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BUILDING STRUCTURES AND MATERIALS

Towards an earthquake-resistant architectural design with the image classification method

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ABSTRACT

Architectural design is an interdisciplinary process which involves multiple stages that are interconnected. In this process, it is common for major decisions to be changed during the final stage, the analysis of the structural system. After making substantial corrections, the architect has to revisit the early stages, the preliminary project. This back-and-forth process can result in significant losses in time and cost. The proposed Irregularity Control Assistant (IC-Assistant) aims to provide architects with feedback on the conformity of structural system decisions to the irregularities defined in the Turkish Building Earthquake Code (TBEC-2018), using image processing methods at the early stages of the design process. The IC-Assistant was preliminarily created to evaluate the torsional irregularity of plan organization using deep learning methods. In this study, the results of the IC-Assistant were verified by structural analysis with the Prota-Structure program. The novelty of this study is the use of the image-classification method in earthquake-resistant architectural design. Up to this point, the method has been mainly used in facial recognition systems. This method minimizes time, human error, and cost losses and includes awareness of load bearing and earthquake resistance as inputs in the early stages of architectural design.

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Earthquake resistant architectural design; earthquake regulations; machine learning; deep learning; artificial intelligence

1. Introduction

The effects of 20th-century technology on architecture first appeared after the release of AutoCAD V1, the first generation of commercial 2D drawing programs, in 1982. The adoption of 2D drawing programs by architectural offices started during the 1990s but CAD became the dominant trend when programs gained 3D solid modelling functions. In one or two decades, 2D drawing programs had been replaced by 3D design programs. Subsequently, these programs were transformed into Building Information Modelling (BIM), which provides a range of analytical functions besides their 3D modelling abilities. These programs diversified and their capabilities increased with products such as energy and acoustical calculation programs, cost estimates, structural analysis, and environmental comparison programs. Despite the increase in the capabilities of the tools and the partial transformations they brought in architectural design stages, the main decisions in the design process continue to belong to the architect. Architects still make the main decisions according to their own knowledge, experience, and skills and, in situations where they cannot decide, they consult with an expert.

Today, digital tools are an indispensable part of architecture, especially for drawing, modelling, and analysis. But still, they have not been fully integrated with the design process.

Architects are forced to follow a number of regulations during the design process. The earthquake code is one of the most important and complicated ones, especially in countries like Türkiye, where the risk of earthquakes is high. Hence, architects feel constrained when making decisions about structural systems and need the expert assistance of a civil engineer. At this stage, the question arises of whether they can use artificial intelligence (AI) or AI applications in the absence of such expert assistance.

The use of AI techniques, such as deep learning and image processing, can facilitate the workflow in making decisions at an early stage, especially in fields that require expertise and experience (Lu, Chen, and Zheng 2012). In this context, in the early stages of an architectural project, the capabilities of artificial intelligence in decision-making regarding the structural system can be of great importance for the design process.

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The question therefore arises whether it is possible to evaluate the regularity/irregularity of a structural system, just as an expert might by an empirical investigation of drawings, using an AI with deep learning, image processing, and image classification methods. In this study, deep learning and machine learning methods were used to constitute an Irregularity Control Assistant (IC-Assist), which would give information about whether the structural system was regular or irregular. A dataset made up of selected correct and incorrect samples was entered into the machine and it was asked to establish a logic to examine the samples and to evaluate a newly designed project in terms of its similarity to the correct and the incorrect diagrams.

Along with this hypothesis, an application was constructed, and the early version of this app was published in 2020 (Bingöl et al. 2020). The IC Assistant would check the "torsional irregularity" from the irregular situations that could occur in a building, due to irregular structural design in floor plans. The "PYTHON" programming language, which is widely used in the academic field, and the "PYTHON IDLE" (Integrated Development and Learning Environment), also presented with the Python programming language, were used to create the application (Kapanowski 2014).

The "Image AI 2.0.3-Framework" library was used to develop the application. Image AI is a Computer Vision Python library that can be easily integrated into the most developed artificial intelligence methods, and into the new and existing applications and systems. It is used for developing rapid prototypes by developers, students, researchers, educators, and experts ((Olafenwa 2018)). Likewise, the ResNet model, which is an effective learning model in image processing, was used as a model in the formation of the IC-Assistant [8].

The application developed within the scope of the study with Python and Image AI was asked to interpret images of given floor plans, with image recognition and deep learning methods. The IC-Assistant was presented with new floor plans that were not previously given and asked whether the structural system diagrams in these plans are regular or irregular according to the earthquake codes. The results show that the IC-Assistant can successfully provide information on the percentage of the regularity or irregularity of any structural system diagram presented to it.

An architect at the stage of preliminary design would upload to the IC-Assistant the photographs of his/her structural system sketches of the architectural plans. Then, the assistant evaluates the sketches by comparing the previously learned regular/irregular plan schemas (based on planimetric irregularities defined in the TBEC-2018) and gives a numeric result that will help the architect with the verification of the structural system proposal. Thus, the architect can take firm steps forward (in terms of earthquake-resistant design) to the final stage of the project in a shorter time with AIAD (artificial intelligence-aided design) than the traditional design methods.

Although architectural design and structural system design are perceived as within the expertise of two different professional groups, the two processes are not independent of each other and serve the same purpose. As architects and civil engineers share their design responsibilities, a certain level of knowledge is required in both areas in order to communicate and work together. As the main designer of the building, the duty of closing this gap from the preliminary draft falls in particular on the architect. This application will enable the architect to make more reliable decisions about the structure at the preliminary design stage, and more efficient communication will be created between the two professions.

Although torsional irregularity is a problem for all types of structures and the IC-Assistant can evaluate torsional irregularity in all kinds of frame structures, the scope of this study focuses on the structural design of reinforced concrete housing structures, which is a serious problem due to its widespread use in residential architecture in Türkiye. Considering that 90% of Türkiye's population lives in earthquake zones, this problem becomes even more important (Öcal and İnce 2012). Hence, the proposed approach in this study is limited to the torsional irregularity defined in the TBEC-2018 as a horizontal irregularity. Therefore, the height and section of the structures which may cause vertical irregularities are out of the scope of this study.

2. Literature review

As basic architectural decisions play vital roles in the seismic performance of buildings in different ways, architects and engineers have acknowledged the necessity of earthquake-resistant design as a fundamental part of building practice and education (Dutta, Das, and Sengupta 2017; Shojaei and Behnam 2017; Gokdemir et al. 2013; Ozmen, Er Akan, and Unay 2011; Soyluk and Ilerisoy 2012; Bingöl 2020; Erman 2005; Giuliani 2000; Mendi 2005; Morales-Bertran and Yıldız 2020; Slak and Kilar 2008; De Stefano and Pintucchi 2008). However, although there is extensive knowledge of earthquake engineering, the literature on earthquake-resistant architecture is rather limited. The existing literature for defining the seismic design guidelines, which can be used as a reliable tool to produce earthquake-resistant architecture, is mostly intended to set the seismic principles for better and safer built environments (FEMA Federal Emergency Management Agency 2010, 2014; JASO The Japan Institute of Architects and Japan Aseismic Safety Organization 2015). For this reason, countries at risk of earthquakes have to use special regulations and regularly update them (ECS European Committee For

Standardization 2004; ICC International Code Council 2018; ASCE American Society of Civil Engineers 2017). The latest regulations in Türkiye came into force in 2018 (CMDE Chairmanship For The Management of Disasters and Emergencies 2018).

