The impact of Geometry on the construction of buildings and its interplay with computational design and Digital fabrication

Msc. Thesis in Architectural engineering

Author: Eyob Alene (GSR-7345-14)

Advisor : Dr. Asgedom Haile

Co- Advisor : Arch. Belay Getachew

Ethiopian Institute of Architecture, Building Construction and City Development, EiABC, Addis Ababa University

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Title of Thesis

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By Eyob Alene

February - 2016 E.C

Approved by Board of Examiners:

Dr. Asgedom Haile	____________________	____________________
Advisor	Signature	Date
Belay Getachew	____________________	____________________
Co - Advisor	Signature	Date
________________	____________________	____________________
External Examiner	Signature	Date
________________	____________________	____________________
Internal Examiner	Signature	Date
________________	____________________	____________________
Chairperson	Signature	Date
Dr. Dagnachew Adugna	____________________	____________________
Graduate program Director	Signature	Date

DECLARATION

I, the undersigned, declare that this thesis is my own original work and has not been presented for a degree at any other university. I also confirm that I have duly acknowledged all sources of material used for the thesis, following the scientific guidelines of the institute.

Student's Name: Eyob Alene

Signature ________________

Date ___________________

CONFIRMATION

As the thesis advisor and co-advisor from the Institute, we have jointly approved the submission of this thesis.

Advisors Name: Dr. Asgedom Haile

Signature _____________

Date ________________

Co-Advisor Name: Arch. Belay Getachew

Signature _____________

Date _________________

Contents

Table of figures

List of Tables

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List of Acronyms

AIC - The Akaike Information Criterion

API - Application Programming Interface

AEC - Architecture Engineering and Construction

ACSI – Amhara Credit and Saving Institution

BIM - Building Information Modeling

BUR – Built Up Roofing

CFT – Concrete Filled Tube

CNC - Computer numerical control

CAD - Computer-Aided Design and Drafting

CBE – Commercial Bank of Ethiopia

ETFE - Ethylene Tetra Fluoro Ethylene

FRP - Fiber Reinforced Plastic

FAR - Floor Area Ratio

MLR - Multinomial Logistic Regression

MTSE - Maritime Transit Shipping Enterprise

PMR - Protected Membrane Roof

RD - Residual Deviance

SLS - Selective Laser Sintering

ORDA - Organization for Rehabilitation and Development in Amhara

WAAM - Wire Arc Additive Manufacturing

Abstract

This thesis looked at the Impact of geometry on the construction of buildings and its interplay with computational design, digital fabrication and presence of specialized professionals in the AEC industry of Addis Ababa. It mainly focused on high-rise and all buildings of the city. For the two focus areas two different research methods were applied to answer the research question of the study accordingly. The first research method was an intensive building analysis based on 24 building parameters to identify the impact of geometry on the construction method and material of buildings, 40 high-rise buildings were deeply studied based on the parameters. The second research method was mainly based on a systematic questionier survey to identify the impact of geometry on the construction method and material of the entire buildings of the city. Besides the second method was used for realization of the level of the AEC industry in using advanced design and construction approaches and tools in deciding the architectural geometry and construction of all buildings of the city. The questionier survey was applied on 102 design and engineering firms. The main parts of buildings in which the research was focused on are the three major parts of a building, when combined they make a perfect geometrical solid, as a geometric solid is a combination of three surfaces to make a 3D volumetric object these are the base, vertical and overhead surfaces. Here in this thesis the base surface is the floor or slab of a building, the vertical surface is the façade of a building and the overhead top surface is the roof of a building. SPSS, STATA and advanced programing tools such as R-studio was used as a tool to make statistical analysis of data in a scientific manner. The former tools were used for descriptive statistics, correlations and multinomial regression model tests and the later tool was used to run complex multinomial logistic regression tests for datas which needs high performance statistical tools. Overall this thesis results a deeper understanding of the substantial role that geometry plays in determining construction practices and materials in the AEC industry. Through a comprehensive building analysis method, the research identified how geometric design choices influence the construction of high-rise buildings under method type one approach of the research. The findings provide a valuable knowledge in understanding the relation between building design and construction. Further, on method type two study approach, the thesis deeply explored the interplay of geometry with construction and identified the impact of computational design, digital fabrication and presence of specialized professionals on the geometry of our buildings to know how much our firm are applying such advanced design and construction approaches in the AEC industry or how much the geometry of the buildings is driven by advanced design and construction tools, approaches and professionals.

Key words – Geometry, Construction, Computational design, digital fabrication, specialized professionals.

1.0. Chapter 1: Introduction

The Impact of geometry on the Construction of Buildings and Its Interplay with Computational Design and Digital fabrication

(Based on all buildings and high-rise buildings of Addis Ababa)

1.1 Background

Lack of collaboration and professionalism, along with a weak capacity among contractors and consultants, has been identified as a major problem in the AEC industry in Ethiopia (Mahesh et al., 2021). In contrast, in other countries' AEC industries, advanced geometries in architecture are erasing the boundaries between various professionals such as architects, engineers, construction experts, scientists, and technologists (Helmut et al, 2008).

Geometry plays a fundamental role in the field of architecture, engineering, and construction. Throughout history, from ancient times to the present day, the architectural accomplishments and construction of buildings worldwide have been greatly influenced by geometry. Many architectural styles have acquired their distinct character through the innovative and unique application of geometrical principles.

Excluding vernaculars and historical architectural and construction achievements of the past, currently the Ethiopian AEC industry is not contributing a new, modern and outshining construction method and material for self and the world (Abebe, 2020). But in accordance with Helmut et al. (2008) challenges and problems related to construction, engineering and design can be solved easily with a concrete realization of geometry. Moreover, although geometrical complexity remains the precondition for efficient structures in architecture and this simple paradigm can be observed in nature (Sigrid et al., 2016), the AEC industry is not producing geometrically intricate buildings in the skyline of Addis Ababa.

According to Helmut et al. (2008) “Geometry lies at the core of the architectural design process. It is omnipresent, from initial form-finding stages to actual construction. It also underlies the main communication medium; namely, graphical representations obtained by precise geometric rules. Whereas the variety of shapes that could be treated by traditional geometric methods has been rather limited, modern computing technologies have led to a real[1] geometry revolution**.** Scale and construction technologies pose new challenges to engineering and design. Such challenges can be met more effectively with a solid understanding of geometry.”

Moreover, According to Sigrid et al. (2016) “Architecture and geometry have always been intrinsically linked. However, their operational relationship has been dramatically strengthened by the recent advent of computational design and digital fabrication techniques. These distinct developments are reciprocally dependent, as the digital fabrication of complex architectural components induces the need for advanced geometric strategies, and in return the potentials of geometrical computing instils a need for efficiency in the production of complex forms. The conjecture of speculation that the decline of complex form in

[1] Real – Actual happening

architecture may be amplified by the current accumulation of global political, social, and environmental emergencies demanding fast and pragmatic architectural solutions rather than extravagant shapes; however, this critical assumption proves to be short-sighted and simplistic. As a matter of fact, geometrical complexity remains the precondition for efficient structures in architecture, and this simple paradigm can be observed in nature, beyond time-dependent stylistic and formal discourse."

Architecture and geometry have been interwoven for thousands of years. Throughout this time, the architect and the geometer have been one and the same person. The term 'architect' means master-builder, while 'geometer' can be translated as Earth-measurer. This master-builder-geometer had a comprehensive knowledge of his trade, from contemporary design rules of mathematics and geometry, to a profound understanding of its expression through material and structure, and of course considerable skill in financing, managing and constructing a complex structure, of which we find the highest expression in the work of the most masterful of these architect-geometers in their respective eras. As we consider what 'architecture' and 'geometry' imply for us today, it is worth remembering what their significance has been in the past (Wallner et al., 2010).

The earliest scientists were physicians, astronomers and mathematicians. Plato, Euclid, Pythagoras, Archimedes, and on through the likes of Piero della Francesca, Leonardo da Vinci and Descartes provide a continuous and unbroken line of geometric knowledge that has been used by architects and builders throughout history. The acquisition of this knowledge, the achievement of mastery, was a necessary requisite for architects as unlike today, knowledge was held in the minds of a few, and 'consultants', as one might think of them today, did not exist. In other words, the integration of multiple domains of knowledge into a unified set of skills and mental abilities were fundamental to the successful master-builder, such that geometry and architecture were inextricably fused into a single body of knowledge (Wallner et al., 2010).

A distant point of departure could be Imhotep, the architect and engineer who designed and built the Step Pyramid of Djoser at Saqqara in Egypt (2468 BC), in fact predating Greek thought on geometry. Such was the level of accomplishment of Imhotep that he was deified and revered in antiquity as one of the great thinkers of his time. Though layered in its geometry, the Step Pyramid proved to be the first viable pyramid design in Ancient Egypt and formed the basis, through multiple refinements, of the great pyramids in Egypt, including those at Gaza. Indeed, the pyramid builders of Ancient Egypt ultimately achieved a level of execution on par with their vision of the buildings: the fact that the Great Pyramid of Khufu at Gaza built by Hemon is less than 0.001% out of horizontal level and that the gap between most stones is less than the width of a human hair is a remarkable achievement of executed geometry even by today's exacting standards (Wallner et al., 2010).

Just as the pyramid-builders had understood the material geometry of stone, the formidable Gothic cathedral-builders of medieval times further pushed the boundaries of the same material by expressing the geometry of structural forces — in their most sublimated form through an intimate knowledge of stone masonry, construction and ultimately the ability to coordinate and manage a multi-man-year, multi-trade construction project at all levels, from aesthetics, to construction, to politics and finance. In other words, geometry formed one of the core components of the early universal man, the master-builder, who later found his maximum expression in the Renaissance (Wallner et al., 2010).

1.2 Problem statement

The prevalence of be nature-friendly and complex project demands creates challenges on architecture to go beyond traditional production and modern architecture philosophy in the AEC industry. Due to this some of the world renowned architectural firms are trying to use geometry as a means to solve these challenges (Wallner et al., 2010). Although, The potentials of complex and efficient geometrical buildings establishes a need for efficient construction method in the production of complex forms to reality (Sigrid et al., 2016), delay is common in the construction industry development of Ethiopia (Mahesh et al., 2021).

Moreover, although geometrical complexity remains the precondition for efficient structures in architecture, and this simple paradigm can be observed in nature (Sigrid et al., 2016), the AEC industry is not producing geometrically efficient buildings in the skyline of Addis Ababa. There is too much of a boundary and a lack of joint effort between AEC professionals in the city (Mahesh et al., 2021). Therefore, one of the causes of this problem might be the low level of geometric development in the design and construction practices in the city (Helmut et al, 2008).

The geometry of a building significantly influences the selection of materials and construction techniques. However, aside from historical architectural and construction achievements and vernacular practices, the Ethiopian AEC sector is currently not generating innovative and superior building materials or techniques for use by both the global community and itself (Abebe, 2020).

The other problem is most materials which we are using in the Ethiopian AEC industry is mainly imported from foreign countries. According to (Falcioni, 2016) Ethiopia imports over 70% of all its required construction materials from outside, including cables, steel, ceramics, locks, furniture and electrical fittings. The Ethiopian construction industry is heavily dependent on imports. Only cement, steel, which only amounts to roughly half of local need, sand, gravel and paint are sourced locally Aluminum, ceramics, the remaining half of the local requirement for steel panels, welding panels, bitumen and all finishing materials are imported. There is no local supply for these products. So to answer does the geometry of our buildings forced contractors to use such imported materials for the construction of buildings.

There is unavailability of adequate research which reveals the relationship between construction and geometry of buildings in Ethiopia. As a result it is hard to identify the reciprocation between the geometry of buildings with construction and it will be necessary for Ethiopian construction firms to develop different methods of operation in order to be competitive in the global construction markets, because currently full-scale architecture is increasingly relies on digital fabrication for complex geometries (Wirasmoyo et al., 2019).

1.3 Objective

The objective of this research is identifying the impact of geometry of a building on the construction technique and material of buildings envelope and to identify the effect of computational design, digital fabrication and specialized professionals on the geometry of buildings of Addis Ababa buildings through exploring the interplay of geometry, construction, presence of specialized professionals, computational design and digital fabrication.

1.4 specific objective

- To identify the impact of floor geometry in the construction technique and material of floors or slabs.
- To identify the impact of façade or exterior wall geometry on the construction technique and material of façade or exterior wall.
- To identify the impact of the roof geometry in the construction technique and material of roof.
- To identify the impacts of volumetric geometry of buildings in the construction technique and material choices of floor, façade and roof of buildings.
- To identify the influence of specialized professionals, computational design and digital fabrication methods on the floor, façade and roof geometry of buildings.

1.5 Research questions

- What is the impact of floor or slab geometry on the construction technique and material of building’s floor or slab?
- What is the impact of façade or exterior wall geometry on the construction technique and material of building’s façade or exterior wall?
- What is the impact of roof geometry on the construction technique and material of building’s roof?
- What is the impact of volumetric geometry of a building on the construction technique and material of floor, façade and roof of a building?
- What is the influence of computational design, digital fabrication and specialized professionals on the floor, façade and roof geometry of buildings?

1.6 Significance of the research

By focusing on the geometrical character of a buildings, the research will have a great role in recognizing the influence of geometry on the construction technique and material of a building and give suggestions by realizing which geometries related with which construction method and material in the current construction trend of the city. On the top of that, it aids to point out our level of geometry and helps to suggest ways to improve or sustain our geometrical approaches.

Moreover, varied and complex geometries in architecture rises during the introduction of computational design, digital fabrication and specialized professionals (Sigrid et al., 2016). So this research helps to realize the level and presence of specialized professionals in the AEC industry of the city and gives an indication to our level and usage of digital fabrication and computational design tools and approaches in the design and construction of buildings which are the factor for the development of geometry in the industry.

Over and above that, it will aid architects and engineers by providing hint and ideas in producing geometrically efficient buildings in terms of material usage and construction techniques.

Finally this research will inspire professionals in the AEC industry in the creativity of new building geometries and construction techniques which may help in easing the construction systems. Introduce new geometric approaches and concepts which may help in the creation of new techniques and materials which becomes a source of new style and construction for the development of new architecture.

Moreover this thesis will be a solid reference for researchers who aspire to make a related research works in the future, besides this research will be a major input for policy makers and other professionals.

1.7 Scope of the study

1.7.1 Thematic scope

The theme of the research is mainly focused on identifying the impact of envelope geometry on the construction technique and material of building's envelope. for the reason that, the envelope of a building includes wall, window, doors, floor and ceiling or roof this research focuses only on the floor or slab, exterior wall or façade and roof of a building based on all and selected buildings of Addis Ababa. Additionally, the research targeted on pointing out whether the geometry of buildings are driven by advanced design and construction methods such as computational design, digital fabrication methods and specialized professionals or not.

1.7.2 Spatial scope

The study focuses in the AEC industry of our country specifically in Addis Ababa the capital city of Ethiopia, as a typical example of other Ethiopian urban areas and a major center for the construction industry that many big and mass buildings are constructed and a home of many buildings compared to other cities of Ethiopia.

1.7.3 Temporal scope

The temporal scope of this thesis has two time period ranges. The first one is the temporal scope defining the time period of high-rise buildings, and the second time period pertains to all buildings in Addis Ababa. The temporal scope of the high-rise buildings study spans from the earliest building, the Nani High-rise completed in 2004 E.C (CTBUH, 2023), to the beginning of 2016 E.C, covering the segment of high-rise buildings. To encompass all buildings in Addis Ababa, the temporal scope of this research extends from the emergence of earlier consulting architects, engineers, and contractors until the beginning of 2016 E.C, considering that the existing buildings are the products of such AEC firms.

1.8. Limitation and Delimitations

The obstacle of this thesis was the absence of previously done researches related to geometry and construction in Ethiopia, which creates a challenge for the researcher when referring to local cases in the process of the research writing. On the other hand, the geographical extent of the study is limited to the examination of the city buildings. On top of that, this research delimited to the major elements of a building namely floor or slab, exterior wall or façade and roof, they makes a perfect geometrical solid when combined, along with the overall volumetric product formed by the three elements.

