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A Review of Using Deep Learning Technology in the Built Environment of Disaster Management Phases

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Abstract

Türkiye is a country on the Alpine-Himalayan earthquake zone and needs an effective disaster management plan, with its geography experiencing severe seismic activities. In this respect, natural disaster risks can be reduced by using developing artificial intelligence technology and deep learning applications in the mitigation, preparedness, response, and recovery phases that constitute the disaster management plan. This study examines deep learning models, application areas, deep learning layers and libraries used, and how deep learning can be used in the four stages of disaster management through study examples in the literature. The study aims to examine the use of deep learning in architecture and disaster management phases based on the earthquake factor as a result of the literature review. As a result, when studies on deep learning are examined, disaster management studies closely related to the discipline of architecture are mainly in the response phase. However, the discipline of architecture plays an important role at every stage of disaster management. In this respect, as holistic studies and applications related to deep learning, architectural science, and effective disaster management increase, the loss of life and property due to disasters, especially earthquakes, will decrease. The study carried out is thought to be an important guide for future research.

Keywords: *Artificial intelligence, deep learning, disaster management, earthquake, architecture.*

Yapılı Çevrede Afet Yönetimi Aşamalarında Derin Öğrenme Teknolojisinin Kullanımına İlişkin Bir İnceleme

Öz

Türkiye Alp Himalaya deprem kuşağı üzerinde olan ve şiddetli sismik aktivitelerin yaşandığı coğrafyası ile etkin afet yönetim planı olması gereken bir ülkedir. Bu açıdan, gelişen yapay zeka teknolojisi ve derin öğrenme uygulamaları kullanılarak afet yönetim planını oluşturan risk ve zarar azaltma, hazırlık, müdahale ve iyileştirme evrelerinde doğal afet riskleri azaltılabilir. Bu çalışmada, derin öğrenme modelleri, uygulama alanları, derin öğrenme katmanları ve kullanılan kütüphaneler incelenerek, literatürde yapılmış çalışma örnekleri üzerinden derin öğrenmenin afet yönetiminin dört aşamasında nasıl kullanılabileceği irdelenmiştir. Çalışmanın amacı yapılan literatür taramasının sonucunda deprem faktörü baz alınarak mimarlık ve afet yönetimi aşamalarında derin öğrenmenin kullanımını incelemektir. Sonuç olarak derin öğrenme ile ilgili çalışmalar incelendiğinde, mimarlık disiplini ile yakın ilişkili olan afet yönetimi çalışmaları en çok müdahale aşamasında bulunmaktadır. Oysaki mimarlık disiplini afet yönetiminin her aşamasında önemli görevler almaktadır. Bu açıdan derin öğrenme, mimarlık bilimi ve etkin afet yönetimi ile ilgili bütünsel çalışmalar ve uygulamalar arttıkça, afetler özellikle deprem nedeniyle yaşanacak can ve mal kayıpları azalacaktır. Yapılan çalışmanın ilerideki araştırmalar için önemli bir klavuz niteliği taşıdığı düşünülmektedir.

Anahtar Kelimeler: *Yapay zekâ, derin öğrenme, afet yönetimi, deprem, mimarlık.*

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1. Introduction

The 21st century is an era of big data, advancing rapidly in technology and information with the fourth industrial revolution. Artificial intelligence technology has come to the fore in recent years due to this age. Deep learning, the result of technological developments in machine learning, is an artificial intelligence algorithm that can produce results and perform complex operations by learning the information in a data set on its own (Figure 1). In deep learning, which is more advanced and faster than machine learning, the qualities of the data are created by the system itself. In machine learning, these attributes are given to the system. While doing this, it takes the nerves in the human brain and the network structure between them as an example. The artificial neural networks it uses consist of many layers. The result that one layer obtains from data is the input value of the next layer. Deep learning studies, whose basic logic and features can be summarized in this way and which have become widespread today as a result of increasing interest, are encountered in many areas such as classification, control, prediction, and diagnosis, but are primarily used in the field of image classification (Baran Ergül, Varol Malkoçoğlu & Acun Özgünler, 2022; Gültekin, 2022).

Although the 21st century has made significant progress in these areas, especially with deep learning, on the other hand, natural disasters, one of the critical problems affecting the world, continue to exist in a way that is difficult to avoid. For this reason, this study is based on the concepts of natural disasters and deep learning. In this regard, the study aims to question and analyze from an architectural perspective whether this technology can be used in disaster management by associating the concept of natural disaster with deep learning. Since the most common type of natural disaster in Turkey is earthquake, the study focused on earthquake-related research. However, although studies on natural disasters and deep learning have begun to increase in the literature in recent years, very few studies can be found, especially based on earthquakes. For this reason, the literature sources examined throughout the study are limited in number within the scope of the research.

The study is organized as follows In the first part, the study is introduced, and the definition and basic features of deep learning are explained. In the second section, the methodology used in this study is explained, and deep learning models, application areas, layers, and libraries used are explained. In the third section, existing studies in the literature are organized, categorized, and examined according to disaster management stages. In the fourth section, the results of this study are summarized and discussed. Systematic findings obtained by examining case studies show that studies in this field will increase in the future, and deep learning will reach a critical point in natural disaster management.