On the other hand, although computer-aided design is an accepted method in architectural practices, when the literature on deep learning and image classification is examined carefully, a limited number of studies are encountered on the utilization of expert systems in architecture. Many of the related publications were about computational design (Nan-Ching 2023; Caetano, Santos, and Leitão 2020; Chang and Huang 2014; Erdoğan and Sorguç 2011; Çolakoğlu and Yazar 2007) or computerized layout modelling (Jamali, Leung, and Verderber 2020). Among these studies, İdemen's dissertation was distinguished as an earthquake-related expert solutions proposal. He studied the torsional irregularity defined as the A1 irregularity specified in the Turkish Earthquake Codes, and by using artificial intelligence applications, he examined the center of gravity and rigidity of the buildings (Idemen 2003).

Among work on deep learning and image processing, Radziszewski's study titled "Artificial Neural Networks as an Architectural Design Tool- Generating New Detail Forms Based on the Roman Corinthian Order Capital" was an Artificial Neural Network model constituted with a dataset composed of geometrical shapes of the column capitals in the Corinthian order. The author, by constituting the geometrical relationships in this set and new geometrical shapes, sparked a new debate about the effects of AI applications (Radziszewski 2017).

Another example of deep learning in architecture is the work of Uzun & Çorakoğlu. Their study looked at determination of pixel-based architectural drawings as a floor plan or a section by deep learning methods. The authors examined the possibility of using deep learning and image processing in architecture to develop a model that can read and classify architectural drawings, regardless of whether they are hand drawn or digital (Uzun and Çorakoğlu 2019).

In the literature on deep learning, image classification, and earthquake-resistant design, the use of artificial intelligence in earthquake architecture has been barely discussed (Moustafa et al. 2021, 2022; Moustafa, Abdalzaher, and Abdelhafiez 2022; Abdalzaher et al. 2022; Omar et al. 2022; Abdalzaher et al. 2023). This is despite the rapid penetration of artificial intelligence into several areas in recent decades.

The objective of this research is to leverage the potential of artificial intelligence in the architectural design process for earthquake-prone regions. Specifically, the study proposes using deep learning and image classification techniques to identify the torsional irregularity status of a building based on the structural asymmetry of its load-bearing elements in floor plans. The research workflow is presented in detail in the accompanying flowchart (see Figure 1). The first two stages of the study -Generating Dataset and Training Classification Models- were previously conducted and published (Bingöl et al., 2020), and the current study focuses on executing the third and

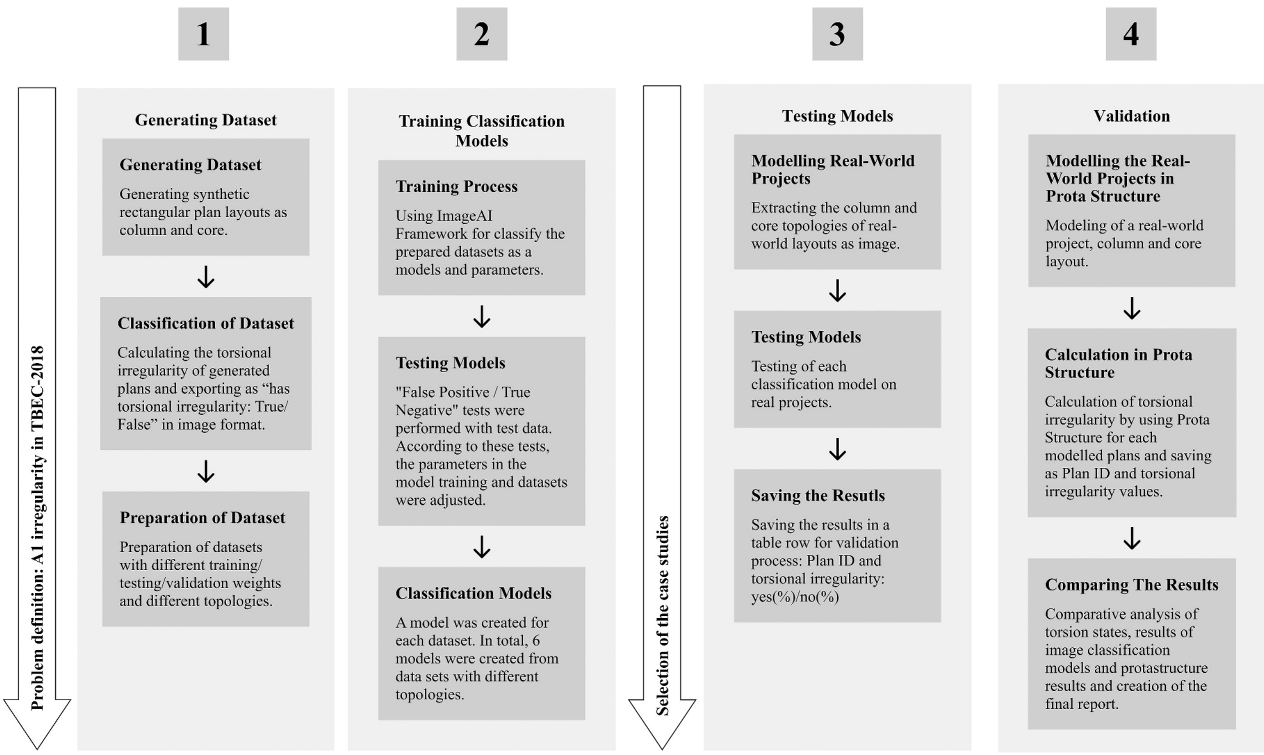


Figure 1. Flowchart of the study.

fourth steps -Testing models and Validation- of the workflow.

3. Definition of the problem

The structural system of a building is what keeps it standing. Therefore, the most important rules of earthquake-resistant building design are the necessity of designing the structural system in accordance with the regulations, using adequate and suitable materials during its construction, and setting it up according to earthquake scenarios (Celep 2018). The most important principle of the structural system design is to be as simple and plain as possible to render the earthquake behaviour of the building foreseeable and calculable. As conveyed in TBEC-2018, the design of a structural system as regular and symmetric in the floor plans transfers the moments of inertia stemming from the distributed loads in the most appropriate manner to the vertical load-bearing elements (CMDE Chairmanship For The Management of Disasters and Emergencies 2018).

3.1. Irregular buildings

Irregular buildings are classified as buildings that should be avoided due to disadvantages in their structural behaviour during earthquakes. The Turkish earthquake code divides irregularities into two groups: irregularities in floor plans, and irregularities in sections (CMDE Chairmanship For The Management of Disasters and Emergencies 2018).

