Department of Civil Systems Engineering
Modelling Civil Engineered Systems WS 23/24
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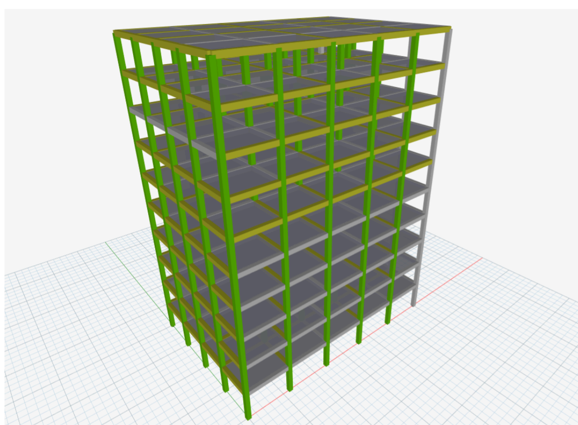
*2nd Assignment (Individual)*

# Parametric Modeling (Dynamo BIM)



## Multi-story Building

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# Introduction

Parametric modeling is one the most quick and comprehensive methods that engineers can apply in order to find the most optimized and diverse solutions for a design challenge. During this assignment I will implement a parametric modeling design using Dynamo BIM for my system of interest which is a multi story building. As we all are aware, a building comprises various subsystems, each of which can have parametric models created separately for them, including the structure, facade, foundation, and MEP systems. Nevertheless, providing parametric models for each of them is far beyond the scope of this project. Hence, I am focusing on providing parametric modeling for the structural system that has a determining role in all the above-mentioned subsystems within a building.

# Design challenge

The design challenge is to find and provide the optimal configuration for the structural design of the building. The challenge lies in developing a solution that not only ensures structural integrity but is also economically optimized as well, because most asset owners and stakeholders prioritize a safe yet cost-effective building. Additionally, the chosen structural setup must seamlessly align with the architectural layout.
There are several parameters that are influential in shaping the physical embodiment of the structure. In this assignment, I aimed to create a highly parametric model, ensuring its versatility to be applied across a wide range of buildings, ranging from small single-story structures to large multi-story ones. Undoubtedly, many of these parameters are completely dependent on factors including the type of the structural load bearing system, the nature and magnitude of loads, site planning, land conditions, architectural preferences, and the specific requirements of the building owners. However, since the project lacks specific information on these factors, their constraints are not accounted for. Nonetheless, I tried to enhance the model's completeness to ensure its practicality across a broader spectrum of functions.

# Parameters

The following parameters were selected to make a complete control on the parametric model;

- ***Building’s dimensions***

Without a doubt, a building's length and width are two of the most influential factors that have a key role in determining the entire design process and  have impact on nearly all the design parameters. Normally, these parameters are included in the design requirements based on the land conditions and asset owners preferences.

- ***Number of Stories***

  Number of stories has a determining factor in a building’s configuration contributing to the building's height which directly affects the structural analysis. Normally, the number of stories is determined based on the project requirements and local building codes. Typically, the number of stories is dictated by project specifications and local building regulations. Cities with ample land often favor low-rise buildings, whereas densely populated urban areas like Tokyo tend to favor high-rise structures

- ***Story Height***

  Story height is another influential factor which particularly affects the design of the column. It varies based on the function, architecture, and owner's preferences. Based on building codes this height must always stay below a specific number.

- ***Number of Column in each direction***

  This is another super important parameter in designing every building which is set based on so many factors and has a huge impact on other aspects. Primarily, architecture has the most influential factor in deciding the location as well as the number of columns or their spans. Notably, fewer columns or longer spans create larger open spaces offering greater flexibility in architectural design. Furthermore, from an economical point of view, longer spans result in lighter structure and reduce the quantity of material used in the structure. However, from a structural point of view, minimizing the span of columns is preferred for a more desirable structural analysis.

- ***Structural elements sections***

  In addition to above-mentioned parameters which have the greatest effect on geometrical and physical embodiment of a building, I have also established the dimensions of columns, beams, and slabs as parametric. Although the precise dimensions of these structural elements are determined through structural analysis and design, in this context, I defined them parametrically to enhance our understanding of usable spaces and facilitate material quantity estimations.

