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BIM Technologies at Structural Design

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Abstract: Building Information Modeling (BIM), also referred to as the digital twin of a building, is a widely used methodology for digitalizing building properties and parameters throughout the entire building lifecycle, from the planning stage to demolition. This process enables effective management of information, thereby increasing profitability and productivity while saving time. Compared with conventional design approaches, BIM coordination during the preliminary design stage has been shown to provide significant savings during construction and throughout the subsequent stages of a project. Recent BIM software has increasingly incorporated algorithm-assisted design tools to automate repetitive tasks. These tools perform a series of analyses based on constraints defined by the user and subsequently identify the most suitable solution. In addition, BIM models can be connected to external software through Application Programming Interfaces (APIs). Data transfer to SAP2000 can be achieved through the use of genetic algorithms within Grasshopper and Dynamo. Structural design under seismic loading requires considerable experience and time. Reinforced concrete shear walls are commonly used in buildings because of their substantial stiffness against lateral forces. The aim of this study is to obtain an optimum shear wall layout by utilizing Building Information Modeling (BIM) technologies. The optimization of the shear wall arrangement is formulated as a topology optimization problem that aims to minimize cost, provide accurate analytical results, and reduce the time required from the engineer. In a typical project, the arrangement of shear walls is generally determined during the preliminary design stage through a coordination process involving architectural, mechanical, and electrical (MEP) disciplines. The main workflow of this study consists of identifying potential shear wall locations from architectural models and subsequently performing a series of structural analyses using different wall layout alternatives. Genetic algorithms and finite element software APIs are employed iteratively until an optimum solution is achieved. Dynamo visual programming software and the Python programming language are used to create BIM and structural models, establish connections between BIM models and structural analysis software, retrieve structural analysis results, and execute the optimization algorithm.

Keywords: Shear wall optimization, Computational design, Earthquake and structural engineering

Introduction

This study presents an innovative method that integrates Building Information Modeling (BIM) technologies and the Genetic Algorithm (GA) to automatically determine the optimal reinforced concrete shear wall layout (topology optimization) under seismic loads. Main purpose of the study is to automatically determine the lowest-cost shear wall layout (minimizing concrete volume) that fully complies with structural design code regulations without disrupting the coordination of architectural, mechanical, and electrical (MEP) disciplines or aesthetic decisions during the conceptual design phase and to save design time for engineers (Carlos, 2018). In design, significant amount of time is often spent during the conceptual design phase (Nouredine, 2022). A key aspect of structural design work is the placement of load-bearing elements without conflicting with voids, service channels, or architectural spaces. When all the mentioned concerns are considered together, it becomes

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necessary to generate analysis models through programming and intervention within Building Information Modeling (BIM) software and to identify the optimal configuration for these models via a series of analyses. (Aydoğdu, 2021)