The two main irregularities affecting the earthquake behaviour of the building in floor plans are the displacement of the centre of rigidity and the extension of the ends that can be made up to the free oscillation. These are defined as the group-A irregularities in the Turkish Earthquake Codes. Group-A irregularities also have subbranches of A1, A2, A3, and A4. Among these, torsional irregularity (A1), slab discontinuity (A2), and nonorthogonal irregularity of the axis of structural elements (A4) occur due to asymmetrical column arrangement in floor plans and change the centre of rigidity. Ultimately, they cause sudden decreases in strength, since the centre of gravity and the centre of geometry (centroid) are not at the same point. Within the scope of the study, the irregularities in floor plans were examined and a pilot application was developed that determines the A1 irregularity type by using deep learning and image classification methods.

3.2. Centre of rigidity

The centre of rigidity is related to the dimension and position of load-bearing elements in floor plans, such as shear wall, column, circulation core, etc. The centre of rigidity of a floor is the point around which it can rotate without making a reciprocating motion. Furthermore, this point is also defined as the centre of the inertias of the vertical load-bearing elements. It is necessary to have the centre of geometry and the centre of gravity overlapped or placed close to each other to decrease the torsional moment.

3.3. Eccentricity

According to TBEC-2018, torsional irregularity means that for either of two perpendicular earthquake directions, the torsional irregularity coefficient ηbi, which expresses the ratio of the maximum relative story translation (Δimax) at any story to the average relative translation (Δiort) in the same direction at that story, is greater than 1.20. The calculation of the relative storey drifts is made according to the torsional irregularity equation given in Figure 2, taking into account the additional eccentricity effects of ±5%" (CMDE

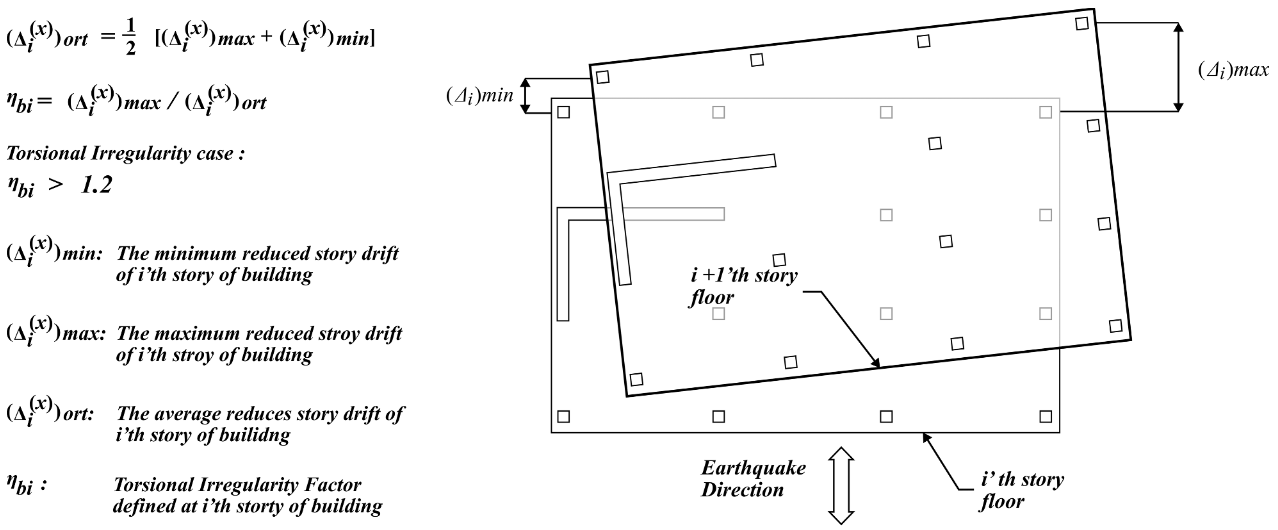


Figure 2. Torsional irregularity (Redrawn by Bingöl based on the description of TBEC-2018).

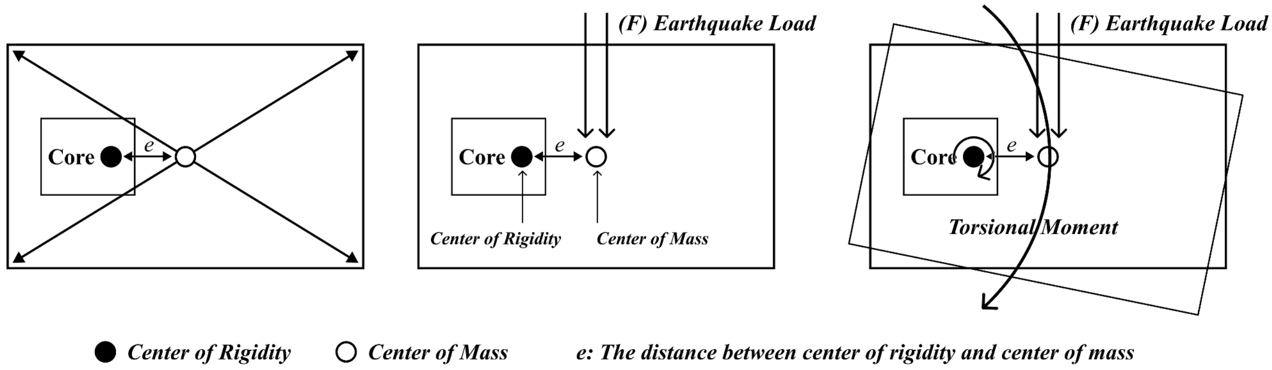


Figure 3. Diagram of torsional irregularity (Redrawn by Bingöl based on the description of TBEC-2018).

Chairmanship For The Management of Disasters and Emergencies 2018).

In any floor plan of a building, the centre of gravity is found due to the plan geometry, while the centre of rigidity is determined due to the vertical load-bearing elements such as shear walls and columns. The distance between points on these two centres is called eccentricity (e). This distance should not exceed L/20 of the longest edge in that floor plan, as defined in the "Regulations About Buildings to be Constructed in the Disaster Areas" (Figure 3).

In cases where that value is exceeded an additional moment would be formed as much as the distance between them, hence, that floor would make a rotational movement under the effect of a horizontal F force. This displacement would be dependent on the amount of F, and it may lead to results that could extend as far as the destruction of the building.

4. Materials and methods

4.1. Selection of case studies

Turkey was struck by two devastating earthquakes on 6 February 2023, causing widespread damage across 12 provinces. In the aftermath of these disasters, there is an urgent need for a rapid assessment of the building stock. This task is particularly challenging as there are millions of structures that require immediate evaluation, many of which were constructed prior to 1990. Compounding the issue, the municipal archives of pre-1990 buildings are not digitized, making it difficult to conduct a comprehensive and efficient evaluation.

