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Seismic Analysis of a building through Rhino/Grasshopper Software

Master Thesis

International Master of Science in Construction and Real Estate Management

Joint study Programme of Metropolia UAS and HTW Berlin

from

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Conceptual Formulation
Master Thesis for Mr./Ms.: - Shantanu Chauhan
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Topic:
Seismic Analysis of a building through Grasshopper software

Background: -

Structural engineering is a field of civil engineering that requires high logical ability and analytical thinking of an individual. An individual must learn lots of things about the behavior of a member and must learn about the analysis of a particular member. On the daily basis, structural engineering faces lots of hard work and rigorous activities to get efficient results. It also requires lots of repetitive tasks, that require lots of manpower to complete the task. If these repetitive tasks can be reduced to some extent, the potential and mental abilities of a person can be utilized somewhere else.

With the help of Parametric design, the repetitive and rigorous task can be reduced to a certain extent. Parametric design is a great tool to have flexibility on the different parameters in a particular geometry. The dimensions of a particular object in geometry can be modified easily, and the resulting behavior can be observed without modeling the geometry again. This is the flexibility required in structural engineering that can reduce so much work in structural engineering. In addition to that, the parametric design allows structural engineers and architects to discuss alternatives of a particular geometry.

As earthquake is one of the major forces for which a structure has to design. Many areas around the globe are earthquake governing zone. Especially if the height of a building is more than certain limits. Therefore, a building geometry will be considered in the earthquake governing zone, and seismic analysis will be done according to European code. In addition to that, during the preparation of this thesis, programming tools such as Python will be combined with the previous condition. The inclusion of the programming tool Python with seismic analysis is optional in this thesis.

Research Questions: -

- How seismic analysis of a building can be done through parametric design tools such as Grasshopper?
- How to implement a parametric design in structural engineering?
- How programming tool Python can be included in the parametric design of a structure (optional)?

Methods: -

- Study of European code for seismic analysis.
- Modeling of a building with the help of Grasshopper and Rhino.
- Analysis of that building through Grasshopper.
- Analysis of that building through python programming tool(Optional).

Resources: -

- Google scholar (https://scholar.google.com/)
  For different articles and jouranals which has been already published regarding this topic.

References: -

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Signature of the Supervisor

Abstract

Parametric design is a tool by which the parameters are used to develop geometry. Architects have already started using parametric design tools such as Rhino/Grasshopper in the AEC industry and taking benefits from these tools while preparing the geometry. But that is not the same case with structural engineering. Structural engineers are still using a software tool based upon a CAD system. It means the structure must be redrawn or remodeled again if there are specific changes in the structure system. Therefore, this research utilizes the parametric tool from a structural engineer's perspective.

Earthquake is one of the significant forces on a structure. Seismic waves generated by earthquake sometimes damages the system severally. In this research, a framed structure is considered in Italy in Seismic zone 1. As Italy comes under a seismic-prone zone, the structure is considered in the same country. As the building considered in this research is located inside Europe, therefore European code of seismic analysis (EN 1998-1) is utilized.

In this research, the framed structure is modeled with the help of the Parametric design tool Rhino/Grasshopper. To apply the seismic force on the building, the forces are calculated as per EN 1998-1. After that, the forces are applied with the help of the KiWi3D plugin available in Rhino/Grasshopper. After that, the analysis is conducted, and the reaction forces are compared with the SOFiSTiK Software tool.

Keywords: Parametric Design, Seismic Analysis, Earthquake Analysis, EN 1999-1, Rhino/Grasshopper, Kiwi!3D

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List of Abbreviations

CAD	Computer Aided Design
3D	Three dimension
EN 1998-1	Eurocode 8 Part-1
BIM	Building Information Modelling
GPM	Generalized Parametric Model
P-waves	Primary Waves
S-waves	Secondary waves
SDF	Single Degree of freedom
MDF	Multiple Degree of Freedom
DOF	Degree of Freedom
IGA	Isogeometric Analysis
NURBS	Non-uniform Rational B-splines

List of Symbols

f_s	Lateral Force
k	Stiffness
u	Deformation
F_b	Base Shear
$S_d(T)$	Design Spectrum
m	Total Mass of the Building
λ	Correction Factor
a_g	Design Ground Acceleration
S	Soil Factor
T	Time Period of Vibration of Building
T_B	is the lower limit of the period of the constant spectral acceleration branch
T_C	is the upper limit of the period of the constant spectral acceleration branch
T_D	is the value defining the beginning of the cnstant displacresponse range of the spectrum
a_{gR}	Peak Ground Acceleration
γ_1	Importance Factor of the Building
q	Behavior Factor
q_0	Basic Value of Behaviour Factor
k_w	Prevailing Failure Mode in Strctural System
z	Height
G	Dead Load
Q	Imposed Load
Ψ	Combination Coefficient

1. Introduction

In the past, the architect needed to produce drawings before construction. Engineers and architects need to anticipate its behavior under applied loading conditions: they must gain suitable levels of confidence that it will be structurally sound by providing the necessary thermal, lighting, and acoustic conditions, and with the consideration of time and budget, among other things. Apart from this, architects had faced many problems producing a drawing because of limited options available for drafting. Parallel bars, triangles, compasses, scales, and protractors were used as drafting instruments. As a result, it was tedious for architects to make some modifications. (WILLIAM J. MITCHELL, 1999)

In the past few years, digital tools have transformed architectural and structural design. Modern CAD systems have changed many things in the architectural and structural industry. (WILLIAM J. MITCHELL, 1999) But one thing that is always the same is that the design of a particular structure changes too many times from the inception of design to completion. Therefore, software such as CAD got more popular because it allows a designer to change a digital drawing in a few clicks. Which might be challenging to do with the paper. (Preisinger and Heimrath, 2014)

1.1. Problem description

The decision-making abilities of the project's stakeholders are one of the variables affecting the project's success or failure. The decisions made throughout the planning and design stages significantly influence the project's outcome. (Robert S. Kaplan, David P. Norton, 2005) In this research, only one design stage is presented. This research will depict how a parametric design could benefit structural engineering.

The architectural community has already started taking the benefits of parametric design, and it provides flexibility to architects. Even though some architects still do not want to adopt this new technology because it is hard to switch to new technology for some people. The same thing is happening with structural engineers as well. (Monedero, 2000) But with the help of the parametric design, engineers may have more flexibility to the structures. They can do changes quite frequently and give the result as per changes compared to other traditional options.

1.2. Research Questions

This research will mainly focus on the several questions: -

1. How can seismic analysis of a building be done through parametric design tools such as Rhino/Grasshopper?
2. How to implement a parametric design in structural engineering?

In answering the questions mentioned above, some tools will also be referred. Those tools are mentioned as below: -

- EN 1998-1: - The standard for seismic analysis as per European standard, this standard will be referred for the analysis,
- Kiwi!3D: - Plugins inside Rhino/Grasshopper for structural analysis
- SOFiSTiK: - For the comparison of reaction forces with Kiwi!3D

1.3. Research Approach

In the Earthquake prone regions, earthquakes are one of most destructive forces. The seismic waves generated by the earthquake can demolish buildings and take so many human lives. That generally results in loss of money too. (BigRentz, 2019) Therefore, earthquake is one of the significant forces on the structure a structural engineer must consider while analyzing a system. Since parametric design is new in the structural engineering, this research combines parametric design with structure engineering. A structure will be modelled parametrically, and seismic analysis will be done according to EN 1998-1.

The software tool utilized for the parametric design will be "Rhino." It has a plugin The software tool utilized for the parametric design will be "Rhino." It has a plugin inside it with "Grasshopper" that can draw algorithms/scripts. The algorithms/scripts drawn on the Grasshopper can be seen in the Rhino interface in real-time. It allows the designer to witness the change and modification of the geometry in real-time. Apart from that, Grasshopper has many plugins like "Kharamba 3D" and "Kiwi!3D" that can be used for structural analysis. The "Kiwi!3D" plugin will be utilized for this research.

2. Literature review

2.1. Parametric Design

The origin of the term “parametric” is from mathematics. It signifies that if specific parameters are being modified or changed, it will affect the result of an equation. For example, a linear equation $x = 2y$, considering y is a parameter. If the value of y changes, the outcome of this equation will change. (MathWorld, 2021)

Parametric design is a process in which a set of rules/statements/algorithms establish relationship parameters with design. (Jabi, 2013; Woodbury, 2010) The parametric design process has several stages, including selecting the parameters, defining the relationship between parameters, generating the geometry, developing variations, and evaluating the finished goods. These stages are inextricably linked to one another. As soon as the parameter is altered, the shape of the simulated geometry can be adjusted. When a model needs to be changed, it is unnecessary to redraw it. It allows user to experiment with several alternative solutions. As a result, it is possible to choose more efficient architectures with reduced weight, smaller dimensions, and greater element use, giving environmental and economic benefits. (Victor Andersson and Cecilia Hillberg, 2018)

A parametric model is a computer representation of a design made up of geometrical elements with fixed and variable characteristics (properties). The fixed qualities are limited, whereas the variable attributes are termed parameters. To find multiple potential solutions to the problem at hand, the designer alters the parameters in the parametric model. The parametric model adapts or reconfigures to the new parameter values without deleting or redrawing in response to the changes. (Barrios Hernandez, 2006)

Designers employ defined parameters to define a shape in parametric design. Developing a elegant geometrical structure integrated into a complicated model flexible enough to conduct modifications requires rigorous reasoning. As a result, to establish the modification of the parametric model, the designer must predict which types of variants he wishes to investigate. Due to the unpredictability of the design process, this is a challenging endeavor. (Barrios Hernandez, 2006)

Hudson lists six advantages of parametric design in architectural practice, according to Hudson (2010): (1) the conversion of design concepts into parametric models, (2) the justification of designs into buildable shapes and components, (3) the supervise and layout of architectural forms, (4) the preparation and changing of design alternatives based on different criteria and expert input, i.e., optimization and efficiency-centered design investigation, (5) the coordination of information, and (6) the capture of design knowledge from various stakeholders. (Hudson, 2010)

It should also be highlighted that there is no apparent distinction between parametric design and what is now known as computer-aided drawing or modeling from a fundamental standpoint. Forms are constructed in these circumstances by merging basic entities introduced into the model once a basic template is filled with their "appropriate parameters." For example, to draw a line in a model, its two parameters (length and direction) should be provided. A polyline is a collection of lines linked at their vertices that must have their position parameters when generated. (Monedero, 2000)

2.2. Parametric Design, Past

In parametric design, the term “parametric” was first discovered by Luigi Moretti. Between 1940 and 1942, he underwent a couple of studies under the title “Architettura Parametrica” on the subtitle of “architectural design and parametric equations”. These studies could not make use of the computer’s capabilities at the time. Using a "IBM 610" computer, he was able to develop the parametric models of the "Progetti di strutture per lo sport e lo spettacolo" stadium by 1960. (A. Heidari, S. Sahebzadeh, M. Sadeghfar, B. Erfanian Taghvaei, 2018)

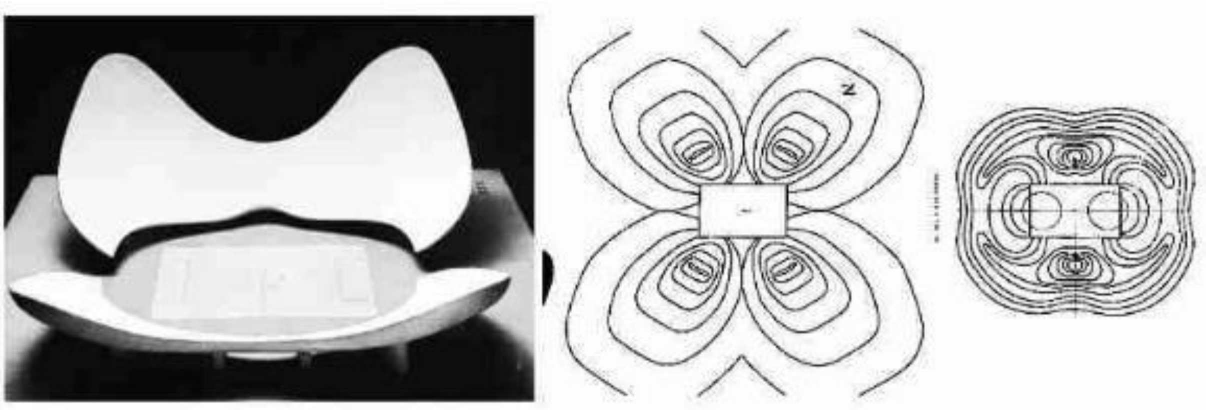

Figure 1: A model of stadium by Luigi Moretti (Luigi Moretti et al., 2002)

Similarly, the early works of Antonio Gaudi were parametrically designed in nature. This information was not uncovered by Gaudi's writings and scripts but through Mark Burry. He was one of the significant persons who has been involved in the building of Gaudi's ideas for the cathedral of "Sagrada Familia Basilica" in Barcelona for a long time. Rather than Gaudi, Burry should be given credit for the parametric analysis of Gaudi's works. (A. Heidari, S. Sahebzadeh, M. Sadeghfar, B. Erfanian Taghvaei, 2018)

Architects have benefited from the works and experiences of the distinguished architect, Antonio Gaudi. Like many other architects, Gaudi went through a transition phase during his 43-year career, beginning as a historicist architect, progressing to an organicist, and then, via his geometry demand, to a geometer. During this time, he worked on hyperbolic paraboloids and hyperboloids, both of which are parametrically adaptable and flexible designs in the proper sense of the word. His work of Sagrada Familia Basilica in Barcelona finest displays these designs. Because of the appearance of such structures, some critics saw the announcement of parametric architecture's emergence as a diversion from the primary problem, which they said was thinking and acting parametrically rather than just debating styles and style principles. (A. Heidari, S. Sahebzadeh, M. Sadeghfar, B. Erfanian Taghvaei, 2018)

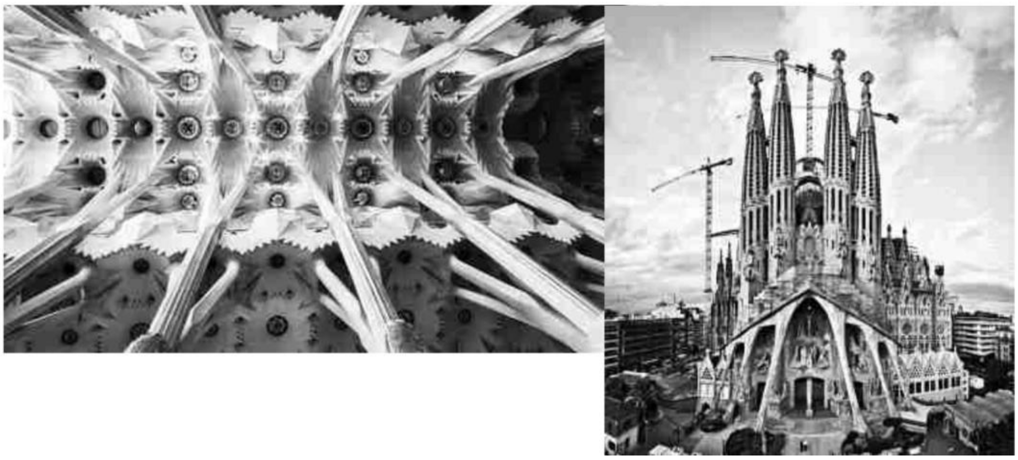

Figure 2: Gaudi's designs in Sagrada Familia Basilica (A. Heidari, S. Sahebzadeh, M. Sadeghfar, B. Erfanian Taghvaei, 2018)

Figure 3: Otto's designs in olympic Stadium (A. Heidari, S. Sahebzadeh, M. Sadeghfar, B. Erfanian Taghvaei, 2018)

Parametric design and parametric architecture have a long and illustrious history. When Patrick Schumacher initially declared the advent of a modern architectural style called parametric architecture in 2008, the people in the architecture world were not startled because they were already aware of the qualities and principles of this type of design, but not under this name. As a result of Schumacher's remark, the modern age of architects has emerged who are intimately conversant with the essence of design parameters and how digital computation and design may be utilized using parametrically variable inputs to build more complex projects. (A. Heidari, S. Sahebzadeh, M. Sadeghfar, B. Erfanian Taghvaei, 2018)

