Civil Systems Engineering
Modeling Civil Engineered Systems
Individual Project Assignment 2

Parametric Modeling of a Multi-Story RCC Residential Building

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1. Introduction

The designs of buildings whether architectural or structural, have been reshaped through parametric modeling. It allows them to create flexible and efficient structures, changing certain key characteristics. This approach facilitates exploring various design alternatives and identifying the appropriate trade-offs between appearance, functionality, and durability of a building. There are so many balancing acts to be made when it comes to RCC (reinforced cement concrete) residential building design, particularly in metropolitan cities, where space is at a premium but structural integrity is a necessity. With parametric modeling, these tricky problems can be solved.

This project focuses on parametric modeling to design a multi-story RCC residential building in Germany. The software tool used for the design is Dynamo BIM built in Revit 2025 version. The main goal is to explore how different design elements interact, assess their performance, and suggest design options that balance structural strength and material use. We must follow local building codes (Eurocode 8) to ensure buildings are safe and can handle earthquakes.

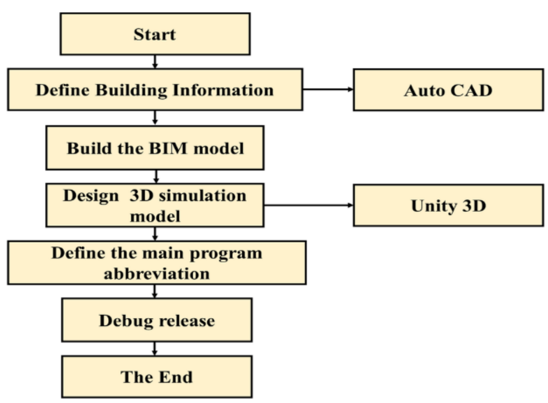

Fig 1: System development flowchart in BIM (Hailing et. al., 2021)

2. Design Challenge

2.1 Balancing Structural Stability and Material Efficiency

The core design challenge of this project lies in balancing structural stability with material efficiency. Talking about the structural strength, the building must withstand various loads and environmental conditions. On the other hand, material efficiency focuses on optimizing resource use to minimize costs and environmental impact.

Wall Thickness: The thickness of walls directly impacts the building's ability to bear loads and resist lateral forces. In parametric modeling, we can apply dynamic adjustments to wall thickness to optimize both stability and material usage.
Column Spacing: The distance between columns must be carefully calibrated to support the building's slabs. When we adjust column spacing, it helps to create balance structural support with open interior spaces.
Slab Depth: We can vary the slab depth in the parametric model to see how it affects the building's structural capacity and insulation properties.

2.2 Location and Structural Code

Germany's seismic considerations require compliance with Eurocode 8, which outlines the design principles for earthquake-resistant structures. The code emphasizes the need for ductility, energy dissipation, and appropriate detailing to ensure that buildings can endure seismic forces without significant damage. Integrating these requirements into the parametric model guarantees that the design adheres to local regulations and safety standards.

2.3 Purpose and Users

The building is designed to serve urban families and professionals with flexible living arrangements that change over time as lifestyle demands evolve. The model prioritizes functionality and comfort of residential units for high standard habitation**.** Also, the design has enough flexibility to be modified in the future such as turning the residential premises to commercial units or extend the building to have more residents.

3. High-Performance Criteria

3.1 Structural Stability

To become structurally stable, a building has to withstand loads like gravity, wind, and seismic forces without collapsing or deforming excessively. In seismic regions, stability means absorbing and dissipating earthquake energy to lower the damage. Two key measures are:

- **Maximum Allowable Displacement**: This assesses how much a building can sway during an earthquake without being damaged. Research shows that controlling displacement is critical to preventing structural failure during seismic events (Priestley et al., 2007).
- **Stress Distribution**: Evaluating how forces are spread throughout the structure ensures no part is overstressed. Proper stress distribution reduces the risk of structural cracks or failures, especially in load-bearing elements like walls and columns (Chopra, 2012).

3.2 Material Efficiency

Material efficiency involves the strategic use of construction materials to meet performance requirements while minimizing waste and costs. Sustainable design focuses on reducing the environmental impact of construction by optimizing material usage. Key metrics include:

- **Material Volume per Square Meter**: Measuring the material used per square meter helps identify opportunities to reduce material consumption without compromising structural integrity (Guggemos & Horvath, 2005).

- **Cost Analysis**: Comparing the costs of different material configurations helps find the most economical solutions that still meet performance standards (Asif et al., 2007).