Method

The study focused on mid-rise structures and linear modal analysis scenarios. Three actual construction projects were selected based on engineering experience. These examples exhibit diverse characteristics, such as floor plans featuring non-orthogonal or angled layouts. Furthermore, the structural systems vary, encompassing both flat-slab systems and beam-column-wall frame systems (Yu, 2017). As a starting point, architectural plans were converted into BIM objects. Subsequently, a structural model was created using Dynamo; grid lines, columns, walls, beams, and floor elements were derived from the architectural model (Korus, 2021). Wall elements were segmented at 1-meter intervals to allow for adjustments to the wall layout length, and each segment was tagged as a shear wall component. Preliminary design thicknesses were assigned to the shear walls and columns. The structural BIM model was then exported to ETABS software. Definitions from the Turkish Earthquake Code were used to establish various story height categories and seismic load levels; specifically, four seismic levels and eight height categories were considered. In total, thirty-two analyses were conducted for each building type. After defining the height and seismic parameters in ETABS, a genetic algorithm was executed via the API to determine the optimal shear wall layout. Dynamo features a built-in genetic algorithm function known as Generative Design (GD) (Alanani, 2024). It was determined that the GA (Genetic Algorithm) employs a genetic algorithm approach to achieve the optimal result (Wenjie, 2021). The genetic algorithm draws inspiration from the biological principle of "survival of the fittest." It is a practical, widely used method for addressing engineering problems (Bekdaş, 2016). The algorithm operates by conducting trials with random parameters for each population. Once results are obtained, favorable alternatives are filtered; the selected "offspring" then undergo mutation and crossover—mimicking biological processes—to generate new alternatives. Through successive iterations of this evolutionary process, the optimal result is identified. Moreover, custom code was developed to define Revit objects and transfer them to ETABS. Each shear wall segment was then tagged with a binary value (1 or 0) to define the configuration: a "1" indicated an existing shear wall, while a "0" signified a wall to be removed during the trial. Multiple configurations—represented by binary strings—were randomly generated and sent to ETABS, with the results of these sequential runs forming the population. custom algorithm coded by the designer. The advantages of using a custom program include reduced data storage requirements, increased speed, and optimization tailored specifically to the target problem. The program executed sequential analyses using a population of two hundred samples at each step. Following the selection of the best results from a given step via "elitist selection," a new population was generated using variations derived from the most promising samples of the previous generation. Additionally, adaptive mutation and crossover rates were defined. Since each successive step brought the process closer to the final result, the expected duration for any given analysis was six to eight hours. The final step automatically yielded the optimal layout.

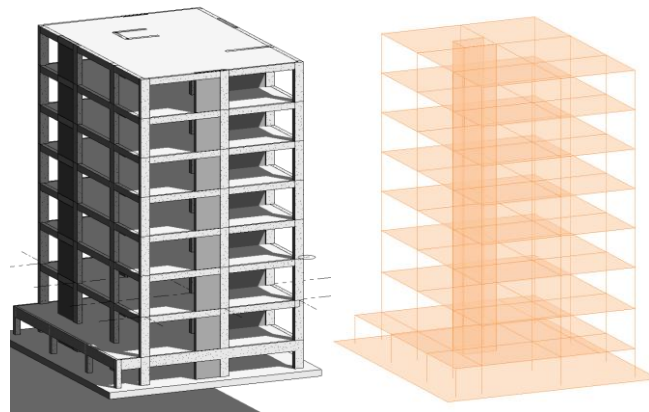


Figure 1. (a) Solid BIM View (b) Analytical Model Representation

Formulation of Problem

The design philosophy was outlined in the previous section. The process described in the previous section is practically applied as follows: Design workflow is summarized at Figure 2. 3D model, initially created as a BIM

model, is parameterized within the Dynamo environment. This parametric model is then transferred to ETABS via the API. The structural design software verifies compliance with code requirements; these constraints are illustrated in Figure 2. Subsequently, trials involving the placement of shear walls are conducted, and for each iteration, it is checked whether the design remains within the specified constraints (Gradisar, 2024). The program computes the total shear wall area, at each calculation step. The objective is to determine the minimum required area; however, if a given trial violates the constraints shown in Figure 3, the calculated shear wall area is multiplied by a fictitious coefficient to ensure that such alternatives are disregarded.