The connection between the work of Gaudi (from 1900 to 1914) and the work of Otto Studio in the 1960s and 1970s illustrates that Gaudi and Otto worked with freeform using flexible models. Gravity was used as one of the parameters of nature to mold the form of their creations based on their force. Gaudi, for example, employed hanging models to achieve this on the basis of the idea that bending the architectural volume based on gravity reduces the forces that a building or structure must withstand. To determine the shape with the least surface area and internal stress, Otto used water bubbles to imitate tensile structures. (A. Heidari, S. Sahebzadeh, M. Sadeghfar, B. Erfanian Taghvaei, 2018)

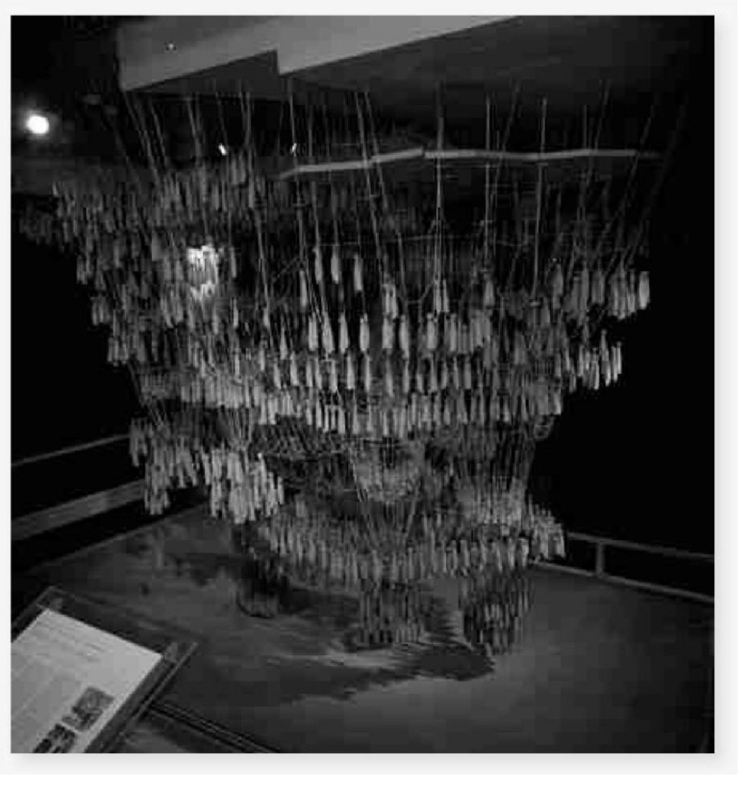

Figure 4: Recsonstruction of Gaudi's Model (Schumacher, 2016)

Apart from the previous reasoning, Schumacher's declaration of the creation of parametricism allowed this way of design to be viewed as more than simply a special remark on a certain access approach to design but as a distinct style. As a consequence of Schumacher's remark, a new generation of architects is now intimately conversant with the nature of design parameters and how digital design and computation using parametrically variable inputs may be utilized to build more complex projects. (A. Heidari, S. Sahebzadeh, M. Sadeghfar, B. Erfanian Taghvaei, 2018)

2.3. Parametric Design, Present

Patrick Janssen discusses how parametric design relies on a parametric model; he comprehended certain parametric modeling approaches, including associative, dataflow, object modeling, and procedural; the main point of differentiation is each technique's capability to repeat the parametric modeling process. The following is his definition of a parametric model:

“An algorithm that generates models consisting of geometry and attributes (e.g. material definitions). This algorithm uses functions and variables, including both dependent and independent variables. Some of the independent variables can be given a more prominent status, as the interface to the model – these are referred to as the parameters of the model”. (PATRICK JANSSEN and RUDI STOUFFS, 2015)

This formulation has the benefit of presenting a clear explanation of how distinct parametric systems might have entirely different principles and allowing for the identification of these principles. Consider a traditional column with a set of design factors that specify and govern the proportion between distinct elements such as the base, capital, and entablature. (A. Heidari, S. Sahebzadeh, M. Sadeghfar, B. Erfanian Taghvaei, 2018)

That is why Patrick Schumacher coined the terms "Parametricism," which refers to artistic intentionality, and "Parametricism 2.0," which refers to the second phase of this style's progression. The purpose of this phase is to address real-world socio-environmental concerns, as envisaged by the inventors of parametric thinking at the outset. (A. Heidari, S. Sahebzadeh, M. Sadeghfar, B. Erfanian Taghvaei, 2018)

Initially, computer-aided design (CAD) technology was too expensive to become widely used in architecture. AutoCAD was developed in 1982, at a time when most people could afford a personal computer. However, it wasn't until AutoCAD 2010 that the parametric feature was incorporated into the application. Pro/ENGINEER, designed by Samuel Geisberg in 1988, was the first commercially successful parametric engineering program. It was a three-dimensional and multi-user software, unlike SketchPad. Dassault Systèmes introduced several aspects of Pro/parametric ENGINEER's functions with CATIA v4 in 1993. These features were employed by Gehry Partners in CATIA for projects such as the Guggenheim Museum in Bilbao in the early 1990s and eventually constituted the foundation for the creation of Gehry

Technology's Digital Project software in 2004. (Reza_Assasi-Paper-ICETAD_2019_ryerson-final-revised)

Architects might utilize parametric software like ArchiCad and Revit as early as 2000. AutoDesk bought Revit in 2002 after being created by Revit Technology Corporation. Building Information Modelling (BIM) was coined by AutoDesk and has become a generic word for any similar software platform used in the building sector. The parametric equations used in Revit were often concealed behind the user interface, leaving designers with little options for defining parameters and equations. On the other hand, the scripting interfaces enabled parametric modeling in the projects. Even the AutoCAD creators in 1982 recognized the importance of the scripting interface. (Reza_Assasi-Paper-ICETAD_2019_ryerson-final-revised)

These accessible interfaces and coding languages gained appeal among designers, especially once certain visual programming packages were available to generate complicated equations and algorithms utilizing CAD or BIM software settings. Architects have also employed various 3D modeling tools not initially created for architecture design, such as 3D Studio Max, Maya, and Rhino, which were all based on parametric equations in the last two decades. Visual parametric programming tools such as Rhino Grasshopper 3D, Maya Embedded Language (MEL), and Max Creation Graph have been developed for these computer applications. Dynamo, a widely-used open-source application that can even include Python scripts to develop new programming functions, has become the visual programming package for Revit users. (Reza_Assasi-Paper-ICETAD_2019_ryerson-final-revised)

2.4. Parametric Modelling

Conventional Design systems or methods are very iterative and straightforward. It allows only add and erase. For example, if pencil, eraser, and paper are being considered for design, The pencil draws and eraser removes. The same concept is being used in the CAD systems but the digital form. The parametric design adds two extra layers. Apart from adding and erasing, the design can relate and repair. The designer has the flexibility to repair and relate in a coordinated way. (Woodbury, 2010)

The introduction of computers and other design tools has transformed the design process from drafting on a drafting table to computer-assisted design on a computer screen. The architectural and construction industries are embracing modern design with radical geometrics. On the other hand, traditional modeling techniques make forming complicated structures difficult and time-consuming. The problem was solved using a computer-assisted parametric modeling method. Parametric modeling is distinguished from other forms of representation by relating and repairing.

Parametric CAD software currently offers powerful three-dimensional interactive interfaces that can execute real-time modifications, giving the designer additional control and fast reaction when a parameter is altered. When the script is executed with varied parameter values, highly developed structures are based on parent-child relationships and hierarchical dependencies. Structures representing the model's historical history are included in computer implementations of parametric models, allowing the designer to return to a prior design stage and make modifications. These modifications will be communicated through a chain of updated parameter dependencies, allowing a designer to go to any level, alter the parameters' values, and reassemble the model. (Barrios Hernandez, 2006)

A parametric model will either proliferate the modifications through the structure and rearrange the geometry to the new values or notify the designer if the changing parameters cause any issues in the result. More advanced parametric modeling software includes knowledge-based systems, which allow the designer to make stronger inferences about the effects of the parametric adjustments he or she makes. Knowledge-based systems with parametric modeling are still in the works, and they rely on a sophisticated computational framework based on artificial intelligence. Still, they might be the next great phase in the next formation of expert CAD systems. (Barrios Hernandez, 2006)

Although architects are not unfamiliar with parametric thinking as a technique of addressing geometric issues, the introduction of advanced parametric CAD tools for architects in the last two decades has turned to produce complicated parametric shapes into a design problem rather than a problem-solving tool. This is known as parametricism. In other words, parametric equations that might be used to approach design to become the design itself, rather than a tool. (Reza_Assasi-Paper-ICETAD_2019_ryerson-final-revised)

Parametricism is a self-referential framework in which the elements are linked via abstract mathematical equations, with real-world variables having minimal (if any) influence. In principle, this phenomenon results from our fixation with mathematical certainty, which has robbed contemporary architecture of lyrical connotations and direct linkages with nature while urgently seeking meaning in its self-referential mathematical formulae. As a result, architectural design has been reduced to a series of formal games that define aesthetics in a formal extravagance enabled by computer algorithms. (Reza_Assasi-Paper-ICETAD_2019_ryerson-final-revised)

2.5. Types of parametric modelling

In general, a parametric model comprises a series of modeling operations that can be topologically classified, indicating that the degree in which the modeling operations are executed can be determined before execution. A generalized parametric model is given and used as a tool to study how different parametric modeling approaches handle iteration over list structures. (PATRICK JANSSEN and RUDI STOUFFS, 2015)

2.5.1. Generalized Parametric Model

A GPM graph is made up of nodes that are linked by directed edges. There are two types of nodes: operation nodes and data nodes. The operation nodes denote both geometric and non-geometric computing activities. The data nodes indicate the geometric, non-geometric, or a combination of geometric and non-geometric input and output data for the operations. The movement of data from and to the operations is represented by edges, which connect operation nodes with data nodes.

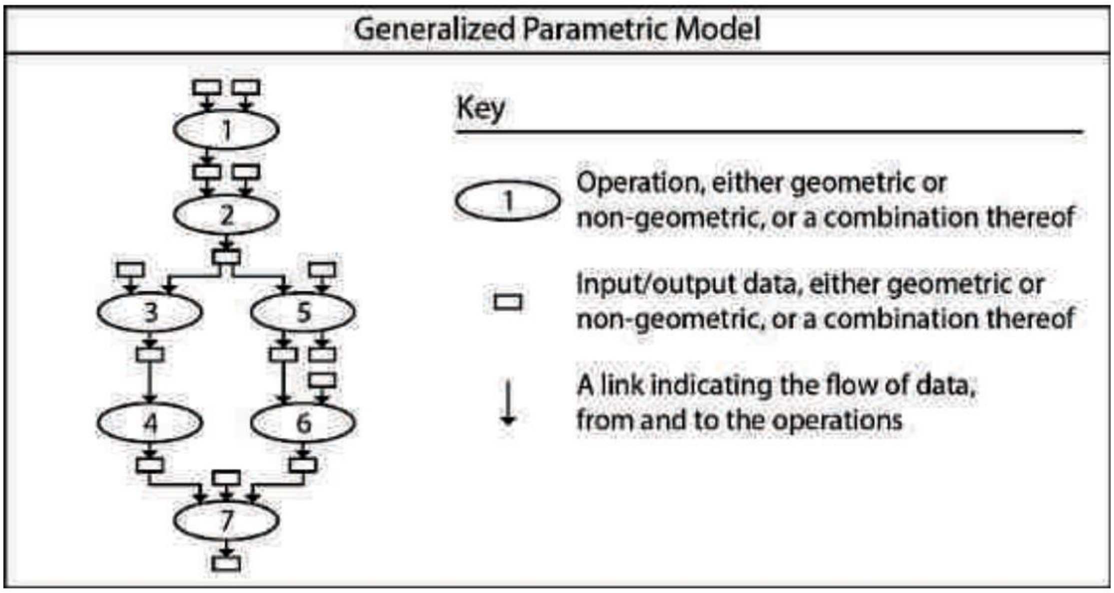

Figure 5: An example of GPM graph (PATRICK JANSSEN and RUDI STOUFFS, 2015)

Operation Nodes

Operation nodes are often executed in an important programming language and can carry out any sophisticated process. The functions that can be executed in the basic modeling engine limit the capability of an operation node. Different modeling approaches, such as spline-based modeling, polygon-based modeling, and solid modeling, may emphasize modeling engines. Advanced solvers that accept details as inputs and utilize repetitive techniques to determine a result are also included as operations in certain systems. Multiple inputs and outputs are possible for each operation node. The inputs may comprise a collection of parameters necessary for the operation, such as a list of polygons, a direction vector, and the extrusion distance for a 'extrude' action. (PATRICK JANSSEN and RUDI STOUFFS, 2015)

Data Nodes

A data node can be both an input and an output for different operations. The representative data structure utilized for data nodes may differ depending on the system. The user might have little influence over the data structure in certain systems, while in others, users may be given actions and tools that allow them to create personalized data structures. Flat lists, nested lists (or multi-dimensional arrays), and topological data structures (such as hierarchical data (tree) structures) are three often-used data structures. (PATRICK JANSSEN and RUDI STOUFFS, 2015)

Edges

The flow of data is represented by edges, which attach operation nodes to data nodes and vice versa. The data sets consumed by an operation are represented by the (directed) edges entering into it; the data set created by an operation is represented by the edge coming out of it. A data cloning procedure is represented as a data node consisting of more than one edge exiting it; the relevant inputs will be perfect copies of one other. (PATRICK JANSSEN and RUDI STOUFFS, 2015)

Execution

The execution of a GPM graph is assumed to be synchronous (E. A. Lee, D. G. Messerschmitt, 1987), with the order of execution determined by running the graph via a topological sort algorithm. There are several correct orderings for every collection of nodes, and the numbering of the operation nodes identifies one of them. The output data sets are replicated each time the graph is run. Changing the input data causes the graph to be re-executed, resulting in fresh output data. Only operation nodes downstream of the altered data will be re-executed in most systems. (PATRICK JANSSEN and RUDI STOUFFS, 2015)

Iteration

Loops cannot be defined in the GPM graph due to their acyclic nature. It does not mean the iteration can not be done. There are three types of iteration specified are single-operation iteration, implicit multi-operation iteration, and explicit multi-operation iteration. (PATRICK JANSSEN and RUDI STOUFFS, 2015)

An iteration that performs the same operation to numerous geometric elements simultaneously is the simplest sort of iteration. If the input to a 'extrude' operation is a list of polygons, for example, the node may traverse through the list, extruding each polygon in turn. If the operation requires more arguments, they will have the same input value. Single-operation iteration is the name for this sort of iteration. (PATRICK JANSSEN and RUDI STOUFFS, 2015)

If extra parameters have multiple input values, the iteration gets more complicated. If the extrusion distances are also supplied as a list, for example, the process may traverse both lists, doing more complicated data matching. Implicit multi-operation iteration is the name given to this sort of iteration. In general, it permits the usage of bespoke data structures made up of nested lists and data matching algorithms that understand these nested lists correctly. To accomplish the required iterative behavior, the user must verify that the data is formatted properly. (PATRICK JANSSEN and RUDI STOUFFS, 2015)

Explicit multi-operation iteration illustrates the iterative process with extra nodes with specific semantics that change the control flow. This is done in contemporary modeling systems in two ways: data sinks or recursion. Two nodes with particular semantics are required for data sinks: A 'for each' operation node loops over a list, extracting one data item at a time; a 'sink' data node gathers the results of one or more operations applied to each data item. The 'for each node will activate the sink node after all items in the list have been processed, allowing downstream operation nodes to be executed. This method also allows for the nesting of 'for each' nodes. (PATRICK JANSSEN and RUDI STOUFFS, 2015)

Only one node with particular semantics is required for explicit multi-operation iteration using recursion: the 'this' node, which represents the current subgraph. When data is entered into the 'this' node, it is the same as re-running the subgraph with fresh data. Using the split operator, a recursive iterator divides an input list into a head and a tail. The head is made up of a single data item that is subjected to one or more processes. The tail is a list of remaining data items that are entered into the 'this' node. Finally, the output of the various operations is appended to the result of the 'this' node. It's worth noting that dealing with the circumstance when the tail is an empty list necessitates a 'switch' operation. (PATRICK JANSSEN and RUDI STOUFFS, 2015)