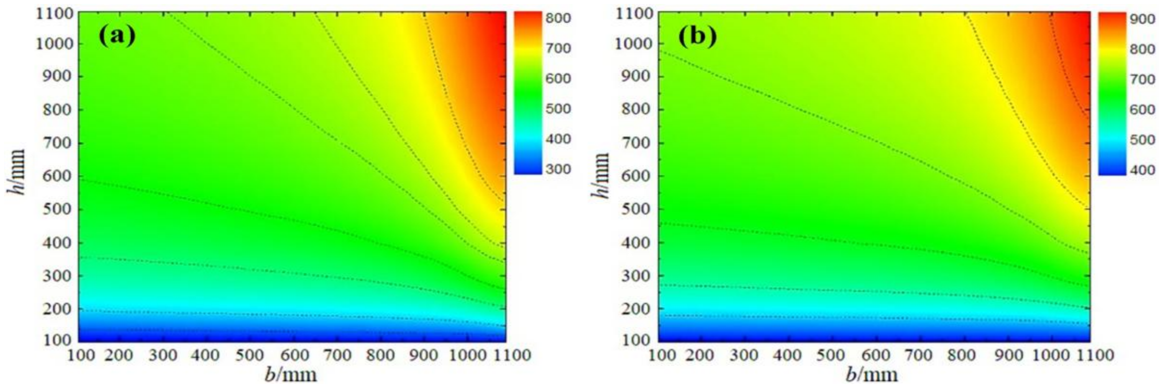

Fig 2: Domain of energy efficient building designs. (a) Total section cost (CNY) and (b) Total embodied energy (MJ) (Zhang et. al., 2024)

4. Parametric Model Description

4.1 Key Parameters

I. **Wall Thickness**: It is critical to understand how well the building will withstand load and its insulation capabilities. Thinner walls can have lower thermal resistance but can get weak if we make it thinner than needed.

II. **Column Spacing**: Column spacing will have an effect on the stability factor and material used for a building. Whether by configuring this spacing in a parametric model or any technique you prefer, you will ensure the structure will be adequately supported without wasting any material at the same time.

III. **Slab Depth**: The thickness of slabs determines the load-bearing capacity of the structure and the insulating properties. In the parametric model, the depth of the slab can be increased or decreased to find the best performing configurations.

IV.

Table 1: Design Parameters of the Building Model

Parameters	**Component**	**Minimum Value**	**Maximum Value**
Building Length	Building	8 meters	15 meters
Building Width	Building	8 meters	15 meters
Number of Story	Building	2	6
Story Height	Building	2.7 meters	4 meters
Wall Thickness	Wall	0.2 meters	0.4 meters
Slab Thickness	Slab	0.15 meters	0.25 meters
Column Cross-section (B * D)	Column	0.2 * 0.2 meters	0.5 * 0.5meters
Column Spacing in X and Y directions	Column	3 meters	5 meters

4.2 Model Logic

The parametric model of the multi-story RCC residential building is created using Dynamo BIM in Revit 2025. First of all, we assign the basic building parameters like length, width to form the building footprint and then number of story and story height. The model uses sequences and Cartesian products to generate a grid for column placement and defines wall and slab geometry based on adjustable parameters. Using this step, we can explore different design alternatives to optimize the layout for stability and efficiency.