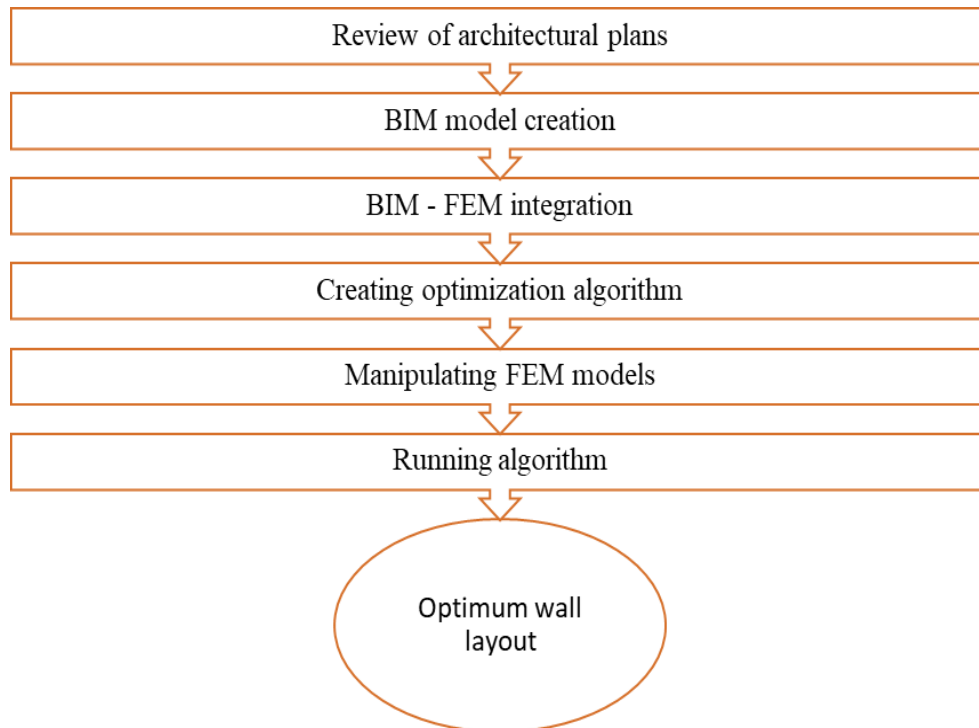


Figure 2. Topology optimization flowchart

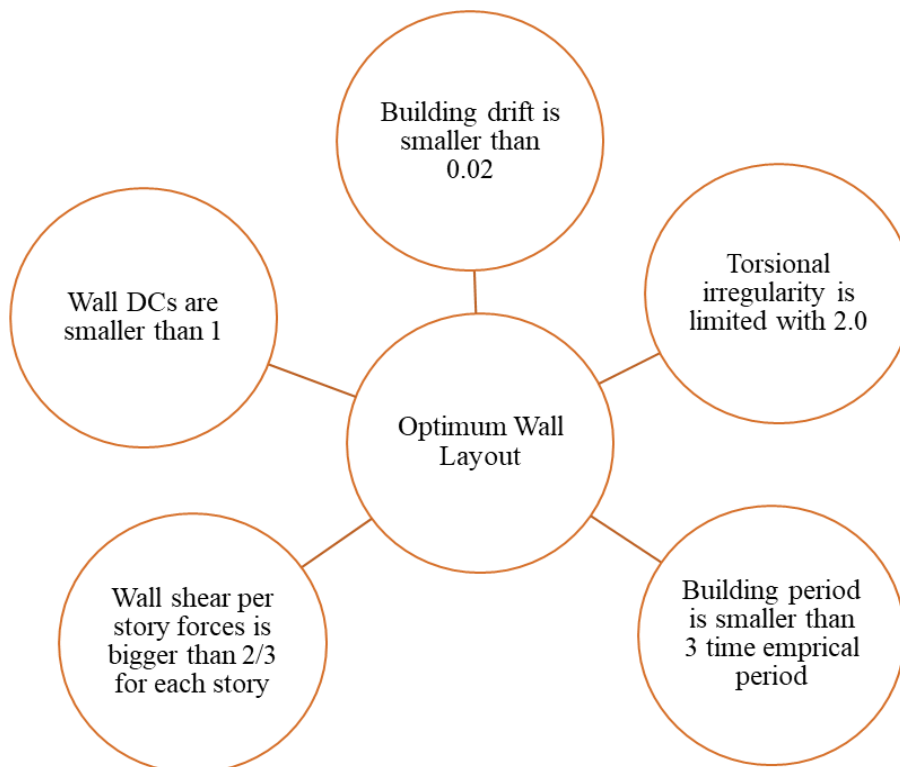


Figure 3. Optimum design constraints

Case Buildings

Three different building types exhibiting distinct behavioral characteristics are shown in Figure 4. The first is an example featuring flat-slab construction where shear walls carry the entire lateral load and are concentrated near the center of the structure. The second is an angular structure susceptible to torsional irregularities. The third utilizes a combination of moment-resisting frames and shear walls, though the shear walls are not arranged in a regular grid pattern.