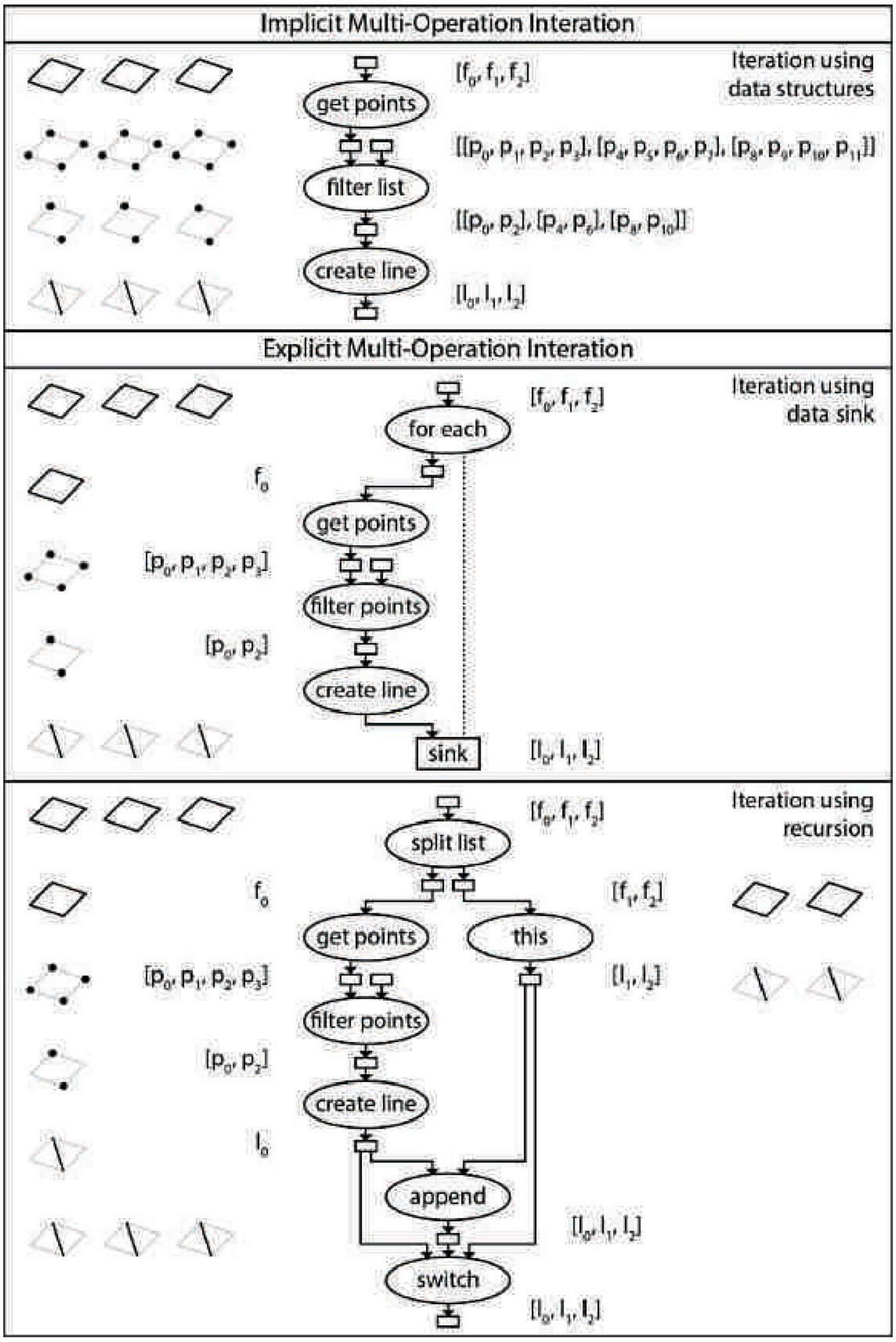

Figure 6: Three different approaches for multi-opration iteration (PATRICK JANSSEN and RUDI STOUFFS, 2015)

Classification of parametric modelling methods

The taxonomy separates parametric modeling into four major categories: 'object modeling,' 'associative modeling,' 'dataflow modeling,' and 'procedural modeling.' The way these modeling approaches facilitate iteration is what sets them apart. Iteration is not supported by object modeling, and the graph is only specified implicitly. Single-operation iteration is supported by associative modeling, implicit multi-operation iteration is supported by dataflow modeling, and explicit multi-operation iteration is supported by procedural modeling. (PATRICK JANSSEN and RUDI STOUFFS, 2015)

Current parametric modeling tools enable these three forms of iteration to vary degrees. The most advanced systems allow the user to directly design and control the dependency graph. Bentley's GenerativeComponents and Rhino Grasshopper are two examples of graph-based systems. These systems use layered list data structures to provide the implicit multi-operation iteration. The data in the nested lists are then iterated over using various data-matching methods. Sidefx Houdini and Autodesk Dynamo are two graph-based systems that offer explicit multi-operation iteration. Both of these systems allow for explicit iteration of several operations. The use of data sinks in Houdini allows for iteration. Dynamo supports recursive iteration. (PATRICK JANSSEN and RUDI STOUFFS, 2015)

The user can edit the dependency graph using various intermediate representations in scene-based and feature-based systems. These systems support Single-operation iteration; however, multi-operation iteration is not. Scene-based systems were primarily created to aid the animation and film industries. Autodesk Maya and Autodesk 3DS Max are two examples. Feature-based systems were primarily created to aid mechanical engineers. Dassault Solidworks, Dassault Catia, and Autodesk Inventor are other examples. (PATRICK JANSSEN and RUDI STOUFFS, 2015)

2.5.2. Scene-Based Systems

Users may construct scenes using items using scene-based systems. Objects are specified through a series of modeling procedures known as modifier stacks' or 'dependency graphs,' among other terms. On the left, you can see an example of a scene-based model, and on the right, you can see the comparable GPM graph. (PATRICK JANSSEN and RUDI STOUFFS, 2015)

When utilizing scene-based systems, the two primary modeling chores are generating individual objects and building the object scene hierarchy. The latter is made up of a hierarchical tree of geometric objects that are moved about in space using transformations like translation, rotation, and scaling. Objects inherit their parents' changes. (PATRICK JANSSEN and RUDI STOUFFS, 2015)

Each item comprises a series of modeling procedures that aren't affected by the scene hierarchy. These modeling operations sequences can also be coupled to one another, forming a dependency network. The order in which objects are created in the dependency network may be different from the order in which they appear in the scene hierarchy. (PATRICK JANSSEN and RUDI STOUFFS, 2015)

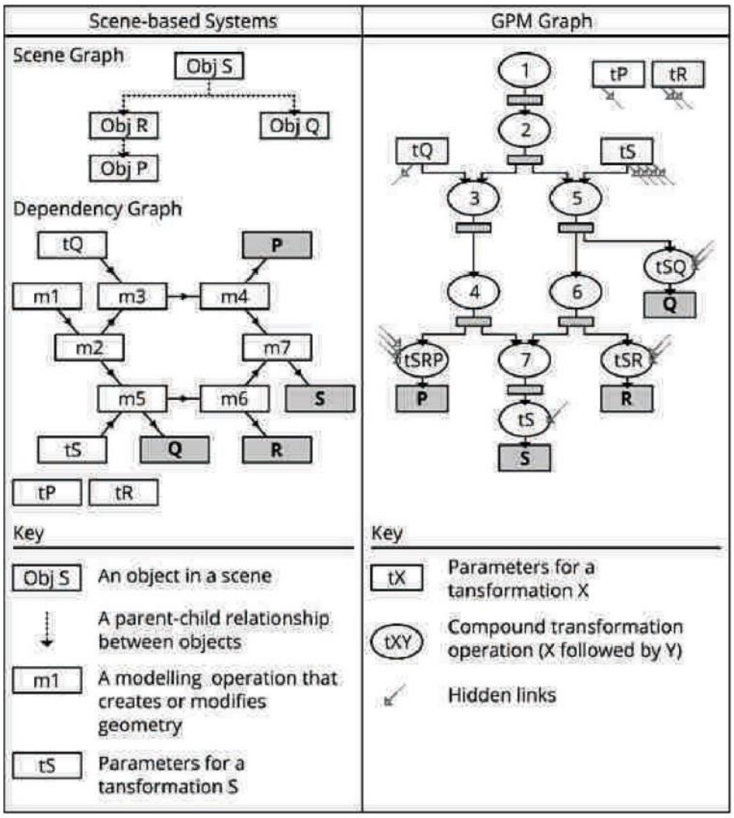

Figure 7: An example model from a scene-based system and the corresponding GPM graph (PATRICK JANSSEN and RUDI STOUFFS, 2015)

2.5.3. Feature-Based Systems

Users can design parametric models made up of component assembly using feature-based methods. Feature trees define the components, with each feature representing a modeling procedure. On the left, an example of a feature-based model is shown, and on the right, the comparable GPM graph. (PATRICK JANSSEN and RUDI STOUFFS, 2015)

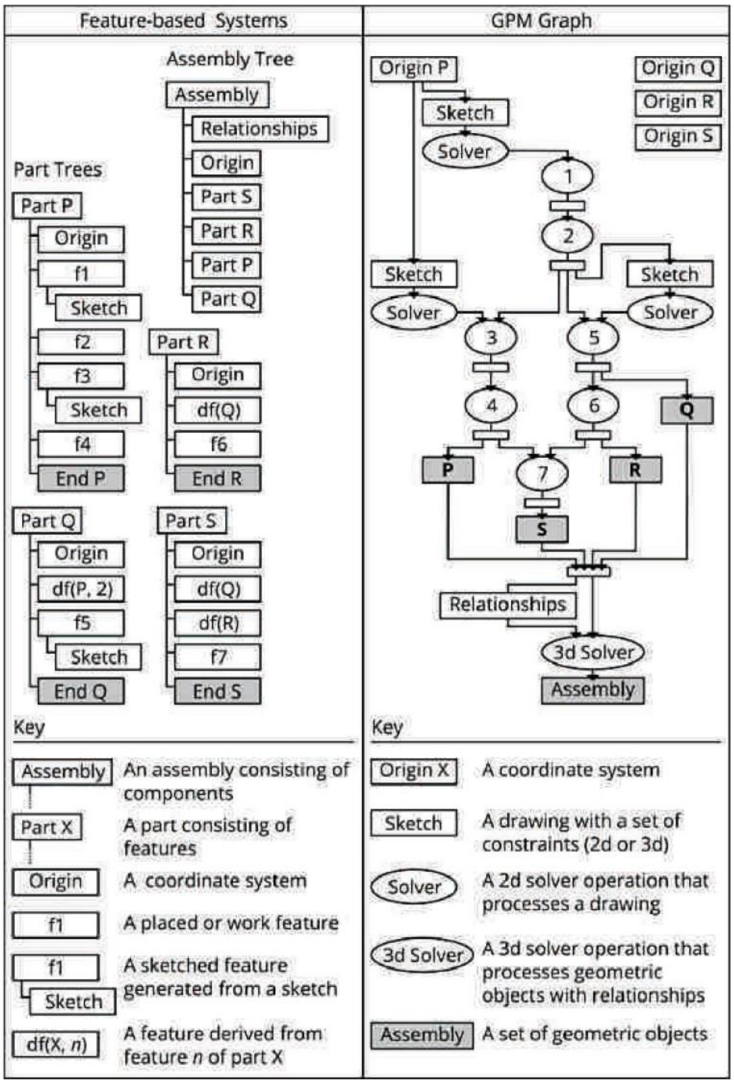

Figure 8: An example model from a feature-based system and the corresponding GPM graph (PATRICK JANSSEN and RUDI STOUFFS, 2015)

When utilizing feature-based systems, the two major tasks are developing individual components and making assemblies of parts. Parts are situated in an assembly by specifying relationships with other parts, defined by constraints and joints. After that, a 3D solver is utilized to look for configurations that meet these relationships. (PATRICK JANSSEN and RUDI STOUFFS, 2015)

A series of modeling techniques, or features, are used to generate each particular part. Sketched features, placed features, and work features are the three most common forms of features. Drawn features are processes that produce geometry from 2D or 3D drawings, which are referred to as "sketches." These drawings are either related to a plane in the geometric model or one of the planes in the origin coordinate system. Requirements can be included in sketches, and a solver changes the drawing to meet the constraints. Operations that change the current geometry in some manner are known as placed features. Work features, on the other hand, are actions that generate construction geometry that is not included in the part's final output. (PATRICK JANSSEN and RUDI STOUFFS, 2015)

'Derived pieces' can also be used to connect parts. A derived part gets parts of its geometry from another component's geometry. This interconnection of pieces allows for the creation of a dependency graph. Feature-based systems, on the other hand, seldom give an explicit representation of this dependency network; instead, the dependency graph must be inferred from the multiple component trees. (PATRICK JANSSEN and RUDI STOUFFS, 2015)

When mapping the assembly tree and part trees into a matching GPM graph, the multiple-part trees must be integrated into a single graph (Figure 4). A data node and solver are added to the graph for each drawn feature. The assembly tree is mapped into a collection of relationships and a 3D solver in the graph. The connections between the geometric objects form a set of constraints and joints. After that, the solver is used to place the items in such a way that all of the relationships are met. (PATRICK JANSSEN and RUDI STOUFFS, 2015)

2.6. Seismic Analysis

2.6.1. Cause of seismic waves: -

Seismic waves are created when elements within the Earth move suddenly, such as when a fault slips during an earthquake. Seismic waves can be caused by volcanic eruptions, explosions, landslides, avalanches, and even flowing rivers. Seismic waves flow through and around the Earth, and seismometers may detect them. (Britannica, 2021)

2.6.2. Types of seismic Waves

There are two types of waves generated by Earthquake, Body waves and Surface waves. These both waves further have two kinds of waves. The body waves consist of Primary and secondry waves (often denoted as P-waves and S-waves), whereas surface waves have Rayleigh and Love waves. (Britannica, 2021)

Primary waves (P-waves)

The main body wave is the first seismic wave to be observed by seismographs, and it may travel through both liquid and solid rock. (IRIS)

Secondry waves (S-waves)

S-Waves are secondary body waves that oscillate the ground perpendicular to the wave's travel direction. They move at 1.7 times the speed of P waves. S waves will not flow through liquids such as water, molten rock, or the Earth's outer core because liquids cannot withstand shear forces. The ground surface is moved vertically and horizontally by S waves. (IRIS)

Reighleigh waves

Rayleigh Waves are elliptical surface waves that produce both a vertical and horizontal component of motion in the wave propagation direction. (IRIS)

Love waves

Surface waves that travel parallel to the Earth's surface and perpendicular to the wave's propagation direction are known as love waves. (IRIS)

2.6.3. Why do we need earthquake analysis?

Stiffness and Strength

To design or analysing the strucutre for earthquake, the structure should possess enough resistance to vertical and lateral stiffness and strength. (Eventure, 2019)

Regularity

This characteristic depicts the movement of a structure when pushed by the lateral forces. Building designers and safety experts want the structure to move evenly to disperse energy without putting too much strain on one side or the other. If a structure is irregular, flaws will become obvious when the structure sways. The vulnerability will be exposed, and the structure will sustain concentrated damage, putting the entire structure at risk. (Eventure, 2019)

Redundancy

Redundancy is one of the most critical safety qualities to consider when designing for safety. It guarantees that numerous procedures are in place if one fails. These can increase the cost of construction, but redundancy proves their worth in a natural calamity, such as an earthquake. So that strength isn't completely based on one aspect, safety experts recommend evenly dispersing mass and strength across the building. (Eventure, 2019)

Foundations

Regardless of the risk of natural disasters, a strong foundation is essential when constructing a huge project. It is essential for a building's long-term survival, and a stronger foundation is required to withstand the intense force of an earthquake. Different places have different foundational qualities, determining how a structure's foundation should be strengthened. Before constructing, professionals must carefully watch how the earth reacts and moves. Deep foundations and driven piles are used in earthquake-resistant structures. The foundations are linked so that they move as a unit to stabilize these severe changes. (Eventure, 2019)

Continuous Load Path

Structural and nonstructural components of a structure must be integrated for inertial forces to dissipate, which ties into the stable foundation feature. Instead of the quake ripping the foundation apart, several places of strength and redundancy share the strain. This is the feature of a continuous load path that safety experts, architects, and engineers must be aware of throughout design. Components will move independently if the building is not thoroughly connected and imminent collapse. The earthquake's trip through the building — both laterally and vertically – is the continuous load path. The passage mustn't be damaged since it won't be able to disperse the intense shudders of an earthquake. (Eventure, 2019)

