOLO	You Only Look Once	SPP	Spatial Pyramid Pooling
DCNN	Deep Convolutional Neural Network	ASPP	Atrous Spatial Pyramid Pooling
PRISMA	Prefe Reporting Items Systematic Reviews and Meta-Analyses	FC	Fully Connected layers
RNN	Recurrent Neural Network	AR	Augmented Reality
LSTM	long short-term memory networks	RS	Remote sensing
AE	Auto Encoder	IRT	InfraRed Thermography
DBN	Deep Belief Networks	BIM	Building Information Modeling
DQN	Deep q-networks	SSAE	Stacked Sparse Auto Encoder
GNN	Graph Neural Networks	SVM	Support Vector Machine
LIDAR	Light Detection and Ranging	DAN	Dual Attentional Network
DSM	Digital Surface Model	PSPNet	Pyramid Scene Parsing Network
CAHM	Condition Assessment and Health Monitoring	DETR	Detection Transformer
CAM	Class Activation Mapping	RPN	Region Proposal Network
SHM	Structural Health Monitoring	FCN	Fully Convolutional Network
TL	Transfer Learning		

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