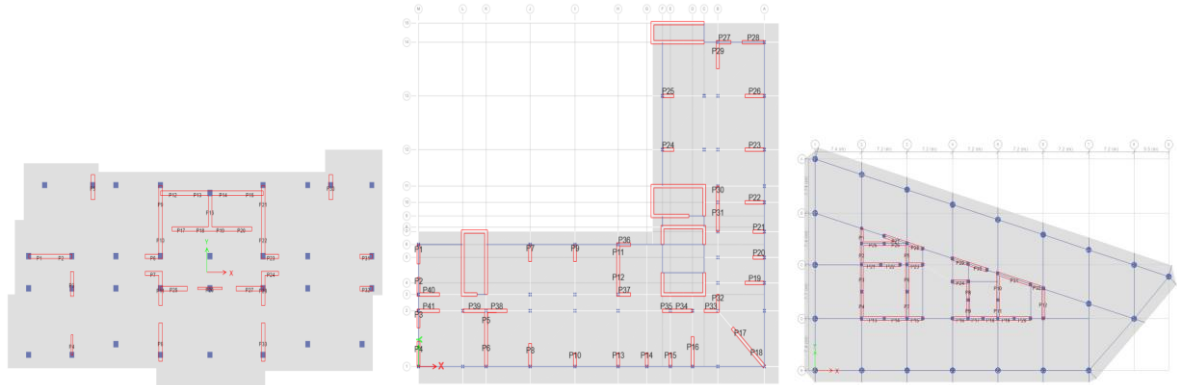


Figure 4. Case buildings

Sample Algorithmic Design Results

The analysis results for the sample building height are presented in Figure 4. As can be seen, as seismicity increases, the frequency of shear walls increases, and they are positioned towards the building's exterior axes.