2.6.4. Earthquake analysis theory

Single degree of freedom(SDF) system

To understand the structural dynamics of simple structures, two kinds of structures have been considered. The considered structures are Pergola (Figure 9) and the elevated water tank (Figure 10). Because of lateral force generated by Earthquake, the vibration of these structures will be analyzed, and try to depict how these structures will behave under the lateral Earthquake force. (Chopra, 2012)

To better understand the seismic analysis, the two simple structures have been considered. These structures are simple because they may be modeled as a concentrated or lumped mass m supported in the lateral direction by a massless structure with stiffness k. This idealization is suited for this pergola, which has a strong concrete roof supported by massless light-steel-pipe columns. The concrete roof is exceedingly strong, and the columns solely give the structure's lateral (or horizontal) motion flexibility. The idealized arrangement is seen in Figure 9, with a pair of columns supporting the concrete roof's tributary length. This system has a lumped mass m and lateral stiffness equal to the sum of the stiffness of individual columns.. (Chopra, 2012)

Figure 9: the pergola at the Macuto-Sheraton Hotel near Caracas, Venezuela (Chopra, 2012)

A similar idealization, shown in Figure 10, is appropriate for the tank when it is full of water. With sloshing of water not possible in a full tank, a lumped mass m supported by a relatively light tower that can be assumed to be massless. The cantilever tower supporting the water tank provides lateral stiffness k to the structure. For the moment, we will assume that the lateral motion of these structures is small in the sense that the supporting structures deform within their linear elastic limit. (Chopra, 2012)

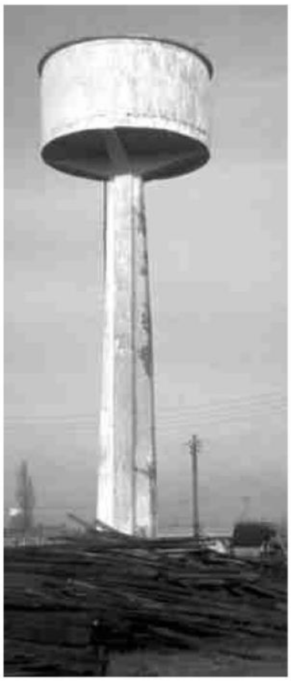

Figure 10: The Reinforces-concrete tank on a 40 feet tal single concrete column. Located near the Valdivia Airport (Chopra, 2012)

The next example can understand the vibration of these structures. Figure 11 depicts the system under consideration. It comprises a mass m concentrated at the roof level, a massless frame that provides system rigidity, and a viscous damper that dissipates the system's vibrational energy. Axial inextensibility of the beam and columns is assumed. This structure can be considered of as a one-story idealization. The inertial (mass), elastic (stiffness or flexibility), and energy dissipation (damping) qualities of the real structure will be contributed by each structural part (beam, column, wall, etc.). (Chopra, 2012)

The number of degrees of freedom (DOFs) for dynamic analysis is the number of independent displacements required to specify the displaced positions of all the masses relative to their original positions. Compared to the DOFs required to indicate inertial qualities, more DOFs are often required to specify a structure's stiffness attributes. Consider the one-story frame shown in Figure 11, which can only move in the excitation direction. To calculate the frame's lateral stiffness, the static analysis problem must be formulated with three DOFs lateral displacement and two joint rotations. If the building is idealized with mass concentrated at one location, often the roof level, the structure has only one DOF lateral displacement for dynamic analysis. (Chopra, 2012)

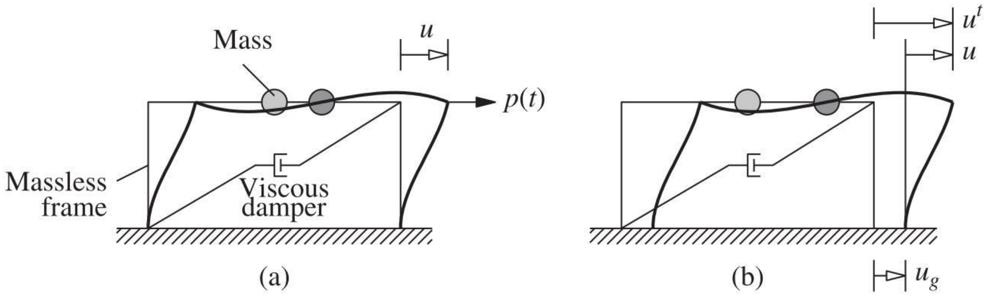

Figure 11: Single degree of freedom system: (a) applied force *p(t)* ; (b) earthquake induced ground motion (Chopra, 2012)

Force displacement Relation

Figure 12 shows a applied static force fs along the DOF u. The internal force u resisting displacement is equivalent to and opposes the external force fs (Figure 12 (b)). The relationship between the force fs and the relative displacement u associated with deformations in the structure during oscillatory motion is wanted to be determined. This force–displacement relationship would be linear at small deformations but nonlinear at higher deformations (Figure 12 (c)); both nonlinear and linear relationships are taken into account (Figure 12 (c&d)). (Chopra, 2012)

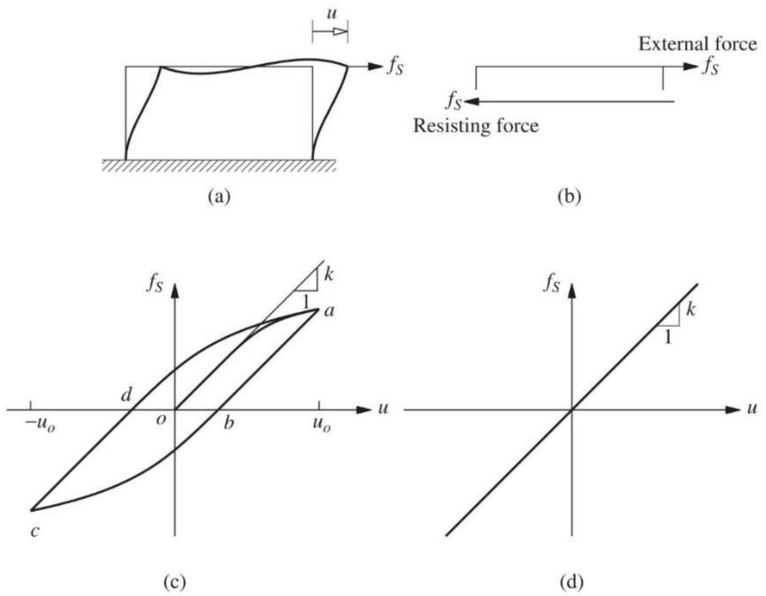

Figure 12: Non linear and linear relationship (Chopra, 2012)

Linear Elastic system

The relationship between the lateral force f_S and the subsequent deformation u is linear for a linear system, that is,

$$f_s = ku \qquad \textbf{2.1}$$

Where k is the system's lateral stiffness and its units are force/length. The assumption implicit in eq. no. 2.1 is that the linear *fs* –u relationship obtained for small structural deformations is also valid for greater deformations. Because of this linear relationship, *fs* is a single-valued function of u. A system like this is considered to be elastic, which is why we use the term linearly elastic system to stress both of these characteristics. (Chopra, 2012)

Inelastic System

The force–deformation relationship for a structural steel component undergoing cyclic deformations expected during earthquakes, as determined by tests, is depicted in Figure 13. At bigger deformation amplitudes, the initial loading curve is nonlinear, and the unloading and reloading curves diverge from the initial loading branch; such a system is considered inelastic. This means the force–deformation relationship is route-dependent, meaning it changes depending on whether the deformation is rising or decreasing. As a result, the resistive force is a function of deformation:(Chopra, 2012)

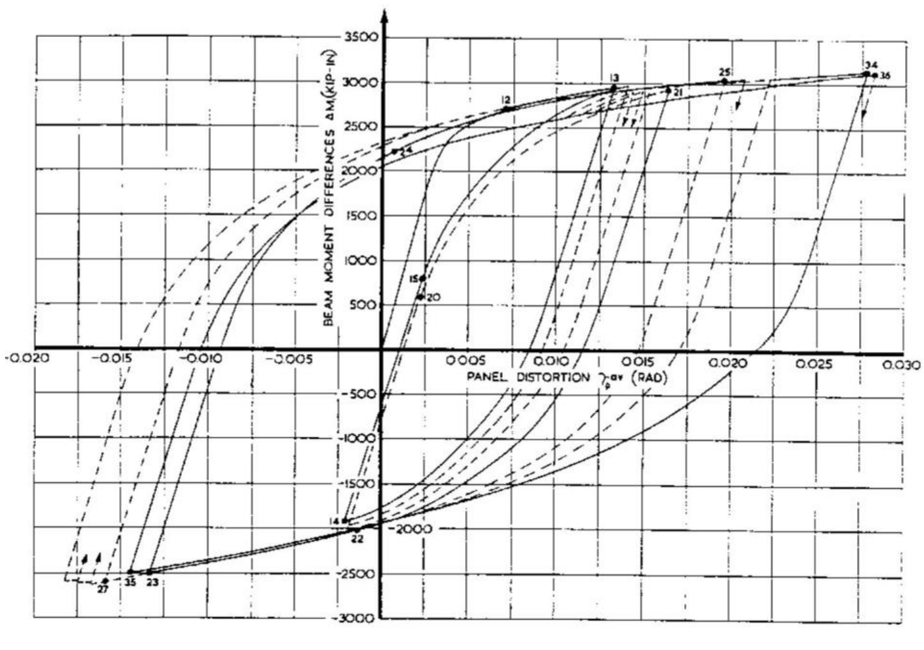

Figure 13: Force-deformation relation for a structural steel component (Chopra, 2012)

One of two methods can be used to establish the force–deformation relationship for the hypothetical one-story frame (Figure 12 (a)) deforming into the inelastic region. One technique is to use nonlinear static structural analysis tools. To get the initial loading curve (o–a) illustrated in Figure 12 (c), an analysis of a steel structure with assumed stress-strain law keeps track of the beginning and spreading of yielding at important sites, as well as the production of plastic hinges. The unloading (a–c) and reloading (c–a) curves can be computed similarly or specified utilizing existing hypotheses from the original loading curve. Another option is to represent the inelastic force–deformation relationship as an idealized representation of the actual data, as shown in Figure 13. (Chopra, 2012)

Multiple degree of freedom (MDF) system

The structural dynamics problem for structures discretized as systems with finite degrees of freedom is formulated in this section. The equations of motion for a simple multi-degree-of-freedom (MDF) system are first established. A two-story shear frame is chosen to easily visualize elastic, damping, and inertia forces. (Chopra, 2012)

The equations of motion for the simplest MDF system, a highly idealized two-story frame subjected to external forces p1(t) and p2(t), are first formulated (Figure 14 (a)). The beams and floor systems are rigid (infinitely stiff) flexure in this idealization. Many aspects are ignored: axial deformation of the beams and columns and the influence of axial force on column stiffness. Although impractical, this shear-frame or shear-building idealization is useful for explaining how the equations of motion for an MDF system are constructed. Later, we expand the formula to more realistic idealized buildings that include beam flexure and joint rotations, as well as structures other than buildings. (Chopra, 2012)

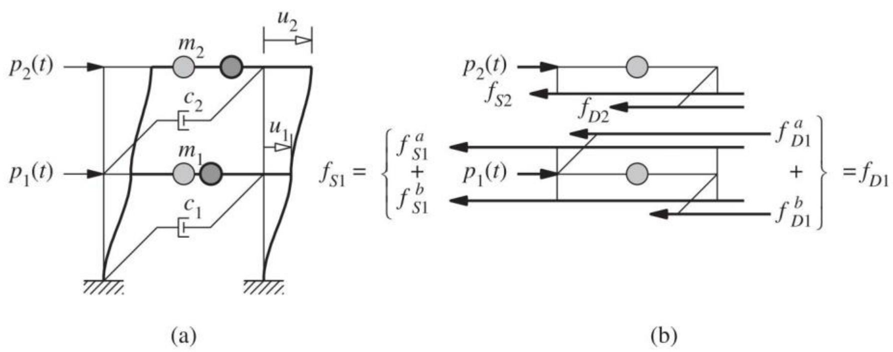

Figure 14: (a) two-storey shear frame; (b) forces acting on the two masses (Chopra, 2012)

2.7. Parametric Modeeling Software tool (Rhino/Grasshopper)

2.7.1. Rhinoceros

Rhinoceros sometimes referred to as Rhino, is a 3D modeling program. It also allows you to develop a model using algorithms and direct modeling. By establishing the parametric relationship between variables, a variety of geometrical forms may be constructed. (Rhinoceros)

Rhino's Grasshopper is a computational design framework. Robert McNeel & Associates were the ones that came up with the idea. It's a tool for algorithmic design. It is built on a visual scripting language, which is a new programming environment. It represents operations using a group of visual nodes rather than individual lines of code. Several visual nodes can be linked to each other to produce a specific instruction. A live connection exists between a Grasshopper script and Rhino. In Rhino, the effect of every script in Grasshopper is immediately visible. It's easy to use and doesn't require a lot of programming or scripting experience. (Rhinoceros)

The capacity of polygon-based 3D modeling software packages to recreate curves smoothly is restricted, but their superior rendering and shading functions can accurately reproduce 3D surfaces. As a result, they're commonly employed in sectors including computer graphics, advertising, animation, and visual effects. However, NUBRS-based 3D modeling software such as Rhino has been most widely used in fields where precision work is required because products are built in reality rather than in a virtual space, such as industrial design (e.g., aircraft and vessels), architectural design, and craft design (e.g., furniture and accessories). (Shi and Yang, 2013)

Rhinoceros 3D (often abbreviated to Rhino) software, which includes the graphic algorithm editor Grasshopper as a plug-in, is not like other text-based techniques. It makes it possible for off-the-shelf compilers to be used as commands. In Grasshopper, modeling is done by arranging "components" that match pre-defined commands (icons, connecting lines, and arrows, for example). Modeling can be intuitively undertaken continuously when "wire" is connected between "components" that act as input and output parameters. Components can be used to input parameter values, which can be readily altered by dragging the mouse pointer. In real-time, details of changes can be seen in Rhino's Viewport. (Hsu et al., 2015)

When using Rhino and the Grasshopper editor, the detail of algorithm changes can be viewed directly in the 3D Rhino interface. As a result, Rhino and Grasshopper are now widely used in various applications, including architectural design and aircraft manufacturing. These programs have only been used for 3D printing design research and accessory design in the apparel industry. (Lee and Song, 2021)

2.7.2. Grasshopper

Coordination System

There are 4 types of coordinate system that grasshopper is providing. As XYZ is the universally accpeted coordiante system. Therefore, for this research the same coordiante system is used. (parametrichouse, 2010)

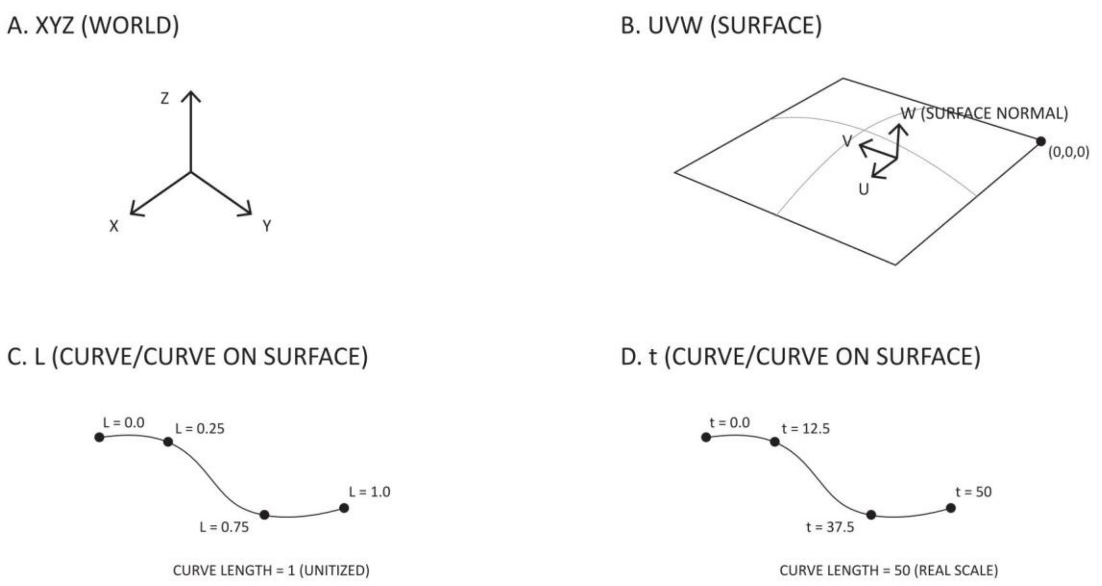

Figure 15: grasshopper coordinate system (parametrichouse, 2010)