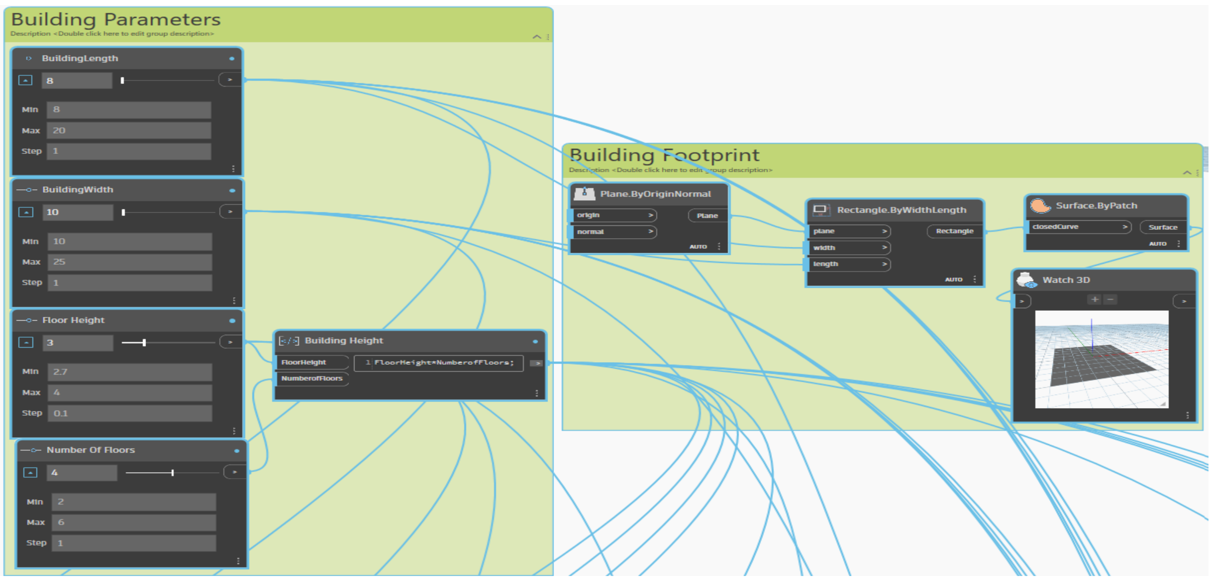

Fig 3: Defining Building Footprint in Dynamo

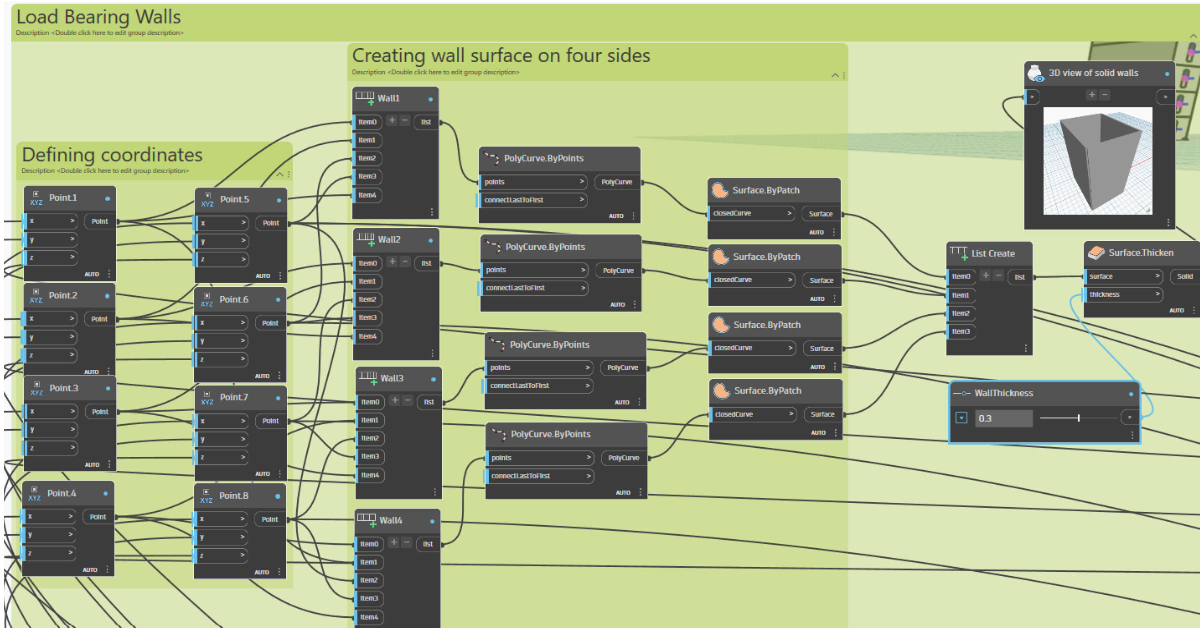

Fig 4: Defining Load-Bearing Walls in Dynamo

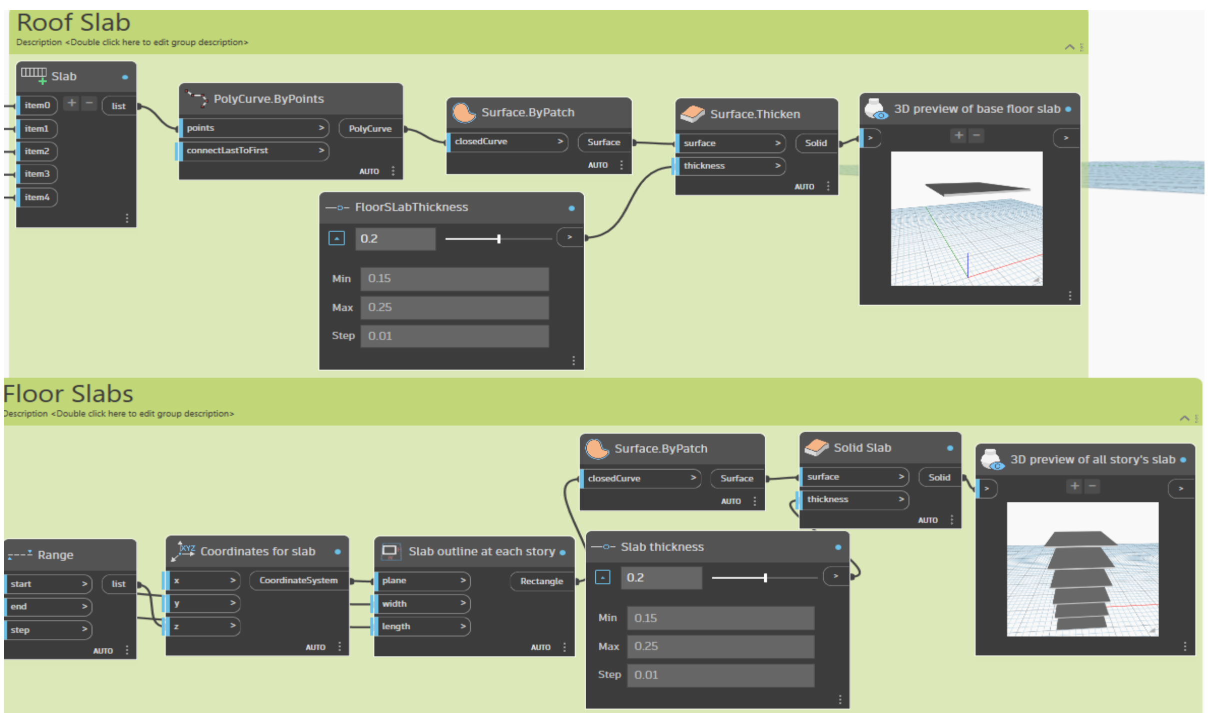

Fig 5: Defining RCC Floor Slabs and Roof Slab in Dynamo

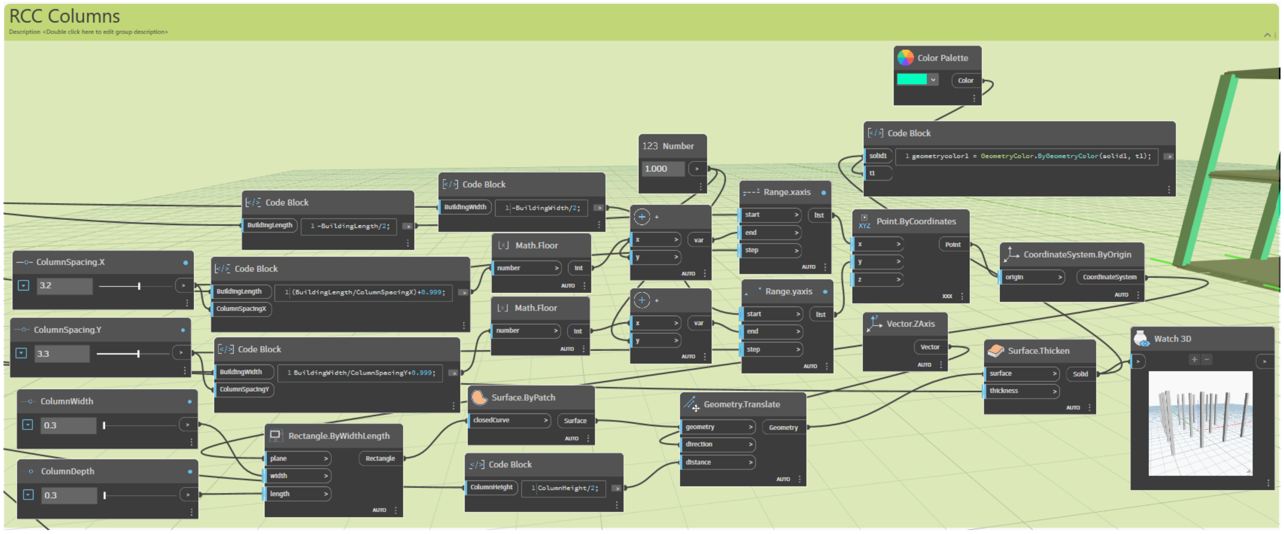

Fig 6: Defining RCC Floor Slabs and Roof Slab in Dynamo

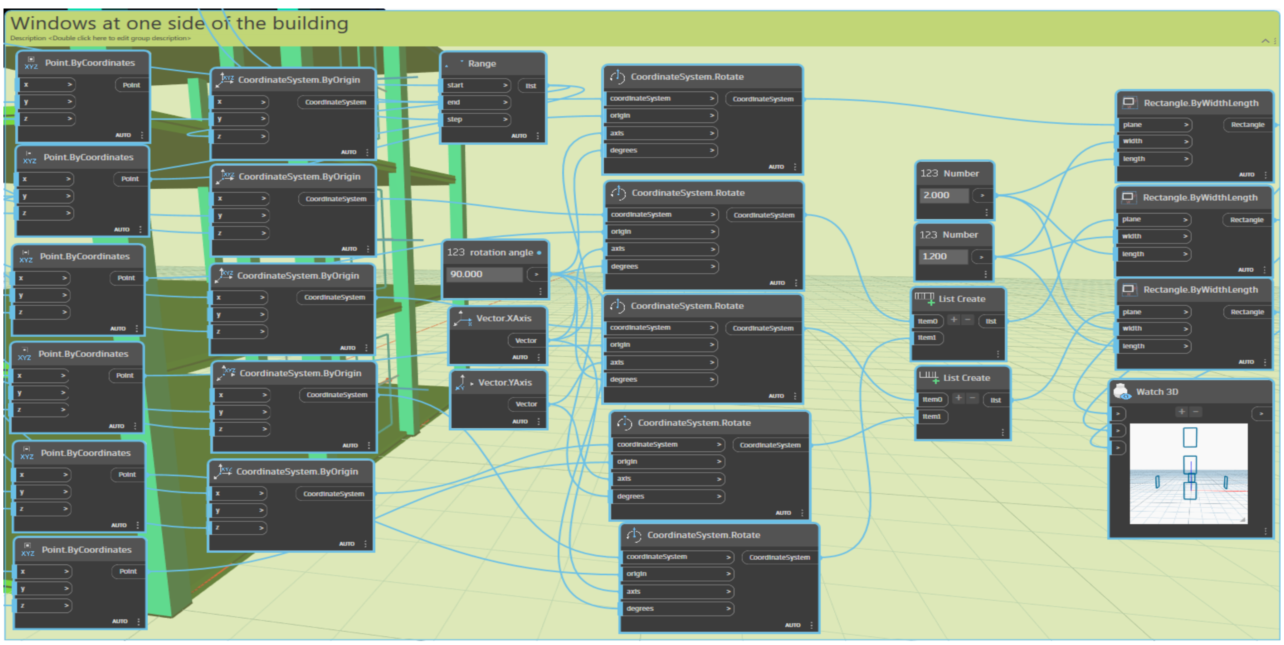

Fig 7: Defining Window Frame in Dynamo

5. Design Space

In parametric modeling, a range of possible designs are generated by varying parameters such as number of stories, wall thickness, column spacing, and slab depth. Understanding this space involves identifying the extremes and limits of these parameters to explore how they affect the building's performance. We shall discuss the boundaries of the design space for the multi-story RCC residential building. For this, we focus on the minimum and maximum values of key parameters and their impact on structural stability and material efficiency.

- Wall Thickness: Varying from a minimum of 200mm to a maximum of 400mm.
- Column Spacing: Ranging from 4 meters (close spacing for maximum support) to 6 meters (wider spacing for material efficiency).
- Slab Depth: From a shallow 150mm to a deeper 250mm for enhanced load-bearing capacity.

Reducing wall thickness, column spacing, and slab depth to their minimum values creates a lightweight structure with less material use. However, this can lead to potential safety risks due to compromising the building's ability to withstand seismic forces.

While on the other hand, increasing these parameters enhances the building's stability and load-bearing capacity, making it more resilient to seismic events. However, it significantly increases material use and construction costs.

The limits of the design space are defined by the constraints of the building's environment, code compliance (Eurocode 8), and practical construction considerations. We can dynamically adjust the parametric model within these limits, ensuring that the design remains feasible and compliant with safety standards.

6. Design Alternatives

In the parametric model, three design alternatives are proposed to explore different solutions within the design space. Each alternative focuses on balancing structural stability and material efficiency based on the parameters set in Dynamo BIM. The wall section is hidden in all design alternatives to obtain the clear view of other structural components.