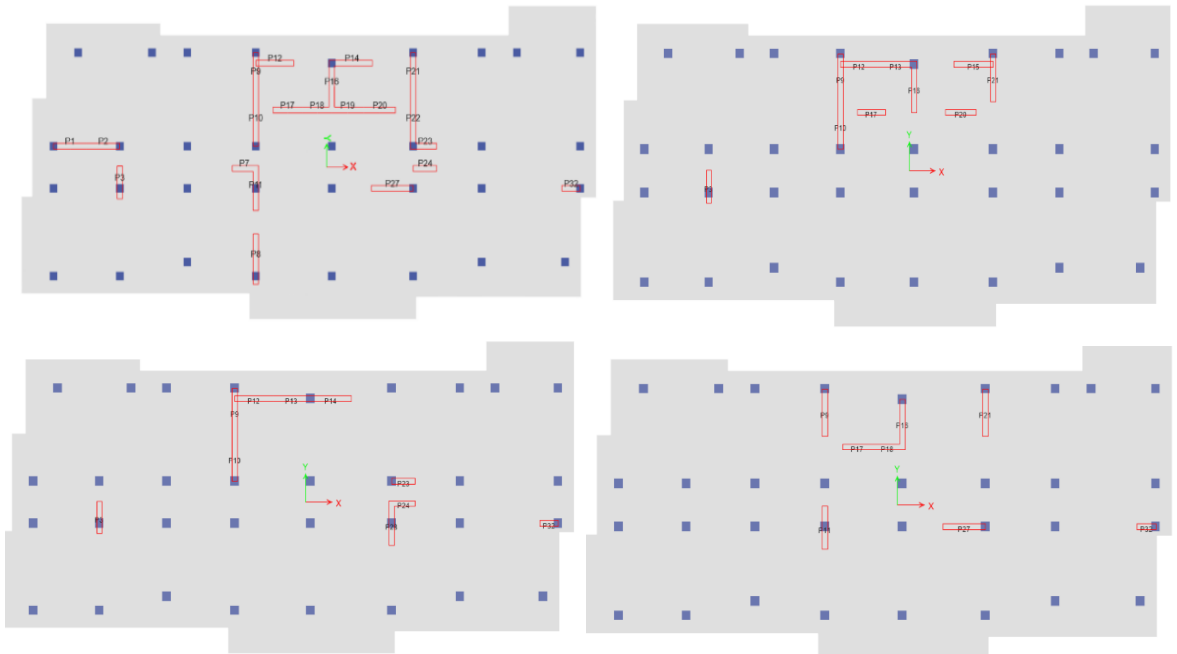


Figure 4. Optimum wall layout for a) Seismic class 1, b) Seismic class 2, c) Seismic class 3, d) Seismic class 4

Similarly, the algorithm was run for the other two building types using comparable building heights, and the results are presented in the subsequent figures. Each analysis result was recorded, and the correlations between them were examined. The study demonstrated a linear relationship across all building samples. As the study was limited to various iterations of three primary sample types, it established a general correlation. With an increased sample size, it would be possible to create a database of the existing building stock and use the information derived from the developed method to formulate design guidelines for new buildings.

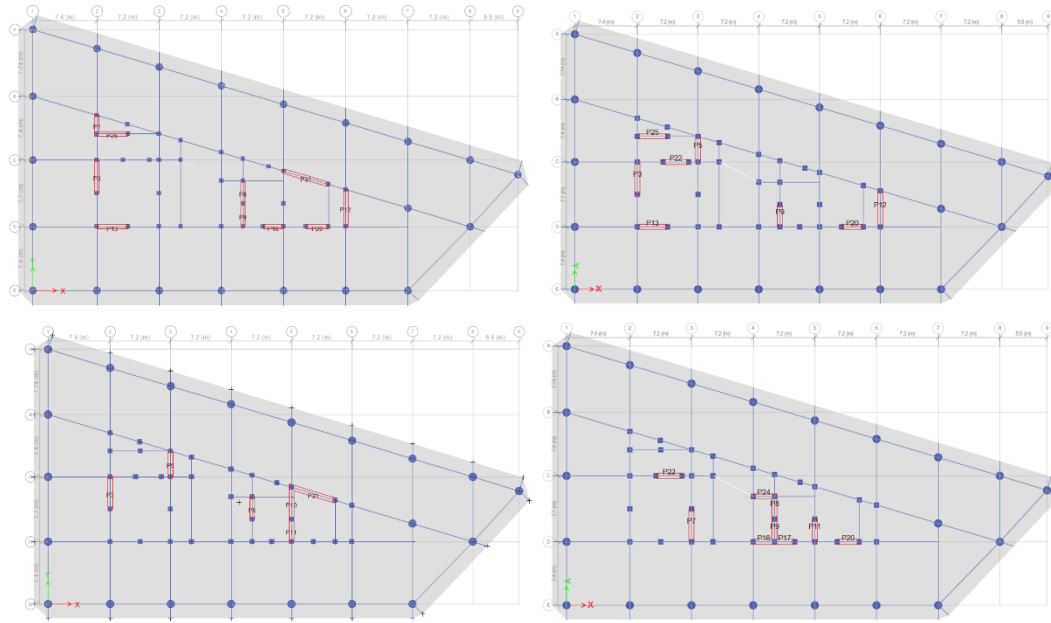


Figure 5. Optimum wall layout for a) Seismic class 1, b) Seismic class 2, c) Seismic class 3, d) Seismic class 4