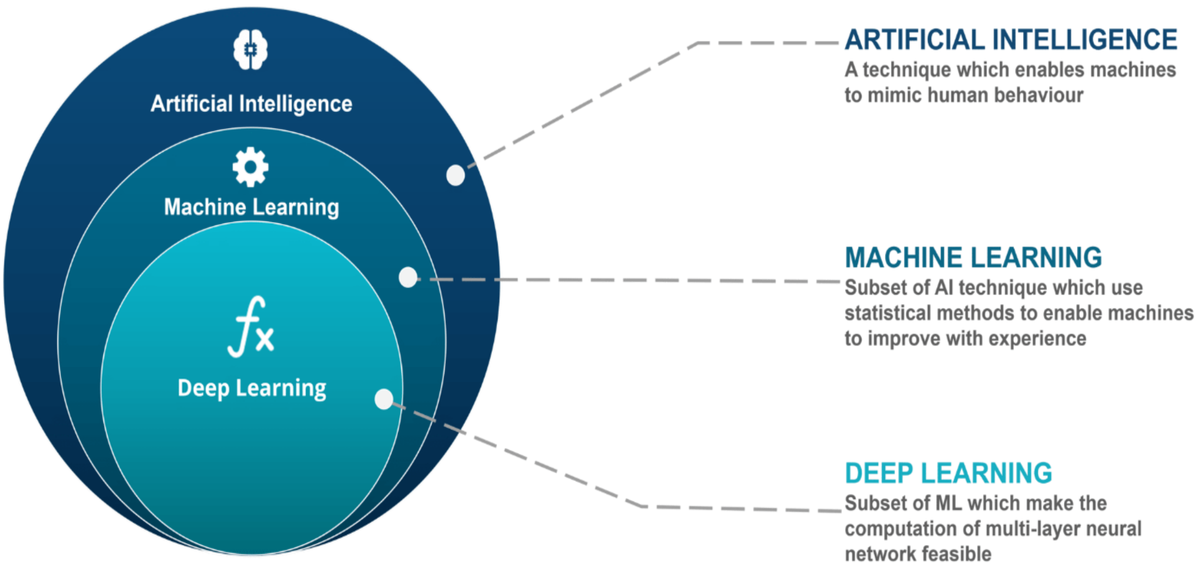

Figure 1. Artificial intelligence systems (Harsha, 2018)

2. Material and Method

Deep learning models are a widely used technology in many fields, such as health, classification, and object detection. This developing technology has started to become one of the methods used to reduce disaster risk in recent years. This study gives general information about the network models used in deep learning, application areas, and libraries, and case studies are analyzed concerning the four stages of disaster management. The study analytically reviews and examines the literature to reveal the relationship between deep learning and earthquakes. The findings obtained as a result of the evaluations are explained with tables and graphs, and the statements are translated into data. The study aims to associate deep learning with earthquakes, a critical natural disaster in Turkey, and to compile the studies done in this field within the scope of disaster management stages and bring them together as a resource. The small number of literature studies on deep learning specifically for earthquakes determines the study's limitations.

2.1. Deep Learning and Artificial Neural Network Models

Deep learning models, a product of the digital age, are widely used in many fields, such as medicine, classification, industry, and sound. These models which differ from each other according to the number and complexity of their layers (Figure 2), the programming language, the characteristics of the data sets, and the library they use, offer different solutions to different problems (Figure 3).

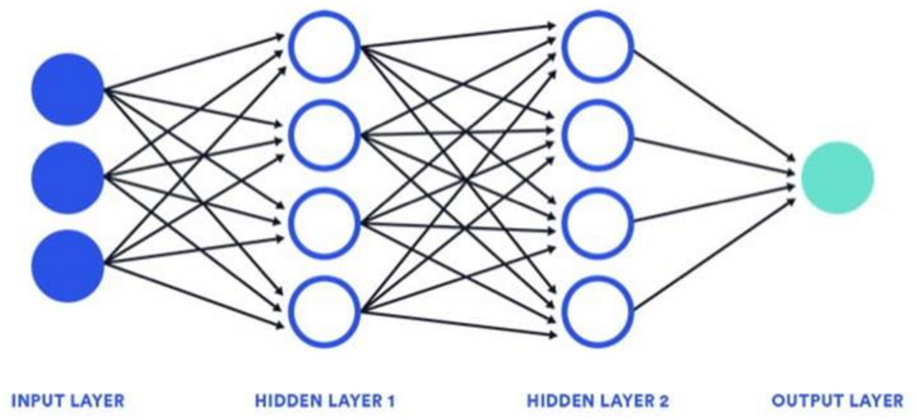

Figure 2. Basic artificial neural network model (CloudTime Talk, 2022)

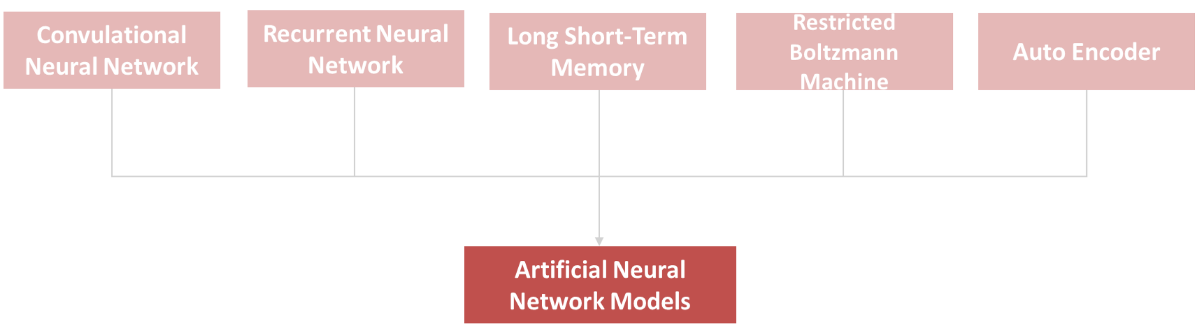

Figure 3. Artificial neural network model types (edited by the Author)

(Convolational Neural Network) Convolutional neural network (CNN), which can be used in areas such as drug discovery and video recognition but is frequently preferred, especially for image analysis, is a multi-layered and filter-based model. It is a feed-forward convolutional neural network and was basically developed from characteristics of the visual cortex of the human (Shrestha & Mahmood, 2019).