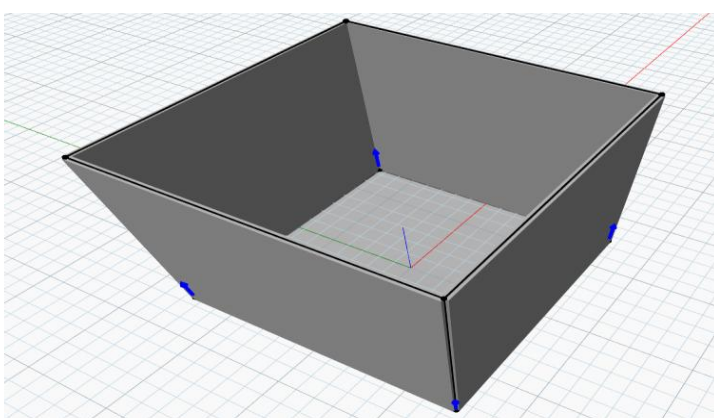

Fig 8: Model of Load-bearing walls of the building in Dynamo

6.1 Alternative 1: Minimalist Design

The main objective of this design alternative is to maximize material efficiency while maintaining basic structural stability.

- Parameters:
  i. Number of Stories: 2
  ii. Story Height: 3 meters
  iii. Wall Thickness: 200mm
  iv. Column Spacing in x and y-directions: 5 meters
  v. Column cross section: (0.3 meters*0.3 meters)
  vi. Slab Depth: 150mm

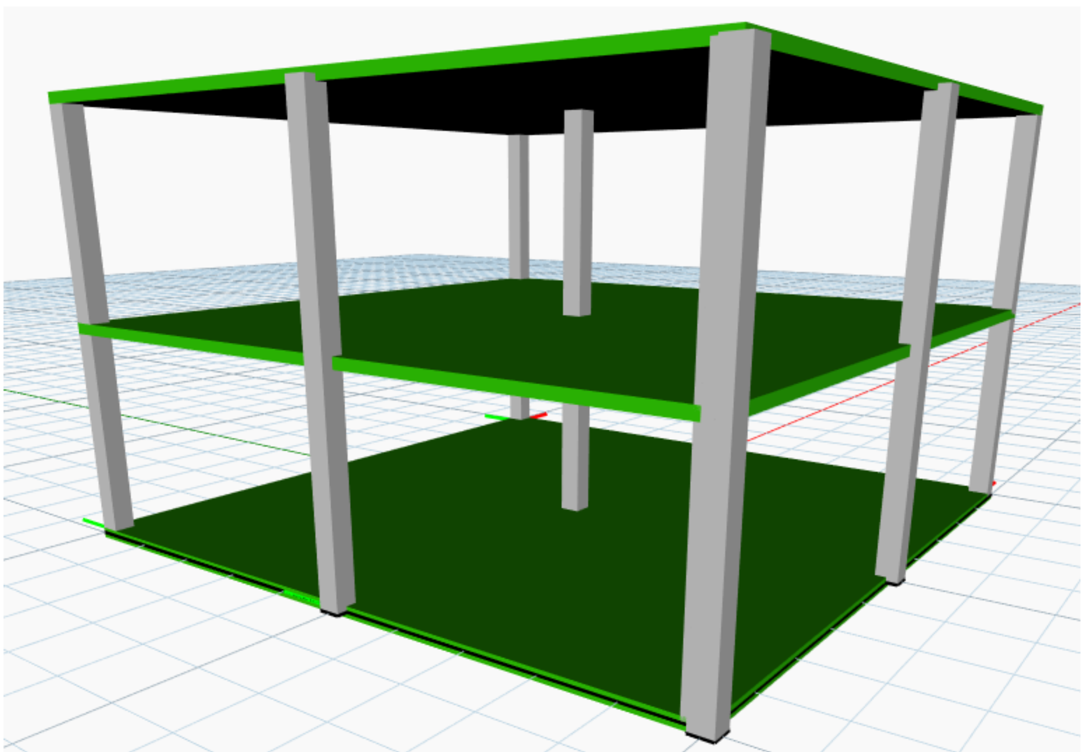

Fig 9: Parametric Model of the Building for Alternative 1

This alternative represents a well-embodied solution for areas with low seismic risk like Berlin and Hannover where cost and material efficiency are priorities. By reducing material use, we can align the designs with sustainable construction practices, minimizing the building's environmental impact.