1.9. Structure of the thesis

In general the thesis structured based on the nature of the research. So according to the main portion of the research, introduction about the research comes first to give an overall view of the research. Then an intensive literature review was used to know the major concepts of the thesis, then research methodology of the thesis was carried out to clarify how the research question can be answered and objective of the research is accomplished. Following this an intensive statistical analysis was taken in company with results and discussions portion to answer the research questions effectively. Finally, the research ended by conclusion and recommendations.

2.0. Chapter 2: Literature review

2.1 Geometry

2.1.1 Definition of geometry

Geometry is the science which deals with the properties of geometric figures (Hart, 2014). Geometry, derived from the Greek words meaning "earth-measure," initially emerged as a method for surveying land areas. At its core, it involves the study of shapes that can be depicted on a perfectly smooth, flat plane. Plane geometry serves as the fundamental basis for trigonometry, solid and analytic geometry, as well as calculus. The origins of geometry lie in solving practical problems. Architectural remnants from ancient civilizations such as Babylon and Egypt demonstrate their understanding of basic geometric principles. Activities like canal construction, building erection, and city planning necessitated calculations involving lengths, areas, and volumes. Surveying likely developed in Egypt to enable the relocation of land tracts following the annual flooding of the Nile. Additionally, ancient civilizations employed geometry in astronomical observations and the development of calendars. The Greeks played a pivotal role in transforming the practical geometry of the Babylonians and Egyptians into a structured body of knowledge (Africk, 2013).

Figure 2.1. *Nautical theme Frank Gehry's Foundation Louis Vuitton is covered in 12 billowing glass sails. Photograph: Justin Lorget/Justin Lorget/Corbis.*

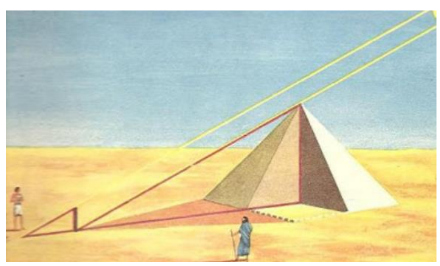
Besides The term "geometry" has its roots in ancient Greek, combining the words "geo" meaning "earth" and "metria" meaning "measuring." This etymology reflects the origin of geometry as a field that addresses the fundamental questions that have intrigued humanity for ages, such as determining the relative sizes of given patches of land. Initially, the focus was on using primitive measuring tools to find the answers. However, various measuring instruments possess subtle distinctions, while scientists share a common inclination to abstractify the problems they investigate. During the Hellenistic period, geometry had firmly established itself as a scientific discipline concerned with the principles of measuring the Earth. It examines the properties, such as shape and size, of points, lines, and other idealized representations of real-world objects. Additionally, it explores the relationships between these elements, such as distance and angle, in relation to one another (Logvinenko, 2023). Moreover, Geometry is a game of logic played with shapes (Parker, 2018).

2.1.2 Notable geometers

Thales (636 BC – 546 BC)

Thales, one of the renowned "seven wise men" of antiquity, is attributed with the significant achievement of obtaining geometrical results through logical reasoning, departing from the reliance on pure intuition and experimental approaches. Thales pioneered the use of deductive reasoning in geometry, introducing a more systematic and rigorous approach to the subject. Instead of relying solely on personal intuition and empirical observations, Thales employed logical arguments and proofs to derive geometric conclusions. This marked a crucial development in the history of geometry, paving the way for the formalization and advancement of the field (Africk, 2013).

Figure 2.2. *Thales – left and Thales finding of the height of a pyramid by its shadow – right (Cássio, 2023).*



As per Plutarch's account, Thales utilized the method of measuring shadows to calculate the height of the Pyramids of Egypt. Plutarch presents a dialogue in which Thales is approached with a statement, "By positioning your stick at the end of the pyramid's shadow, you formed two triangles using the same rays. In doing so, you demonstrated that the ratio of the pyramid's height to the length of the stick is equal to the ratio of the pyramid's shadow to the shadow of the stick." (Hart, 2014).

Pythagoras (582 BC – 507 BC)

Building upon the foundation laid by Thales, Pythagoras carried forward his work and established the Pythagorean School, a mystical community dedicated to the integrated pursuit of philosophy, mathematics, and science. Within this school, Pythagoras and his followers explored a broad range of disciplines, seeking a unified understanding of the world and its principles. This included delving into the realms of mathematics, philosophy, and scientific inquiry, with a particular emphasis on the interconnectedness of these subjects (Africk, 2013).

Pythagoras possessed knowledge of incommensurable numbers and demonstrated that the diagonal and side of a square cannot be expressed as a ratio of whole numbers. The person who initially proposed a theory regarding incommensurability is said to have encountered misfortune, even facing shipwreck, due to the belief that such numbers were considered sacred and held symbolic significance related to the Divine (Hart, 2014).

Plato (429-348 B.C)

Plato was among the early pioneers who found a solution to the renowned problem from ancient times known as the duplication of a cube. This problem involved determining the length of an edge of a cube that would result in a volume twice that of a given cube (Africk, 2013).

Plato is recognized more for his role as an educator rather than as a trailblazing innovator in geometry. His contributions to the field revolved around refining the methodology of geometry rather than introducing new content. Plato viewed geometry primarily as a tool for fostering correct perception, thinking, and the ability to conceive abstract processes. It is widely acknowledged that Plato played a significant role in the progression of Greek geometry, with some sources even suggesting that his influence on the field was nearly as substantial as that of Pythagoras (Hart, 2014).

Euclid

Around 300 BC, Euclid, a Greek mathematician and teacher at the University of Alexandria, composed a comprehensive and systematic treatise on elementary geometry known as the Elements. In this seminal work, Euclid utilized a set of fundamental principles, referred to as axioms or postulates, to deduce the majority of mathematical knowledge available during that period. Euclid's Elements has endured for over 2000 years as the primary textbook on geometry and serves as the foundation for numerous other introductory geometry texts (Africk, 2013).

Figure 2.3. *Pythagoras – left Plato – middle and Euclid – right*

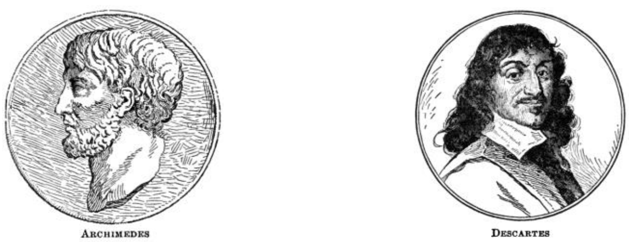
Archimedes (285 B.C. - 212 B.C)

Archimedes, originally from Syracuse, Sicily, pursued his studies at the University of Alexandria in Egypt. He made significant contributions to mathematics, particularly in the field of geometry. His notable achievements include determining the circumference and area of the circle. However, it is his groundbreaking investigations into the mechanics of solids and fluids, his profound understanding of the circle's measurements, and his advancements in solid geometry that are most highly regarded. Archimedes himself held these works in great esteem, solidifying his reputation as one of the greatest mathematicians in history (Hart, 2014).

Rene Descartes (1596-1650)

Rene Descartes was the first to recognize the significance of a key idea: that the position of a point within a plane can be determined by knowing its distances, denoted as x and y, from two perpendicular fixed lines within that plane. He demonstrated that geometric shapes can be represented using algebraic equations, pioneering the field of analytic geometry, which is now commonly referred to as Cartesian geometry, named after him. Descartes's insightful observations and developments laid the foundation for the integration of algebra and geometry, revolutionizing the study of mathematics. Due to the immense significance of his contributions to philosophy, he earned the title of the Father of Modern Philosophy (Hart, 2014).

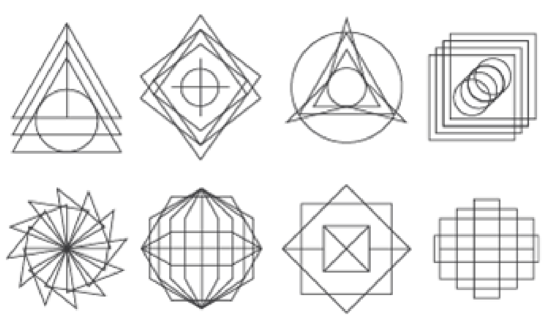
Figure 2.4. *Archimedes – left and Descartes – right*



2.1.3 The four fundamental geometric concepts (Geometric figures)

A geometric figure can be described as an individual entity or a combination of various elements such as a point, line, surface, or solid (Hart, 2014).

Figure 2.5. *Geometric figures (Next.cc, 2023)*

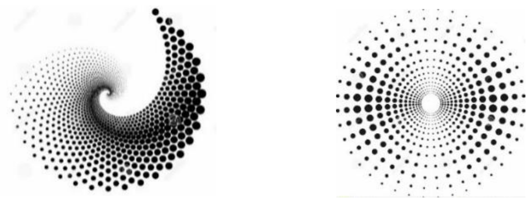


The foundation of all visual representation lies in the point, which initiates the process of creating form. As the point moves, it gives birth to the line, representing the first dimension. When the line extends to create a flat surface, we enter the realm of two-dimensional elements. The transition from a plane to three-dimensional space occurs when multiple planes intersect, giving rise to solid bodies. This progression summarizes the kinetic energies that propel the point into a line, the line into a plane, and the plane into a spatial dimension (Klee, 1961).

2.1.3.1 Geometric point

A tiny mark created by a fine-point pencil on a sheet of paper can be seen as an approximation of a geometric point. A geometric point is devoid of size, lacking any dimensions whatsoever (Hart, 2014). A point is the fundamental unit in geometry, representing a precise position in space with no dimensions or measurable attributes. It lacks physical size or shape and has zero dimensions. Points are used to define lines, shapes, and spatial relationships in geometry, serving as the building blocks for constructions and calculations (Fitzpatrick, 2008).

Figure. 2.6. *A spiral and circular dot elements (Dreamstime, 2022)*



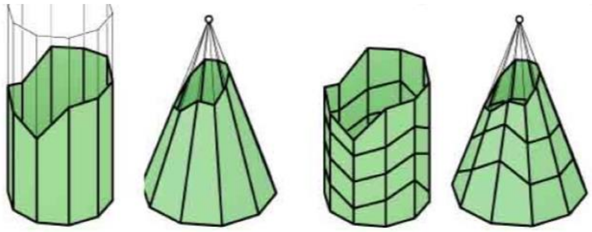
2.1.3.2 Geometric line

When a point is given the freedom to travel through space, its trajectory traces a line. An approximation of a geometric line can be represented by a thin wire or a line drawn on paper using a sharp pencil. However, even though these representations may possess a certain thickness, they are not ideal or geometric lines. A geometric line, in contrast, lacks any width or thickness, existing solely in one dimension. It extends infinitely in both directions without interruption, serving as a fundamental concept in geometry (Hart, 2014).

2.1.3.3 Geometric surface

When a line moves freely in three-dimensional space, it forms a geometric surface. Unlike a line, a geometric surface has two dimensions and occupies an area in space. Geometric surfaces are important in geometry as they provide a basis for understanding and analyzing shapes and structures. They can be flat, curved, or irregular in shape, resembling a flat sheet, a sphere's surface, or undulating terrain. The study of geometric surfaces involves examining their properties such as curvature, area, and relationships with other surfaces or objects. By understanding these features, mathematicians and scientists can describe and analyze complex physical phenomena, from planetary shapes to artistic sculptures *(Hart, 2014)*.

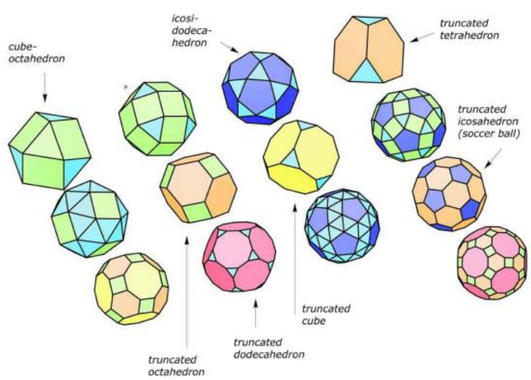
Figure.2.7. *Approximation of cylinders and cones by polyhedral geometric surfaces (Helmut et al., 2007)*



2.1.3.4 Geometric solid

When a surface moves in space, it typically follows a path that aligns with a geometric solid. Geometric solids are three-dimensional objects that encompass length, width, and depth. They play a crucial role in fields such as architecture, engineering, and computer graphics, enabling precise measurements, calculations, and simulations. Understanding the properties of geometric solids enhances our ability to analyze and visually represent the physical world, driving innovation and progress in various areas of study (Hart, 2014).

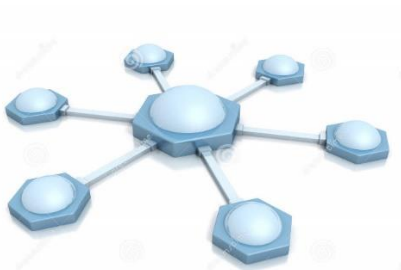
Figure.2.8. *from the 13 Archimedean solids the seven named in this figure can be generated from Platonic solids via corner cutting. The classic soccer ball is one of them (Helmut et al., 2007).*



2.1.4 Properties of geometric figures

The characteristics of geometric figures encompass their size, shape, and form, serving as fundamental indicators and measurement units within the realm of geometry. These properties define the dimensions and configurations of geometric figures, enabling us to quantify and analyze their various attributes. Size refers to the magnitude or scale of a figure, while shape pertains to its overall outline or arrangement of its constituent elements. Form encompasses the three-dimensional structure and arrangement of a figure, providing insights into its overall appearance and spatial characteristics. These properties collectively establish the foundation for understanding and studying geometric figures within the field of geometry. (Hart, 2014).

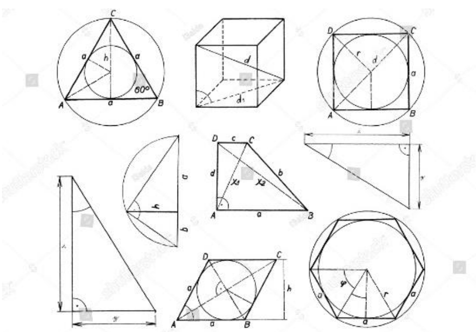
Figure 2.9. *A geometric figure (Dreamstime, 2023) – left and*



2.1.4.1 Size of geometric figure

Size refers to the magnitude or dimensions of an object. Specifically within the realm of geometry, size can encompass various aspects such as linear dimensions (length, width, height, diameter, and perimeter), area, or volume. Mathematically, size is a concept that is derived from the process of measurement, where objects are compared or measured to determine their relative magnitude. This comparison allows for the determination of quantities, such as length, in relation to a chosen unit of measurement. Typically, size is expressed numerically using specific units on a predetermined spatial scale, such as meters or inches. The concept of size in geometry plays a crucial role in quantifying and comparing geometric figures, providing a means to understand their dimensions and spatial relationships (Smoryński, 2008).

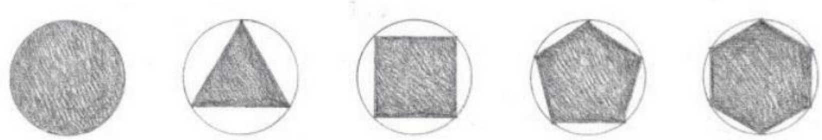
Figure 2.10. *Sizing formula of geometric figures (Shutterstock, 2023) – right*



2.1.4.2 Shape of geometric figure

Shape is the fundamental attribute that defines a plane. It is established by the outline created by the lines that constitute the edges of the plane. However, our perception of shape can be influenced by perspective, causing distortion. To perceive the true shape of a plane, it is necessary to observe it directly from the front. Additionally, shape represents the distinct contour or surface configuration of a specific form. It is the primary quality that enables us to recognize and classify various forms (Ching F. , 2015).