(Recurrent Neural Network) Simple recurrent neural networks (SRN), designed by Elman, are generally used for language translations. It performs the process of estimating the next point based on consecutive data. The process of guessing the word, which shows how the continuation of the sentence will be after the words that are formed in an incomplete sentence, can be given as an example of this situation (Doğan & Türkoğlu, 2019).

(LSTM- Long Short-Term Memory) LSTM, one of the variations of the Recurrent Neural Network, was discovered by Hochreiter in 1997. Unlike RNN, which can memorize short-term information, it can process long-term data and keep previous input or status information and has automatic control that decides which of this information to retain.

In the LSTM model, there are three gates in total: the input gate that checks new information, the forget gate that deletes previously unused information, and the output gate that regulates the information (Shrestha & Mahmood, 2019; Hung, 2023).

(RBM Restricted Boltzmann Machine) The Boltzmann machine, used in classification and feature learning, is a neural network that creates probabilistic graphical models from input data. It has a two-layer structure called the input and hidden layers, respectively (Fischer & Igel, 2012).

(Auto Encoder) Deep automatic encoders, one of the artificial neural network models, is a system that uses an unsupervised learning algorithm. In this model, which has no classification feature, the dimensions in the input data set are reduced in the first step to obtain a smaller vector. In the next step, the input is tried to be reconstructed in order to obtain the output data set with the same properties as the input data set (Kaynar, Görmez & Işık, 2016; Uçar & Uçar, 2019).

2.2. Application Areas of Deep Learning

Computer Vision In case studies, black and white images from many years ago were colored (Larsson, Maire & Shakhnarovich, 2016), and low-resolution face images were converted to high-resolution face images (Dahl, Norouzi & Shlens, 2017).

Classification There are many studies on image classification. Deep learning models used for classification have a significant impact on success rates. Classification of plant diseases (Saleem, Potgieter & Arif, 2019), face recognition and classification (Alimovski, 2019; Safalı & Avaroğlu, 2021), and classification of breast cancer tumors (Özgür & Bozkurt Keser, 2021) can be cited as exemplary studies.

Object Detection Image classification and object detection are application areas that are thought to be similar but different from each other. In classification, images are separated into a class according to the tags in the current situation. In object detection, an object in an image is searched, and its location is estimated. Anomaly detection (Chalapaty & Chawla, 2019) and cardiac arrhythmia detection (Isın & Ozdalili, 2017) studies can be examples.

Medical Research on deep learning has revealed many approaches that can benefit human health in a positive way. Medical findings used for purposes such as classification, detection, etc., are very important. For example, in a study using deep learning in neural networks, a good performance result was achieved in disease prediction. In another study, an image from a human brain from Magnetic Resonance Imaging (MRI) was used to predict a possible Alzheimer's disease. (Vaezipour, Mosavi & Seigerroth, 2013; Vargas, Mosavi & Ruiz, 2018).

Other studies Apart from the areas mentioned above, there are also deep learning studies in many areas. For example, it is seen in different areas such as building damage assessment in structural engineering (Gültekin, 2022), analytical chemistry (Debus, Parastar, Harrington & Kirsanov, 2021), nanophotonics and nanostructure (Wiecha & Muskens, 2019).

2.3. Application Layers of Deep Learning

Input Layer

It is the first layer, and data entry is provided. Input data size is a factor that affects the model to be created. In image analysis, the selection of input image size is important because it affects the neural network depth, hardware computation cost, and neural network success. The input data forms the data set (İnik & Ülker, 2017).

Convolution Layer

The purpose of this layer, which forms the basis of convolutional neural networks, is to enable the input properties to be revealed by hovering a specified filter over the input data. As a result of this operation, a smaller matrix than the input data is obtained (Doğan & Türkoğlu, 2019) (Figure 4).

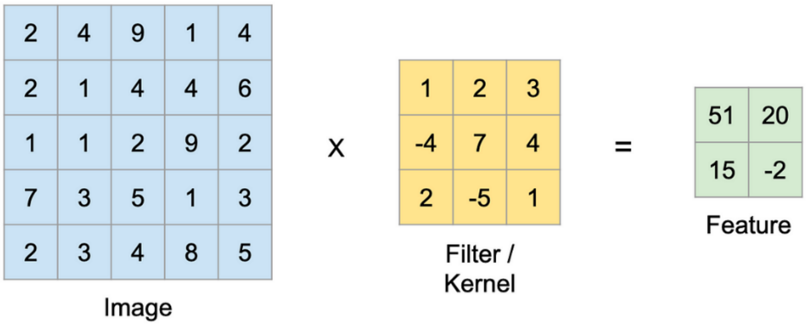

Figure 4. An example of convolution layer (Patel, 2019)

Relu Layer

It comes after the convolution layer and is also called the activation layer. It takes negative values to zero by acting on the input data. This layer aims to transform the linear network into a nonlinear structure due to the mathematical operations performed in the convolution layer. So the network learns faster (İnik & Ülker, 2017).

Pooling Layer

In the optional pooling layer, which is mainly located after the relu layer, the data is reduced due to the operation, and the input size of the data for the next layer is reduced. With the pooling process, data is lost, but because it reduces the computational load for the next layer, it makes the network work faster. This layer also has filtering inputs. (İnik & Ülker, 2017).

Full-Connected Layer

It comes after the pooling layer and all the neurons here are in array form. All neurons in the layer are fully connected to all the activations in the previous layer. For example, if the matrix size of the pooling layer is 25x25x256=160000x1 and the matrix size in the fully connected layer is 4096x1, a total of 160000x4096 weight matrix is formed. So, in the end, this means that each of the 160000 neurons is connected to 4096 neurons (İnik & Ülker, 2017).