6.2 Alternative 2: Balanced Approach

The main objective is to find a middle ground between stability and material efficiency.

- Parameters:
  i. Number of Stories: 3
  ii. Story Height: 3 meters

iii. Wall Thickness: 250mm
iv. Column Spacing in x and y-directions: 4 meters
v. Column cross section: (0.35 meters*0.35 meters)
vi. Slab Depth: 200mm

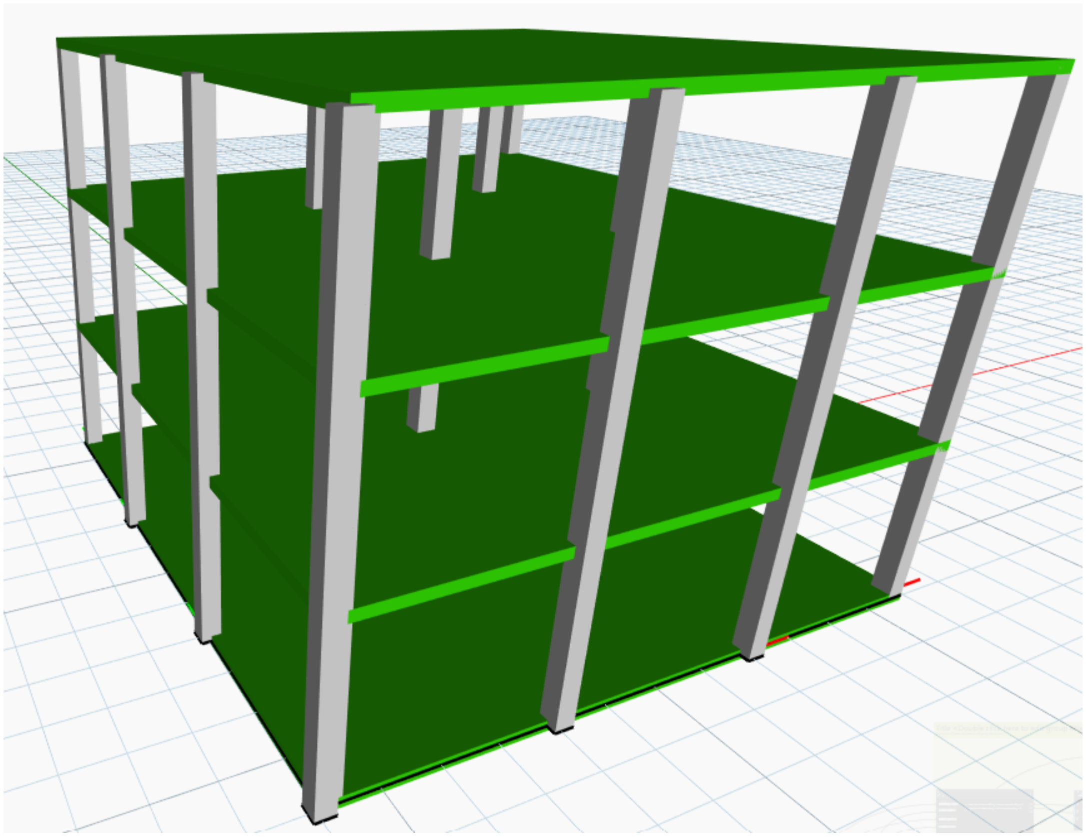

Fig 10: Parametric Model of the Building for Alternative 2

The balanced approach is a practical solution for urban environments with moderate seismic activity. Specifically in Germany, such areas can be Rhön Mountains and Baden-Württemberg. It optimizes material use and gives sufficient stability at the same time, making it a cost-effective and safe option for residential buildings. The flexibility in this design allows for future modifications or expansions, catering to changing urban needs.

6.3 Alternative 3: Maximum Stability

The objective is to ensure maximum stability, prioritizing safety over material efficiency.