To address this problem, this study proposes an image-processing method as a viable solution. Given the urgency of the situation and the fact that most pre-1990 municipal documents are not digitized, the use of image processing techniques can expedite the evaluation process. This approach can be especially helpful for rapidly assessing buildings that require urgent attention.

The present study focuses on earthquake-prone areas of Turkey, as illustrated in Figure 4, and specifically examines reinforced concrete residential buildings in three cities: Düzce, Istanbul, and Afyon. These regions have experienced major earthquakes in the past, including the Afyon Çay-Sultandagi Earthquake in 2002 (magnitude 6.5), the Düzce Earthquake in 1999 (magnitude 7.5), and the Gölcük-Kocaeli-Istanbul Earthquake in 1999 (magnitude 7.6).

To conduct the study, a total of 25 actual building plans were selected based on their relevance to the study's objectives and their representation of the most common building typologies in the three cities. As a result, eight plan types were identified among the selected 25 case studies and these types are presented in Table 2. It is worth noting that the case studies presented in this article are limited to these eight plan types and are confined to the aforementioned earthquake-prone regions of Turkey.

4.2. The Irregularity Control Assistant App (IC-Assistant)

The IC-Assistant, which was developed within the scope of the study, is a deep learning-supported computer application. It aims to determine the level of irregularity in the structural design of vertical load-bearing elements on floor plans. The IC-Assistant is based on the principles of the A1 torsional irregularity defined in the TBEC-2018. The flow diagram of the application is given in Figure 5.

The designed model for IC-Assistant evaluates the level of A1 irregularity from floor plans, according to their similarities with the structural plan diagrams defined as regular and irregular that were previously taught to the machine. The main difference of IC-Assistant from structural analysis programs is that it operates as an early warning and control system on whether the structural system of the building is regular or irregular at an early stage of the design. In this way, the issue of earthquake safety is included in the architectural design process in the initial phases of building design.

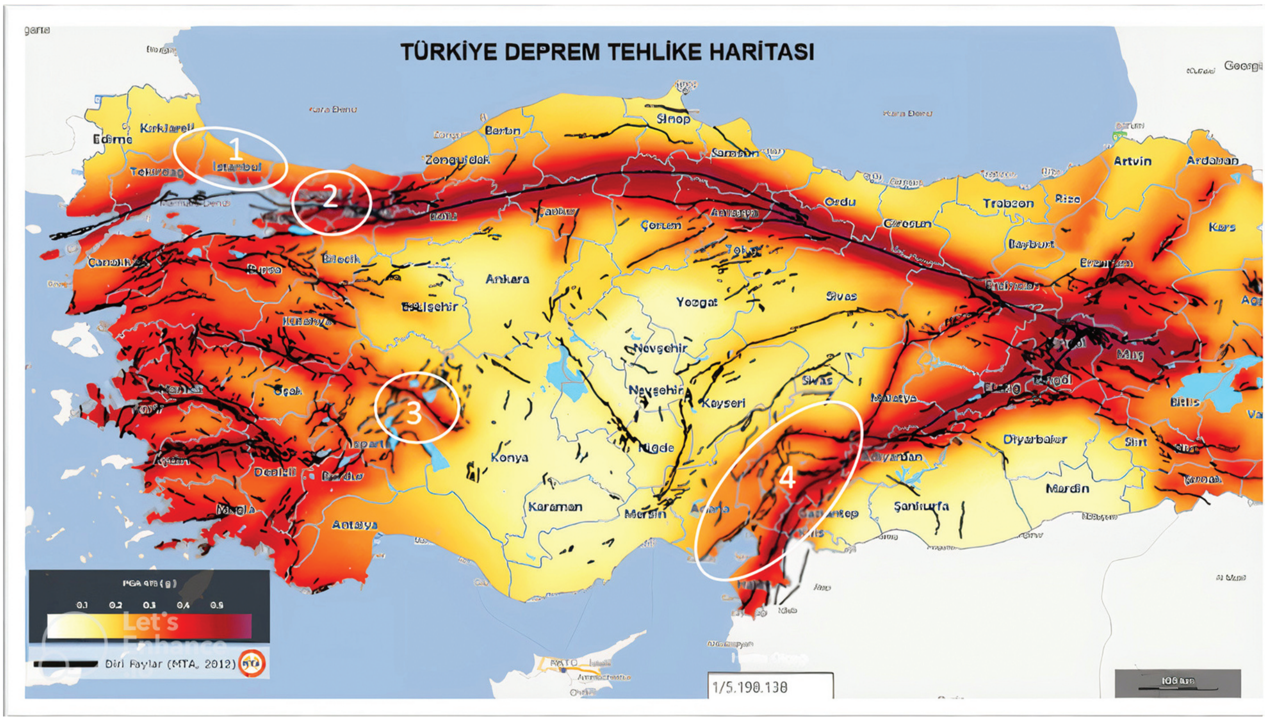


Figure 4. Earthquake map of Türkiye showing the locations of the 1999 earthquake in Istanbul (1), the 1999 earthquake in Düzce (2), the 2002 earthquake in Afyon (3), and the 6 February 2023 twin earthquakes in Kahramanmaraş/Gaziantep/Şanlıurfa/Diyarbakır/Adana/Adıyaman/Osmaniye/Hatay/Kilis/Malatya/Elazığ (4). (Source: https://www.afad.gov.tr/turkiye-deprem-tehlike-haritasi).

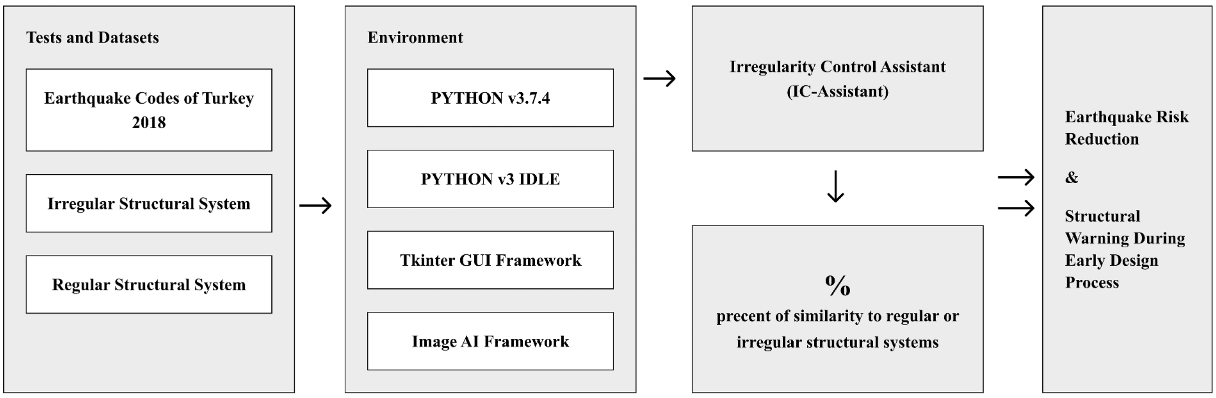


Figure 5. Working diagram of the IC-Assistant.