Figure 2.11. *Different geometric shapes*



Gestalt psychology suggests that our minds simplify the visual environment to enhance comprehension. We naturally reduce complex compositions to their simplest and most regular shapes. This simplification aids in easier perception and understanding. Geometrically, the circle is recognized as the most regular polygon shape, with an infinite series of regular polygons inscribed within it. The primary shapes of circle, triangle, and square hold significant importance in our perception and categorization of forms. (Ching F. , 2015).

Figure 2.12. *A geometric figures (Rare-gallery, 2023)*

Circle

A circle is a 2D shape with a curved circumference. Inside the circle, all lines from a point to the circumference are equal in length. What makes circles fascinating is the consistent distances between any point inside the circle and the circumference. When connecting a point inside to any point on the circumference with a straight line, we find that all those lines have the same length (Fitzpatrick, 2008).

Figure 2.13. A circle

The equal lengths of radii in a circle create symmetry, balance, and harmony. This property has practical applications in various fields like architecture, engineering, physics, and art. Circles are valued for their aesthetic appeal, mathematical precision, and ability to efficiently distribute forces. (Fitzpatrick, 2008).

Figure 2.14. *Ancient Greek circular theatre (Kavas, 2019).*

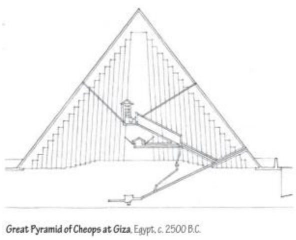
Triangle

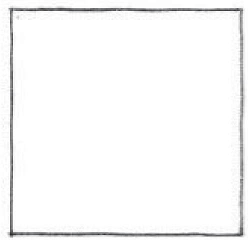
The three-sided shapes known as triangles can be categorized into different types based on the lengths of their sides. An equilateral triangle is one with three sides of equal length, while an isosceles triangle has two sides of equal length. On the other hand, a scalene triangle is characterized by all three sides having different lengths (Fitzpatrick, 2008). The triangle symbolizes stability, but its stability depends on its position. Resting on one side, it provides great stability. However, when positioned on a vertex, the triangle becomes precarious and prone to falling onto one side (Ching F. , 2015).

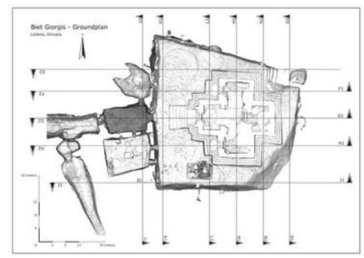
Square

The square is a plane figure characterized by four equal sides and four right angles. It symbolizes purity and rationality. With bilateral symmetry, the square possesses two equal and perpendicular axes (Ching F. , 2015).

Figure 2.15. *Great pyramid of cheops at Giza, 2500 B.C – Left and Bete Giyorgis Lalibela, Ethiopia (Ruan, 2021)- right.*







Rectangles can be seen as variations of the square, deviating from the norm by adding height or width. Similar to the triangle, the square is stable when resting on one of its sides, but becomes dynamic when standing on one of its corners. However, when its diagonals are vertical and horizontal, the square achieves a balanced state of equilibrium (Ching F. , 2015).

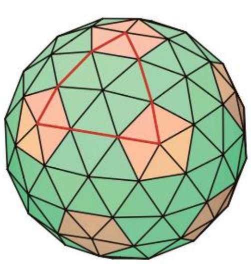
2.1.4.3 Form of geometric figures

Primary shapes like circles, triangles, and squares can generate recognizable volumetric forms. Circles produce spheres and cylinders, triangles yield cones and pyramids, and squares give rise to cubes. In this context, "solid" refers to three-dimensional geometric bodies. Le Corbusier stated that cubes, cones, spheres, cylinders, and pyramids are considered the most aesthetically pleasing forms due to their distinctness, tangibility, and visual appeal when illuminated (Ching F. , 2015).

Sphere

A solid generated by the revolution of a semicircle about its diameter, whose surface is at all points equidistant from the center. A sphere is a centralized and highly concentrated form.

Figure 2.16. *Spherical form – right (Helmut et al., 2007) and Amazon Corporate Offices Washington, USA – right (Molina, 2018).*

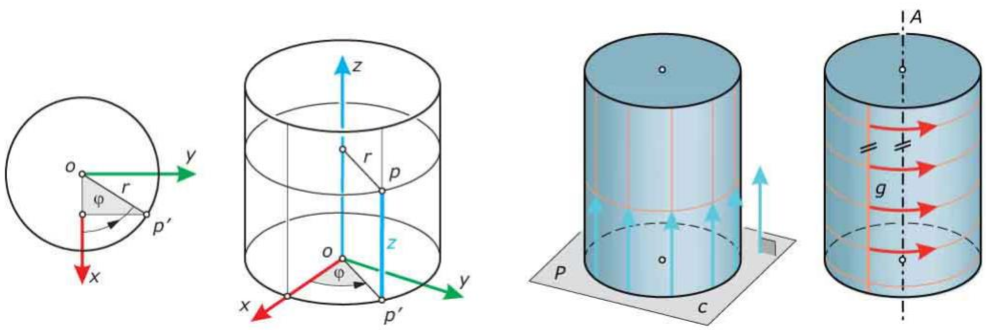


Like the circle from which it is generated, it is self-centering and normally stable in its environment. It can be inclined toward a rotary motion when placed on a sloping plane. From any viewpoint, it retains its circular shape (Ching F. , 2015).

Cylinder

A solid generated by the revolution of a rectangle about one of its sides. A cylinder is centralized about the axis passing through the centers of its two circular faces. Along this axis, it can be easily extended. The cylinder is stable if it rests on one of its circular faces; it becomes unstable when its central axis is inclined from the vertical (Ching F. , 2015).

Figure 2.17. *A cylindrical form (left) a rotational cylinder can be generated by extrusion of a circle c lying in a plane P. (right)*

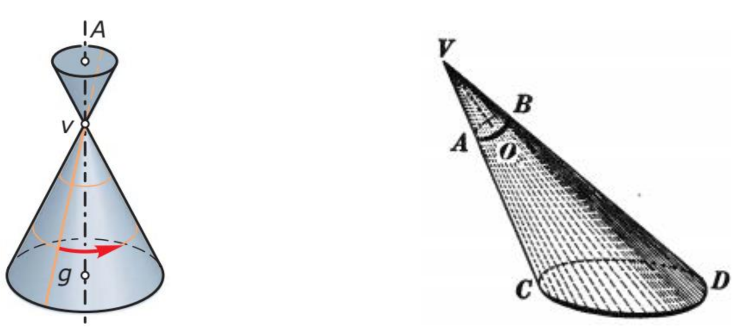


Note: The extrusion direction is orthogonal to P. An alternative generation is performed by rotating a straight line g around an axis a parallel to g (Helmut et al., 2007).

Cone

A solid generated by the revolution of a right triangle about one of its sides. Like the cylinder, the cone is a highly stable form when resting on its circular base, and unstable when its vertical axis is tipped or overturned. It can also rest on its apex in a precarious state of balance (Ching F. , 2015). A cone is a solid closed figure whose boundary consists of the portion of a conical surface extending from its vertex to a plane cutting all its elements, and the section formed by this plane (Hart, 2014).

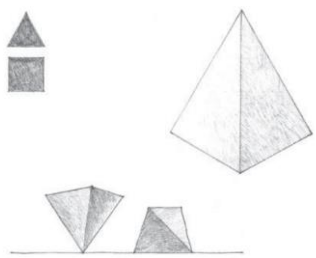
Figure 2.18. *A rotational cone is obtained by revolving a line g around an intersecting axis A – left and a circular cone – right*



Pyramid

A polyhedron having a polygonal base and triangular faces meeting at a common point or vertex. The pyramid has properties similar to those of the cone. Because all of its surfaces are flat planes, however, the pyramid can rest in a stable manner on any of its faces. While the cone is a soft form, the pyramid is relatively hard and angular (Ching F. , 2015).

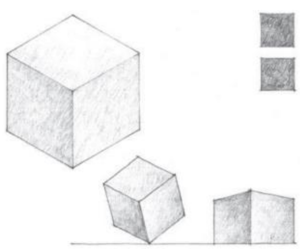
Figure 2.19. *Pyramidal form - left and Louvre Pyramid – right (Ching F. , 2015) & (One life tours, 2015)*



Cube

A prismatic solid bounded by six equal square sides, the angle between any two adjacent faces being a right angle. Because of the equality of its dimensions, the cube is a static form that lacks apparent movement or direction. It is a stable form except when it stands on one of its edges or corners. Even though its angular profile is affected by our point of view, the cube remains a highly recognizable form.

Figure 2.20. *Cubical form – Left (Ching F. , 2015) and the orange cube by Jacob MacFarlane - Right (Warmann, 2011)*



Regular forms

Regular forms refers to those whose parts are related to one another in a consistent and orderly manner. They are generally stable in nature and symmetrical about one or more axes. The sphere, cylinder, cone, cube, and pyramid are prime examples of regular forms. Forms can retain their regularity even when transformed dimensionally or by the addition or subtraction of elements. From our experiences with similar forms, we can construct a mental model of the original whole even when a fragment is missing or another part is added (Ching F. , 2015).

Irregular forms

Irregular forms are those whose parts are dissimilar in nature and related to one another in an inconsistent manner. They are generally asymmetrical and more dynamic than regular forms. They can be regular forms from which irregular elements have been subtracted or result from an irregular composition of regular forms. Since we deal with both solid masses and spatial voids in architecture, regular forms can be contained within irregular forms. In a similar manner, irregular forms can be enclosed by regular forms (Ching F. , 2015).

Figure 2.21. *An Irregular Array of Regular Forms in the Vertical Dimension: Poteries du Don, Le Fel, France, 2008, Lacombe–De Florinier (Ching F. , 2015)*

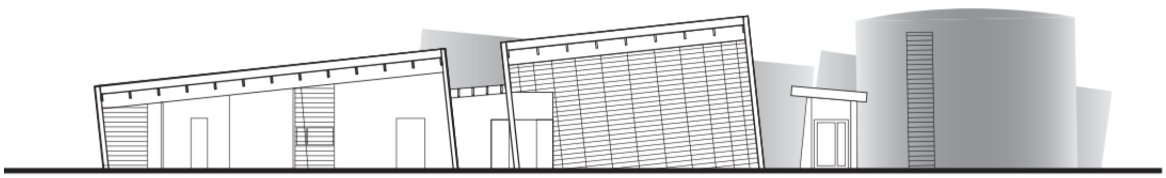


Figure 2.22. *The gherkin – A regular conical form (Twomey, 2021) – Left and China Central Television Headquarters (CCTV), Beijing China 2004 – 2012 Rem Koolhaas and Ole scheeren,*

Note: The gherkin – A regular conical form (Twomey, 2021) – Left and China Central Television Headquarters (CCTV), Beijing China 2004 – 2012 Rem Koolhaas and Ole scheeren, what may appear to be a random pattern is often based on rational structural principles. Note how the diagrid pattern becomes denser in areas where moment stresses are higher (Ching F. , 2015) and (Gstatic, 2023). – Right.

2.1.5 Main branches of geometry related to the AEC industry

The various divisions of geometry equip AEC professionals with essential skills and information to effectively examine, plan, and build constructions and edifices. The following branches of geometry provide the AEC professionals with the necessary tools and knowledge to analyze, design, and construct buildings and structures effectively**.**

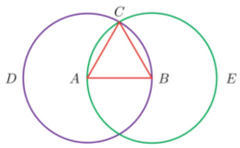
Euclidean Geometry

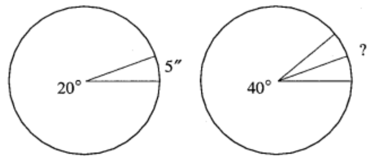
Euclidean geometry focuses on the characteristics and connections between points, lines, angles, and shapes within a flat or two-dimensional space. It serves as the fundamental framework for various architectural principles and construction methods (Dillon, 2018).

Trigonometry

Trigonometry is the study of relationships between angles and sides of triangles. It is particularly relevant in architectural calculations involving angles, measurements, and geometric constructions. Two of the most basic figures studied in geometry are the triangle and the circle. Trigonometry will tell us more than we learned in geometry about each of these figures (Gelfand, 2001).

Figure 2.23. *Construction of an equilateral triangle by a line segment that forms two circles (Dillon, 2018)- Left and The arc cut off by a central angle of 20° to 40° doubles the arc (Gelfand, 2001) – right.*





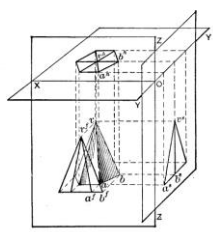
Projective Geometry

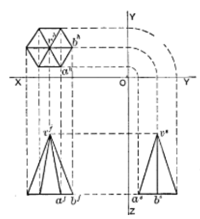
Projective geometry focuses on the properties of geometric figures and their transformations, particularly those related to perspective and the projection of three-dimensional objects onto a two-dimensional plane. This branch of geometry is essential for understanding architectural drawings, plans, and representations (Bobenko, 2020).

Descriptive Geometry

Descriptive geometry involves the representation of three-dimensional objects in two dimensions, using techniques such as orthographic projections, sectional views, and auxiliary views. It is crucial for architects to communicate their designs accurately through drawings and plans (James, 2016).

Figure 2.24. *The photograph shows the central projection of a circle onto a hyperbola (Bobenko, 2020) – left and Horizontal, front vertical, and side vertical projections (James, 2016)and –right*

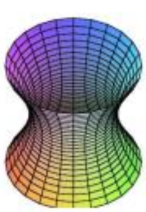


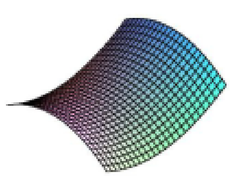


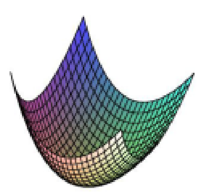
Differential Geometry

Differential geometry deals with the curvature and smoothness of surfaces and shapes. It finds applications in architectural design, especially when dealing with curved forms, such as domes, arches, and curved facades (Joel W. Robbin, 2022).

Figure 2.25. *Elliptic Hyperboloid, Hyperbolic Paraboloid and Elliptic Paraboloid from left to right (Joel W. Robbin, 2022).*







2.2 Geometry and architecture

All the buildings we frequent, such as schools, libraries, houses, apartment complexes, movie theaters, and even our favorite ice cream shops, are constructed using mathematical principles in their design and construction. Architects heavily rely on mathematics, specifically geometry, algebra, and trigonometry, during the design phase. These mathematical concepts are used to create accurate blueprints and initial sketches that ensure precise measurements and proportions. Additionally, architects use mathematical calculations to predict and address potential construction issues that may arise when translating the design into a tangible three-dimensional structure (Dream box, 2019).

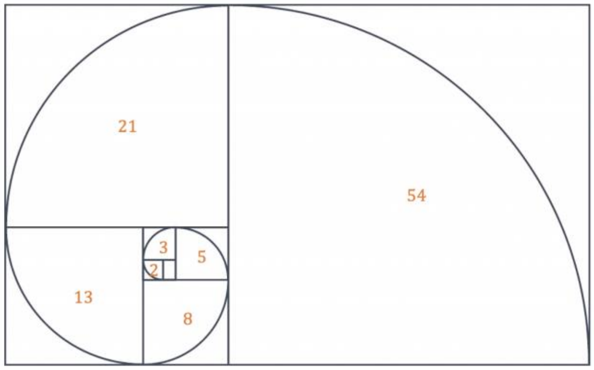
Figure 2.26. *Al Janoub Stadium, Qatar – Geometrically complex masterpiece of architecture becomes real through the use of computational design.* (Shanaza, 2023).

Geometry is a fundamental aspect of the entire design process, playing a crucial role from beginning to end. Architects employ geometry to analyze and divide space while developing intricate building plans. Builders and engineers heavily depend on geometric principles to ensure the safe construction of structures. Within the realm of interior design, designers utilize geometry, in conjunction with color and scale, to craft visually appealing and harmonious spaces. The incorporation of geometry in design is an essential and inevitable practice that permeates every stage of the creative process (Lehner, 2018).