Grasshopper Object

Objects in grasshopper generally have five different parts. These five parts are input Tab, Input Option, Body, Output Option, Output Tab. But the certain object has only three parts that can be seen in the figure shown below. (parametrichouse, 2010)

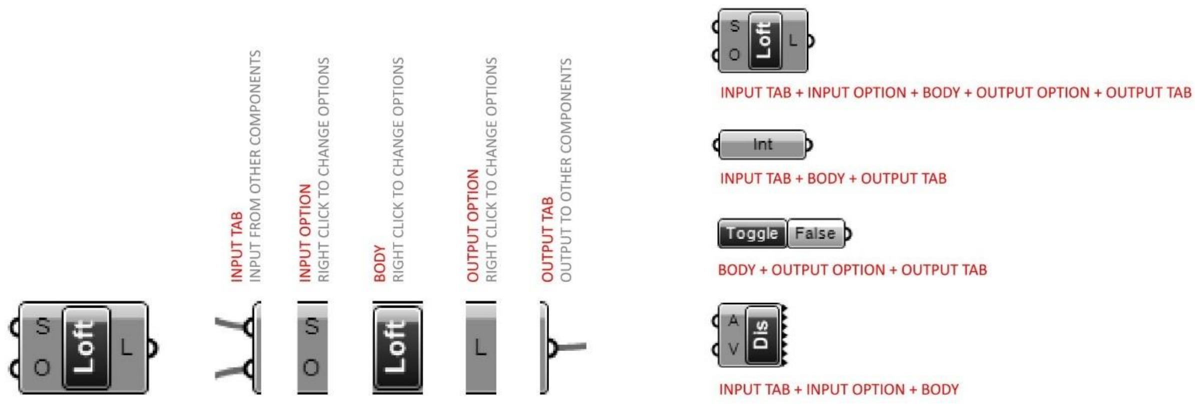

Figure 16: Grasshopper object (parametrichouse, 2010)

The object gets one or more inputs by 'input tab' from the output data of other tabs. Whereas the 'output tab' stores the data that can be passed to other object and act as input data for other objects. (parametrichouse, 2010)

Object Connection

To connect the output tab of an object to the input tab of the other object, a user has to click on the bubble next to the output tab and drag it into the input tab of the other object. The process of connecting the two objects can be shown in the below image. (parametrichouse, 2010)

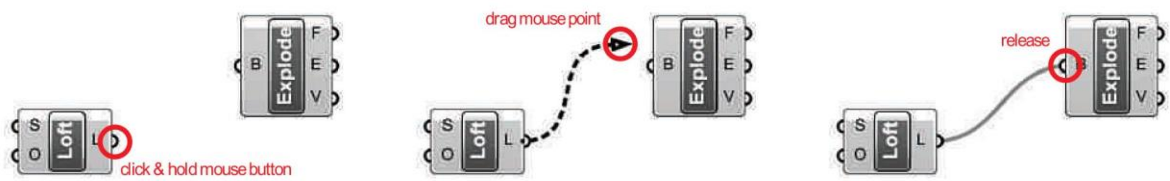

Figure 17: Grasshopper object connection (parametrichouse, 2010)

Object Status

As per the grasshopper, there are different statuses of the object, and it can be seen as per different colors. The different status color shows the different description of the object. The next picture depicts the meaning of all colors of an object. (parametrichouse, 2010)

Figure 18: Grasshopper object status (parametrichouse, 2010)

Parameters Object: -

There are mainly two types of objects in grasshopper; parameters and components. Parameters are generally used to store the data; on the other side, components do certain actions of the parameters. Some parameters can work as bridges between Rhino and grasshopper data. For example, it a curve is drawn in rhino. To assign the rhino curve to the grasshopper curve, Right-click on the curve parameter on the grasshopper select set one curve. Then select the curve in the Rhino interface. The same can be seen in the next picture. (parametrichouse, 2010) The same concept is being used to exture the inner core of building in this research.

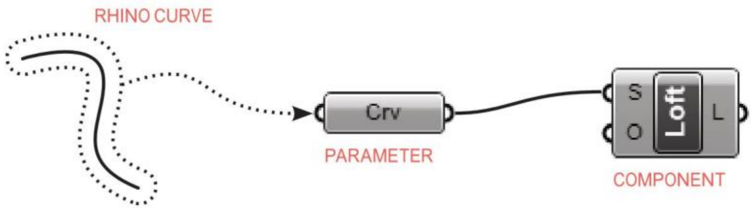

Figure 19: Rhino refrence data (parametrichouse, 2010)

Component Object

Components, unlike parameters, generally perform something with data received from other members or parameters. Data manipulation and geometry construction are the two fundamental tasks that components do. Some components, for example, perform numerical data operations, including addition, subtraction, multiplication, and division. Other components, on the other hand, perform physical tasks such as producing points, curves, and surfaces. (parametrichouse, 2010)

2.7.3. KIWI 3D

Kiwi!3D is a new Grasshopper and Rhinoceros plug-in that uses Isogeometric Analysis (IGA) to integrate structural analysis directly into CAD. IGA is a Finite Element Methods subgroup. Its unique feature is using Non-Uniform Rational B-Splines (NURBS) as basis functions for Finite Elements, which are widely used in CAD for geometry description. As a result, comprehensive CAD model reparametrization (meshing) for analysis is avoided. (Kiwi!3D)

Isogeometric Analysis

Isogeometric analysis is a modern type of computational analysis that uses a unified geometric representation to combine design and analysis into a single model. NURBS (Non-Uniform Rational B-Splines) is the most widely used technology in today's CAD modeling programs and are thus used as analysis' foundation functions. (Josef M. Kiendl, 2011)

2.8. FEM software Tool (SOFiSTiK Structural Desktop (SSD))

The SOFiSTiK Structural Desktop offers you access to all of SOFiSTiK's software. You may use various tools to add and alter materials and sections, construct calculation and design jobs, or view and assess the analytical model inside a single graphical environment. (SOFiSTiK, 2020)

3. Methodology

3.1. Research Overview

Structural engineering is a branch of civil engineering that necessitates a high level of logical ability and analytical thinking. A person must understand a great deal about a member's behavior and the analysis of a specific member. Structural engineering tackles a lot of hard labor and tough tasks daily to get effective results. It also necessitates many repetitive tasks that require a large number of people to execute. If repetitive work can be eliminated to some level, a person's potential and mental powers can be put to better use elsewhere.

The repetitious and rigorous labor can be reduced to some amount with the help of parametric design. Parametric design is an excellent method for gaining flexibility in various geometry parameters. The size of a geometry object can be quickly changed, and the ensuing behavior can be examined without modeling the geometry afresh. This is the flexibility required in structural engineering that may save so much time and effort. Furthermore, the parametric design allows structural engineers and architects to consider other geometric possibilities.

As an earthquake is one of the most powerful forces that a structure must withstand, it must be designed accordingly. Many parts of the world are in earthquake-prone zones. Especially if a building's height exceeds specific standards. As a result, a building's geometry will be taken into account in the earthquake governing zone, and seismic analysis will be performed in accordance with European standards.

3.2. Reason for the reasearch

The main focus of this research is how parametric design can help in the structural engineering field. In many parts of the world, structural engineering did not adapt BIM appropriately. Parametric design is an entirely new story to adapt. As in the parametric design, not only does a new software tool has to be learned, but also an individual should have enough analytical abilities. So that one can develop the relationship between the parameters and geometry they are working on.

To adapt parametric design into structural engineering, there are several reasons for that: -

1. Due to client and cost optimization, the structural engineer has to design/analyze a structure more than once. It takes a lot of energy and effort of a structural engineer to build a model and analyze it again.
2. As many of the industries are adopting automation. But construction field is still far behind in adopting automation. Because of that construction industry faces lots of criticism; for this reason, so does structural engineering. It might have lots of reasons. But one of the main reasons is that people in this industry do not want to adopt new technologies.

P arametric design can not solve these two problems properly. But it can solve the problem to a certain extent. At least it could help people in the industry to adopt new technology. Algorithms made up of boxes and lines (Grasshopper) along with graphical representation (rhino) could be exciting for the people in the industry. So that they can easily witness the changes in real time as they are making some algorithm.

Earthquake is one of the main governing concern around the globe. Lots of places around the globe are earthquake-prone regions, including southern Europe. Because of that reason, a building has to be analyzed for the earthquake before it is being constructed. As mentioned earlier, seismic waves are generated because of earthquakes. Because of these seismic waves, the motion of the ground can be witnessed. The building should be earthquake resistant to control the damage because of these seismic waves. Since the geometry is considered in this research in southern Europe, the geometry would be analyzed as per the EN 1998-1.

As there are lots of software available in the market, that could do seismic in a matter of certain clicks, As that software have design code inbuilt in it. Just take an example of the software tool "Staad pro." It has various kinds of regulations that have been published by many governments/organizations around the globe. A designer/engineer must command the software; the software will calculate the forces and apply certain combinations according to infeed data. But with the implementation of parametric design, an engineer has to indulge himself more for the analysis, and the engineer can witness the behavior of the structure in front of himself.

3.3. Research Method

3.3.1. Design Approach

In conventional structural analysis, geometry is developed by working in software by creating dots and lines in the geometry. But in this research, a new approach has been adapted to analyze the structure. First, the geometry will be developed by defining the parameters and the algorithm. Those algorithms would define the geometry of the building. By modifying those parameters, the geometry can be changed. For example, if the width or length of the building is adjusted, the seismic load on the structure will be modified. Later, parameters will be defined to apply the loads and to define the material with the help of the “Kiwi!3D” plugin inside the rhino/grasshopper. The loads will be defined as per the EN 1998-1. Parameters will be defined for loading as well. So that, if the dimension of the building is changed, the load on the structure will change automatically. That will result in a change in reaction too.

3.3.2. Design Code (EN 1998-1)

There are certain investigations has to be done before analysis or constructing a building on a ground. In the case of an earthquake, the building site and the nature of the supporting ground should be free of dangers of ground rupture, slope instability, and permanent settlements produced by liquefaction or densification. Ground investigations and/or geological studies should be conducted to determine the seismic activity, depending on the structure's importance class and the project's specific conditions. (European Committee for Standardisation, 2004)

Ground Condition

Ground types A, B, C, D, E, S1, and S2 as characterized by the stratigraphic profiles and characteristics given in Table 1 and explained subsequently, should be employed to account for the effect of local ground conditions on seismic activity. This may also be accomplished by factoring in the impact of deep geology on Seismic activity. (European Committee for Standardisation, 2004)

Ground Type	Description of stratigraohic profile
A	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of meters in thickness, characterized by a gradual increase of mechanical properties with depth.
C	Deep deposits of dense or medium dense sand, gravel or stiff clay with thickness from several tens to many hundreds of meters.
D	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.
E	A soil profile consisting of a surface alluvium layer with *Vs* values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with Vs > 800 m/s.
S1	Deposits consisting, or containing a layer at least 10n thick, of soft clays/silts with a high plasticity index (PI> 40) and high-water content
S2	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A - E or S1

Table 1: Ground types (Catherine De Wolf, 2014; European Committee for Standardisation, 2004)

Base Shear Force

“Base shear is an estimate of the maximum expected lateral force on the base of the structure due to seismic activity. It is calculated using the seismic zone, soil material, and building code lateral force equations." (Mohiuddin Ali Khan, 2013; Ritu T Raj, Dr. S Vijaya, Dr. B Shivakumara Swamy, Mary Bhagya Jyothi. J, 2020)

As per Eurocode 8 EN 1998-1 (European Committee for Standardisation, 2004), The base shear force for horizontal direction F_b can be determined by the following expression: -

$$F_b = S_d(T) .m. \lambda \qquad \textbf{3.1}$$

where

$S_d(T)$ = is the ordinate of the design spectrum at period T_1

T = is the fundamental period of vibration of the building for lateral motion in the direction considered;

m = is the total mass of the building, above the foundation or above the top of a rigid basement,

λ = is the correction factor, the value of which is equal to: λ = 0,85 if *Tl* 2 *Tc* and the building has more than two stories, or λ = 1,0.

Design spectrum for elastic analysis ($S_d(T_1)$)

The design spectrum for the horizontal components of seismic action must be defined by the following formulas.

$$0 \leq T \leq T_B : S_d(T) = a_g.S.[\frac{2}{3} + \frac{T}{T_b}.\left(\frac{2.5}{q} - \frac{2}{3}\right)] \quad \textbf{3.2}$$

$$T_b \leq T \leq T_c : S_d(T) = a_g .S.\frac{2.5}{q} \quad \textbf{3.3}$$

$$T_C \leq T \leq T_D : S_d(T) = \{a_g .S.\frac{2.5}{q}.[\frac{T_C}{T}] \quad \textbf{3.4}$$

$$T_D \leq T : S_d(T) = a_g.S.\frac{2.5}{q}[\frac{T_C T_D}{T^2}] \quad \textbf{3.5}$$

a_g = is the design ground accleration on type A ground

S = is the soil factor

T = is the vibration period of a linear single degree of freedom system

T_B = is the lower limit of the period of the constant spectral acceleration branch

T_C = is the upper limit of the period of the constant spectral acceleration branch

T_D = is the value defining the beginning of the cnstant displacresponse range of the spectrum

$S_d(T)$ = is the design spectrum

q = is the behavior factor

As per Eurocode EN 1998-1 (European Committee for Standardisation, 2004), there are two types of elastic response spectrum, Type 1 and Type 2. If the earthquake magnitude is less then 5.5, type 2 spectrum is suggested. The value of S, T_B, T_C, and T_D are mentioned in the table below: -

Ground Type	S	T_B	T_C	T_D
A	1,0	0,15	0,4	2,0
B	1,2	0,15	0,5	2,0
C	1,15	0,20	0,6	2,0
D	1,35	0,20	0,8	2,0
E	1,4	0,15	0,5	2,0

Table 2: Values of the parameters for the Type 1 design spectrum (European Committee for Standardisation, 2004)

Ground Type	S	T_B	T_C	T_D
A	1,0	0,05	0,25	1,2
B	1,35	0,05	0,25	1,2
C	1,5	0,10	0,25	1,2
D	1,8	0,10	0,30	1,2
E	1,6	0,05	0,25	1,2

Table 3: Values of the parameters for the Type 2 design spectrum (European Committee for Standardisation, 2004)

Fundamental Period of vibration (T)

As per Eurocode EN 1998-1 (European Committee for Standardisation, 2004), The following equation can be used to approximate the value of t1 for structures up to 40 meters tall: -

$T = C_t \cdot H^{3/4}$ **3.6**

where

C_t = 0.085 for moment resistant space steel frames

= 0,075 for momoent resistant space concrete frames and for eccentrically braced steel frames

= 0.050 for all other structure

H = is the height of the buildings(in meters), from foundation

Design Ground Acceleration (a_g): -

As per Eurocode EN 1998-1 (European Committee for Standardisation, 2004), the design ground acceleration can be calculated as: -

$a_g = \gamma_1 . a_{gR}$ **3.7**

γ_1 = is the importance factor of the building

a_{gR} = Reference peak ground acceleration

Peak ground acceleration usually refers to the maximum acceleration that occurred during the Earthquake at the particular location. (Chen Houqun, Wu Shengxin, Dang Faning, 2016)

As the building in this research is just the ordinary building, therefore as per Eurocode 8 caluse 4.2.5 the value of γ_1 is considered as 1.0.