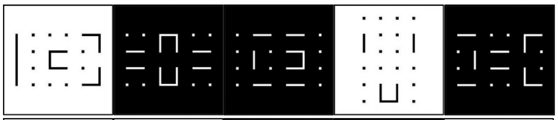
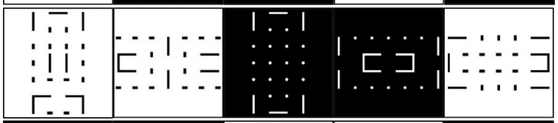
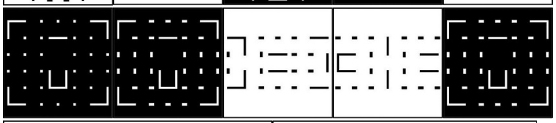
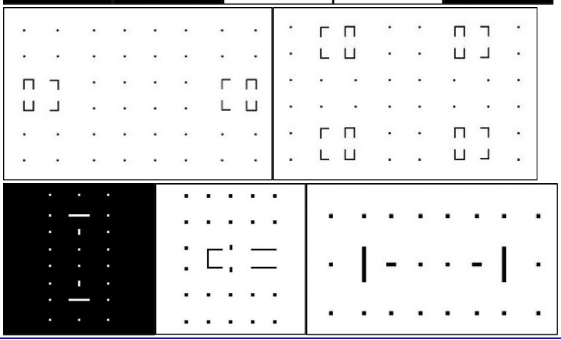
In this model, after deciding on the structural diagram of the building on the floor plan, the architect will be able to get structural-design feedback from an image of the floor plan, without the need for any additional steps. Hence, the IC-Assistant will reveal any structural problems at the initial stage and will prevent major revisions that may arise later during the construction drawings.

4.3. Dataset models

The IC-Assistant is written in the Python script language. The dataset models have been processed in Colab (coLaboratory) Notebook with Image AI structure where deep learning algorithms and architectures are available. The Colab Notebook is a web-based interactive environment used for the research and development of machine learning. It provides a virtual environment to the user by operating on Google Cloud without any installation. The dataset training is carried out using Google Colab Notebooks. Image AI, on the other hand, is an open-source Python library that enables image classification with a method that alleviates the coding load.

The datasets are formed from the diagrams with or without the "Type of Irregularity-A1: Torsional Irregularity", included under the heading of irregularities in the floor plans. They are composed of a total of six different model combinations, two different floor plan types, and three different column types. Each model combination has been classified as regular or irregular, according to the definitions and formulas of

Table 1. Table of dataset models (M1, M2, M3, M4, M5, and M6) (Bingöl 2020).

Dataset Code	The Dataset Samples
M1 and M2 Dataset	
M3 and M4 Dataset	
M5 Dataset	
M6 Dataset	

rigidity and centre of gravity defined in the Turkish Earthquake codes. The datasets are diagrams showing the arrangement of reinforced concrete columns, shear walls, and vertical circulation cores. They all have different rigidity centres.

It is necessary to accurately classify the data used for deep learning. In the study, the datasets were formed and were classified as regular/irregular by taking into consideration the formula of eccentricity. Within the context of this study, these models were tested and their results were compared. The aim was to interpret irregularity by loading an image of a floor plan on the CNN model as shown in Figure 6.

There is a total of 1,344 original diagrams that are different from each other. The number of these diagrams increased to 21,504 after the image multiplexing operation. The data were multiplexed to obtain more consistent results and to increase the number of diagrams found in the datasets. Deep neural networks support batch training. Therefore, the multiplexing process for the multiple artificial neural network layers of the taught plan schemes was applied to the created datasets (Figure 7).

While forming the datasets, diagrams that are generated structural schemes are used instead of real architectural floor plans. These diagrams were used to measure the consistency of the problem stated earlier, with the deep learning method. Furthermore, obtaining real architectural plans and classifying them for datasets is a costly and time-consuming procedure. For this reason, models consisting of diagrams similar to actual structural schemes were used instead of real architectural plans. In this context, six datasets (M1, M2, M3, M4, M5, M6) were produced in total.

4.3.1. M1 and M2 dataset models

The characteristic of these data models is the formation of plans with square-section columns and a 6×4 (x-y axis) configuration. There is a total of 2,512 images in this group. Twenty percent of the dataset is "test data" and 80% is "training data", while 40% is irregular and 60% is regular on the basis of classification (Table 1).

4.3.2. M3 and M4 dataset models

Although the ratios are the same as in M1 and M2, these dataset models have different column types. New diagrams were produced adding oval and rectangular column types to the datasets composed of square columns. The total number of images is 6,992 (Table 1).

4.3.3. M5 dataset model

The M5 dataset model, on the other hand contains 7×6 (x-y axis) and the 6×4 (x-y axis) plan types together. Unlike the other data models, it was generated as a mixture of both the column types and the plan types. The ratios are the same as the other datasets. This dataset is composed of a total of 6,997 diagrams (Table 1).

4.3.4. M6 dataset model

In addition to the qualities of M5 model, the M6 model has been formed from scaled and more realistic plan diagrams. The ratios in this data model are the same as the other datasets. The total number of diagrams in this dataset is 12,815 (Table 1).

4.4. Dataset models for training

The ready-made infrastructure provided by ImageAI was used for the image classification process. This infrastructure is based on the ResNet algorithm and model. Since the model training operates with batch logic, it requires high processing power.

Batch is the operation of a set of mathematical problems in a computer that "can run without the interaction of the end-user or can be scheduled to run as resources permit" (IBM 2006). Since Batch requires intensive processing power, Colab Notebook, which is offered by Google for academic studies and machine learning, was preferred in this study. It provides an extra Graphics Processing Unit (GPU) for the training of the model, allowing faster completion of the training.

There are two different folder structures under the ImageAI structure in model training. These are the training folder and the test folder, and the datasets have been classified within these folders. The test folder tests if the model has been trained correctly or not. The plan diagrams placed in this folder are not found in the training folder. The ratios of the test and training datasets are 20% to 80%, respectively.

The IC-Assistant has been designed to be flexible and modular to allow it to be used later with other trained models. For this reason, the training models do not come embedded in the application. The model and the images to be tested can be selected through the user interface of the application so that the user can use their own models.

4.5. User interface of the IC-Assistant

As it is intended to create an application that is easy to use by architects and people who are not familiar with structural analysis programs, a user-friendly interface has been created for the application. The interface of the IC-Assistant is simply composed of three windows: a) the area where the model is loaded, b) the area where the image is selected, and c) the area where the results of the analysis are printed (Figure 8).

The first part (window a) is the area where the previously trained file with the "modelAdı.h5" extension is uploaded. The application of this model is required for the function of assessment. The application will not operate correctly if the file with the "modelAdı.h5" extension is not uploaded.

The image of the architectural plan that is to be tested will be uploaded in the middle section (window b). The user will upload an image of their plan by using the "upload image" button. The file uploaded must be in.jpg format. The application does not operate correctly with PNG or other graphics compression forms.