2.2.1 Historical development of geometry and architecture

Throughout history, architects have employed geometric principles to shape and organize the spatial forms of buildings. One notable mathematical concept is the Golden Ratio, first defined by the Greek mathematician Euclid around 300 B.C. This natural law has been used by architects for over two thousand years to establish pleasing proportions in structures that evoke a sense of balance and visual harmony. Known as the Golden Constant, this ratio is found ubiquitously in nature and remains a fundamental geometric principle in architecture. It is considered a timeless archetype as it elicits a universal feeling of harmony when people observe or inhabit buildings designed with this principle. Interestingly, the Golden Ratio is also prevalent in the natural world, revealing its significance in the fundamental structures and patterns found in nature's own architecture (Dream box, 2019).

Figure 2.27. *The Golden Spiral (Essendelft, 2020)*



Accurate ratio calculations are crucial in construction, particularly for roofs. Professionals achieve the correct ratio by dividing the length by the height. The Pythagorean Theorem, developed in the 6th century B.C., is used to measure right angles in structural design. The Egyptian pyramids, built between 2700 B.C. and 1700 B.C., demonstrate the Egyptians' advanced understanding of geometry. These remarkable structures feature a consistent angle of approximately 51 degrees, showcasing their mastery of architectural principles (Dream box, 2019).

2.2.2 Purpose of geometric architecture

Geometric architecture aims to optimize building efficiency by minimizing material usage and maximizing space utilization. This approach emphasizes the economical use of materials and avoids unnecessary wastage of space. In geometric architecture, elements and designs are created using straightforward and precise techniques. By correctly applying geometry in architectural design, the calculation of structural loads is simplified, and the relationship between geometry and the logic of construction is carefully considered. This integration of geometry in architecture allows for more efficient and effective building practices, ensuring structural integrity while minimizing construction complexities (Deplazes, 2021).

2.2.3 Geometric solution through collaboration of professionals

Collaborations between architects and construction professionals have been traditionally infrequent but highly impactful when they occur. Successful partnerships have resulted in innovative geometric solutions for building designs, leading to groundbreaking architectural achievements. Examples like Le Corbusier and Iannis Xenakis (La Tourette et al.), Bruce Graham and Fazlur Khan (John Hancock and Sears Towers in Chicago), Herzog & de Meuron and Ai Weiwei (Beijing Olympic Stadium), and Rem Koolhaas and Cecil Balmond (CCTV Beijing) highlight the transformative power of cross-disciplinary exchange. These collaborations have driven technological innovations and reimagined architectural concepts, ushering in visionary designs rather than incremental advancements (Wallner et al., 2010).

Figure 2.28. *Front façade of taj mehal - Main entrance door frame rectangle is accurately Golden rectangle (Archgeom, 2017) - Left and Beijing Olympic Stadium – right*

Note: Beijing Olympic Stadium – steel and ETFE are the main materials used for the construction of the stadium.it is a combined product of architects - Herzog & de Meuron and artist Ai Weiwei who is the artistic consultant for design (Wikiarquitectura, 2017).

2.2.4 Demand of complex geometries by AEC firms

Architecture firms are embracing complex geometry to achieve innovative designs that meet rigorous aesthetic and functional requirements. In today's competitive global landscape, where environmental consciousness and complex project demands are prevalent, architecture must transcend traditional production and modernist principles. To address these challenges, architects are exploring advanced digital design tools and forming specialized teams with expertise in geometry and computational skills. Examples include Foster and Partners' Specialist Modeling Group and Zaha Hadid Architects' "CODE" unit. These firms are pushing the limits of geometric form expression to create architectural solutions that defy norms and offer visionary design possibilities (Wallner et al., 2010).

Figure 2.29. *Students in the workshop developed algorithmically created geometry studies using physics simulation – left and iterative prints with increasingly complex geometry - right (Formlabs, 2014)*

As demand grows for complex architectural forms, specialized advisory firms like ARUP's Advanced Geometry Unit and Viennese team Evolute offer geometric and mathematical consultancy services. These collaborations hold great potential for remarkable outcomes. It's crucial for these experts to grasp the aesthetic concerns and professional obligations of architects. Geometry in architecture is tangible, intertwined with material performance, fabrication techniques, assembly methods, and the inevitable imperfections that introduce a certain "fuzziness" into precision. Implementing geometric solutions carries costs and depends on financial and legal viability. Practical constraints often require abandoning geometric elegance and optimization. The fruitful interplay between theory and practice, whether embodied in a master builder-geometer or distributed across collaborative teams, is essential. Applying geometry in constructible ways enables architecture to realize its performative, aesthetic, financial, and political aspirations in our complex 21st-century world (Wallner et al., 2010).

2.2.5 Geometry as a challenge for professionals

According to Engineering news and innovation (Engineering News and Innovations, 2023) as architects push the boundaries of design with increasingly ambitious buildings featuring intricate geometric twists and curves, engineers and constructors are faced with the task of translating these visions into tangible structures.

Figure 2.30. *The Museum of the Future in Dubai*

Note: The Museum of the Future in Dubai, United Arab Emirates (UAE) is renowned as the most intricate architectural marvel in the world. Apart from its complex geometric design, the building stands out for its column-free interiors, which posed a significant structural hurdle given its large size and shape. The unique curved form added an immense level of complexity for the contractors, considering the diverse geometrical aspects both above and below ground. Designing and constructing this exceptional building thus presented numerous challenges (Meva, 2023).

Throughout history, geometry has played a fundamental role in the creation of buildings, regardless of their size, shape, or architectural style. Whether it's the timeless concept of the Golden Ratio or the captivating symmetry of structures, geometry has been a guiding principle in every stage of building development, from planning and design to construction, maintenance, and renovation. In the modern era, architects continue to rely on these principles as they strive to achieve a harmonious balance between aesthetics and sustainability in the construction of contemporary complexes and skyscrapers (Grosskopf, 2018).

2.2.6 Geometry and fabrication

Geometry has long been a significant factor in architecture and the construction process, particularly when dealing with intricate shapes and structures. From the early use of vaults and shells to the emergence of digitally fabricated architecture, comprehending the principles of geometry has been essential in the construction and fabrication processes. With the advent of advanced computational design tools, it has become easier to create complex shapes that would otherwise be challenging to manufacture. As a result, the relationship between geometry and fabrication has gained even greater importance in the design phase. Innovative design approaches, such as fabrication-aware design, structurally informed design, and material-based design, demonstrate a growing interest in establishing new connections between geometry and fabrication within the field of architecture (Tepavčević, 2022).

Zaha Hadid's mobile art pavilion for Chanel leverages the benefits of digital imaging and construction techniques to realize a design characterized by fluid geometries and dynamic spatial qualities (Dunn, 2012). Translating complex biomimetic principles into fabrication and physical implementation poses a significant challenge in applying them to architecture and structure and The recent advancements in CNC technology, especially the resurgence of robotic fabrication (Bechthold, 2010) suggest that The economic feasibility of pre-fabricating building elements with intricate geometries, similar to those found in natural systems, has become a reality (Raynaud, 2012).

Figure 2.31. *Zaha Hadid's mobile art pavilion*

Note: Zaha Hadid's mobile art pavilion explores the utilization of Fiber-Reinforced Plastic (FRP), a lightweight, flexible, and durable material commonly employed in aircraft construction. FRP is known for its ability to withstand extreme temperatures, making it an ideal choice for the pavilion's innovative design (Kazan, 2013).

2.2.7 The aesthetic dimension of geometry

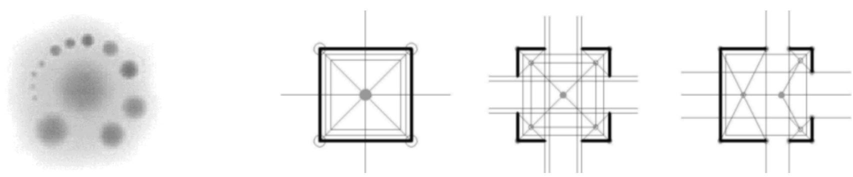
Architectural aesthetics are closely tied to geometry, but they are further enriched by incorporating mathematical principles that involve change and irregularity (Huib, 2008). By comparing the concepts of beauty in architecture with those of geometry and mathematics, a deeper comprehension of the interplay between these disciplines can be achieved (Huib, 2008).

Alexander's fifteen properties, supported by geometric and mathematical principles, reinforce his assertion about the quality of buildings. These properties include scale, strong centers, boundaries, repetition, positive space, shape, symmetries, interlock and ambiguity, contrast, gradients, roughness, echoes, the void, simplicity, inner calm, and interconnectedness. Collaborating these properties results in highly esteemed buildings that offer a comforting experience to individuals (Huib, 2008).

Level of scale - Varied center sizes enhance their prominence. Ideally, centers should differ by a reasonable scale, with one approximately half or twice the size of another. When a well-organized range of sizes is achieved, a field effect emerges, interconnecting the centers to create a cohesive whole (Ibrahim, 2021).

Strong centers - Prominent centers add vitality to architectural structures. According to Alexander's theory, centers play a foundational role in creating architectural beauty, surpassing the significance of other properties (Huib, 2008).

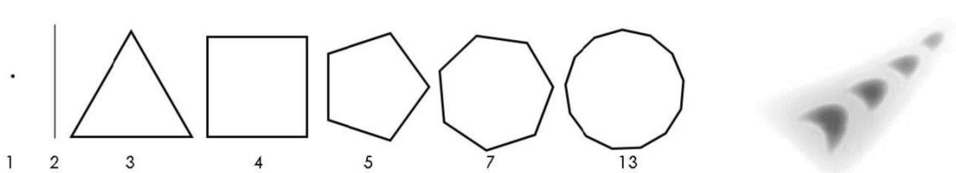
Figure 2.31. *Levels of scale (Iba, 2015)- left and Determination of the center of gravity (Huib, 2008) right*



Boundaries - Boundaries play a significant role in enhancing the prominence and vitality of living centers within a space. By surrounding a center, boundaries establish a distinct field of influence that draws attention and focus towards the central focal point. This interplay between centers and boundaries creates a dynamic relationship, contributing to the overall composition and experience of the space (Huib, 2008).

Alternating repetition - Centers become more pronounced when they are repeated with subtle variations. This concept of alternating repetition goes beyond simple duplication, as the repeated elements are modified based on their placement within the overall composition. It emphasizes the importance of carefully adjusting and adapting the repeated elements to create a cohesive and harmonious whole (Marcelo, 2021).

Figure 2.32. *Polygon boundaries (Huib, 2008) – left and Alternating repetition (Iba, 2015) – right*



Positive space - A dynamic unity is achieved when a composition consists solely of strong centers, where each part of the space embodies a positive shape as a center. In such a whole, there is no leftover or unused space resulting from adjacent shapes. This principle emphasizes the importance of ensuring that every element within a composition contributes to the overall coherence and vitality of the design. (Iba, 2015).

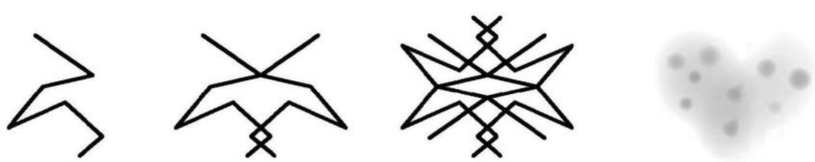
Good shape - A cohesive and harmonious structure is achieved when multiple distinct centers come together to form a unified whole. This interconnectedness of intense centers contributes to the creation of a good shape for the overall composition. The concept of a good shape pertains to the entirety of the structure, while recognizing that each individual center is, in itself, a complete entity. The integration of these intense centers within the whole results in a cohesive and aesthetically pleasing arrangement (Sungwoo, 2019).

Figure 2.33. *Positive space (Iba, 2015) – left and Good shape (Iba, 2015) – right*

Local symmetries - Christopher Alexander's theory posits that the presence of symmetry on various scales is essential for the manifestation of "life" in a design or structure. In other words, a sense of vitality and coherence can only be achieved when symmetry is incorporated across different levels of scale (Huib, 2008).

Deep interlock and ambiguity - A fundamental characteristic of a living whole is the interlocking of forms, which connect the centers with their surrounding environment. This interplay between the elements creates a cohesive and integrated composition, enhancing the overall vitality and harmony of the structure (Ibrahim, 2021).

Figure 2.34. *Creation of a stronger image by using symmetry (Huib, 2008) – left and deep interlock and ambiguity (Iba, 2015) – right.*



Contrast - The intensity of a center is heightened by the clear contrast between its unique character and the characteristics of the surrounding centers. This distinction emphasizes the significance and prominence of the individual center, contributing to the overall visual impact and dynamism of the composition (Iba, 2015).

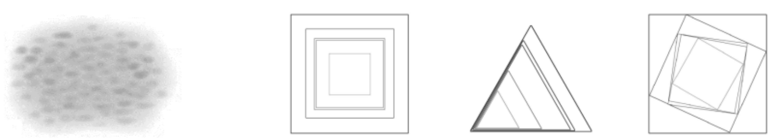
Gradients - In a living whole, qualities exhibit a gradual transition rather than an abrupt change as one moves across space. This principle emphasizes the importance of a smooth and harmonious progression of qualities within the overall composition. By avoiding sudden shifts, the cohesive and organic nature of the living whole is preserved, resulting in a more balanced and aesthetically pleasing design (Ibrahim, 2021).

Figure 2.35. *Contrast (Iba, 2015) – left and Gradients (Iba, 2015) – right*

Roughness - Living wholes exhibit local irregularities within their overall composition, as noted by (Iba, 2015). Christopher Alexander refers to these irregularities as "roughness," which can be understood as intentional imperfections within a predefined pattern or grid. These imperfections add a sense of depth and uniqueness to the design, breaking away from rigid uniformity and allowing for a more organic and dynamic expression (Huib, 2008).

Echoes - An echo involves repeating a core object, potentially with alterations, within a larger context. When exploring echoes, it is crucial to consider the geometric connection to a base shape. Mathematical transformations like translation, scaling, rotation, or their combinations establish relationships among echoing elements within a composition. This enables the creation of visually captivating patterns and variations that enhance the overall aesthetic and coherence of the design (Huib, 2008).

Figure 2.36. *Roughness (Iba, 2015) – first left and repetition by scaling (left), scaling and translation (middle) and scaling and rotation (right) (Huib, 2008).*

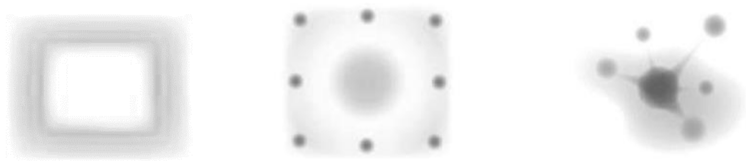


The void - An empty center intensifies other centers within a composition, striking a delicate balance between tranquility and void. This inclusion of emptiness in the design creates a harmonious equilibrium, where calmness and openness coexist with the vibrant energy of other centers (Iba, 2015).

Simplicity and inner calm - A living whole embodies slowness, majesty, and tranquility, resulting in inner calm. Inner calm is achieved through the principle of simplicity, eliminating unnecessary elements and focusing on what is essential and purposeful. Embracing simplicity creates a serene and balanced atmosphere, offering individuals a sense of peacefulness and serenity (Ibrahim, 2021).

Not-separateness - In a living whole, centers harmoniously blend and intertwine with their surroundings. They maintain individuality while seamlessly integrating into the larger context. This profound connection forms a unified and cohesive entity, promoting continuity and coherence. The whole exhibits a cohesive identity while preserving the distinct qualities of its parts (Ibrahim, 2021).