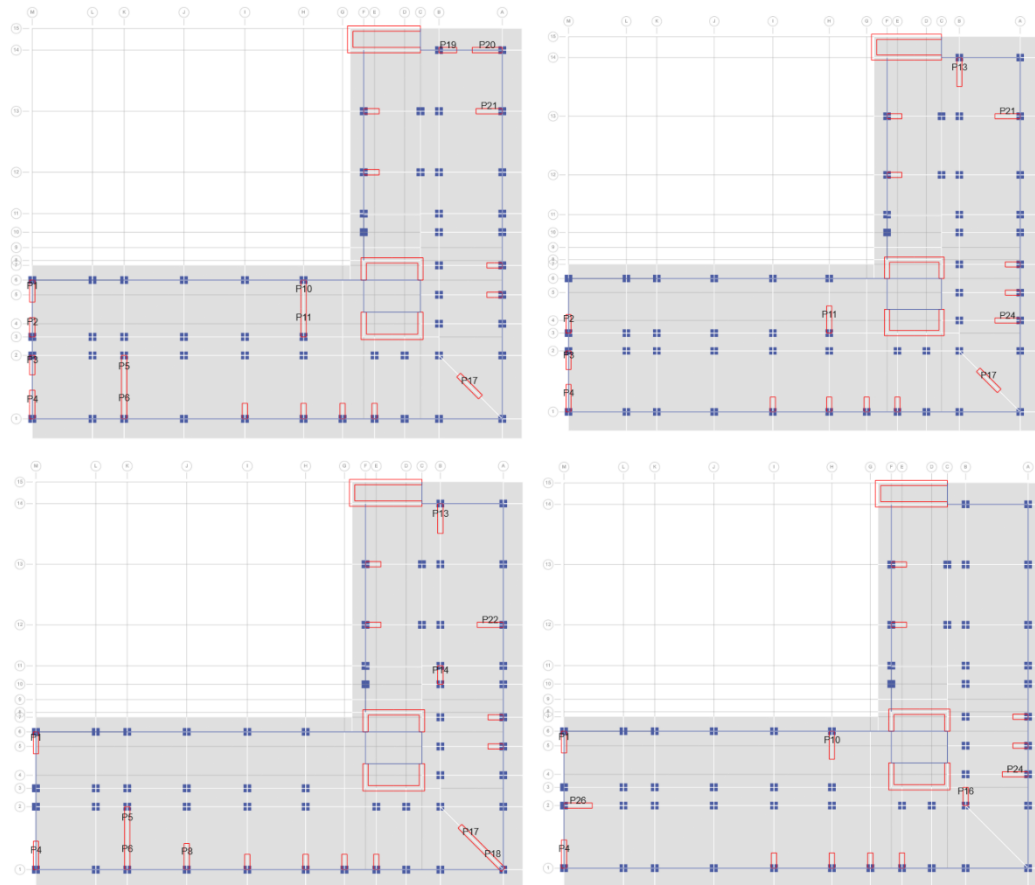


Figure 6. Optimum wall layout for a) Seismic class 1, b) Seismic class 2, c) Seismic class 3, d) Seismic class 4

Results and Discussion

Similar behavioral patterns were observed in the analyzed samples. It was found that the ratio calculated by dividing the required shear wall area (determined by analysis) by the product of the floor area and the short-period spectral acceleration coefficient (S_d) increases as the number of stories increases, exhibiting a trend

close to linear behavior, as shown in Figure 7. When the calculation result is normalized to remove the influence of Sds and the number of stories, a trend approaching horizontal behavior is expected. These relationships are illustrated in Figure 8.