The last window (window c) will be activated when the image is uploaded. After clicking the "Analyze" button, the application starts to compare the uploaded image according to the selected model. In the final stage of the analysis, the result message, previously prepared according to various scenarios, appears on the screen depending on the output value of the analysis.

5. Results and discussion

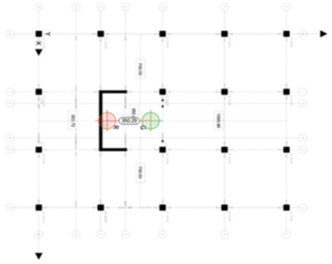
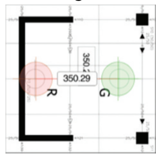
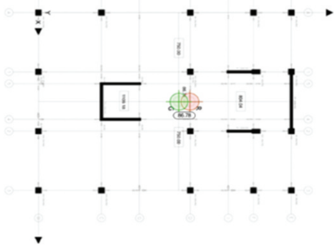
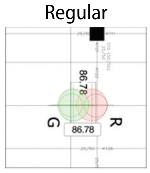
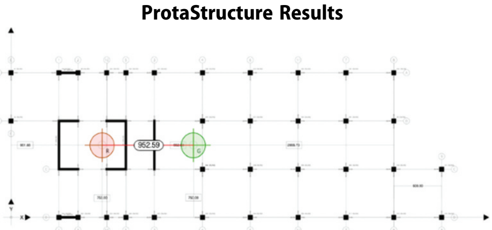
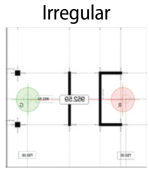
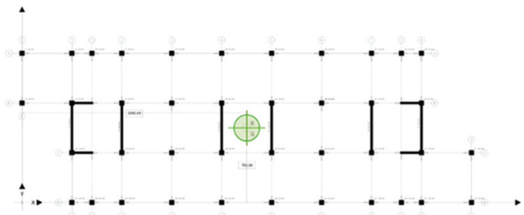
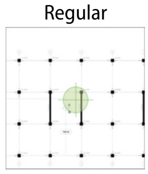
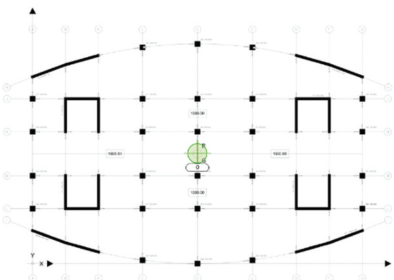
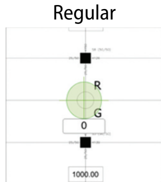
The accuracy of test results based on real cases is an important aspect of any system that uses data analysis to predict outcomes. In this case, the IC-Assistant was used to predict the regularity or irregularity of structural systems based on deep learning models created through a dataset of actual floor plans. To verify the accuracy of the test results, the ProtaStructure software was used, which performs structural analysis in accordance with Turkish earthquake codes. ProtaStructure is a comprehensive software package designed specifically for building system modelling, finite element analysis, code-supported design, performance evaluation, and strengthening (Prota 2021).

The centres of rigidity of the plans were calculated and checked using this software. According to these results, Plans 1, 3, 6, 7, and 8 have torsional irregularity, while Plans 2, 4, and 5 are safe for the torsional irregularity. The results are listed as below.

Irregular Plan Types:

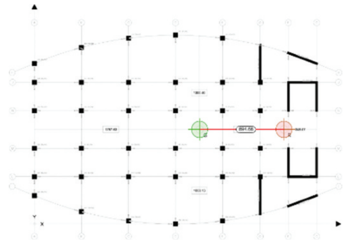
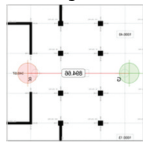
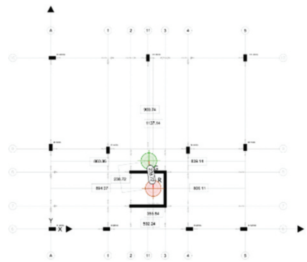
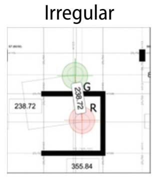
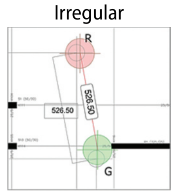
- Plan 1: The distance between the Centre of Rigidity (R) and the Centre of Geometry (G) is 350.35 cm and is longer than 100 cm, which is twenty percent of the longest side.
- Plan 3: The distance between R and G is 952.59 cm and is longer than 225 cm, which is twenty percent of the longest side.
- Plan 6: The distance between R and G is 894.66 cm and is longer than 150 cm, which is twenty percent of the longest side.
- Plan 7: The distance between R and G is 236.4 cm and is longer than 100 cm, which is twenty percent of the longest side.

Table 2. Table of test results from IC-Assistant and ProtaStructure (Bingöl 2020).

Plan 1 5x4 Rectangular Irregular Plan		**Results of ProtaStructure Results** 			**Rule of the Formula of Eccentricity:** (G-R)<1/20B(x, y) B(y) = 2000.00 cm 1/20 B(y) = 100 cm y(G-R) = 350.35 cm 350.35 cm > 100 cm (X) Irregular 	
Results of IC-Assistant (Models)	M6	M5	M4	M3	M2	M1
Regularity	0.%	1.0%	0%	0%	4.0%	1.1%
Irregularity	99.9%	99.9%	99.9%	99.9%	99.9&	99.9%
Plan 2 5x4 Rectangular Regular Plan		**ProtaStructure Results** 			**Rule of the Formula of Eccentricity**: (G-R)<1/20B(x, y) B(y) = 2000.00 cm 1/20 B(y) = 100 cm y(G-R) = 86.78 cm 86.78 cm < 100 cm (✔) Regular 	
IC-Assistant Results (Models)						
Regular	95.6%	90.8%	87.7%	94.4%	0.3%	0.5%
Irregular	4.3%	9.1%	12.2%	5.5%	99.6%	99.4%
Plan 3 10x4 rectangular Irregular Plan		**ProtaStructure Results** 			**Rule of the Formula of Eccentricity:** (G- R)<1/20B(x, y) B(x) = 4500.00 cm 1/20 B(x) = 225 cm x(G-R) = 952.59 cm 86.78 cm > 100 cm (X) Irregular 	
IC-Assistant Results (Models)						
Regular	0%	2.9%	2.4%	7.0%	1.2%	1.3%
Irregular	99.9%	99.9%	99.9%	99.0%	99.9%	99.9%
Plan 4 10x4 Rectangular Regular Plan		**ProtaStructure Results** 			**Rule of the Formula of Eccentricity:** (G-R)<1/20B(x, y) B(x) = 4500.00 cm 1/20 B(x) = 225 cm x(G-R) = 0 cm 0 cm < 100 cm (✔) Regular 	
IC-Assistant Results (Models)						
Regular	82.6%	2.4%	8.9%	98.1%	1.1%	4.4%
Irregular	17.3%	97.5%	99.9%	1.8%	99.9%	99.9%
Plan 5 9x6 Ellipse Regular Plan		**ProtaStructure Results** 			**Rule of the Formula of Eccentricity:** (G-R)<1/20B(x, y) B(x) = 3000.00 cm 1/20 B(x) = 150 cm x(G-R) = 0 cm 0 cm < 150 cm (✔) Regular 	
IC-Assistant Results (Models)						

(*Continued*)

Table 2. (Continued).