Figure 2.37. *The void (Iba, 2015) – left and Simplicity and inner calm (Iba, 2015) –middle and Not separateness - right (Iba, 2015).*



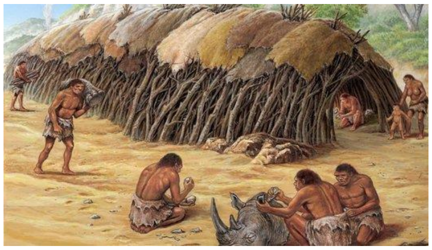
2.3 Building construction

The process of building construction involves the gathering and integration of various materials to create a functional and complete building structure. It encompasses the meticulous arrangement and assembly of these materials to ensure the formation of a secure and durable edifice. Through this process, the individual components, such as concrete, bricks, steel, and wood, etc. are carefully joined together, following architectural plans and engineering specifications, to realize the desired architectural design and functional requirements of the building (Ricketts et al., 2001). Here Ricketts, emphasizes that the construction process can be evaluated by examining the construction methods and materials employed. Building construction entails the creation of structures by utilizing specific materials and implementing a variety of construction techniques or methods.

2.3.1 Construction method

In ancient times, humans sought shelter in caves and adapted their surroundings for better living. They arranged pebbles for easier access, constructed makeshift roofs with branches, and created paths on the ground. They used stone tools to dig traps and built small bridges with logs to manage water. These early activities formed the basis of basic construction techniques, involving digging, compacting soil, transporting materials, and assembling structures. The pursuit of a better life drove humans to refine these techniques, learning from mistakes and overcoming challenges posed by nature. Advancements in construction became essential for the progress of civilization, fueled by the desire for improved living conditions (Ito, 2022).

Figure 2.38. *Ancient human shelter*



Note: Ancient humans sought shelter by utilizing different forms, materials, and construction techniques. They would use tree branches and pebbles to create makeshift structures (Echosciences, 2023).

Development of Construction method

Primitive structures were early human dwellings, like pit houses with natural roofs, found worldwide. Using basic tools, ancient humans built shelters with grass, wood, stone, mud, and animal skins to stay dry. As civilization progressed, buildings gained symbolic significance, serving religious, hierarchical, or commemorative purposes. Prominent examples include temples, palaces, and theaters like the pyramids. Advancements in construction materials and techniques allowed for vertical and horizontal expansion of buildings. Temples and churches in medieval Europe showcase this progress. Different architectural forms emerged globally, shaped by nature, beliefs, religions, and hierarchies (Ito, 2022).

Figure 2.39. *Evolution of Construction and Building Materials (Paspula, 2021)*

Modern architecture emerged during the 19th century in Europe, coinciding with the industrial revolution. This period of rapid industrialization and economic growth necessitated the construction of functional, efficient, and cost-effective factories and industrial facilities. As a result, buildings constructed with reinforced concrete and steel, incorporating materials like steel, cement, and glass, became increasingly common. The demand for vertical and spacious structures grew alongside these changes. The advancement of building technology, allowing the construction of "super high-rises" and large interior spaces, has become more crucial than ever (Ito, 2022).

Figure 2.40. *Notre Dame Cathedral*[2]

[2] Note: During the medieval period, notable construction projects took place, including the construction of iconic structures such as Notre Dame Cathedral (Paspula, 2021).

Super High-rise Building method

Advanced techniques in structural analysis and materials technology support the construction of super high-rise buildings. In the past, buildings over 200 meters tall mainly used steel-frame structures. However, modern super high-rises often opt for reinforced concrete, which offers advantages in terms of construction ease and cost efficiency. These buildings owe their exceptional structural integrity to advancements in high-strength concrete technology, providing significantly greater strength than standard concrete. The new constructions employ concrete with impressive strength ranging from 80 to 130 N/mm2, manufactured under strict quality control measures. Furthermore, the CFT method, involving filling steel columns with concrete to enhance compressive strength, was developed to achieve improved economic efficiency in super high-rise construction (Ito, 2022).

Figure 2.41. *Wuhan Greenland Center*[3] *(Dailymail, 2023)*

Seismic resistant construction method

The conventional standard of earthquake resistance is how to construct a building rigid enough to resist seismic force (rigid structure) or flexible enough to (flexible structure). Buildings constructed with either concept will suffer less damage and will not fail in the face of a major earthquake, but equipment, furnishings and installations inside the building will receive devastating damage (Ito, 2022).

Large Span construction method

The Pantheon, constructed in Rome in the early 2nd century, is the world's oldest surviving large span building. Originally a place of worship, it exemplifies the lasting appeal of wide-span structures.

[3] Note: ‘‘The construction of the Wuhan Greenland Center, a remarkable skyscraper standing at a staggering height of 636 meters (2,086 feet), was completed in 2022. A recent documentary has revealed an extraordinary innovation utilized during its construction—an impressive skyscraper-building machine nicknamed the 'wall-climbing monster'. This machine, which operates independently, possesses the ability to bear weights of up to 2,000 tones and withstand hurricane forces. Engineered by Chinese professionals, CCTV has reported that this machine has the potential to expedite the construction process by 20 percent’’ (Dailymail, 2023).

Figure 2.42. *Rigid frame structure- left and the Pantheon- Right*[4]

Today, there is a continued demand for large span constructions in various building types, such as railway stations, airports, event halls, stadiums, and commercial complexes. The technology used to achieve large spans can be categorized into three techniques: "structure" focuses on designing and constructing the supporting framework, "erection" involves the assembly and installation process, and "simulation" utilizes modeling and virtual analysis to evaluate the structure's performance and behavior (Ito, 2022).

2.3.2 Construction material

Construction materials are the main constituents in the manufacturing of buildings .Given the rise in global population and resource consumption, architects, design team and civil engineers bear the responsibility of selecting building materials that promote sustainable development rather than merely meeting short-term requirements. When making these choices, it is crucial to consider the energy expended in manufacturing and transporting the materials to the construction site, a concept referred to as "embodied energy." This notion of embodied energy is fluid and undergoes constant evolution (Ricketts et al., 2001).

2.4 Building Envelope

The building envelope is the enclosure of a constructed space, encompassing walls, doors, windows, roofs, skylights, and other openings for light and ventilation. It acts as a barrier, separating the indoor environment from the outdoor surroundings. Its main purpose is to protect the building's interior and occupants from weather conditions and external elements. The design of the envelope significantly impacts the visual and thermal comfort of occupants and affects energy consumption. Factors like material choice, building form,

[4] Note: Designers can leverage the strength of structural steel beams through rigid frame construction, which incorporates joints that effectively counteract movement. This feature enables rigid frame buildings to require fewer vertical supports, facilitating the creation of spacious interiors with higher ceilings. Consequently, a wide range of structures, including event venues, sports stadiums, gyms, manufacturing facilities, and large retail stores, utilize these well-established construction techniques (Inc, 2020) - Left and The Pantheon the world's oldest surviving large span building (CNN, 2023) – Right.

pattern, and scale influence the envelope design. The design process considers environmental, technological, socio-cultural, functional, and aesthetic factors (Gul et al., 2003).

Figure 2.43. A basic structure with its exposed structural elements consisting of floors, walls, and a roof (Lexica.art, 2023).

The building envelope includes two types of components: opaque (walls, roofs, slabs, basements, and doors) and transparent (windows, skylights, ventilators, glazed doors, floors and glass block walls). These components aim to offer physical protection from weather, maintain indoor air quality, exhibit durability, and enhance energy efficiency. Moreover, the building envelope should address the psychological and environmental needs of occupants, with outside views playing a vital role (Raheja, 2016). The building envelope comprises the materials and components that form the external shell of a structure. These elements can be load-bearing or non-load-bearing, depending on the building's structural design. The envelope includes the floor, exterior walls, and roof, which define and safeguard the building. The building envelope ensures comfort, safety, and performance while meeting regulatory standards and user requirements (Greeno et al., 2006).

2.4.1 Floor

Floor systems are horizontal surfaces that need to bear both live loads, such as people and furniture, and dead loads, which include the weight of the floor structure. These systems must effectively distribute their loads across space, either transferring them to beams, columns, or loadbearing walls. Additionally, rigid floor planes can be engineered to function as horizontal diaphragms, acting as wide, thin beams to transmit lateral forces to shear walls (Ching, 2014).

To ensure the appropriate choice of floor systems, designers must consider various factors. These include the utilization of lightweight-concrete slabs, subfloors in direct contact with the ground, the potential need for radiant heating or air conditioning, decontamination requirements, dust prevention measures, anticipated traffic loads, and maintenance costs. These considerations significantly impact the selection process for suitable flooring. Additionally, it is important to consider contemporary standards related to aesthetics, comfort, color, and noise reduction (Ricketts et al., 2001).

Figure 2.44. Raised access flooring is a crucial component in commercial workplaces and office environments (Accessflooring.com, 2023) – Left and C-joist steel floor system (Bmp-group, 2015) –right.

Floor-framing design and construction considerations

Choosing appropriate floor system requires careful consideration of various factors, including load-bearing capacity, durability, fire resistance, weight, thickness, and provisions for electrical and lighting systems, air conditioning suitability, sound insulation, aesthetics, maintenance needs, and construction timeline. Building codes may impose maximum load limits for specific floor systems, irrespective of their calculated capacity. It's crucial not to overlook resistance to lateral forces, especially in seismic or windy regions. Lightweight floor systems may require additional reinforcement at points where they transfer horizontal forces to structural elements (Ricketts et al., 2001)

Durability

Durability is crucial for floors subjected to heavy loads or impacts. A light joist system may work for residential or office buildings, but manufacturing facilities require floors capable of withstanding severe vibrations and impacts. Shallow floor systems deflect more than deeper ones, so the chosen system should minimize excessive or undesirable deflections (Garber, 2006).

Fire resistance

Fire resistance and fire rating are crucial considerations due to building codes prioritizing public safety by specifying the required level of fire resistance. Numerous floor systems are assigned ratings by building codes or fire underwriters to ensure compliance with regulations and determine insurance rates (Garber, 2006).

Dead weight

The weight of the floor system, including the framing, is a critical factor that influences the cost-effectiveness of construction. Employing lightweight floor systems can lead to significant savings in both the weight and cost of a steel frame (Ricketts et al., 2001).

Depth of a floor

In some cases, the depth of a floor system is crucial. Building height restrictions, fire-resistant construction requirements, and zoning regulations may limit the number of stories that can be constructed based on the thickness of the floor system. However, deep floors can increase the height of walls, columns, pipes, and other components, partially offsetting their cost-effectiveness (Garber, 2006).

Wiring systems

Efficient electrical wiring is crucial for offices and similar spaces. Easy relocation of devices is necessary for flexible layouts. Floor systems with hidden wiring and support for recessed lighting are advantageous. Cost-effective air conditioning and ventilation should be considered when selecting floor systems, including duct positioning and support methods (Ricketts et al., 2001).

Acoustics

In floor system design, sound transmission and acoustical treatments are vital considerations. Sandwich-type floor systems with air gaps are better at reducing sound transmission compared to solid systems. While achieving complete soundproofing can be costly, there are satisfactory options based on factors like occupancy type, floor coverings, and ceiling finish. Appearance, maintenance, and construction speed also play important roles in floor design (Garber, 2006).

2.4.2 Façade (exterior wall)

Vertical members that have significantly greater length and height compared to their thickness can be considered as walls. Walls that bear vertical loads are called bearing walls. Walls that only bear their own weight, such as panel or enclosure walls, are called nonbearing walls. Walls primarily designed to withstand lateral loads are referred to as shear walls (Ricketts et al., 2001).

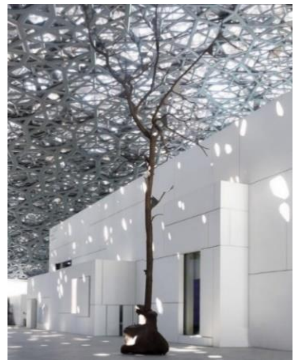
Design and construction consideration of façade (exterior wall)

When designing and constructing exterior walls, various important factors are considered. These include structural integrity and stability, thermal insulation for heat regulation, resistance to weather and moisture, durability with minimal maintenance, fire resistance for safety, adequate ventilation for air circulation, and sound resistance to minimize noise transmission. In summary, exterior walls prioritize strength, thermal resistance, weather and moisture resistance, durability, fire resistance, ventilation, and sound resistance (Lapidus et al., 2023)

2.4.3 Roof

A roof system refers to a collection of roof components that work together to protect and insulate the upper surface of a building. This assembly includes the roof deck, vapor retarder, roof insulation (if present), and the roof covering. Its purpose is to provide weatherproofing and insulation for the building's top surface (Ricketts et al., 2001). Besides The roof system is crucial for protecting the interior spaces of a building. The shape and angle of the roof must match the chosen roofing material, such as shingles, tiles, or a continuous membrane. This ensures proper drainage of rainwater and melted snow through drains, gutters, and downspouts (Ching, 2014).

Figure 2.45. The Louvre Abu Dhabi is an art museum located on Saadiyat Island in Abu Dhabi, United Arab Emirates (VERMA, 2023).



Key design and construction considerations of roof

Designing and applying a roof involves several crucial considerations that are discussed below.

Need for familiarity with roof design

Designers often struggle with roof design due to a lack of familiarity with the principle involved. To overcome this, they should work closely with experienced roofing contractors and consider engaging a professional roofing consultant for comprehensive assistance (Abdelsamee, 2020).

Building owners' requirements

Roof designers must consider the owner's requirements for materials, longevity, and maintenance. Choosing a conservative and durable system is prudent if maintenance funds are limited (Ricketts et al., 2001)

Building-code provisions for roofs

Designers need to be knowledgeable about building-code regulations that impact roof design. Both model building codes and various state and local codes include provisions that pertain to roof systems, applicable to both new construction and reroofing projects (Ricketts et al., 2001).

Effects of climate

The climate of the construction region plays a vital role in roof system design. It is important to consider the anticipated weather conditions both during installation and in the long term. For example, in cold or rainy areas, choosing materials and a system that can withstand these conditions is essential for a successful roof (Garth et al., 2012).

Effects of roof size, shape, and slope

The size and shape of the roof typically influence the choice of materials and systems. For instance, if the roof is relatively narrow, around 60-90 cm wide and several meters long, it may be easier to install a system other than built-up roofing (BUR). The slope of the roof is a critical factor in determining how rainwater flows and reaches the drainage outlet. Therefore, regardless of the selected materials or system, it is important to ensure that the roof has adequate slope for effective drainage (Ricketts et al., 2001).

Deck suitability

When choosing a deck and the roof-covering material and system, compatibility between the materials is crucial. For example, if a mechanically attached single-ply membrane is preferred, the deck must be able to support the fasteners and have adequate strength. Steel decks, wood planks, or thick plywood decks are suitable options in such cases (Abdelsamee, 2020).

Effects of rooftop traffic

When there will be occasional foot traffic on a roof, such as for equipment maintenance, it is important to include traffic walkway pads for roof protection. These pads can also be beneficial around mechanical equipment to prevent damage from dropped tools (Ricketts et al., 2001).

Esthetic considerations

Aesthetics matter more for steep-slope roofs than for low-slope roofs. However, there are cases where an attractive roof is desired even for low-slope applications. In such instances, extra effort is required to achieve the desired aesthetic outcome (Guyer, 2009).

Effects of wind on roofs

In windy regions, designing wind-resistant roof systems is crucial for optimal performance. Different roof systems, such as asphalt shingles, modified bitumen membrane, ballasted single-ply membrane, and mechanically attached single-ply membrane, have varying load capacities and methods of load resistance (Bodwell, 2017).

Protected membrane roofs and plaza decks

In a protected membrane roof (PMR) system, insulation boards are placed above the membrane and covered with aggregate or concrete paver ballast, providing mechanical and weather protection (Ricketts et al., 2001).

Pre-roofing conference

The project designer should arrange a pre-roofing conference involving the roofing contractor, building owner's representatives, general contractor, and possibly an inspector. If there is rooftop equipment, relevant subcontractors should also be present. The conference aims to clarify drawings and specifications, address design concerns, assess the roof deck's readiness, and emphasize the importance of preventing damage to the completed work (Ricketts et al., 2001).

Warranties

While long-term roofing warranties are prevalent, their significance in selecting a roof is sometimes overstated. Instead of solely prioritizing warranties, building owners and designers should pay attention to other factors that have a greater impact on the overall success of a roof (Ricketts et al., 2001).