Dropout Layer

In multilayer neural networks, while the neural network is being trained, the memorization of the network, sometimes known as overlearning, occurs. In order to prevent this undesirable situation, eliminating some memorizing nodes in the network is achieved through the dropout layer. So, this layer works as the editing layer (Srivastava, Hinton, Krizhevsky, Sutskever & Salakhutdinov, 2014).

Classification Layer

In this layer, which comes after the fully connected layer, several results equal to the number of elements to be classified are produced. Each of these results corresponds to a class. Although different types of classifiers are used for this layer, known as the last layer, the softmax classifier with a high success rate is generally preferred (Doğan & Türkoğlu, 2019).

2.4. Application Libraries of Deep Learning

Ready-made libraries, which are important in terms of facilitating the work when using deep learning applications, have different features and functions developed by many universities and companies.

a. TensorFlow

Developed by Google, TensorFlow is a library that facilitates numerical calculations using data flow graphs. It is an open-source library that supports CPU and GPU-based systems. It distinguishes itself from other libraries with its ability to work flexibly with deep learning model architectures such as CNN, RNN, and RBM and its continuous support by the developer team. It is written in Python language (Dixit, Tiwari, Pathak & Astya, 2018; Yapıcı & Topaloğlu, 2021).

b. Caffe

It is a library developed by the University of Berkeley with modular and fast features, supporting CPU- and GPU-based systems. It is open source and has been used in fields such as computer vision, speech recognition, and image processing. It is written in Python (Erickson, Korfiatis, Akkus, Kline & Philbrick, 2017; Rao, 2023).

c. Theano

It is an open-source library developed by the LISA laboratory at the University of Montreal. It is used for mathematical expressions such as multidimensional arrays. It is written in Python (Gündüz & Cedimoğlu, 2019).

d. Torch

It is an open-source library developed by Ronan Collobert et al., with features of speed and flexibility in creating algorithms. Written in the Lua language (Şeker, Diri & Balık, 2017).

e. DeepLearning4J

Deeplearning4j was developed by Andrej Karpathy. It is an open-source library written in Java language (Erickson et al., 2017).

f. Keras

It is a Python library developed by Google software engineer Francois Chollet. It can use both TensorFlow and Theano as backends, but since the size of the input data is different, it requires careful design so that both backends can work using it (Erickson et al., 2017; Gündüz & Cedimoğlu, 2019).

g. DIGIT

It is a non-programming language and a web-based library developed by Nvidia company. Instead, it uses a text file and network visualization tools. It provides GPU support (NVIDIA, 2015).

h. Computational Network ToolKit

It is a library developed by Microsoft, written in Python over C++ code and using a graphical tutorial (Yapıcı & Topaloğlu, 2021).

i. MXNET

MXNet is a multilingual open-source library developed by Amazon. Its multilingual nature and computational and memory efficiency are critical factors in choosing MXNet. It supports different systems, such as GPU, CPU, and mobile devices (Chen, Li, Li, Lin, Wang, Wang, Xiao, Xu, Zhang & Zhang, 2015; Rao, 2023).

3. Disaster Management Cycle and Deep Learning Architecture

Many cities have high building density and population in Türkiye, and these cities are at significant risk and danger when natural disasters occur, especially earthquakes. There are several ways to reduce natural disaster risks, and the development of technology and disaster management stages are significant in this regard. The disaster management process consists of different phases, each with its signature aims and resources. These phases, divided into four groups, differ according to their implementation before and after the disaster and are defined as mitigation, preparedness, response, and recovery (Figure 5).

Figure 5. Disaster management stages (Francoeur, 2023)

3.1. Mitigation Phase

The phase of mitigation of the risks and damages of natural disasters is of great importance for creating safe and resilient societies. Therefore, it is necessary to identify risks, estimate the potential impact, and evaluate sensitivity. This stage includes the measures taken to prevent or reduce disasters' causes, effects, and consequences. Thus, it aims to keep the ecosystem and the social system formed by human communities strong and balanced (Lettieri, Masella & Radaelli, 2009). At this phase, it is very important to determine the hazards and risks of disasters to avoid major losses and to reduce the death rate and destruction. Examples of risk mitigation activities include implementing advanced building codes and standards and informing and raising public awareness about disaster hazards and risks. (McEntire, 2009; Sun, Bocchini & Davison, 2020).

Case studies using deep learning are rarely used at this phase (Sun, Bocchini & Davison, 2020).

3.1.1.Using deep learning in earthquake prediction in mitigation phase

Considering the devastating consequences of earthquakes in the past, earthquake prediction is a critical issue and a challenging subject because earthquakes are a natural phenomenon that needs to be studied and analyzed very well. Many studies have been done to predict earthquakes, but no study that can predict earthquakes precisely has been found yet. However, in some studies, some earthquake patterns are tried to be formed by examining the earthquake records that have occurred before. These studies generally focused on artificial intelligence, statistical methods, and deep learning models.

In a study conducted by Karcı & Şahin (2022), information such as the date of the earthquake, the time of occurrence, latitude, longitude, and depth obtained from the data of the earthquakes that took place in Türkiye in recent years were collected. A model was proposed to estimate the magnitude of a possible earthquake that may occur using this information. Long-Short-Term Memory, one of the deep learning models, was used in the proposed model. The results obtained from this model were examined and compared with the results of the generally used machine learning algorithms, and as a result of the study, it was concluded that the results of the proposed model were more successful.

In a study conducted by Wang, Guo, Yu & Li (2017), long short-term memory models (LSTM) were used to examine the relationship between earthquakes occurring in different locations and to make earthquake predictions based on this relationship. The study achieved results that showed better performance in earthquake prediction with the inputs developed in the research.