Regular	99.9%	55.1%	0.2%	99.9%	0.1%	0%
Irregular	0%	44.8%	99.7%	0%	99.8%	99.9%
Plan 6			**ProtaStructure Results**			**Rule of the Formula of Eccentricity:**
9x6 Ellipse Irregular Plan						(G-R)<1/20B(x, y) B(x) = 3000.00 cm 1/20 B(x) = 150 cm x(G-R) = 894.66 cm 0 cm > 150 cm (X) Irregular 
IC-Assistant Results (Models)						
Regular	0%	5.8%	5.7%	3.1%	6.7%	1.3%
Irregular	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%
Plan 7			**ProtaStructure Results**			**Rule of the Formula of Eccentricity:**
3x4 Square Irregular Plan						(G-R)<1/20B(x, y) B(y) = 2000.00 cm 1/20 B(y) = 100 cm y(G-R) = 236.4 cm 236.4 cm > 100 cm (X) Irregular 
IC-Assistant Results (Models)						
Regular	0%	2.2%	8.7%	92.9%	9.2%	0%
Irregular	99.9%	99.9%	99.9%	7.0%	99.9%	99.9%
Plan 8			**ProtaStructure Results**			**Rule of the Formula of Eccentricity:**
7x4 Square Irregular Plan						(G-R)<1/20B(x, y) B(y) = 2000.00 cm 1/20 B(y) = 100 cm y(G-R) = 646.17 cm 646.17 cm > 100 cm (X) Irregular 
IC-Assistant Results (Models)						
Regular	14.5%	1.2%	0%	0%	0%	0%
Irregular	85.4%	98.7%	99.9%	99.9%	99.9%	99.9%

- Plan 8: The distance between R and G is 646.17 cm and is longer than 100 cm, which is twenty percent of the longest side.

Regular Plan Types:

- Plan 2: The distance between R and G is 86.78 cm and is shorter than 100 cm, which is twenty percent of the longest side.
- Plan 4: The distance between the R and the G is 0 cm and is shorter than 225 cm, which is twenty percent of the longest side.
- Plan 5: The distance between R and G is 0 cm and is shorter than 150 cm, which is twenty percent of the longest side.

The results obtained by IC-Assistant and ProtaStructure software were consistent with each other, indicating the reliability of the IC-Assistant's predictions. However, when examining the results table (Table 2), several differences were observed between the results of the data models used in the training of IC-Assistant and actual plans. Among the training models, the dataset contained in the M6 model was found to be the most similar to actual plans in terms of variations and scale. Therefore, when predictions made by IC-Assistant using the M6 dataset were analyzed with the ProtaStructure program, it was seen that the application made 8/8 consistent predictions. However, when other dataset models consisting of simpler

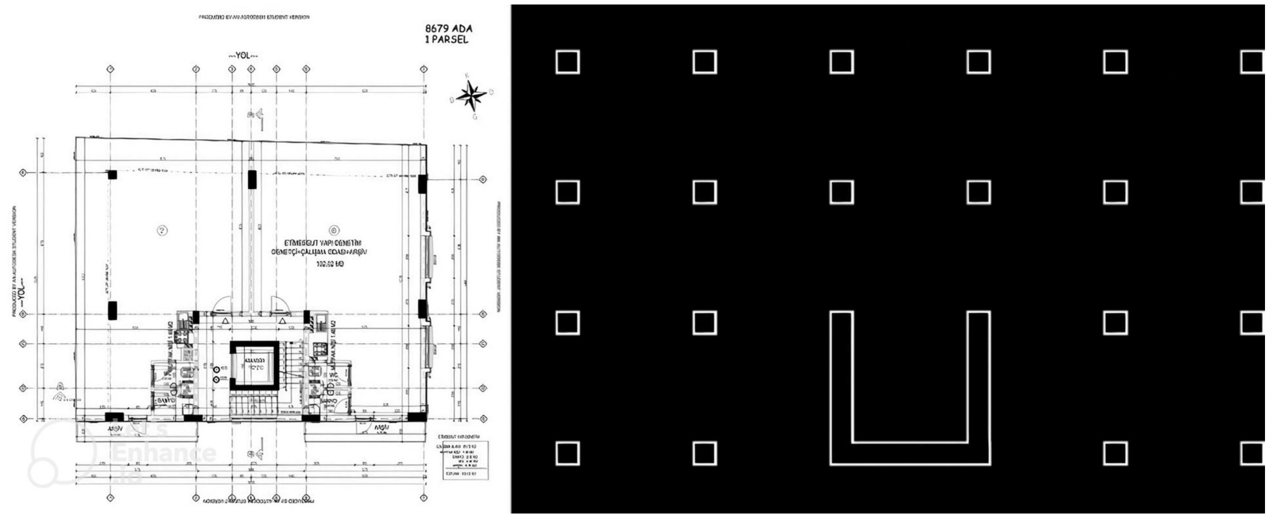


Figure 6. An irregular plan and irregular diagram.

diagrams were examined, consistency rates varied. The M5, M4, and M3 data training models gave results consistent with ProtaStructure at a rate of 7/8, while the M1 and M2 models gave consistent results at a rate of 6/8. This indicates that the complexity and variability of the dataset used in the training of the IC-Assistant is an important factor in determining the accuracy of its predictions.

Furthermore, when tested with images of actual floor plans, inconsistent results were observed for the M5 and M4 10×4 rectangular regular plan diagrams, and the 9×6 ellipse regular plan diagrams; for the M3, the 3×4 square irregular plan diagram; and for the M1 and M2, the 5×4 rectangular regular plan diagrams and the 10×4 ellipse regular plan diagrams. These inconsistencies highlight the need for further refinement and improvement of the dataset used in the