Behaviour Factor(q): -

As per Eurocode EN 1998-1 (European Committee for Standardisation, 2004), the behavior factor can be calulated as: -

$$\boldsymbol{q = q_0 k_w \geq 1,5}$$ **3.8**

q_0 = is the basic value of behaviour factor

k_w = is the prevailing failure mode in strctural system

As per the same code, the value of q_0 can be taken as the table below: -

Structural Type	DCM	DCH
Frame system, dual system, coupled wall system	3,0 α_u / α_1	4,5 α_u / α_1
Uncoupled wall system	3,0	4,0 α_u / α_1
Torsionally flexible system	2,0	3,0
Inverted pendulum system	1,5	2,0

Table 4: Basic Value of behavior Factor q_0 (European Committee for Standardisation, 2004)

α_1 = is the value by which the horizontal seismic design action is multiplied in order to first reach the flexural resistance in any member in the structure, while all other design actions remain constant

α_u = is the value by which the horizontal seismic design action is multiplied, in order to form plastic hinges in a number of sections sufficient for the development of overall structural instability, while all other design actions remain constant. The factor α_u may be obtained from a nonlinear static (pushover) global analysis.

For framed structure, the value of α_u / α_1 are as follows: -

α_u / α_1 = 1,1; for one storey building

α_u / α_1 = 1,2; for multi storey building, one bay frame

α_u / α_1 = 1,3; multi storey and muitibay frame

Distribution of horizontal seismic force: -

As mentioned earlier, base shear is total force on the base of the structure. To get better picture of the behaviour for linear and non linear analysis, the force on each storey has to be determined. As per Eurocode 8 EN 1998-1 (European Committee for Standardisation, 2004), The horizontal force on each storey of the building can be calculated as:

$$F_i = F_b \cdot \frac{z_i \, . \, m_i}{\Sigma \, z_j \, . \, m_j} \qquad \textbf{3.9}$$

F_i = is the horizontal force acting on storey i

F_b = is the seismic base shear

z_i, z_j = are the height of the masses m_i , m_j

m_i , m_j = are the siesmic masses

Seismic Mass

As per Eurocode EN 1998-1 (European Committee for Standardisation, 2004), The seismic mass of the building can be calculated as:

$G + \Psi \, . \, Q$

G = total dead load of the structure

Q = Imposed load of the structure

Ψ = Combination coefficient

3.3.3. Design Commands

As mentioned earlier, the rhino software toll will be utilized to prepare the geometry. For the geometry being done parametrically, the grasshopper plugin will be used. For the reader, some basic commands will be shown to get a basic idea about this software tool.

Like any other software tool, this tool also has plenty of commands that are hard to utilize in a particular project, and at the same time, it is not worth mentioning all the commands used in this research. Therefore, only some of the commands utilized in this research will be shown below.

Number slider

This command is used to input a number for the parametric modeling. As in the research, the number is used to define the structure's height, length, and width, number of floors of the structure, etc. As the number is being changed, the respective parameter will change.

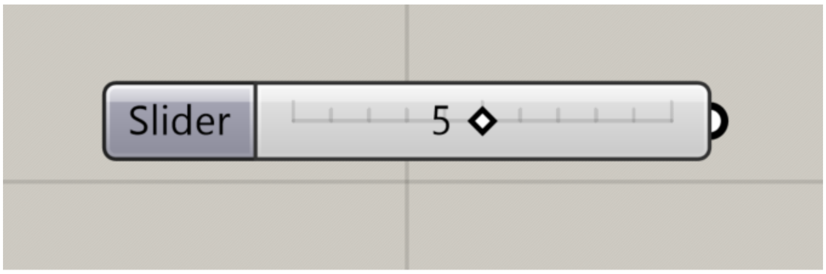

Figure 20: number slider

Square Grid

This command is utilized for the generation of the grid. Before drawing a plan on paper or in a software tool, the grids are mandatory to draw for simplicity and better referencing. It is quite obvious that girds are never square like this in the real world. But the main focus of this research is to utilize seismic analysis with parametric design. Therefore, the geometry being prepared for this research is quite simple. For this reason, the square grid is being considered.

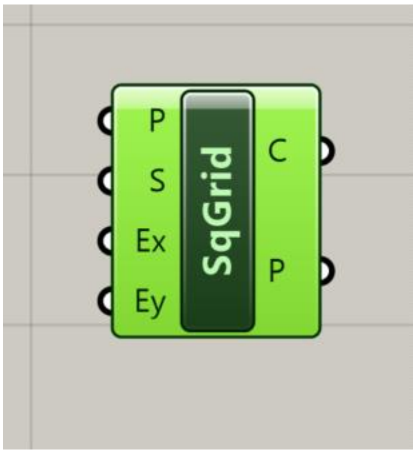

Figure 21: square grid command

Where:- P is the plane of the structure (By default it is XY plane in Grasshopper)

S is the size of the grid

Ex and Ey are the numbers of grids in X and Y direction

C is the outline of the Grid cells

P is the points at grid corners

Series

This command will achieve the number of floors. With the help of this command and with the number slider, the number of floors can be manipulated quickly. This is the purpose of the parametric design so that the designer or engineer doesn't have to prepare geometry if client is adding the additional floorient. It can be done just by modifying the parameter. And that can be achieved by this parameter..

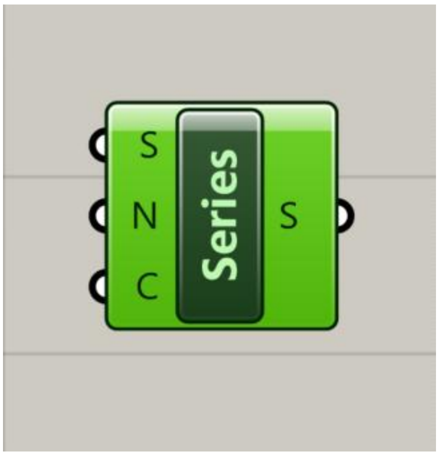

Figure 22: Series Command

Where: - S(on left) first number in the seires (By default it is 0)

N is the size of each segement of the series

C is the value of the series (5 in our case)

S(on right) is the series of number as an output

Move

While making a geometry, at times, an object is required to be moved. This is the command used to move an object.

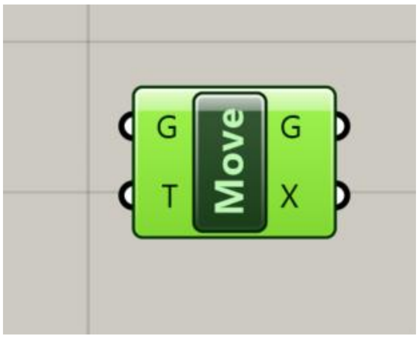

Figure 23: Move Command

Where: - G(on left) is base geometry (the geometry is required to be moved)

T is the direction of the geometry

G(on right) is the translated geometry

X is translated data

Line

This command is used for to make a line between two points.

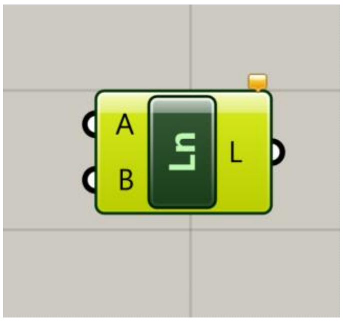

Figure 24: Line Command

Where: - A is the start point of line

B is the end point of line

L is line segment that is generated by this command

Curve

Sometimes in rhino/grasshopper, it is tough to make a geometry parametrically. It can be created parametrically, but it may affect the process later, or it can be said to make the geometry complicated. To solve this issue, the curve command can be used. A boundary can be created in rhino; then, it can be assigned as a curve in grasshopper. After that, a further command can be implemented very easily.

Figure 25: Curve Command

Extrude

This command is used to extrude a curve from its particular position. As mentioned earlier, a core has been created at the center of the structure in this building. That core is created with the help of this command.

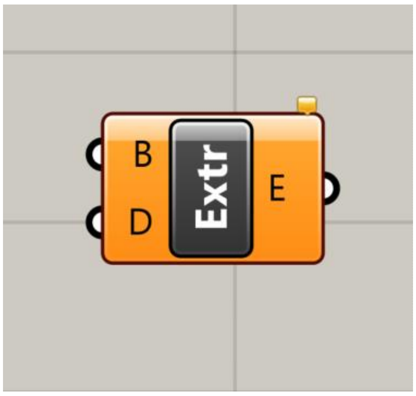

Figure 26: Extrude Command

Where: - B is the curve to be extruded

D is the direction

E is the extruded geometry

3.3.4. Analysis Commands

In this research, the Kiwi!3D plugin inside Grasshopper is utilized for the analysis of the building. There are certain commands that are used for analyzing the structure. These commands are mentioned as below:

Material Defination

This Grasshopper Object is used to define material in grasshopper. A parameter object (value list) connects to the input tab to determine the material. Grasshopper has some inbuilt material such as Steel, Wood, concrete, etc. By defining the material in the input tab, the other properties of that material are defined by the grasshopper automatically as their properties are in the built-in grasshopper.

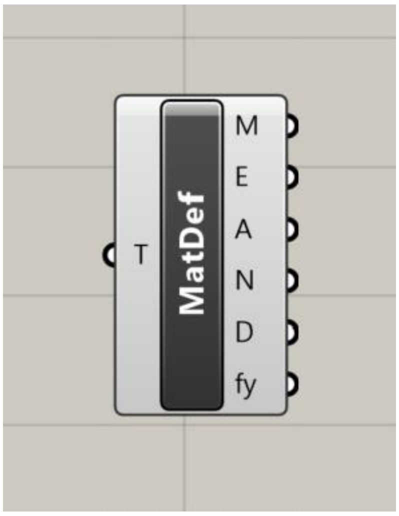

Figure 27: Material Defination Command

Where: - T is the Type of Material

M is the Output Material

E is the Youngs Modulus

A is the temprature coefficient

N is Poissons's Ratio of the Material

D is the Density of the Material

fy is strength of the material

Support

To define the support, this support object can be utilized. This object provides flexibility to restrain the support in any direction and for rotation and Twist. The user has to set the Boolean as True to restrain the support in a particular direction.

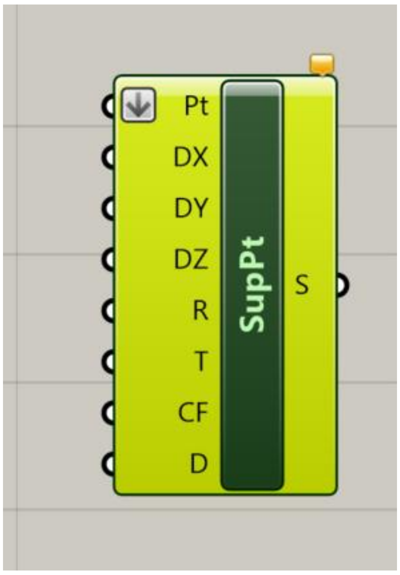

Figure 28: Support Command

Where: - Pt is the points where supportts are required

DX is Constraint in global X

DY is Constraint in global Y

DZ is Constraint in global Z

R is Constraint in Rotation

T is Constraint in Twist

CF is the coupling Feature

D is Constraint in defined direction

Curve load

To define the load on a line/curve in Grasshopper, this object is required.

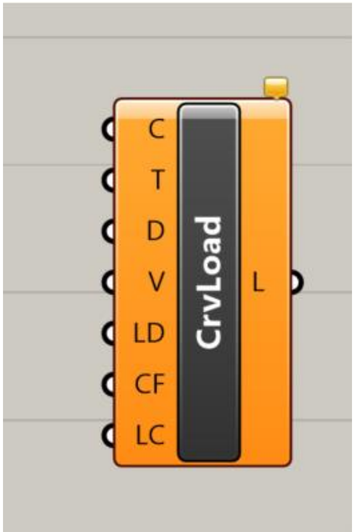

Figure 29: Curve Load Command

Where: - C is for curve, on which the load needs to be applied

T Type of load curve

D is the direction of Load

V is the Value of load

LD is Load displacement curve

T is Constraint in Twist

CF is the coupling Feature

LC is Load case for linear Combination

Beam

This Beam object in the grasshopper provides much flexibility to define the beam. By defining this object, a shaft with varying sections can be determined. Apart from that, prestressed and hinges in the beam can be defined by this object.

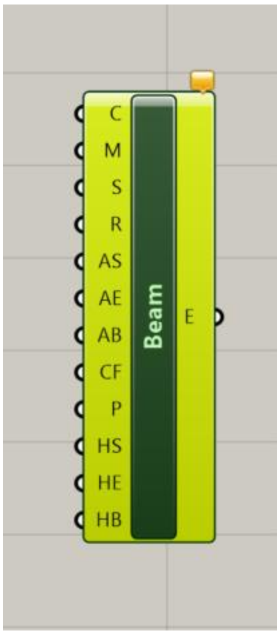

Figure 30: Beam Command

Where: - C is for curve, on which the beam is to assign

M is Material

S is the Section of the Beam

R is Refinement of Curve

AS is Axis of Cross Section at start

AE is Axis of Cross Section at End

AB is Axis of Cross Section in between

CF is Coupling Feature

P is to defined Prestressed Beam

HS is Hinge at Start of Beam

HE is Hinge at End of Beam

HB is Hinge at Coupling

Analysis Model

This primary component object takes data from other objects mentioned above to run the analysis. This Object assemble the Isogeometric Analysis Model and give the output to the solver object to do the further analysis of the building.

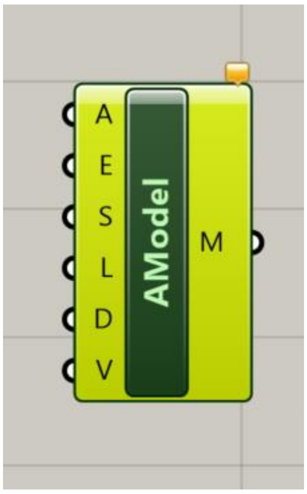

Figure 31: analysis Model Command

Where: - A is the Type of Analysis

E is the Elements of the Structure

S is Supports of Model

L is Loading

D is Displacement Loads

V is Visualizer Options

Solver

This is the last object before running the Analysis. As the name tells, it solves/analyzes the entire model for the given load condition. This object gets the input from the Analysis model into the M symbol in Figure 32. The button object input can start the Analysis into the R symbol in Figure 32.

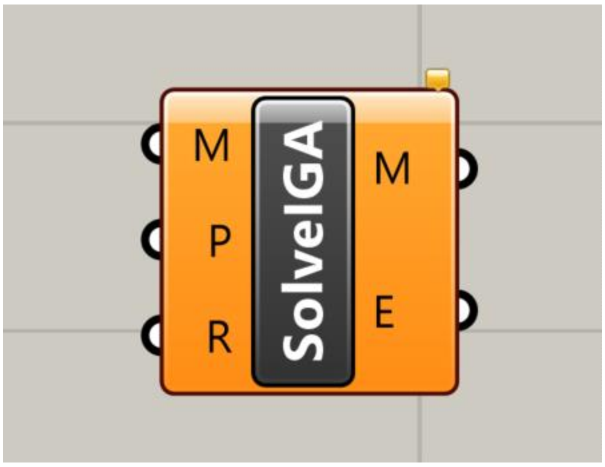

Figure 32: Slover Command

3.3.5. Work Flow

To get the conclusion in the research, several steps will be followed. As in this research, the seismic analysis is the main highlight. Therefore, the European standard for seismic analysis (EN 1998-1) will be studied first, followed by learning Parametric design tool Rhino/Grasshopper. EN 1998-1 standard is considered because the location of the building in this research is considered in Italy as Italy is one of a country that faces lots of earthquakes and comes under critical seismic zones. The detailed work for this research is as mentioned below: -

1. A seismic calculation will be done as per EN 1998-1. In this, all the values required for seismic calculations will be determined, and some values, such as peak ground acceleration will be referred to from the respective standard.
2. The script/algorithm will be created in Grasshopper with the help of objects and lines. This script will give a model in the Rhino interface. This model will be created in such a way that only by changing the parameters in Grasshopper the respectively connected parameters will change in the Rhino interface.
3. The Kiwi!3D plugin will be utilized for the analysis. The different analyses will be added to the design model so that the model can analyzed without any error.
4. The reaction will be determined by the script and model prepared in Rhino/Grasshopper.

5. The same geometry will be modeled in the software SOFiSTiK SSD to verify the result. The same seismic force will be applied in this model, and the reaction will be determined.
6. After determining the result from both the Software tool, a comparison will be done.