Roof maintenance

Once a quality roof has been provided to the building owner, it is crucial for the owner to establish a routine of regular roof inspections and timely maintenance or repairs. While certain systems may require less maintenance, no roof should be neglected once it is installed (Abdelsamee, 2020).

Reroofing

Replacing or installing a new roof over an existing one is complex. Additional issues may arise due to existing building conditions that led to the previous roof's failure. It is crucial to identify the causes and address any underlying issues during the design phase (Guyer, 2009).

Reroofing Procedures

There are two main methods for reroofing: removing the existing system down to the deck or installing a new roof covering over it. Removing the existing system allows a thorough examination of the deck's condition but is costlier and can expose the interior to water damage. Installing a new roof covering preserves insulation and provides protection during installation, which is desirable in certain regions (Ricketts et al., 2001).

Roof Moisture-Detection Surveys

Various methods, such as infrared photography and electronic devices, can effectively locate moisture sources within a roof membrane system. These methods help identify issues like blisters, cracks, and splits that are often found away from the actual leak source (Ricketts et al., 2001).

2.5 Envelope geometry

Envelope geometry is the combination of the three geometries of a building which are the geometry of floor, roof and external wall of a building. So, it is measured by the size, shape and form of the envelope which are the floor, external wall or facade and roof of a building.

2.5.1 Floor geometry

The geometry or shape of a building floor layout is the spatial attribute that defines the outline of the building. It affects the areas and sizes of vertical components such as external walls and associated finishes, windows, partitions and associated finishes, etc., as well as the perimeter detailing such as ground beams, fascia, and the eaves of roofs. The key factors influencing decisions on the outline of a building shape for a proposed project include the shape of the site (plot); functional requirements such as natural lighting and good views; and manner of use such as coordination of manufacturing processes, and the forms of machines and finished products in a factory building (Ibrahim A. D., 2007).

Size of floor

The size of floor is the overall magnitude or dimensions of a floor. This can be quantified using various linear measurements, including length, width, height, diameter, and perimeter. These measurements help us understand the physical extent and boundaries of the floor. Furthermore, the size of a floor can also be expressed in terms of its area, which represents the two-dimensional space it covers, or its volume, which indicates the three-dimensional capacity enclosed by the floor. By considering these different measurement perspectives, we gain a comprehensive understanding of the spatial characteristics and capacity of the floor.

Shape of floor

The shape of a floor pertains to the geometrical characteristics and visual appearance of the floor, specifically referring to the exterior outline determined by its perimeter. It encompasses the overall shape and configuration of the floor, representing the contours and boundaries that define its boundaries. The shape of a floor can vary and may include various geometric shapes such as rectangles, squares, circles, or irregular polygons. It is through the shape of the floor that its distinctive visual features and spatial arrangement are discerned.

2.5.2. Façade (external wall) geometry

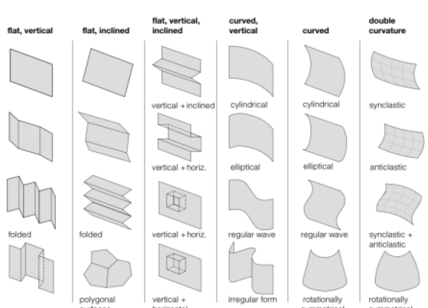
Size of external wall or facade

The size of a facade refers to the overall magnitude or dimensions of the exterior wall. It can be quantified using various linear measurements such as length, width, height, diameter, and perimeter. These measurements help determine the physical extent and boundaries of the facade. Additionally, the size of a facade can also be described in terms of its area, which represents the two-dimensional surface it occupies, or its volume, which represents the three-dimensional space enclosed by the facade. Other factors may also contribute to assessing the size of a facade. By considering these different measurement perspectives, we can gain a comprehensive understanding of the spatial characteristics and capacity of the facade.

Shape of external wall or facade

The shape of a facade refers to the visual and geometric characteristics of the exterior wall. It represents the overall appearance and outline of the facade as seen from the outside, determined by its enclosing area on the building's exterior. The shape of a facade encompasses its distinctive contours, proportions, and design elements that contribute to its visual identity. It is through the shape of a facade that the architectural style, features, and aesthetic appeal of a building are expressed and perceived.

Figure 2.46. *Different geometries of façade (Herzog, 2004).*



2.5.3 Roof geometry

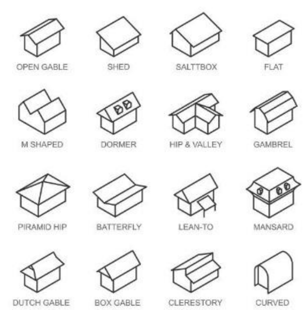
Size of roof

The size of a roof refers to the overall magnitude or dimensions of the roof structure. It can be measured using linear dimensions such as length, width, height, diameter, and perimeter. These measurements provide insights into the physical extent and boundaries of the roof. Additionally, the size of a roof can also be described in terms of its area, representing the two-dimensional surface it covers, or its volume, indicating the three-dimensional capacity enclosed by the roof. Other factors or measurements may also contribute to assessing the size of a roof. By considering these different measurement perspectives, we can obtain a comprehensive understanding of the spatial characteristics and capacity of the roof.

Shape of roof

The shape of a roof refers to the visual and geometric appearance of the roof structure. It represents the overhead outline of the roof plane as seen from above, defined by its covering on the top area of a building. The shape of a roof encompasses its distinct contours, slopes, and architectural design elements that contribute to its visual identity. It is through the shape of a roof that the architectural style, functionality, and aesthetics of a building are expressed and observed.

Figure 2.47. *Different roof shapes (Roof Structure Types: Materials and Shapes for Denver CO Homes, 2023).*



2.6 Envelope construction

It is measured by the size, shape and form of the envelope, which includes the floor, external wall, and roof of a building, and determined by the materials utilized and the construction methods employed during the construction process. The choice of materials and construction techniques influences the dimensions and overall size of the building's envelope. By carefully selecting suitable materials and employing appropriate construction methods, the size and proportions of the floor, external wall, and roof can be effectively determined and implemented in the building's construction.

2.6.1 Floor construction

The construction of a floor system can involve either a combination of linear beams, joists, and decking or a solid reinforced concrete slab. The depth of the floor system is influenced by the dimensions of the areas it needs to span and the strength of the materials employed. Additionally, the presence and positioning of cantilevers and openings within the floor surface should be taken into account when designing the structural supports. The interface between the floor structure and the supporting foundation and walls, along with the edge conditions, impacts both the structural stability of the building and its visual appeal, because it must safely support moving loads, a floor system should be relatively stiff while maintaining its elasticity. The primary concern regarding excessive deflection and vibration in a floor system is their negative impact on the integrity of finish flooring and ceiling materials, as well as human comfort (Ching, 2014).

When incorporating mechanical or electrical lines within a floor system, it is essential to take into account the depth of the floor construction and the spaces available for accommodating these utilities. In the case of floor systems between stacked habitable spaces, it becomes necessary to consider factors like preventing the transmission of airborne and structure-borne sound and ensuring the assembly has an appropriate fire-resistance rating (Ching, 2014).

2.6.2 Façade (External wall) construction

Exterior wall constructions need to withstand horizontal wind loading and have the capability to function as shear walls, transferring lateral wind and seismic forces to the foundation. Their primary role is to provide protection from the elements for the interior spaces of a building, and therefore their design should effectively control the passage of heat, air infiltration, sound, moisture, and water vapor. The exterior skin, whether applied separately or integrated with the wall structure, should exhibit durability and resistance against weathering from sun, wind, and rain. Building codes define the required fire-resistance rating for exterior walls, loadbearing walls, and interior partitions (Ching, 2014).

2.6.3 Roof construction

The construction of a roof involves managing moisture vapor, air infiltration, heat flow, and solar radiation. Fire resistance may also be required. The roof must support its own weight, along with equipment, rain, and snow. Flat roofs used as decks must accommodate live loads. Wind, seismic, and uplifting forces must be considered and transferred to the supporting structure. The roof structure affects interior space layout and ceiling types. The design of the roof, whether flat or pitched, gabled or hipped, wide or detailed, impacts the building's appearance. The roof can be visible or concealed, influencing the upper boundaries of interior spaces (Ching, 2014).

2.7 Envelope construction method

Envelope construction method is a different types of methods applied for the construction of the envelope which includes methods of construction of a floor, external wall and roof of a building.

2.7.1 Floor construction method

Floor construction method is a different types of techniques applied for the construction of a floor.

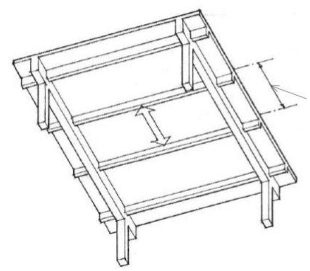
Concrete slab

Concrete slabs are plate structures that are reinforced to span either one or both directions of a structural bay (Ching, 2014).

One-Way Slab

A one-way slab is uniformly thick, reinforced in one direction, and cast integrally with parallel supporting beams (Ching, 2014).

Figure 2.48. *A concrete slab (Seo, 2021)- left and one way slab (Ching, 2014) – right*



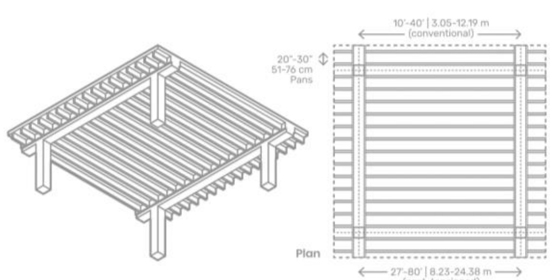
One-Way Joist Slab

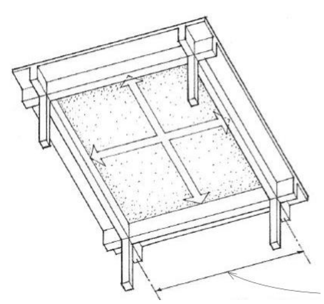
A joist or ribbed slab is cast integrally with a series of closely spaced joists, which in turn are supported by a parallel set of beams. Designed as a series of T-beams, joist slabs are more suitable for longer spans and heavier loads than one-way slabs (Ching, 2014).

Two-Way Slab and Beam

Two-way slabs can be reinforced in two directions and integrated with beams and columns. This construction method is suitable for medium spans, heavy loads, and high lateral force resistance. For cost efficiency, two-way slabs are often built as flat slabs or plates without beams. (Ching, 2014).

Figure 2.49. *One-Way Joist Slab (Dimensions.com, 2023) – Left and Two way slab and beam (Ching, 2014) – right*

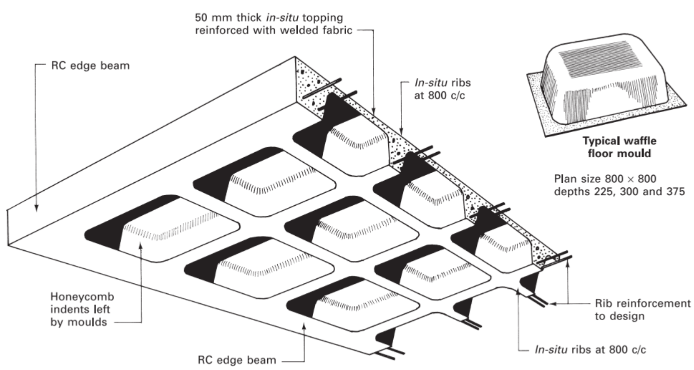




Two-Way Waffle Slab

Two-way waffle slabs are a cost-effective alternative to in-situ flat slabs or suspended floors. They require less concrete and reinforcement, reducing the need for beams and columns and saving on foundations. The distinctive honeycomb pattern on the underside adds visual appeal with attractive shadow patterns. These slabs are cast over lightweight molds or pans made of materials like glass fiber, polypropylene, or steel, creating a ribbed floor in two directions (Chudley et al., 2007).

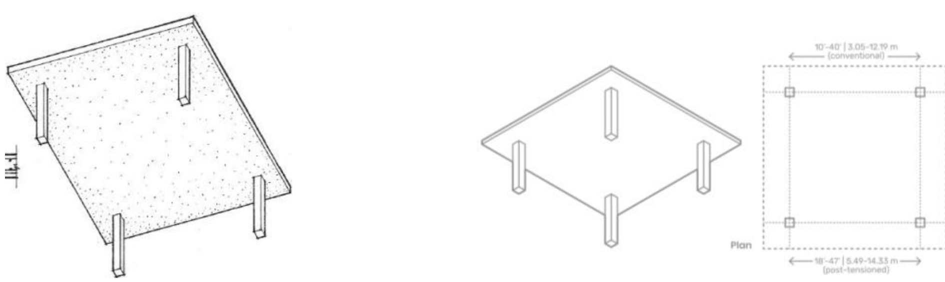
Figure 2.50. *Two-Way Waffle Slab (Chudley et al., 2007).*



Two-Way Flat Plate slab

A flat plate is a concrete slab of uniform thickness reinforced in two or more directions and supported directly by columns without beams or girders. Simplicity of forming, lower floor-to-floor heights, and some flexibility in column placement make flat plates practical for apartment and hotel construction (Ching, 2014).

Figure 2.51. *Two way flat plate slab (Ching, 2014).*



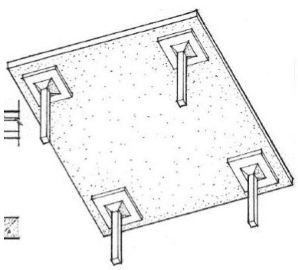
Two-Way Flat Slab

A two-way flat slab refers to a flat plate that is reinforced and made thicker at its column supports. This reinforcement and thickness enhance its ability to resist shear forces and moments.

Pre-stressed concrete floor

Pre-stressed concrete is reinforced by pre-tensioning or posttensioning high-strength steel tendons within their elastic limit to actively resist a service load. The tensile stresses in the tendons are transferred to the concrete, placing the entire cross section of the flexural member in compression. The resulting compressive stresses counteract the tensile bending stresses from the applied load, enabling the pre-stressed member to deflect less, carry a greater load, or span a greater distance than a conventionally reinforced member of the same size, proportion, and weight (Ching, 2014).

Figure 2.52. *Two way flat slab (Ching, 2014) – left and Precast pre-stressed solid floor slabs (Chatfield, 2019) – right*



There are two types of pre-stressing techniques. Pre-tensioning is accomplished in a pre-casting plant, while posttensioning is usually performed at the building site, especially when the structural units are too large to transport from factory to site (Ching, 2014).

Pre-tensioning

This method involves pre-stressing the wires or cables before the concrete is poured around them. The pre-stressing wires are anchored at one end of the mold and then subjected to hydraulic jacks from the other end, until the desired level of stress is achieved. It is common practice to intentionally apply an additional 10% stress to the wires to compensate for anticipated losses due to factors like creep, shrinkage, and relaxation. Once the wires are stressed, the side forms of the mold are positioned, and the concrete is poured around the tensioned wires. Typically, the casting is then subjected to steam-curing for a period of 24 hours to achieve the desired strength, often specified as 28 N/mm2 within the 24-hour timeframe. Pre-tensioning is a method of prestressing commonly utilized by manufacturers of precast elements like floor units and slabs. It involves the use of the long-line casting technique, where precise metal molds up to 120.00 meters in length can be employed (Roger et al., 2006).

Posttensioning

In this method, the concrete is poured around ducts that house the stressing tendons. The stressing process takes place after the concrete has hardened. The tendons are subjected to stress from one or both ends, and once the desired stress level is achieved, the tendons are anchored at their ends to prevent them from returning to their original length. This anchoring creates a compressive force within the structure. The anchors themselves become part of the finished component. Post-tensioning is the preferred method for on-site stressing. It is commonly used when the stressing process needs to be carried out at the construction site. (Roger et al., 2006).