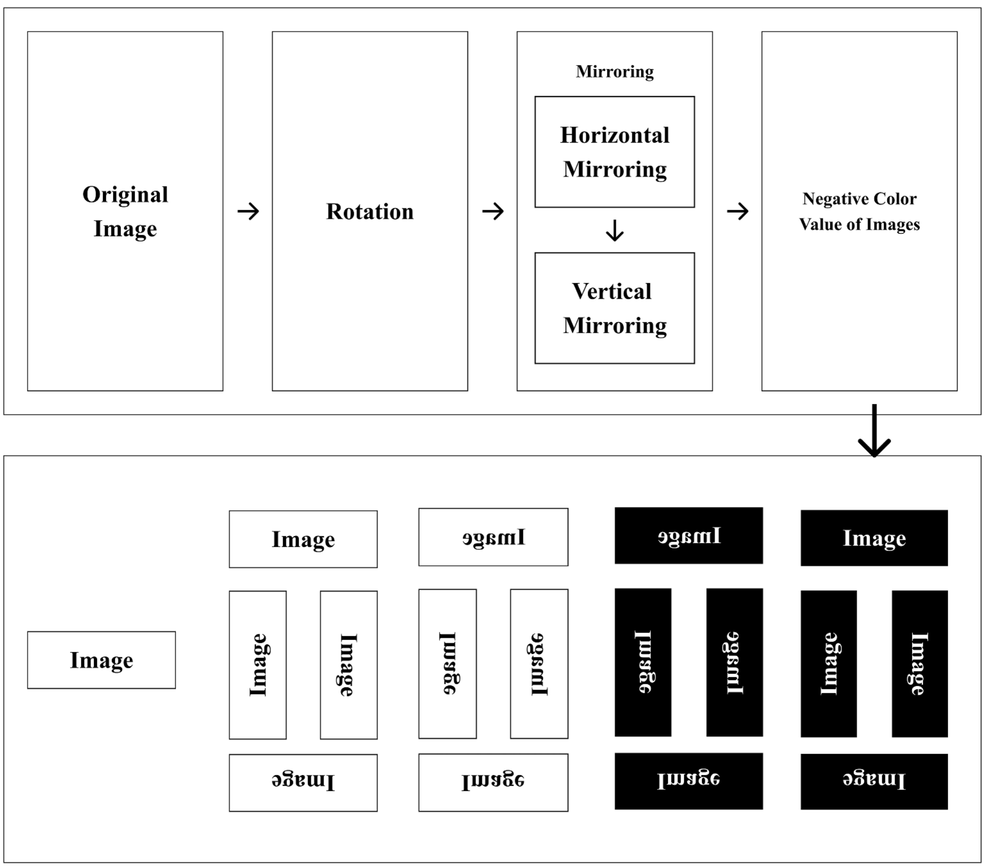


Figure 7. The flow of the image multiplexing operation.

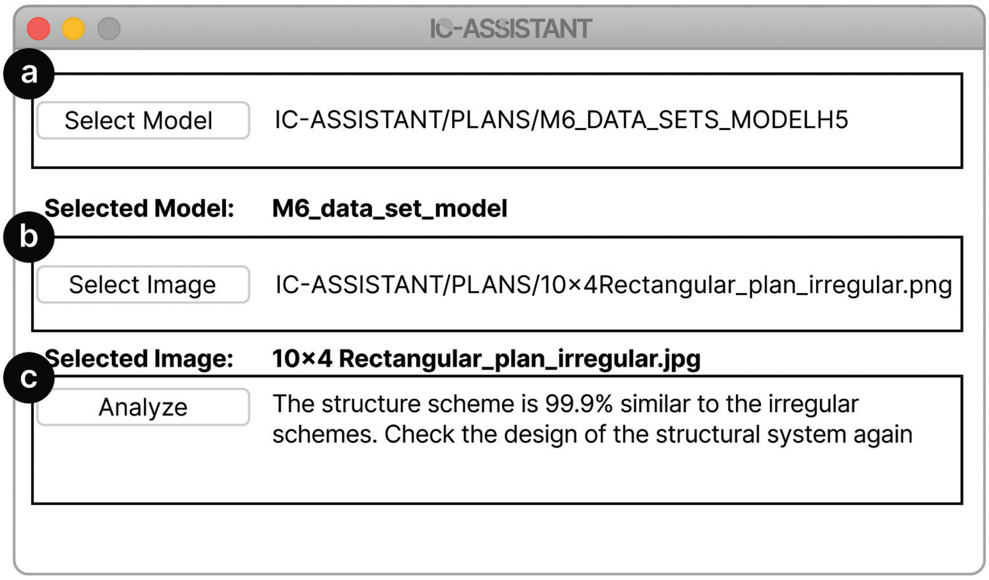


Figure 8. The user interface of the IC-Assistant.

training of the IC-Assistant to improve its accuracy in predicting structural regularity/irregularity.

Despite these inconsistencies, the deep learning method-based models were able to produce predictions about whether the structural systems were regular or irregular in the eight examples provided. This is a promising development, as it indicates that the IC-Assistant has the potential to accurately predict structural regularity/irregularity in a wide range of scenarios. In conclusion, the test stage with a restricted number of diagrams was successful. IC-Assistant was able to make consistent estimations of the regularity/irregularity of the structural system by using deep learning with the created dataset models in the eight actual floor plan cases given. As a result, the testing phase with a limited number of diagrams was successful. However, further refinement and improvement of the datasets used in the training of the IC-Assistant are necessary to improve their accuracy and reliability in a wider range of scenarios.

6. Conclusions

The proposed IC-Assistant, which imitates architects' learning processes, can aid in predicting torsional irregularity in the early stages of design. By assessing structural asymmetry in floor plans using deep learning and image classification, the method can identify and address potential issues. This study tested the previously published IC-Assistant on typologies from real cases, all selected from residential buildings located in earthquake-prone regions of Türkiye. Eight typologies were produced from a total of twenty-five selected cases. The IC-Assistant test results were compared with the results of the rigidity and geometric centre analyses performed with Prota-Structure (Prota 2021) for each typology. The results of the application were consistent with the results of the Prota-Structure, and thus the application was verified.

The use of image-classification methods in earthquake-resistant architectural design is a novel approach that has the potential to transform the field. Typically, image-classification methods are used in facial recognition systems, but this study demonstrates that they can also be implemented in architectural design. This method offers several advantages:

- Incorporating load bearing and earthquake resistance as design inputs in the early stages of architectural design minimizes time and cost losses. Image-classification methods can quickly and accurately determine load-bearing capacity, reducing the need for multiple rounds of analysis.
- Image-classification methods streamline the design process and significantly reduce the potential for human error in determining structural integrity.
- Providing significant benefits in creating earthquake-resistant buildings. By reducing the potential for human error, increasing efficiency, and enabling the creation of earthquake-resistant buildings, this approach can transform the field of architectural design.
- Offering a solution to the problem of rapidly assessing pre-1990 buildings in Türkiye. The image processing method proposed in this study can be used to evaluate the millions of structures that need urgent evaluation, and which are not digitally archived.
- Feedback is important in architectural education, especially for structural design. Detailed feedback helps students improve current projects and develop long-term skills and understanding of structural design principles. With the complex nature of

architectural design, students need a strong structural knowledge to succeed in their future careers.

Future research could expand upon this study to include other types of structural irregularities defined in TBEC-2018. Additionally, research could focus on testing the IC-Assistant on other types of structures rather than reinforced concrete structures.

Overall, this study highlights the importance of considering torsional irregularity in the structural design of reinforced concrete structures in earthquake-prone regions. By taking preventative measures, professionals can help minimize damage and ensure the safety of occupants during earthquakes.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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