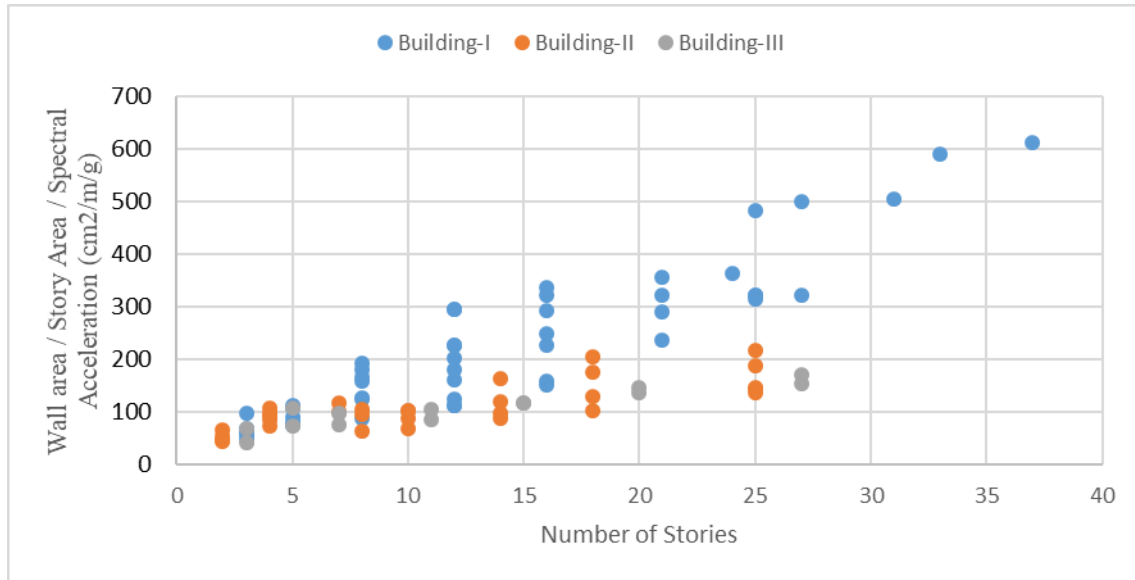


Figure 7. Optimum wall area per (single story area x spectral acceleration)

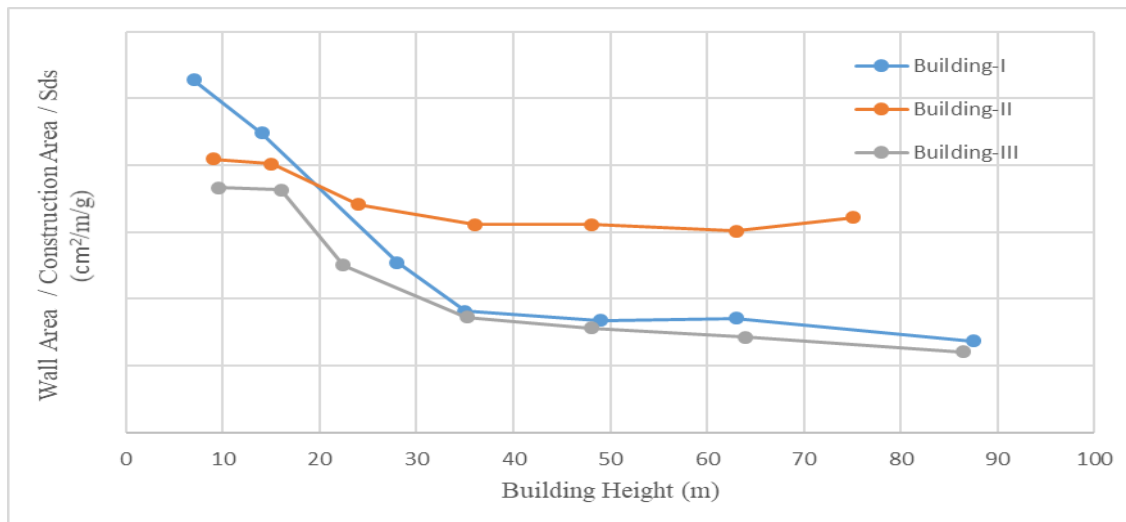


Figure 8. Optimum wall area per (construction area x spectral acceleration)