Figure 2.53. *Installation of pre-tensioned slab (Spanwright, 2023) – Left and A suspended slab with post tensioning cables laid in position (Builderbill, 2012) – Right*

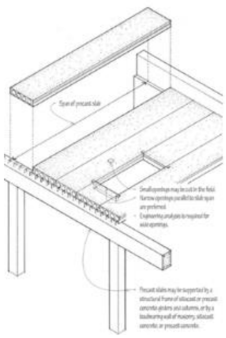
Precast concrete floor systems

Over time, reinforced precast concrete units have been developed as an alternative to in-situ reinforced concrete slabs in order to address or mitigate the drawbacks associated with them. These drawbacks include the requirement for formwork, the time needed for the concrete to cure before releasing the formwork for reuse and making the floor available for use, as well as the limited contribution of a significant portion of the concrete to the overall strength of the floor. In order to achieve maximum cost-effectiveness with a specific precast flooring system, the design of the floors should adhere to the span, width, loading, and layout limitations of the considered units (Chudley et al., 2007).

Structural steel framed floor system

Structural steel girders, beams, and columns play a vital role in creating the framework for various structures, from small one-story buildings to towering skyscrapers. The primary choice for floor framing is typically the standard hot-rolled steel sections. These sections are commonly designed as simply supported beams arranged in orthogonal grids. This framing method has remained largely unchanged over the years for a couple of reasons. Firstly, the manufacturing processes for rolled sections are well-established globally, ensuring their availability. Secondly, these framing systems are straightforward to design and erect. Nevertheless, the field of structural framing continually evolves, with new methods and techniques emerging regularly (Murray, 1990).

Figure 2.54. *Precast concrete floor systems (Ching, 2014) – left and Steel framed floor system (Australian Steel Framing, 2020) - right*



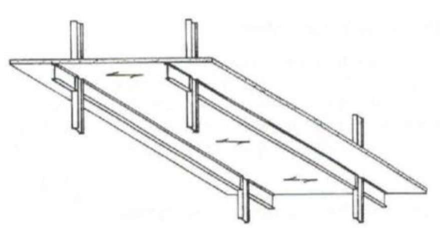
One-Way Steel Beam Floor System

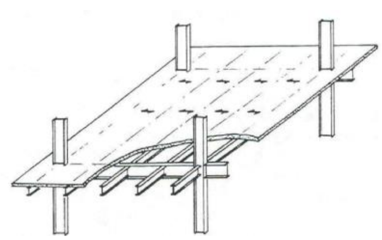
Each pair of external columns supports a long-spanning beam or girder. This system is suitable for long, narrow buildings, especially when a column-free space is desired (Ching, 2014).

Two-Way Steel Beam Floor System

Two-layer system increases floor depth considerably but provides more space for mechanical services. Girders spanning the short axis of a building can contribute to the lateral stability of the structure. Steel framing should utilize rectangular bay units, with comparatively lightly loaded beams spanning farther than more heavily loaded girders (Ching, 2014).

Figure 2.55. *One-way steel beam system – left and two way steel beam system – right*





Triple Steel Beam Floor System

When a large, column-free space is required, long-spanning plate girders or trusses can be used to carry the primary beam, which in turn support a layer of secondary beams (Ching, 2014).

Wood joist framed floor

For wooden joisted floors, the timber can be used as sawn or processed into regular shapes. It is advisable to treat the timber with preservatives at the sawmill to protect against insects and fungi. Stress grading is necessary for structural timber used in accordance with Building Regulations. The grade depends on the span, expected loads, and overall weight of the floor, including additional materials. (Fleming, 2005).

__Figure 2.56.__ Triple beam system – left and wooden framed floor (Gallant, 2021) – right

2.7.2 Façade (external wall) construction method

Facade construction method is a different types of techniques applied for the construction of a building facade.

Concrete and Masonry Bearing Walls

Concrete and masonry walls are noncombustible and rely on their mass for strength. Minimum thickness for reinforced concrete walls is 100mm. Care should be taken with joints in separate sections. Concrete walls have high thermal conductivity and noise transmission, possibly requiring internal insulation and a vapor barrier. Larger structures may require expansion joints every 20 to 25 meters (Abankwa, 1981).

Metal and Wood Stud Walls

Studs in cold-formed metal or wood walls support sheathing materials at regular intervals. Wall cavities can accommodate insulation and mechanical services. Different finishes can be applied to stud framing, with some requiring a nail-base sheathing. Stud walls offer flexibility in form and fastening, and can be assembled on-site or panelized off-site (Ching, 2014).

Precast concrete walls

Precast concrete walls offer superior architectural texture and finish, meeting exterior performance requirements. They save time and labor during construction and can handle larger panels efficiently. These panels are commonly used as cladding, requiring proper anchorage for stability against gravity, wind, and seismic forces (CMHC, 2002).

Tilt-up construction

"Tilt-Up" is a construction method for concrete walls that eliminates the need for formwork. It involves casting concrete slabs horizontally, which are later lifted and tilted into place using a crane. This technique is also known as "tilt-wall" or "site-cast precast concrete walls," but "Tilt-Up" is the commonly used and accepted term. (Wendy, 2011).

Masonry walls

Masonry walls are durable and withstand weathering and physical damage. Reinforced masonry is designed for severe weather conditions. Stone and brick are the primary materials used in masonry construction, along with alternative options (Christine, 2012).

Adobe wall

Adobe mud blocks have a rich history dating back to 8000 B.C. They are sun-dried on-site using local soil, making the process self-sufficient and eco-friendly. Mud mortar is used to hold the blocks together. Adobe structures are often built without skilled technicians, hence known as "non-engineered construction." (Garcia, 2004).

Rammed earth wall

Rammed Earth, also known as pise, is an ancient and widely practiced natural building technique found across all continents of the world. Rammed Earth buildings possess numerous desirable characteristics. They are constructed using a low-tech approach, making them cost-effective to build. Additionally, these structures require minimal maintenance and are well-suited for both cold and hot climates (Dabaieh, 2023).

Figure. 2.57. *Tilt up wall construction method (Randoco, 2023) – left and Adobe wall construction method (Archdaily, 2023) – Right*

Stone masonry

Stone masonry can be categorized as ashlar or rubble. Ashlar consists of precisely crafted stones with thin joints, ideal for prestigious facing work. Rubble walls, on the other hand, use natural and unrefined stones with wider joints, giving them a rugged appearance. (Chudley et al., 2007).

Figure 2.58. *Ruins of the Yeha temple in Yeha, Ethiopia, Africa a photograph by Artush Foto (Pixels, 2020)- left and African children's library with rammed earth walls by BC Architects and Studies (Frearson, 2014) – right.*

Structural steel framed wall

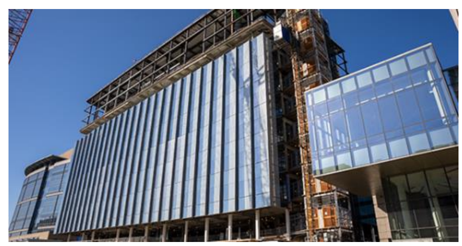
The steel-framed wall is similar to timber framing, using standardized sections to construct the structural frame. Plasterboard is applied to the frame and filled with insulation. The wall consists of cold-formed galvanized steel channels that are rolled, notched, holed, and folded to create a stud frame. These channels can be customized on-site and secured with self-drilling screws. Panels are prefabricated in a factory to modular sizes and assembled on-site to form the complete structure (Chudley et al., 2007).

Balloon framed wall

In balloon-framed wall construction, full-height studs are used, but finding long enough timbers can be challenging. The middle of the studs acts as a connection point for the intermediate floor. It's important to fix all timbers, including joists and roof timbers, at consistent intervals. This allows for direct transfer of loads to the studs and transmission through the ends of the joists. The floor joining, located halfway up the stud length, relies on two types of support: a thin timber called a riband embedded into the inner face of the stud and a halving joint connecting the joist to the stud, reinforced by nailing (Fleming, 2005).

Figure 2.59. *Steel stud wall framing (Stratco, 2019) – left and Balloon framed house (Potter, 2021) – middle and a curtain walled building (Umassmed, 2022) – right*





Curtain walls

Curtain walls are a type of lightweight cladding that is affixed to a framed structure, creating a full covering or protective layer around the structural frame. These claddings do not bear any structural loads and are designed to support only their own weight and any wind loads imposed on them. The transfer of these wind loads to the structural frame is achieved through connectors, typically located at floor levels (Roger et al., 2006). Curtain walls serve their primary function without requiring excessive thickness. In skeleton-frame construction, exterior walls have the main purpose of keeping wind and weather out of the building, which is why they are called curtain walls. Nonbearing walls can be supported by the structural frame of the building, additional framing (such as girts or studs) connected to the structural frame, or the floors. The exterior surface of a curtain wall should be durable, capable of lasting as long as the building, with minimal maintenance (Ricketts et al., 2001).

2.7.3 Roof construction method

Roof construction methods encompass a diverse range of techniques employed during the construction process to create a sturdy and functional roof for a building. These methods involve a combination of structural elements, materials, and installation techniques to ensure a reliable and durable roofing system.

Reinforced concrete roof slabs

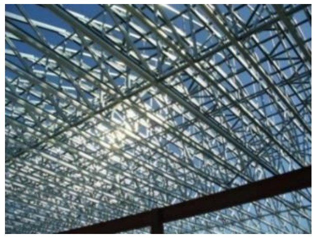
Reinforced concrete roof slabs are formed and sitecast in the same manner as the concrete floor system. Reinforced concrete may be designed and cast into a variety of other roof forms, such as folded plates, domes, and shell structures (Ching, 2014).

Figure 2.60. *An example of pitched concrete roof (Icfmag, 2022).*

Precast concrete roof systems and Structural steel roof framing

Precast roofs are increasingly popular due to their safety, quality, and efficient installation. Compared to traditional methods, precast concrete units save significant time, reducing construction duration and enabling early occupancy. Manufactured under controlled conditions and installed by skilled professionals, precast units meet strict standards and prioritize Health & Safety practices. Supported by concrete or steel beams or solid block walls, they provide structural stability. Additionally, precast roofs offer excellent sound insulation and fireproofing properties, making them highly desirable roofing solutions (Quinn, 2019). A flat roof structure may be framed with structural steel members similar to the way steel floors are framed (Ching, 2014).

Figure 2.61. *Forever home Precast Concrete Roof System (Foreverhome, 2023) – Left and Structural steel roof framing (Robins, 2014) – middle and right.*



Steel rigid frames

A rigid frame consists of two columns and a beam or girder connected at their joints. The rigid joints prevent free rotation of the members, resulting in axial, bending, and shear forces when loads are applied. Vertical loads also create horizontal thrusts at the base of the frame. While statically indeterminate, a rigid frame is only rigid in its plane (Ching, 2014).

Steel trusses

Steel trusses are generally fabricated by welding or bolting structural angles and tees together to form the triangulated framework. Because of the slenderness of these truss members, connections usually require the use of steel gusset plates. Heavier steel trusses may utilize wide-flange shapes and structural tubing (Ching, 2014).

Space frames

A space frame is a lightweight and efficient structural system made up of interconnected grids or frameworks. It allows for large spans without the need for additional supports, making it ideal for creating open spaces in various industries such as construction, stadiums, and transportation infrastructure. Its strength, versatility, and aesthetic appeal make it a popular choice for striking architectural designs (Greeno et al., 2006).

Open-web joist framed roof and Metal roof decking

Roof systems using open-web steel joists are similar in layout and construction to steel joist floor systems. And metal roof decking is corrugated to increase its stiffness and ability to span across open-web steel joists or more widely spaced steel beams and to serve as a base for thermal insulation and membrane roofing.

Cementitious roof planks

Cementitious roof planks are made from Portland cement, lightweight aggregate, and galvanized welded wire fabric reinforcement. They can span wood or steel roof framing, serving as roof sheathing or permanent formwork. They provide thermal and acoustic insulation and can be used in fire-resistant construction.

Rafter framed pitched roof, Wood rafter framing and flat roofs

A pitched roof is characterized by a slope angle ranging from 10° to 70°, distinguishing it from flat roofs below this range and walls above 70°. Pitched roofs encompass various types: gable roofs feature a downward slope from a central ridge, forming gables at both ends; hip roofs have sloping ends and sides meeting at an inclined angle, and gambrel roofs exhibit a steeper slope below a shallower slope on each side and roof structures framed with wood rafters are an essential subsystem of wood light-frame construction. The dimension lumber used for roof joists and rafters is easily worked and can be quickly assembled on site with simple tools. Conversely, flat roofs are constructed using a framing method similar to floor joist framing (Chudley et al., 2007).

Light-gauge roof framing

Roofs and ceilings may be constructed with light-gauge steel members in a manner similar to wood light-frame construction. The light-gauge steel members may also be screwed or welded together to form roof trusses.

2.8 Envelope construction material

Envelope construction material are the material applied for the construction of the envelope that includes material used for the construction of floor, external wall and roof of a building.

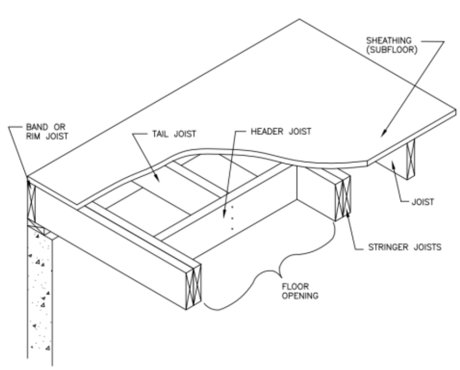
2.8.1 Floor construction material

Flooring materials can be categorized into two groups: floor construction materials and floor finishing materials. Floor construction materials are used in the actual construction of floors, while floor finishing materials are used as coverings for the floor surface (Panda, 2021). This research primarily focuses on floor construction materials, which include cement, limestone, brick, and wood.

Wood

A wood floor is a horizontal structural system made up of joists, girders, and sheathing. Traditionally, solid sawn lumber has been used for floor joists and girders, but there is a growing trend towards using parallel chord wood trusses and wood I-joists due to their dimensional consistency and spanning capabilities. Floor joists are horizontal framing members that support the floor sheathing and transfer the weight of the floor to the walls, girders, or columns below (Coulbourne, 2017).

Figure 2.62. *Wood framing (Coulbourne, 2017).*



Girders are horizontal members that support floor joists not otherwise supported by interior or exterior load-bearing walls. Floor sheathing is a horizontal structural element, usually plywood or oriented strand board panels that directly supports floor loads and distributes the loads to the framing system below (Coulbourne, 2017).

Reinforced Concrete

Reinforced concrete floor systems can provide an economical solution to a wide variety of situations. Concrete, reinforcement, and formwork are the three primary materials and expenses in cast-in-place concrete floor construction to consider throughout the design process, but especially during the initial planning stages. Of these three, formwork comprises about 50 to 60 percent of the total cost and has the greatest influence on the overall cost of the floor system. The cost of the concrete, including placing and finishing, typically accounts for about 25 to 30 percent of the overall cost. The reinforcing steel has the lowest influence on overall cost (David et al., 2011).

Constituent elements of composite slabs – materials

Composite slabs span 3-4.5m between supports, with thicknesses ranging from 100mm-320mm based on load requirements.

Concrete

Composite slabs incorporate both normal weight concrete, made with dense aggregates from natural sources, and lightweight concrete, which utilizes artificially produced aggregates like expanded pulverized fuel ash pellets. Lightweight concrete has higher cement and water contents due to the aggregate's water absorption.

Bar reinforcement

In composite slabs, the bar reinforcement typically consists of a lightweight welded fabric, often complemented by additional bar reinforcement.

Fiber reinforcement

Fiber reinforcement for composite slabs involves incorporating short fibers made of steel, polypropylene, or a combination of both into the concrete mix before placement. In certain conditions, fibers can replace a portion or all of the fabric reinforcement. The inclusion of fiber reinforcement leads to the formation of a three-dimensional composite slab with reinforced concrete (Rackham et al., 2009).

2.8.2 External wall or façade construction material

Facade construction materials encompass the materials utilized for constructing the exterior face of buildings, including the walls and other visible surfaces.

Natural stone

If the "Stone Age" is taken to be the first relevant cultural epoch, then it is because people used the natural materials at hand to produce diverse utensils. Throughout history, the use of natural stone ranges from tools and weapons to tombs and walls and to precision artefacts, such as jewelry (Herzog, 2004).