3.1.2. Using deep learning in earthquake resistant architectural design in mitigation phase

Earthquakes are a very important design input in countries where earthquake events occur frequently, especially in Türkiye, an earthquake-prone country. Therefore, architects should be aware of this; the structural system should be carefully considered and included in the design process. The negative consequences of this situation, which are not considered adequately during the design process, are the losses in the process and the cost required by the revisions encountered during the construction project phase.

In a study conducted by Bingöl, Er Akan, Örmecioğlu & Er (2020), an Irregularity Control Assistant (IC Assistant) was tried to be created by using deep learning and image processing methods. It is aimed that this suggested assistant will be able to give general information to architects so that the structural system decisions made at the beginning stages of the design can follow the principles of the earthquake code. As a result of the study, it has been observed that it is possible to get an accurate interpretation of whether the structural system is irregular with the suggested assistant.

3.1.3. Using deep learning for seismic reliability assessment of transportation networks in mitigation phase

In a study by Nabian & Meidani (2018), a deep learning model was used to evaluate the reliability of systems and optimize the systems based on the factor of the impact of natural disasters on infrastructure systems. The study was analyzed using the example of the California transportation network affected by probabilistic earthquakes. As a result of the study, it was stated that at least 99% accuracy was achieved.

3.1.4. Using deep learning in analyzing social media data and social sentiments in the mitigation phase

In a study conducted by Yang et al. (2019), social media data was used to reduce disaster risks. In the study, the earthquake event in Ya'an in 2013 was examined using a deep learning model with Chinese social media data. The study analyzed geographical information together with social sentiment data. As a result of the study, it was observed that disaster risk reduction strategies can be optimized by emphasizing the concept of emotional action.

3.2. Preparedness Phase

This is a pre-disaster phase where preparedness plans are made, the public is informed, and education and training activities take place.

Establishing plans for what to do, where to go, or from whom to get help in case of a disaster, planning the supply lists of useful materials, and organizing drills are activities that can be an example of this step (McEntire, 2009).

3.2.1 Using deep learning for educational systems to teach earthquake risk

In a study by Amin & Ahn (2021), an education system was proposed to make space users aware of the risks that spatial objects may pose during an earthquake and raise awareness of space users. The authors have built a You Look Only Once (YOLO) with a deep learning algorithm on their 208iter system, which they call Earthquake Situation Learning System (ESLS). They prepared an indoor data set 208iterat system. After users interact with ESLS through images and video, YOLO recognizes spatial objects through these visual resources and creates risk labels. The study stated that the results reached the user in 0.8 seconds, and the detection of harmful spatial objects was 96% accurate.

3.3. Response Phase

The response phase is the phase that includes search and rescue work, first aid, temporary shelter, etc., which takes place immediately after a disaster. In addition, this phase process, in which businesses do not operate normally, is the most important phase of disaster management. Examples of this step are implementing disaster response plans, organizing search and rescue operations, and trying to solve the people's food security problem (McEntire, 2009).

3.3.1. Using deep learning to provide search-rescue support with drone in response phase

Considering the positive features of drones, such as advanced technology and the ability to monitor remote areas, large areas affected by natural disasters can be scanned quickly, and search and rescue operations (SAR) can be carried out faster. However, the use of drones for search and rescue is not an area that is frequently researched and studied.

In a study by Mishra, Garg, Narang & Mishra (2020), a drone dataset for recognizing human actions is proposed for search and rescue activities. Deep learning models were applied to this proposed data set and the Okutama data set, a publicly available data set, and the results were compared and examined. As a result of the study, positive results that can be used for SAR activities were observed in the proposed data set and model.

3.3.2. Using deep learning to identify real post-disaster rescue calls in the response phase

Social media, one of the benefits of the digital age and advanced technology we live in, has become one of the indispensable elements of our daily lives. Thus, it is a common tool people use for emergencies and assistance when natural disasters occur. However, it can be difficult to find actual help posts during these emergencies due to the intensity and chaos they all create while using social media.

A study conducted by Robertson, Johnson, Murthy, Smith & Stephens (2019) investigated whether the intensity of social media could be reduced during natural disasters and whether actual calls for help could be determined by using deep learning models. Human-coded images released when Hurricane Harvey 2017 occurred were compared and analyzed using deep learning classification methods. As a result of the study, it was stated that the desired results could not be achieved, but it was observed that the research could help disaster research in the following years. Although this study is not a research on earthquakes, it was added to the research as an example because it is thought that it can be similarly used in earthquake events.

3.3.3. Using deep learning as a support for the locating of damaged structures and disaster management process in the response phase

Being able to locate damaged houses after a natural disaster quickly is an important and challenging process. In this critical process, there are some problems in correctly directing the organizations with resources such as first aid and food to the damaged areas.

In a study conducted by Tarhan, Özgür, Teke & Komesli (2022), an application that can make damage assessment classification and save location information to the database is proposed using image data of the 2020 İzmir earthquake. As a result of the study, it has been observed that damaged structures can be detected with a high degree of accuracy, and all processes that will occur after the disaster can be assisted.

3.3.4. Using deep learning in detection and classification of damaged structures in response phase

In a study by Maraş & Sarıyıldız (2023), a Mask Zone-based Convolutional Neural Network, one of the deep learning models, was used to detect damaged structures quickly. Image data obtained by uncrewed aerial vehicles from the 2010 Haiti earthquake was used 209iteratü model. In the test process applied in the study, damaged structures could be detected, and these structures could be classified with a high accuracy rate.

In a study conducted by Gültekin (2022), the damages occurring in buildings during and after the earthquake constitute the main problem of the study. The study gave information and explanations about artificial intelligence and deep learning. In the study, an example of an artificial intelligence algorithm that can be used in building damage detection was developed. The Convolutional Neural Networks model was used in the example model. Damage image data collected from the Izmir (Seferihisar), Istanbul (Silivri), and Elazığ (Sivrice) earthquakes were used as the source data set of this model. As a result of the study, it is claimed that the proposed model detects and classifies damages in structural and non-structural elements with a high success rate.