A summary of the input parameters together with their extremes and minimums has been provided in Table.1.

| Num | **Input Parameter** | **Min. Value** | **Max. Value** |
|---|---|---|---|
| 1 | Building’s Length (L) | 10 m | 50 m |
| 2 | Building’s Width (W) | 10 m | 50 m |
| 3 | Number of Stories (N) | 1 | 10 |
| 4 | Story Height (H) | 3 m | 5 m |
| 5 | Number of Columns in each direction | 2 | 20 |

*Table.1. Input parameters, extremes and limitations*

# High-performance criteria

To evaluate the performance of the various design alternatives, which will be introduced at the end of this report, I established three high-performance criteria as follows:

- ***Quantity of Materials***

  The importance of the quantity of materials can be discussed and analyzed from various perspectives. Firstly, it's crucial to prevent overdesign and develop an optimized, cost-effective structural design. Secondly, considering the environmental aspect, it's vital to minimize the use of raw materials in constructing our buildings. To compare design alternatives, I chose reinforced concrete as the structural type. To accomplish this, I will calculate the overall volume of concrete and steel required for the model's structure. However, precise material quantities require conducting a structural analysis and design that accounts for load factors. For the sake of simplification, I will assume certain dimensions for structural elements based on engineering understanding. Subsequently, an approximate calculation of the total steel needed will be derived using the overall concrete volume. Ultimately, based on these values we can easily estimate the cost needed for the implementation of the structure.

- ***Structure's Weight***

  Despite the fact that the structure's weight follows a methodology similar to that introduced in the material quantity assessment, it holds significant importance as a high-performance criterion in structural analysis. From a structural standpoint, the weight of the structure contributes substantially to the overall dead load. Hence, reducing this weight will decrease the imposed loads on the structure, leading to more streamlined and optimized structural components.

- ***Space Efficiency Ratio***

  This factor plays a crucial role in evaluating the performance of specific configurations within buildings. The ratio is determined by dividing the total space provided by the building's structure by the efficient and usable space remaining after deducting the area occupied by structural elements like columns, stairs, walls, and MEP services. Although our experiment focuses on the structure, we will exclusively consider the impact of structural elements. While this effect might be negligible for now, it holds significant importance for future development, allowing for more precise comparisons as explained above.

## Logic of the parametric model

To conduct the experiment, my primary focus was to develop a highly parametric model applicable across a broad spectrum of buildings. As it can be seen from the dynamo file, the experiment starts by defining a set of input parameters. Initially, the user needs to specify the overall dimensions of the building including its length and width based on the architectural layout and site plan conditions. Following this, the number of columns in X and Y direction are required to be determined considering the required spatial spans for creating flexible architectural spaces. At this stage, structural analysis considerations must align with local building codes, delineating our constraints.

In the subsequent phase, the number of stories, along with their respective heights, must be defined according to project requirements and the owner's preferences. Finally, an approximate section must be specified for columns and beams, with options for square or rectangular shapes. Additionally, the thickness of the slab also needs to be defined. Based on these input parameters, the model will compute the total material quantities and the weight of the structure. Additionally, it will calculate the overall usable area and space efficiency ratio by determining the total space across all stories and then subtracting the space occupied by columns.

## Design Alternatives

To be able to make a judgment between different design options, I established a framework that each design alternative needs to be aligned with that, and also satisfy its requirements. It was assumed that we need to create 6000 m2 spaces for the various functions such as commercial, residential, offices, and recreational spaces within the project. There are no constraints in terms of building footprint, shape, and number of stories. To perform this, I created three different design options each with unique specifications. To facilitate the comparison, Table 2. Represents a summary of the proposed design options including input design parameters. Additionally, Table 3. Provides the final comparison indicating the final results.

| | Length (m) | Width (m) | C.span X.direction | C.span Y.direction | N.stories | H.stories (m) | Column Section | Beam Section | Slab Thickness |
|---|---|---|---|---|---|---|---|---|---|
| D1 | 50 | 40 | 5.55 m | 5.71 m | 3 | 4 | 0.5*0.5 | 0.5*0.4 | 0.50 m |
| D2 | 30 | 20 | 4.28 m | 4 m | 10 | 4 | 0.65*0,65 | 0.7*0,5 m | 0.40 m |
| D3 | 40 | 39 | 5 m | 4.28 m | 5 | 4 | 0.6*0,6 | 0.6*0,5 m | 0.45 m |

*Table.2. Three design alternatives with their specifications*

| | Total concrete volume (m3) | Total steel weight (tonnes) | Totals structure wight (tonnes) | Total useable space (m2) | Space efficiency ratio |
|---|---|---|---|---|---|
| D1 | 3180 | 499 | 8133 | 5940 | 99% |
| D2 | 4976 | 781 | 12723 | 5831 | 97% |
| D3 | 4221 | 662 | 10793 | 5870 | 97% |

*Table.3. Three design alternatives indicating final results*

As shown in Table 3, it is evident that the first design alternative has the best performance in terms of the pre-defined HPC. Not only does it have the lowest quantity of materials, but it also boasts the highest space ratio efficiency. However, its implementation requires a substantial site plan of 1000 m², which might not be feasible across all locations and projects. Therefore, in such instances, an alternative approach, such as increasing the number of stories, could offer a viable solution.