3.4. Evaluation of Method

As mentioned earlier, the geometry will be generated in Rhino/Grasshopper, and the analysis will be done according to Kwi!3D. This plugin is rarely is being used for structural analysis of the building, as there are plenty of options available in the market. Therefore the seismic analysis will be done according to this software and plugins in it. The reaction will be determined by the parametric tool Kiwi!3D. To verify the result, the reaction of the geometry with the same features will be modeled in SOFISTiK. After determining the reactions from both software tools, the magnitude and direction of the reaction forces will be compared..

4. Analysis

Based upon the methodology, a building is analyzed with a certain assumption in this section. The building is analyzed for seismic forces in a parametric design tool, rhino/grasshopper. For the cross verification, the seismic analysis is done via SOFiSTiK SSD. Results of both tools will be compared at the later part of this section.

For the analysis of building, there are certain assumption have been made simplicity and to understand the concept properly: -

1. Size of structure is 15m x 15m, with the column spacing of 5 m in each side.
2. Structure is considered as concrete structure.
3. Size of column is considered as 200mmx200mm.
4. Size of beam is considered as 200mmx200mm.
5. The depth of slab is considered as 150mm.
6. Number of floors are considered as 5.
7. Structure is considered as moment resisting framed structure.
8. Structure will be subjected to Linear Analysis.
9. The location of the building is considered in Italy, and in the seismic zone 1.
10. The load is applied only in the one direction of the building. (Horizontal y direction in this case)

Based on the assumption mentioned above, the script is created in grasshopper; the script is created with commands mentioned in paragraph 3.3.3. the script for the modeling is shown the Figure 33.

As the script proceeds, the same can be seen on the interface of the rhino. If any parameters are modified, the same can be seen in the rhino interface. The resulted geometry can be shown in Figure 34. The lines are considered as columns. The flat red is the slabs

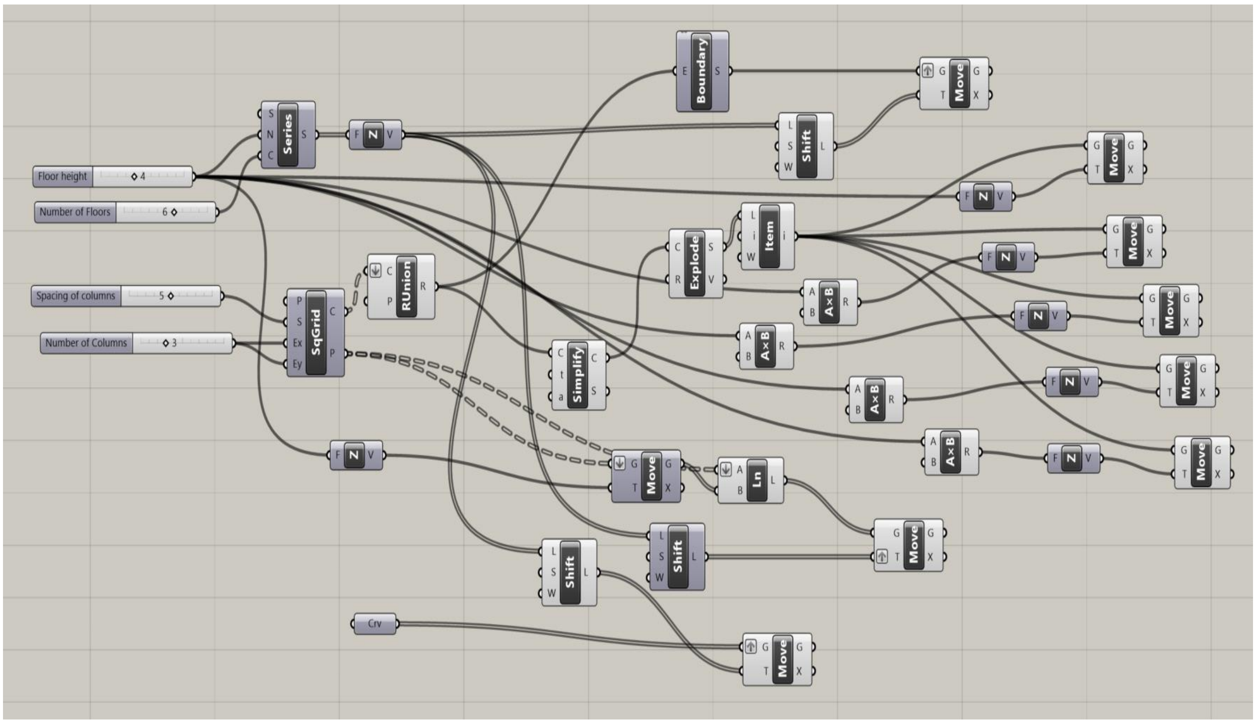

Figure 33: Script of model

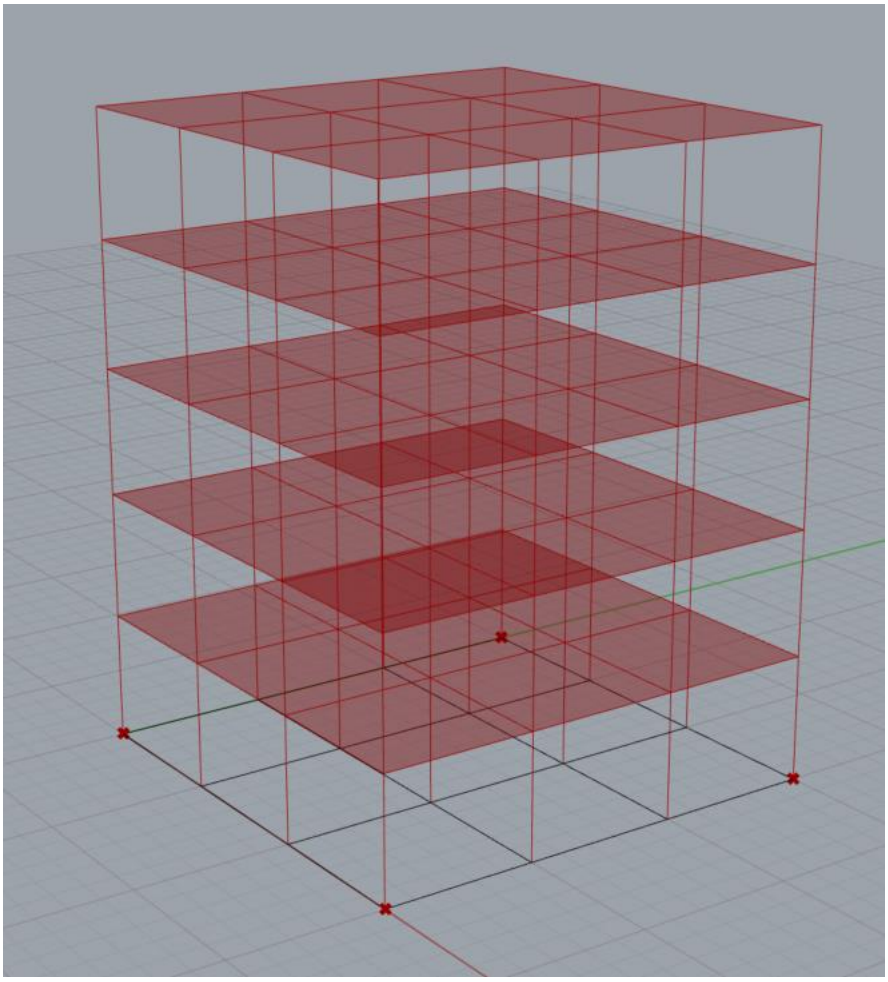

Figure 34: Final Geometry

4.1. Seismic Mass of the Structure

After the preparation of geometry, the applied load has to be calculated. In practice, there are several kinds of loads in a structure, such as dead load, imposed load, wind load, etc. In this research, the main focus is to do a seismic analysis of a building. The horizontal seismic forces are calculated. Dead load and imposed loads are considered for seismic calculation only.

Dead Load of the building

Level		specific weight		Total weight	
5th	slab	25	843.75		
	floor finish	10	22.5		
	Tiles at roof	20	90	956.25	KN
4th	slab	25	843.75		
	floor finish	10	22.5	866.25	KN
3rd	slab	25	843.75		
	floor finish	10	22.5	866.25	KN
2nd	slab	25	843.75		
	floor finish	10	22.5	866.25	KN
1st	slab	25	843.75		
	floor finish	10	22.5	866.25	KN

Table 5: Deal Load Calculation of building

Imposed load of the structure

Level	per sqaure meter load		
5th	2	450	KN
4th	2	450	KN
3rd	2	450	KN
2nd	2	450	KN
1st	2	450	KN

Table 6: Imposed load calculation of building

Seismic mass of the structure

Level	G	Q	Ψ	G+ΨQ	Mass (Tonne)
5th	956.25	450	0.3	1091.25	111.2765
4th	866.25	450	0.3	1001.25	102.0991
3rd	866.25	450	0.3	1001.25	102.0991
2nd	866.25	450	0.3	1001.25	102.0991
1st	866.25	450	0.3	1001.25	102.0991

Table 7: Seismic mass calculation of building

4.2. Time Period(T)

The eq. no. 3.6 can calculate the Natural period of the building. The height (H) of the building is 20m. The value of C_t is 0.075 as this structure is moment resisting concrete structure. By putting these values in eq. no. 3.6, the value in the above formula, the value of T is **0.709306 s**.

H = 20m

$C_t = 0.075$

T = 0.709306 s

4.3. Design Ground Accleration (a_g)

As per the map of Italy, the maximum value of a_{gR} is 0.34g. it means the value of agr is 0.34 x 9.81 = 3.3354 m/s^2. To calculate the value of design ground accleraion, the value can be out in eq no 3.7 and can get the value. By putting the value in eq. No. 3.7, the final value of design ground acceleration will be 3.3354 m/s^2.

$a_{gR} = 0.34g = 0.34 \times 9.81 = 3.3354$ m/s^2

$\gamma_1 = 1$

$a_g = 3.3354$ m/s^2

4.4. Behaviour Factor (q)

The behavior factor can be calculated by the eq. no. 3.8. The value of q_0 is taken from Table 4. The value of α_u / α_1 is 1.3, and it can be taken from eq. no. The value of kw is 1 as per clause. By putting all the values in the eq. no. 3.8. the value of the behaviour factor is 3.9.

$q_0 = 3.0 \times \alpha_u / \alpha_1 = 3 \times 1.3 = 3.9$

$k_w = 1.0$

$q = 3.9$

4.5. Acceleration

As the value of the time period is 0.709306s, therefore the formula used to calculate final acceleration is eq. no. 3.4. By putting all the value calculated before in eq. no. 3.4, the value of acceleration can be calculated. For the convenience of the reader, the calculated value of the respective parameter is mentioned once again

$a_g = 3.3354$ m/s^2

q = 3.9

T = 0.709306 s

The value of soil factor S T_B,T_C, and T_D are taken from the Table 2. For this structure, the ground type C is considered.

S = 1.15

$T_B = 0.2$

$T_C = 0.6$

$T_D = 2$

Design Acceleration S_d (T) = 1.870734 m/s^2

4.6. Base Shear (F_b)

The value of the base shear can be achived by eq. no. 3.1. by putting the values in the mentioned formula the final value of base shear is 1080.858 KN.

Horizontal forces in each floor

	Seismic mass of each floor (m)	Height of floor (z)	m . z	Base shear	horizontal force (KN)	Horizontal force UDL (KN/m)
5th	1091.25	20	21825	1080.858	381.248	25.41654
4th	1001.25	16	16020	1080.858	279.844	18.65627
3rd	1001.25	12	12015	1080.858	209.883	13.9922
2nd	1001.25	8	8010	1080.858	139.922	9.328133
1st	1001.25	4	4005	1080.858	69.961	4.664067
			61875			

Table 8: calculation of loads

After the preparation of geometry, the load will be applied as per Table 8, and support conditions are applied to geometry; analysis commands (mentioned as per paragraph 3.3.4) are added to the script shown in Figure 33. The final script with all the analysis commands can be shown below.

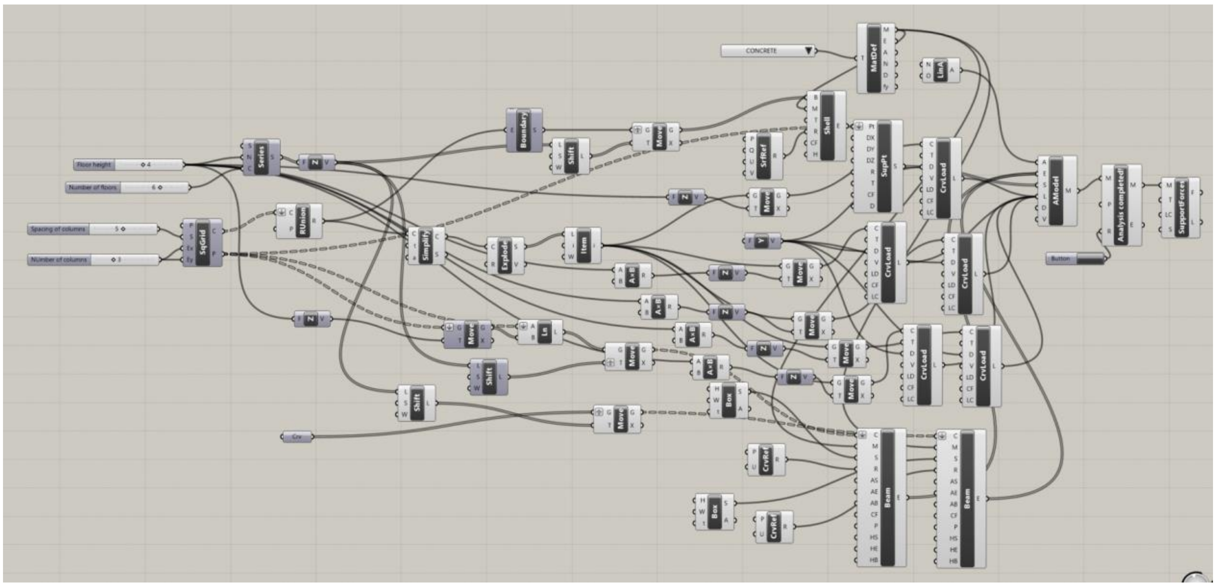

Figure 35: Final Script of the building

As per the script shown in Figure 33, the final geometry, along with loading, support, and section sizes, can be seen in the next figure:: -

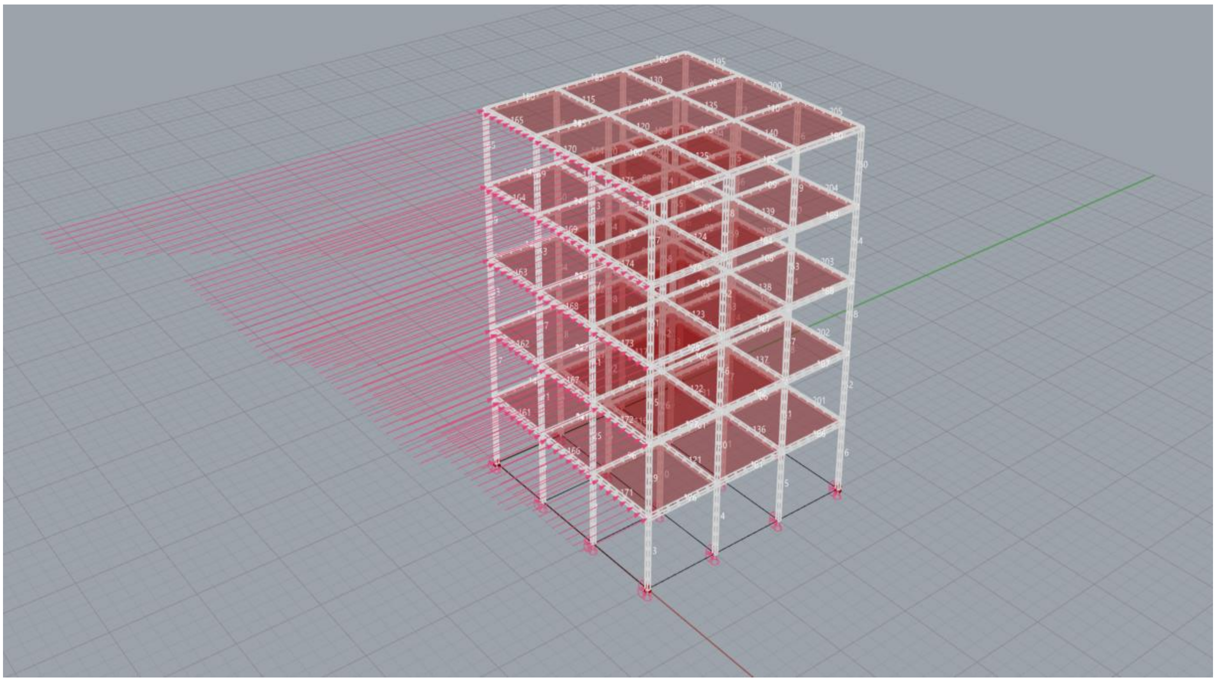

Figure 36: Final model of the building

The support reaction after the analysis of this building can be seen in the following figure.