In a study conducted by Liu, Sui & Zeng (2023), an exemplary model was developed to detect building damage quickly and effectively in post-disaster emergencies. The study created a data set using publicly accessible aerial videos. An example SLDAM method was created to classify building damages according to different levels. The Mask R-CNN deep learning and ShuffleNet classification models were also used. As a result of the research, it was stated that the proposed model achieved successful results in building damage detection.

In a study by Nguyen, Ofli, Imran & Mitra (2017), a CNN-based model was used on social media data to detect post-disaster damage levels. As a result of the study, the model achieved a high degree of accuracy in classification and better results than techniques such as Bag-of-Visual-Words (BoVW).

In a study by Li, Caregea, Zhang & Imran(2018), they proposed a deep learning method to detect and evaluate the damage in disaster-affected places. In this method, they used CNN, class activation maps, and social media images of different disasters. As a result of the study, a success rate of 90.1% was observed in Ecuador earthquake data.

3.3.5. Using Deep Learning for Post-disaster Situation Assessment

In a study by Wang, Tao, Chen & Shyu (2020), a deep learning-based framework was proposed using social media so that emergency response teams can evaluate human and structural damage status after a disaster. A Twitter-based dataset and VGG-19, CNN, and LSTM models were used in this multimodal framework. It has been observed that this framework can establish connections between different concepts and data, and as a result of the study, it performs better than models built on single tasks.

3.3.6. Using Deep Learning to Find Post-disaster Survivors

In a study by Chaudhuri & Bose (2020), a deep learning model based on the classification of images was used to find survivors under the rubble in earthquake-affected areas. Both CNN deep learning (AlexNet, Inception-V3, and ResNet-50) and machine learning models were used in the study. When the results were compared, CNN models performed better than the machine, and among them, the ResNet-50 model performed better than the others.

3.3.7. Using Deep Learning in Predicting Human Evacuation Behaviors

In a study by Song, Shibasaki, Yuan, Xie, Li & Adachi (2017), a DeepMob system is proposed to understand and predict human evacuation behavior after a disaster. This deep learning-based system is also intended to predict and simulate future evacuation behaviors and routes. This system used sources such as transportation network data, Japan earthquake data over four years, and GPS records over three years. As a result of the study, it was found that the system had an accuracy rate of 87.8% in predicting human evacuation behavior.

3.4. Recovery Phase

It covers the activities to return to a safe life and normalized socio-economic conditions in the disaster-affected region. At this stage, restoration work takes place simultaneously with everyday activities.

Reconstruction of damaged structures, providing services such as education and health, and re-establishing infrastructure services can be examples of this stage (McEntire, 2009).

3.4.1. Using Deep Learning in the Recovery Phase

In a study conducted by Pogrebnyakov & Maldonado (2017), an effective emergency response and recovery was aimed at classifying social media data. Facebook message data from the US police department was used for the sample analysis. CNN, RNN deep learning, and SVM machine models were used to classify the messages into four headings, including recovery. The study achieved the best performance results with the RNN deep learning model. Although this study was conducted specifically for hurricanes, it was examined as an example since it can also be applied to earthquakes.

4. Findings and Discussion

Within the scope of this study, 18 literature studies (Table 1) conducted between 2017 and 2023 were examined, and the findings were visualized with graphics to access the most up-to-date data on deep learning and earthquakes. The first graphic analyzes the distribution of research according to disaster management stages (Figure 6). The second graphic analyzes the distribution of research within these stages according to their relationship with the architecture discipline (Figure 7). The findings show that the sample studies are concentrated on the response phase, both in their general distribution according to phases and within the phases according to their relationship with architectural discipline.

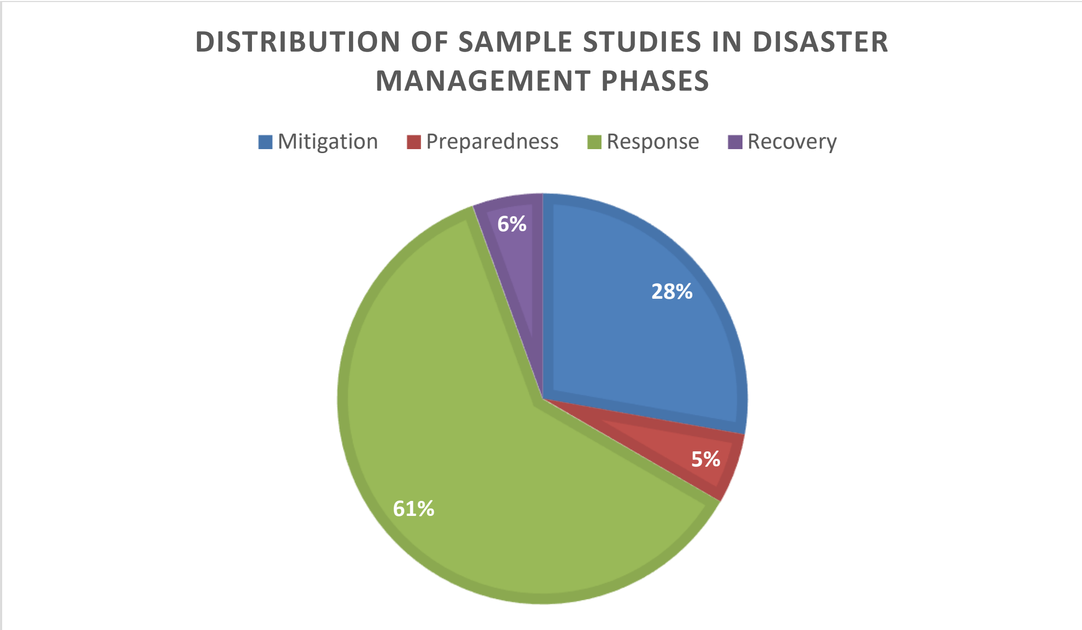

Figure 6. Disaster management stages (edited by Author)