Figures 1, illustrates the configurations for three design alternatives.

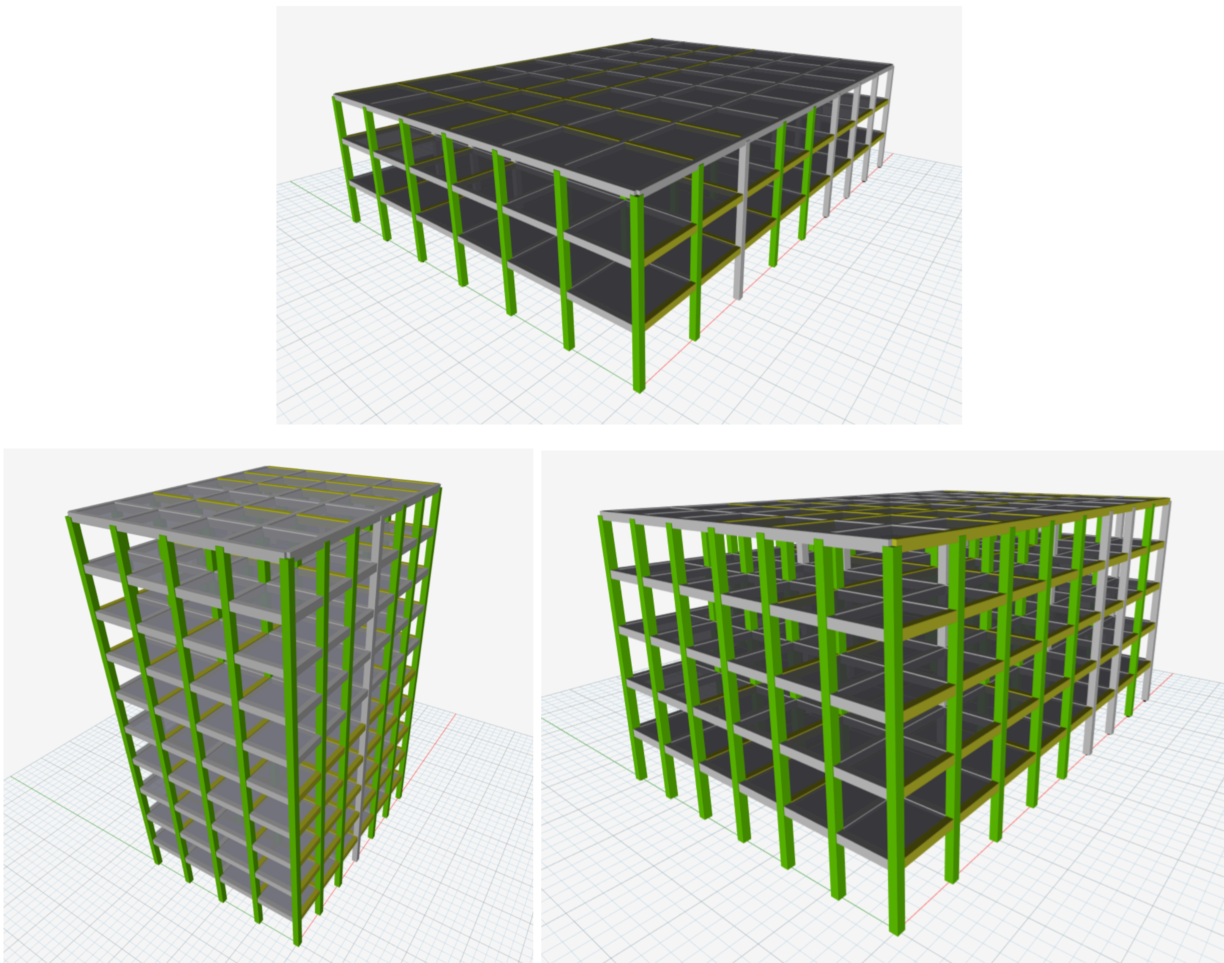

*FIg.1. Three different configurations created through the parametric modeling, Dynamo output*