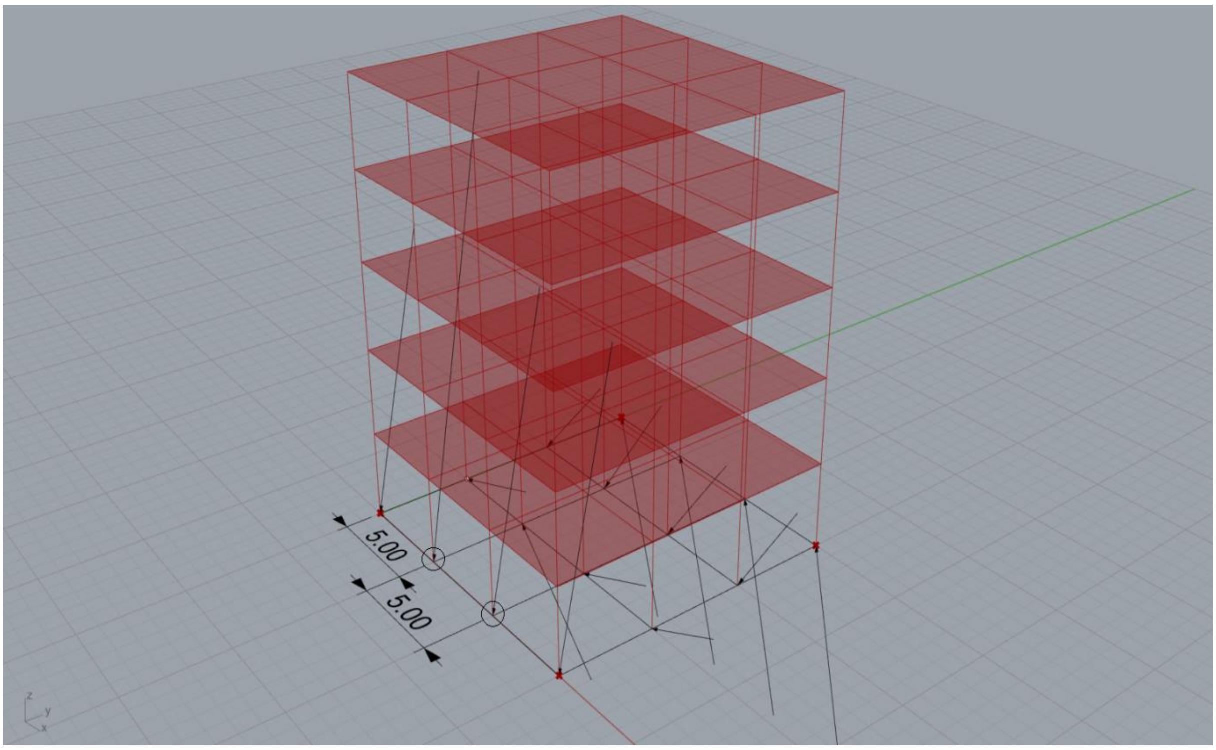

Figure 37: Direction of Support reaction in Rhino/Grasshopper

Coordinate (X,Y,Z)	Reaction in X Direction(KN)	Reaction in Y Direction(KN)	Reaction in Z Direction(KN)	Resultant force (KN)
(0, 0, 0)	-0.55	-57.48	-265.37	271.52
(5, 0, 0)	-0.68	-71.00	-419.45	425.41
(10, 0, 0)	-0.64	-58.97	-275.64	281.87
(15, 0, 0)	-0.53	-57.39	-267.50	273.59
(0, 5, 0)	-0.11	-73.49	40.40	83.86
(5, 5, 0)	-0.17	-83.50	209.59	225.61
(10, 5, 0)	-0.21	-75.44	43.11	86.88
(15, 5, 0)	-0.14	-74.04	42.60	85.42
(0, 10, 0)	0.17	-73.13	-41.19	83.94
(5, 10, 0)	0.22	-75.08	-62.82	97.90
(10, 10, 0)	0.22	-75.09	-43.58	86.82
(15, 10, 0)	0.17	-74.03	-42.98	85.60
(0, 15, 0)	0.50	-56.82	266.16	272.16
(5, 15, 0)	0.63	-59.29	272.68	279.05
(10, 15, 0)	0.63	-58.35	276.11	282.21
(15, 15, 0)	0.49	-57.35	267.88	273.95

Table 9: Reactions from Rhino/Grasshopper

Rhino/Grasshopper gives reactions in the coordinated system as an output. To compare these forces to another software tool (SOFiSTiK in this case), these forces need to convert into resultant force. Because other software tools give resultant force as an output. Only Y and Z direction forces are considered to convert these coordinate forces into resultant force. As the reaction forces in x directions are comparatively much less than other forces. Therefore, their effect on the resultant force has been ignored.

4.7. SOFiSTiK Result

The loading diagram in SOFiSTiK can be seen the Figure 38. The same geometry is modeled in the Software tool SOFiSTiK SSD. All the loadings support conditions and geometry are considered as same as before.

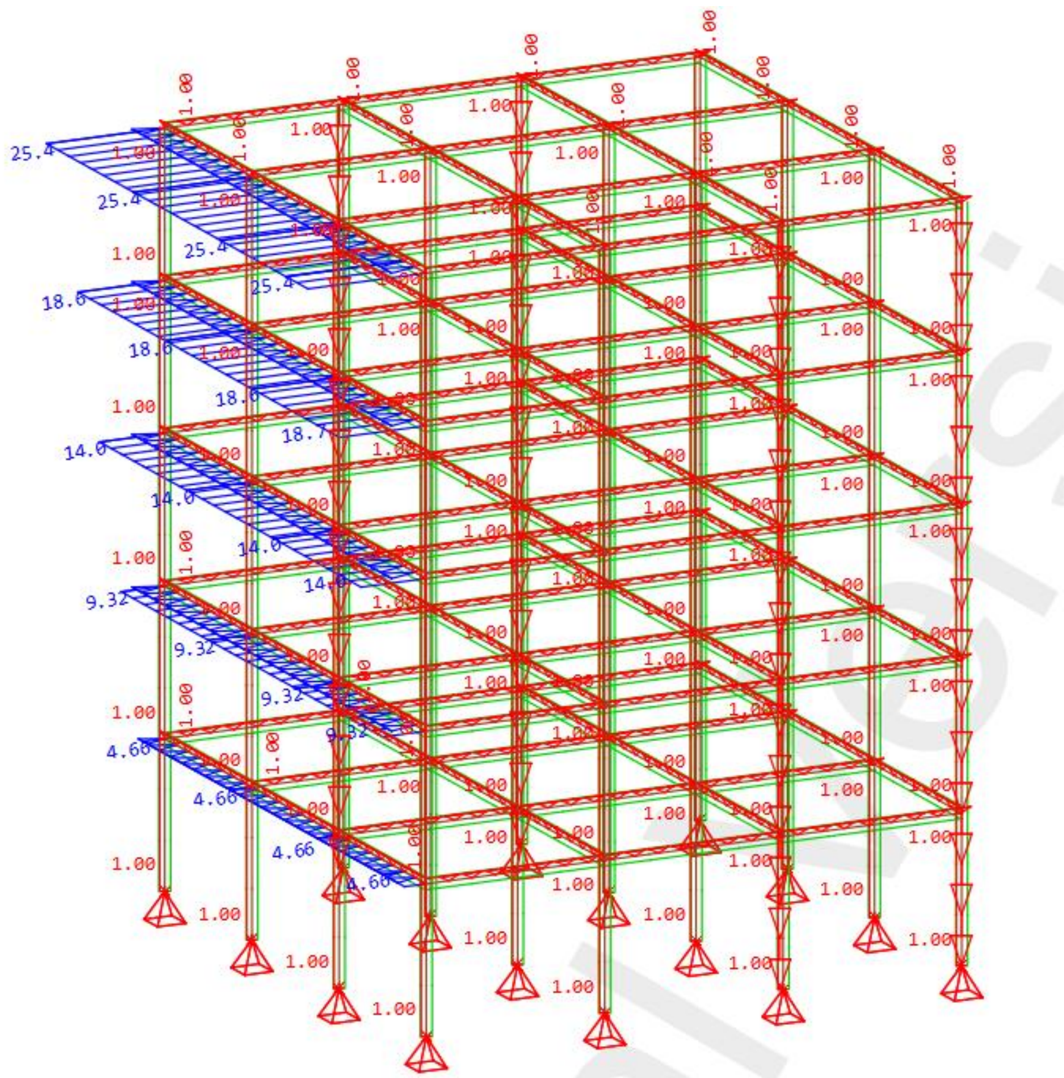

Figure 38: SOFiSTiK Loading Diagram

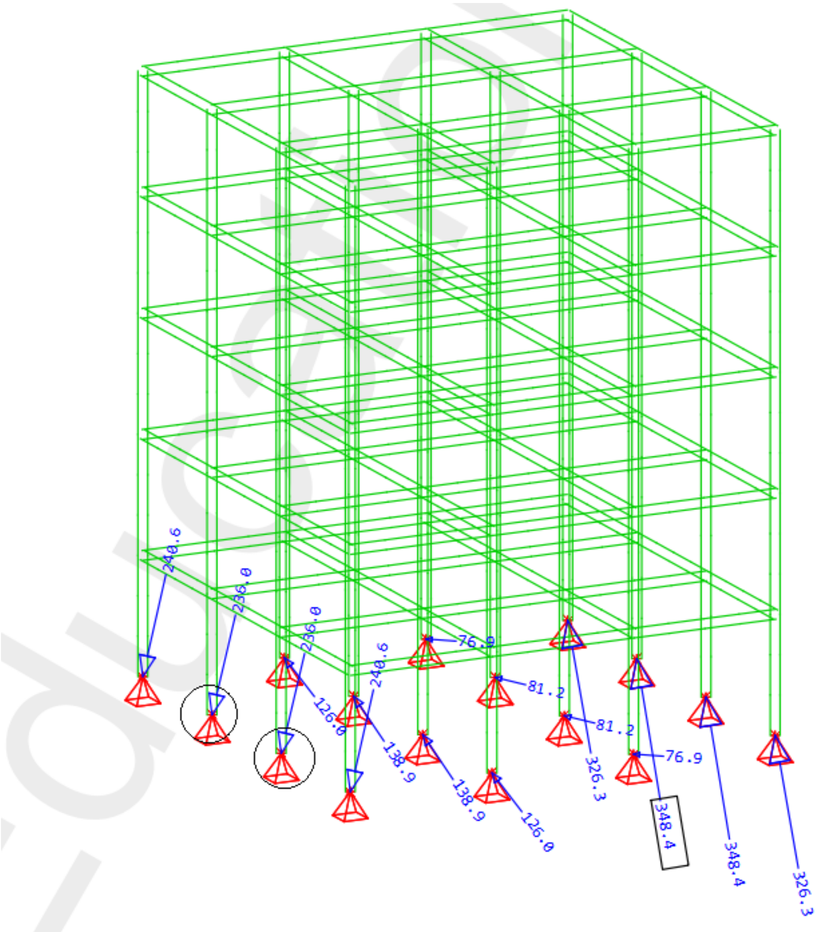

Figure 39: SOFiSTik Support reaction

4.8. Analysis Result

As can be seen from the reaction of both the software, the direction of all the reactions are matching, but the magnitudes of the supports differ. Some reactions have a significant difference. The support reactions differ from each other. First of all, as the loading on the structure is symmetrical, the reaction should be symmetrical too. The same kind of reaction can be in the result of SoFiSTiK (Figure 39). But not for the result in Rhino/Grasshopper. The reactions are not matching at the specified locations. For the better picture of the reactions at the pointed location, the reactions can be compared in the following table: -

Comparisions of reactions		
Coordinate (X,Y,Z)	Rhino/Grasshopper Reaction (KN) (from Table 9)	SofiSTik reaction(KN) (from Figure 39)
(0, 0, 0)	271.52	240.60
(5, 0, 0)	425.41	236.00
(10, 0, 0)	281.87	236.00
(15, 0, 0)	273.59	240.60
(0, 5, 0)	83.86	126.00
(5, 5, 0)	225.61	138.90
(10, 5, 0)	86.88	138.90
(15, 5, 0)	85.42	126.00
(0, 10, 0)	83.94	76.90
(5, 10, 0)	97.90	81.20
(10, 10, 0)	86.82	81.20
(15, 10, 0)	85.60	76.90
(0, 15, 0)	272.16	326.30
(5, 15, 0)	279.05	348.40
(10, 15, 0)	282.21	348.40
(15, 15, 0)	273.95	326.30

Table 10: Comparision of Reactions

It can be seen from the above table that the maginutes of the forces are not matching at all. At certain locations, the difference between the forces are significant(for coordinate (5, 0, 0) and (5, 5, 0)). But the direction of forces are same, the same can be from the .Figure 37 and Figure 39.

5. Conclusion

Parametric design is spreading its legs to the AEC industry. The architects have already started using the parametric design tools but not the structural engineers. In the practical world, the structure's design is being changed either by the client or because of constraints present in the site and many other reasons. If the change is minute, it does not take much human resources and time. But if the change is significant, it could take lots of effort—for example, removing the column in a building. From the architect's perspective, it is not a big deal. The architect just needs to remove a column, and the structure is fine. On the other side, it is big task for a structural engineer. Because it can change the section sizes of the member next to that column, and to design the structure, the structure has to be modeled and analyzed again. It takes lots of energy, time, and resources.

The parametric design can solve this problem up to a certain extent. In this research, a parametric design tool is utilized to analyze the structure, and the reaction forces are compared with another conventional structural analysis software tool. Even though the analysis was not too complicated. But to adopt a parametric design approach for structural analysis is great learning. Because of that reason, the linear analysis is done in this research to understand the concept of parametric design properly.

By comparing the result between the Parametric Design Tool (Rhino/Grasshopper) and SOFiSTik SSD, it can be concluded that the direction of the reactions matches with each other. But the magnitude of the forces is not matching. There might be some bugs in these parametric tools. These parametric tools might have some bugs as they are not designed for structural engineers at first. Therefore, it is genuine that it will take time to make these software tools compatible with structural engineering. This research would suggest not to use a parametric design tool (Rhino/Grasshopper) for the analysis purpose. However, a structural engineer can utilize this tool for modeling purposes and then import that file to other analysis software tools.

In practical life, the structures are not as simple as this research considers. Those structures have many complexities. This Parametric tool utilized in this research could not analyze the structure properly. The reaction forces are not symmetrical, even though the applied force on the structure is symmetrical. As a result, it can be said that there are some bugs in this tool for analysis: that have to resolve. After that, it can be a great tool for structural engineers too. Because it provided flexibility to change certain geometry items without changing the while geometry.

Suppose these bugs are resolved in this parametric tool. It can open many possibilities for structural engineers.

1. A structural engineer can develop a new tool for geometry and analysis in this tool, as it has a plugin of programming language “Python.” But the downside is a structural engineer must learn the programming language to implement the ideas.
2. As programming will be the future, learning the parametric tools would help structural engineers understand logic with structural engineering.
3. The shapes of extra-terrestrial (Such as Moon and Mars) structures can be easily analyzed by utilizing the parametric tools. It provides so much flexibility on the structures with the help of parameters. Apart from that, it might be easy to generate the environment of extra-terrestrial surfaces in the parametric design tool.

Declaration of Authorship

I hereby declare that the attached master's thesis was completed independently and without the prohibited assistance of third parties, and that no sources or assistance were used other than those listed. All passages whose content or wording originates from another publication have been marked as such. Neither this thesis nor any variant of it has previously been submitted to an examining authority or published.

Berlin, 31.01.2022

Location, Date

Signature of the student

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