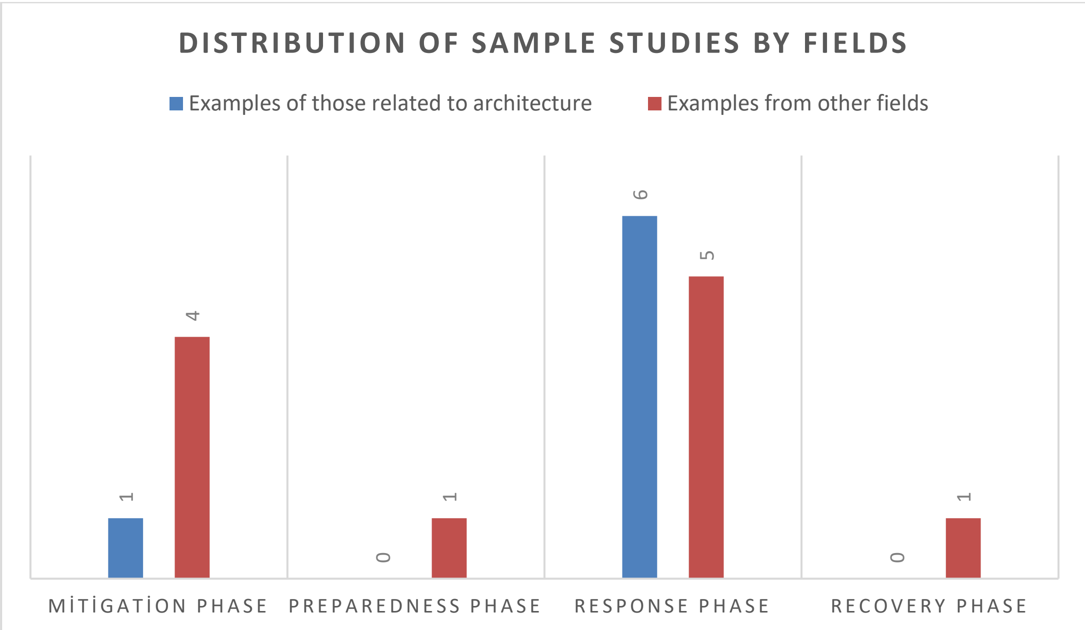

Figure 7. Disaster management stages (edited by Author)

5. Conclusion and Recommendations

Natural disasters, especially earthquakes, are difficult to avoid in the world and Türkiye and cause loss of life and property. Türkiye is an earthquake country with many cities with high building density and population, and these cities are in significant danger when natural disasters occur. Architects and engineers have a significant responsibility in this regard. Therefore, the disaster management process is of great importance. Disaster management stages that are effectively implemented play a critical role in reducing natural disaster risks. In addition, technological developments in the world also provide a significant advantage in reducing risks in this regard.

Artificial intelligence, a product of the 4th Industrial Revolution, is an application that performs functions related to the human mind using large data sets. With the increasing interest in this subject, deep learning models within machine learning, a sub-branch of artificial intelligence, have begun to be used in many areas, such as health, construction, and analytical chemistry. In recent years, this technology has begun to be associated with natural disasters. Therefore, this study reviewed existing literature studies to examine the relationship between deep learning and earthquakes. The sample studies and models examined were categorized and compiled within the scope of disaster management stages. A table was created by arranging the purpose of the sample studies, the deep learning models used and recommended, the library, and software languages (Table 1). The table shows that these models can be used in the four phases of disaster management: mitigation, preparedness, and response and recovery. Deep learning can be used for earthquake prediction and earthquake-resistant building design in the first mitigation phase. It can be used to create educational systems to teach earthquake risk in the preparation phase. According to Table 1, it was concluded that deep learning could be used in various ways during the response phase, such as supporting search and rescue efforts, distinguishing actual calls for help in emergencies, locating damaged buildings, analyzing and classifying damage in buildings, finding people trapped under debris after an earthquake, and predicting human evacuation behavior. It is observed that sample studies are mainly concentrated in the response phase. Although there are rare examples of studies that can be used in the recovery phase, it is thought that there may be studies on deep learning in these phases in the future. In addition, another table was created within these stages of the sample literature, considering only their relationship with architecture (Table 2). When the findings are examined this way, it is noteworthy that deep learning is used in earthquake-resistant building design and mostly in damage detection and classification of buildings. The studies were primarily concentrated on the response phase in architecture. Considering the findings, it is thought that using deep learning in disaster management stages will increase over time and play a significant role. Although the resources examined in the study are limited, it is thought that sample studies will increase rapidly in the literature, considering the fact that Türkiye is an earthquake country. Thus, the four phases of disaster management, critical, “Mitigation, Preparedness, Response, and Recovery,” will be carried out more easily and quickly.

As a result, although natural disasters cannot be prevented, the damages that may occur after the disaster can be reduced by taking effective measures against the effects of the disaster. The impact of technology on this issue is quite large. There are many studies on disaster management worldwide, and architectural ethics should play a more significant role in these studies. The discipline of architecture, which consists of many subheadings such as design, structure, environment, history, and sociology with its tectonic structure, should not isolate itself from the developments in the world of informatics and technology. It is thought that this study will contribute to the literature on this subject and will be a guide source with its compilation feature.