- Parameters:
    i. Number of Stories: 4
    ii. Story Height: 3.5 meters
    iii. Wall Thickness: 300mm
    iv. Column Spacing in x and y-directions: 3.5 meters

v. Column cross section: (0.4 meters*0.4 meters)
vi. Slab Depth: 250mm

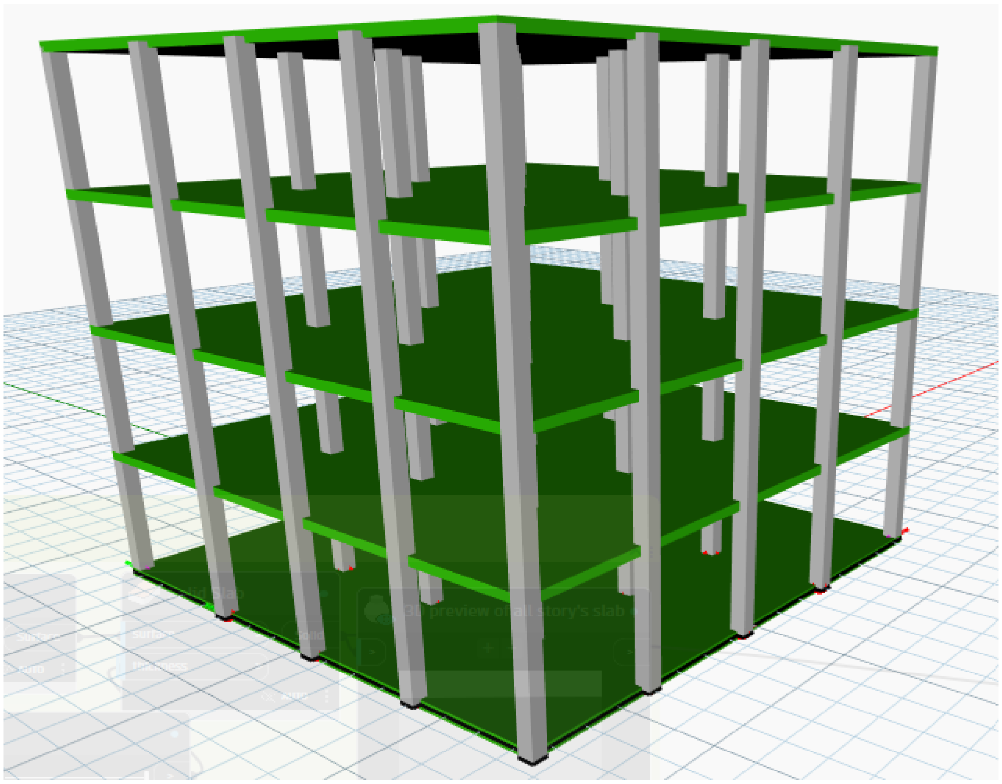

Fig 11: Parametric Model of the Building for Alternative 3

When we keep safety at first, the maximum stability alternative is ideal for high-seismic regions like Rhineland and Swabian Jura. The robust structural elements ensure the building's resilience against seismic forces, aligning with Eurocode 8 standards for earthquake-resistant structures. Though it uses more materials, the design ensures long-term safety and durability, justifying the higher costs.

7. Conclusion

This project involved the parametric modeling of a multi-story RCC residential building using Dynamo BIM within Revit. The primary purpose was to build a flexible design, with the ability to alter important parameters such as wall thickness, column spacing, and slab depth, to explore different design alternative. Through the comparison of these different options, our goal was to discover a solution that is structurally sound, and built with the least amount of material possible in accordance to Eurocode: 8 for seismic safety. The result of this parametric model is a set of design options that cater to different scenarios, from minimal material use to maximum structural stability. This project showcased how instead of relying on the trial-and-error process of exploring different variations of architectural solutions, parametric modeling can elegantly solve complex design problems and hone building performance.

Nonetheless, there are some **limitations** to the model. A major limitation noticed is no inclusion of beams — these structural elements are very much part of construction practices. The model was kept simple, focusing on just the essentials, the walls, columns, and slab components. Excluding beams, as well as parapet walls and staircases, means the model does not fully represent all structural components. Such elements are necessary to perform a more detailed structural analysis and to have a realistic load transfer. Additionally, the model does not consider any design attributes other than structural strength and material optimization, and fails to account for the overall thermal performance or acoustically sound properties of the residential building.

In upcoming enhancements, the missing structural components can be included, as well as expanding the model to include non-structural elements such as HVAC systems and energy saving measures. Applying these things in the model would set a wider scope of civil engineering problems. Advanced parametric models may be developed to account for the real-time inputs of environmental conditions, enabling more accurate and adjustable models.

The model can be a valuable tool for architects, engineers, and urban planners. Architects can use it to quickly iterate on different design scenarios and structural engineers can use it as a baseline for more detailed analysis. Urban planners could use it to visualize how various building designs fit into a city's landscape. Such a systematic and innovative approach to structural design has paid off, as this example demonstrates the effective utilization of parametric modeling in contemporary civil engineering, which is merely a precursor to advanced structural analysis and optimization.

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