The observed relationship indicates that the demand for shear walls is higher in low-rise structures lacking shear wall-frame interaction; conversely, as the number of stories increases, the frame engages, thereby minimizing the load on the shear walls (Hu, 2025). In Example I, since a system featuring entirely flat slab was designed, this interaction did not occur, resulting in a strictly linear relationship. Consequently, when creating an idealized model, distinct equations should be employed for shear wall-frame structures versus systems with flat slabs where seismic loads are ensured exclusively by the shear walls. The first scenario can be idealized using a curve that begins with a large shear wall area, shows a relative decrease in this area as the number of stories rises, and levels off to a constant value once the building height exceeds 35–40 meters. The second scenario, however, can be idealized simply as a horizontal line. The idealization of the trendline can be expressed with a two-segment curve equation by establishing a building height of 35 meters as the threshold.

Ideal bilinear curve, including the consideration of building irregularities can be expressed as follows:

$$Aw = C \times (-0.00005 \times H_n + 0.0036) \times (Ap_j \times N \times S_d) \quad \text{For } H_n \leq 35 \text{ m:}$$

$$Aw = C \times (0.0018) \times (Ap_j \times N \times S_d) \quad \text{For } H_n > 35 \text{ m:}$$

Where :

Apj : Floor plan area
Aw : Required shear wall area
Hn : Building height
N : Number of stories
Sds : Short period spectral acceleration coefficient

$$C = C1 \times C2 \times C3 \times C4 \times C5 \times C6$$

Where :

C1 : Frame components. 0.9 if a system detailed with high-ductility frames exists in addition to shear walls (excluding ribbed or waffle slab systems); 1.0 if seismic loads are resisted solely by shear walls.
C2 : Mass distribution. 1.1 if the structure exhibits regular behavior due to efficient distribution of architectural functions or a live load participation ratio of 0.6 or 0.8; 1.0 otherwise.
C3 : Stiffness distribution between adjacent stories. 1.15 for configurations involving soft story irregularity; 1.0 for other types.
C4 : Shear wall arrangement. 1.15 if at least one rigid core (such as an elevator or stairwell) is located on an exposed outer axis; 1.0 otherwise.
C5 : Plan orthogonality. 1.2 for asymmetric or L-, C-, or T-shaped buildings; 1.0 otherwise.
C6 : Plan dimensions. 1.1 if the ratio of the long side to the short side of the plan is 3 or greater; 1.0 otherwise.

Conclusion

This study demonstrates how structural design can be manipulated using BIM technologies, specifically through examples of parametric and computational design. The main objective of the study is to use a visual programming language to iteratively analyze various shear wall layout configurations and verify their compliance with code requirements. An optimal layout was achieved by applying a genetic algorithm to three sample structures in accordance with the Turkish Earthquake Code. Required shear wall areas derived from these examples were multiplied for various building heights and seismic hazard levels. Based on the resulting analysis data, the required shear wall areas were plotted against building characteristics. In addition to calculating the required area, the specific layout of shear wall elements was determined for each analysis set; it was observed that as seismic hazard levels increased, the walls tended to shift toward the building's outer axes, whereas layouts showed more randomness at lower seismic hazard levels.

Recommendations

The study is based on algorithmic design which requires computational time and effort. AI and machine learning studies can be developed in order to automate the algorithmic process. Accuracy of study can be ensured with increasing the number of observed real projects. Projects can be coordinated with municipalities or construction ministries of each country that is compatible with design code that is studied. Observed buildings will create a data pool for AI training; mapping of layout will be the guide for new designs and automation of shear wall layout can be done without executing any calculation effort. Moreover, optimum layouts can be verified by executing time history analysis and nonlinear behavior can be observed.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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