Table 1. Examples of usage of deep learning in disaster management phases (edited by the Author)

Disaster Management Phase	Example Study Purpose	Model / Method	Library and Program Language	Example Study Conducted By
Mitigation Phase	Using Deep Learning in Earthquake Prediction	Long-Short Term Memory (LSTM) Model	Keras / Python	Metin Karcı, İsmail Şahin
Mitigation Phase	Using Deep Learning in Earthquake Prediction	Long-Short Term Memory (LSTM) Model		Qianlong Wang, Yifan Guo, Lixing Yu, Pan Li
Mitigation Phase	Using Deep Learning in Earthquake-Resistant Architectural Design	IC Assitant Which Uses Deep Learning And Image AI Methods	Image AI / Python Ide	Aslı Er Akan, Arzu Er, Hilal Tuğba Örmecioğlu, Kaan Bingöl
Mitigation Phase	Using Deep Learning for Seismic Reliability Assessment of Transportation Networks	Proposed Model		Mohammad Amin Nabian, Hadi Meidani
Mitigation Phase	Using Deep Learning in Analyzing Social Media Data and Social Sentiments	CNN		Tengfei Yang, Jibo Xie, Guoqing Li, Naixia Mou, Zhenyu Li, Chuanzhao Tian, Jing Zhao
Preparedness Phase	Using Deep Learning for Educational Systems to Teach Earthquake Risk	Object detection algorithm with YOLO	-	Muhammad Sadiq Amin, Huynsik Ahn
Response Phase	Using Deep Learning to Provide Search-Rescue Support with Drone	Faster R-CNN, Region-based Fully Convolutional Networks, Suggested Model	TensorFlow / Python	Balmukund Mishra, Deepak Garg, Pratik Narang, Vipul Mishra
Response Phase	Using Deep Learning to Identify Real Post-Disaster Rescue Calls	VGG-16 Convolutional Neural Network, Multilayer Perceptron Classifiers	-	Brett W. Robertson, Dhiraj Murthy, Matthew Johnson, Keri K. Stephens, William Roth Smith
Response Phase	Using Deep Learning as a Support for the Locating of Damaged Structures	Proposed Model, Google Colaboratory	TensorFlowLite Model Maker, TensorFlow / Python	Murat Komesli, Ahmet Selçuk Özgür, Çiğdem Tarhan, İlknur Teke
Response Phase	Using Deep Learning in the Detection and Classification of Damaged Structures	Mask Region-based Convolutional Neural Network	- / Python	Erdem Emin Maraş, Halil İbrahim Sarıyıldız
	Using Deep Learning in the Detection and			Beyza

Response Phase	Classification of Damaged Structures	Convolutional Neural Networks	-	Gültekin
Response Phase	Using Deep Learning in the Detection and Classification of Damaged Structures	Mask Region-based Convolutional Neural Network, ShuffleNet model	-	Chaoxian Liu, Haigang Sui, Shan Zeng
Response Phase	Using Deep Learning for Post-disaster Situation Assessment	VRR-19, CNN, LSTM	-	Tianyi Wang, Yudong Tao, Shu-Ching Chen, Mei-Ling Shyu
Response Phase	Using Deep Learning in the Detection and Classification of Damaged Structures	CNN	-	Dat T. Nguyen, Ferda Ofli, Muhammad Imran, Prasenjit Mitra
Response Phase	Using Deep Learning in the Detection and Classification of Damaged Structures	CNN (AlexNet, Inception-V3, and ResNet-50)	-	Xukun Li, Doina Caragea, Huaiyu Zhang, Muhammad Imran
Response Phase	Using Deep Learning to Find Post-disaster Survivors	-	-	Neha Chaudhuri, Indranil Bose
Response Phase	Using Deep Learning in Predicting Human Evacuation Behaviors	Proposed Model DeepMob	-	Xuan Song, Ryosuke Shibasaki, Nicholas Jing Yuan, Xing Xie, Tao Li, Ryutaro Adachi
Recovery Phase	Using Deep Learning in Recovery	CNN, RNN	-	Nicolai Pogrebnyakov, Edgar Maldonado

Table 2. Disaster management studies in deep learning, which are closely related to the discipline of architecture (edited by Author)

Disaster Management Phase	Example Study Purpose	Model / Method	Library and Program Language	Example Study Conducted By
Mitigation Phase	Using Deep Learning in Earthquake-Resistant Architectural Design	IC Assitant Which Uses Deep Learning And Image AI Methods	Image AI / Python Ide	Aslı Er Akan, Arzu Er, Hilal Tuğba Örmecioğlu, Kaan Bingöl
Preparedness Phase	-	-	-	-
Response Phase	Using Deep Learning in the Detection and Classification of Damaged Structures	Mask Region-based Convolutional Neural Network	- / Python	Erdem Emin Maraş, Halil İbrahim Sarıyıldız
Response Phase	Using Deep Learning in the Detection and Classification of Damaged Structures	Convolutional Neural Networks	-	Beyza Gültekin
Response Phase	Using Deep Learning in the Detection and Classification of Damaged Structures	Mask Region-based Convolutional Neural Network, ShuffleNet model	-	Chaoxian Liu, Haigang Sui, Shan Zeng
Response Phase	Using Deep Learning in the Detection and Classification of Damaged Structures	CNN	-	Dat T. Nguyen, Ferda Ofli, Muhammad Imran, Prasenjit Mitra
Response Phase	Using Deep Learning in the Detection and Classification of Damaged Structures	CNN (AlexNet, Inception-V3, and ResNet-50)	-	Xukun Li, Doina Caragea, Huaiyu Zhang, Muhammad Imran
Recovery Phase		-	-	

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National and international research and publication ethics have been complied with in the article. Ethics committee approval was not required in the study.

Author Contribution and Conflict of Interest Declaration Information

All authors contributed equally to the article. We hereby state that there is no conflict of interest.

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