Clay

Fired materials made from clay, the main component of all ceramic building materials, have been used in building for more than 7000 years. Although the basic principles of their production have hardly changed in that time, ceramic materials tend to be classed among the "modern" building materials (Herzog, 2004).

Concrete

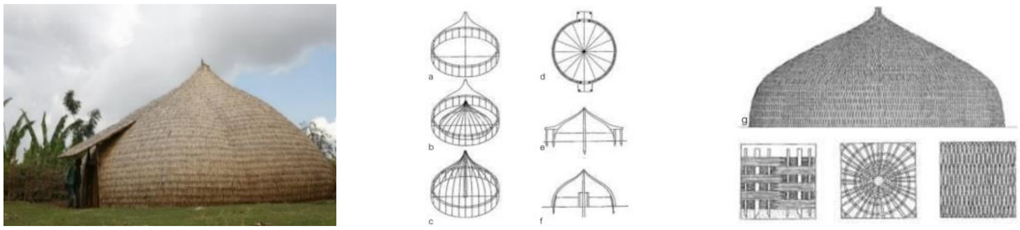
Concrete, the very first artificial and heterogeneous building material, marked an important stage of development in the history of building. Concrete is extremely durable, easy to work with, easy to connect and, in conjunction with steel, has a high loadbearing capacity. Reinforced concrete was therefore widely adopted for structural purposes and, thanks to its mold-ability, opened up new avenues to (completely) different forms of construction (Herzog, 2004).

Figure 2.63. *Mountain village in Ticino (CH) (Herzog, 2004)- Left, Clay - Church, Atlantida (ROU), 1959, Eladio Dieste (Herzog, 2004) – middle and concrete Pilgrimage church, Neviges (D), 1968, Gottfried Böhm (Herzog, 2004) – right*

Timber

Wood has been widely used as a building material throughout history. From the Neolithic period, timber was used to create frameworks and woven walls using trunks, branches, and other natural timber products. Over time, squared logs and round logs were utilized for buildings, long spans, log cabins, and stave churches. The methods of working timber we use today, such as sawing and chipping, developed over the past thousand years and became more prevalent during the Industrial Revolution. The roots of modern timber engineering can be traced back to the nineteenth and early twentieth centuries (Herzog, 2004).

Figure 2.64. *Sidamo House, Hagara Salam (Ethiopia)*



The development of timber walls and facades can be traced back to the glasshouses in England and timber frame buildings in Central Europe. A notable example is the Crystal Palace in London (1851), which combined timber and cast iron for its frame construction. Today, timber facade technology ranges from traditional craftsmanship to highly advanced solid timber wall elements produced in automated factories. These elements, in the form of large panels and room modules, can be quickly assembled to create entire buildings (Herzog, 2004).

Metal

Metalworking technologies have played a significant role in the advancement of human civilization. The discoveries of bronze and iron were revolutionary, initially enhancing tools and weapons, but also sparking a wider cultural revolution. Metal has been used in construction since ancient times, with lead, bronze, and copper commonly used for roofing. The Greeks employed bronze, iron, and molten lead to fix stones and seal joints in their temples and walls. In some cases, Gothic buildings rely on concealed iron anchors and ties for stability (Herzog, 2004).

Figure 2.65. *Facade to the offices of the "Maison du Peuple",Clichy (F), 1939, Jean Prouvé – left and Prototype of a "Dymaxion Deployment Unit", 1929/45, Buckminster Fuller* - *right (Herzog, 2004)*

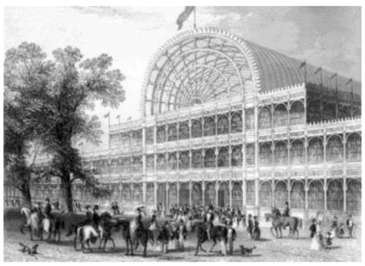
Glass

Glass is among the oldest building materials. Evidence for the use of natural glass from a volcanic origin for making knives and arrowheads, as well as for the production of opaque glass, has been discovered in finds dating back to 5000 B.C. One significant development on the road to the glass we use today was the invention by the Syrians of the blowing iron in the second century B.C. This invention made it possible to produce hollow vessels for the first time. Later, a casting method enabled the Romans to produce the first flat, albeit hardly transparent, glass (Herzog, 2004).

Plastics

Plastics that are widely used in the modern building industry were invented and developed for large-scale production between 1931 and 1938. PVC, for example, became marketable for pipes and fittings by 1935. Initially, plastics were primarily used for internal fittings and furniture. However, in the late 1950s, there was a significant advancement in the development of complete buildings made from synthetic materials. This progress was facilitated by new processes like laminating and the production of molded parts reinforced with glass fiber (Herzog, 2004).

Figure 2.66. *Crystal Palace, London (GB), 1851, Joseph Paxton – left and Tanzbrunnen Pavilion, Cologne (D), 1957, Frei Otto – right.*



Double glass façade

The development of multi-leaf, transparent building envelopes is closely linked with the increasing use of glass in buildings during the seventeenth and eighteenth centuries. This was made possible by progress in the manufacture of glass, such as the invention of the cast glass process in 1687, which allowed flat panes of glass to be produced with a better quality but with reduced effort. The first references to the use of multi-leaf window systems are found in a publication dating from the late seventeenth century (Herzog, 2004).

2.8.3 Roof construction material

Roof construction materials are crucial for building roofs. In recent years, there has been a notable shift in roof design, with some roofs seamlessly integrating with the underlying façade. Previously, roofs were either traditionally tiled or slated pitches, or completely hidden as flat roofs. Now, roofs are recognized as a visible part of the building envelope, equal in importance to the external walls, both aesthetically and technically. The improved performance of roofing systems across different materials has fostered greater experimentation, pushing the boundaries in both technical aspects and visual appeal. Recent projects demonstrate a growing trend of unifying the structural form of walls and roofs. This approach utilizes the same construction methods, materials, and detailing for both elements, enabling more ambitious designs. However, there is a vital distinction between facades and roofs. Facades handle rainwater flowing across their surface, while roofs can experience water submersion. Therefore, roofs require complete sealing in areas prone to water collection, like parapet gutters, assuming rainwater may persist if outlets are blocked. Even pitched roofs anticipate a thin film of water running across (Watts, 2005).

Figure 2.67. *Giant dome over Manhattan (USA), 1960, Richard Buckminster Fuller – left and Corridor facade, office building for Olivetti, Ivrea (I), 1940, Figini & Pollini - Middle and The Eden project Cornwall - primarily ethylene tetrafluoroethylene (ETFE) polymer material was used (Arup, 2023) – Right.*

Some designs employ a watertight, single-layer membrane concept, extending it to encompass the entire external envelope, not just the roof. This leads to innovative sculptural forms that integrate walls and roofs. Moreover, roof systems and facade designs mutually influence each other. Techniques such as bolt fixed glazing, rain screens, silicone bonding, and unitized panels are now incorporated into roof designs, while facades integrate elements like ETFE cushions, polymer membranes, and fabric structures. This exchange of ideas and materials between roofs and facades fosters innovative and integrated design solutions (Watts, 2005).

Metals

A development in metal roofs over the past 10 years has been to improve the visual appearance of all metal roof systems. By the late 1970's, profiled metal sheet roofs had added curved eaves and pressed metal corners to provide concealed gutters that gave the roof a strong 'linear' texture that formed an important part of the design of industrial buildings. The increased reliability of jointing together with the increased use of aluminum sheet instead of steel sheet (with its increased flexibility) led to more adventurous roof forms without affecting the its waterproofing performance (Watts, 2005).

Glass

Over the past 25 years, glass systems have advanced to enhance weather tightness. Initially, 'patent' glazing used metal bars and clips to secure glass in greenhouse systems. Nowadays, patent glazing systems are thermally broken and hold double glazed units. These systems have improved outer seals that can withstand higher wind pressures and are designed for internal drainage and ventilation, similar to facade systems. To address past issues of rainwater penetration due to pressure differences, drainage grooves are now incorporated near the edges of double glazed units. These grooves effectively drain any water that enters through the outer seals. The pressure plate holding the glass in place ensures bottom drainage while allowing air to equalize the pressure inside and outside the system in the drainage chamber (Watts, 2005).

Figure 2.68. *BYU sports facility has a curved metal roof (Infante, 2022) – right and the great glasshouse The Great Glass House Rises from the Ground like a Giant Blue Egg (inhabitat.com) – right*

Concrete

Advancements in waterproofing membranes for concrete roofs in the past 25 years have focused on increasing flexibility. Traditional asphalt used on concrete decks had limitations in accommodating movement and solar gain. An 'inverted' roof configuration was introduced to address this, with thermal insulation placed above the waterproof membrane to maintain a stable temperature. Polymers added to asphalt have improved flexibility, especially in torch-on membrane sheets. Polymer materials like thermoplastics and elastomers are now more affordable and can be exposed to sunlight, allowing roofs to be self-finished with these materials. Some buildings extend the membrane down the facades for a complete envelope. Smooth substrates can form waterproofing layers similar to fabric membranes, with welded joints for an attractive roof finish resembling fabric 'tent' membranes (Watts, 2005).

Figure 2.69. *Santiago Calatrava's auditorium in Santa Cruz de Tenerife – left and science Hills museum in Komatsu – right (Martin, 2016).*

Timber

Timber-based roofs have developed over the past 20 years to improve their thermal insulation performance. Most techniques of tiles and slates are based on long tradition, but not with the high levels of thermal insulation required in recent years with the need to reduce energy consumption within buildings (Watts, 2005).

Plastics

Translucent plastics are used mainly both to imitate the appearance of glass roof lights as flat sheet materials, and as composite panels. This is gradually changing as plastics are no longer seen as economic substitutes for other materials but as construction materials in their own right. Earlier examples of plastic roof lights suffered from the effects of color fading or of yellowing in transparent or translucent roof lights. The materials and finishes used in bonding are superior to those used 30 years ago, ensuring that color fading is far less pronounced than it was. This is partly due to the coatings used, which are often paint based finishes on opaque panels (Watts, 2005).

Figure 2.70. *Synegics head office - a timber roof structure (Swedishwood, 2020) – Left and The National Aquatics Center in Beijing*[5]

2.9 Computational design

Computational design has played a significant role in establishing a strong relationship between geometry and architecture. Computational Design has revolutionized the AEC industry and design sectors, introducing an entirely new realm of possibilities. The integration of fluid shapes, automation, and robotics has brought about significant improvements to the construction landscape. In essence, computation can be defined as a sequential transformation process driven by precise rules and logical procedures. Computational Design represents the merging of computational power and design techniques, facilitated by a series of logical processes. Throughout history, architects have traditionally relied on their experience and intuition to create innovative designs. However, with the advent of advanced technology, this approach has been completely transformed (HnIn, 2022).

[5] Note: Synergic head office - a timber roof structure (Swedishwood, 2020) – Left and **The National Aquatics Center** in Beijing features a skin made with ETFE, a durable plastic used for roofing, inspired by soap bubbles. Informally known as the Water cube, the structure was designed by PTW Architects and Arup, an engineering firm, for the 2008 Summer Olympics (Allen, 2016) – right.

2.9.1 Types of Computational Design

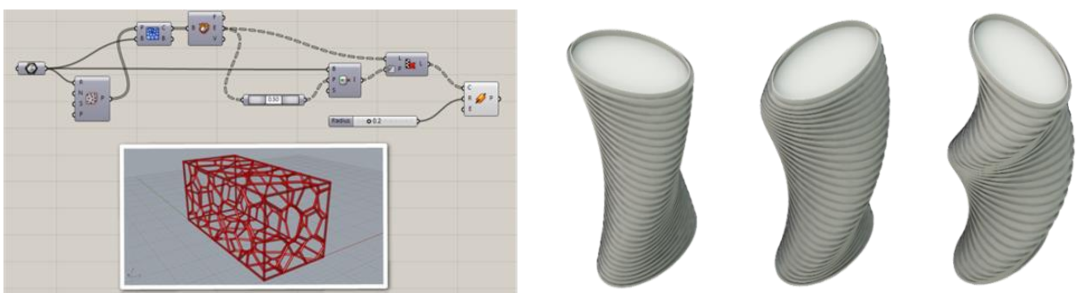
2.9.1.1 Parametric Design

Parametric design, also known as Parametricism, is an approach that involves manipulating parameters using programming languages. Architects like Frank Gehry, Zaha Hadid, and Patrik Schumacher played a significant role in popularizing parametric design. The key feature of this approach is treating the geometric properties of a model as flexible variables (HnIn, 2022).

2.9.1.2 Algorithmic Design

Although parametric design is driven by the manipulation of model parameters, algorithmic design relies on the utilization of algorithms to generate design concepts. These algorithms are sets of rules that define information in a logical sequence to produce a design. Unlike parameters, which typically represent adjustable existing conditions, algorithms are rule-based systems. Algorithmic design not only enables the creation of dynamic forms but also allows for the generation of numerous iterations of such forms within a matter of minutes (HnIn, 2022).

Figure 2.71. *Parametric Design work flow (Sharma, 2022) - left and Algorithmic Design enables the creation of intricate geometries that would present difficulties when using traditional manual design tools. (Antonio, Menezes Leitao, 2022) – Right*



2.9.1.3 Generative design

Generative design often works in conjunction with parametric and algorithmic design approaches, utilizing both methodologies. While the term "generative" implies that it produces designs, it is important to note that parametric and algorithmic design methodologies are closely interconnected with generative design. Algorithmic design employs parameters and algorithms to generate design iterations based on specific constraints. Additionally, there is a more advanced form of generative design known as Evolution-based Generative Design, which involves the evolution of designs by adapting to their environment, similar to natural selection (HnIn, 2022).

2.9.1.4 Performative Design

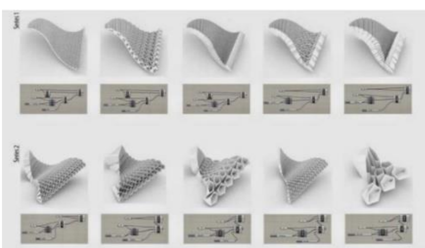
Per-formative design, also known as performance-based architecture, is an important and fruitful design methodology in contemporary times. It revolves around the concept of using simulation-based building design as a fundamental approach for generating forms through per-formative simulation processes. Algorithms play a crucial role in this process, allowing us to analyze, formulate, and create designs that are adaptable to the ever-changing conditions of nature (HnIn, 2022).

Figure 2.72. *Generative design revolutionizes products and the way they are made (McClintock, 2023) – left and The Kunsthaus in Graz by Peter Cook, Colin Fournier; Bollinger and Grohmann (2000-2003) integrates performative method in the design process (Rivka Oxman et al., 2008) – right*

2.9.1.5 Form Finding

Performative design, combined with form finding, has transformed the linear design development process. Computational Design has replaced the outdated reliance on personal preferences and architect visualization. By utilizing performance modeling and simulation, this approach incorporates natural elements and algorithms to achieve optimal forms and dynamic adaptability (HnIn, 2022).

Figure 2.73. *Computational form finding process (Hnin, 2023).*



2.9.2 The Benefits of Computational Design

In accordance with HnIn (2022) Proficiency in Computational Design involves transforming conceptual visions into tangible outcomes, leading to enhanced designs and the discovery of new business prospects. It enables the development of superior solutions, automation of repetitive tasks, mitigation of design risks, cost reduction, and facilitates the exploration of architectural possibilities in terms of geometry.

2.9.3 Popular Computational Design Tools in the AEC Industry

Computational Design differs from traditional CAD processes in two key ways: the use of algorithms and parameters in visual programming. Unlike conventional CAD tools, Computational Design software primarily employs visual programming as its workflow, with text-based programming being an additional skill. This benefits architects by providing an easier way to assemble sequences or programs through graphical interfaces, rather than writing code. Inputs are connected through nodes in a network, resulting in the desired output. Any changes made to the nodes automatically update the 3D model, streamlining the design process (HnIn, 2022).

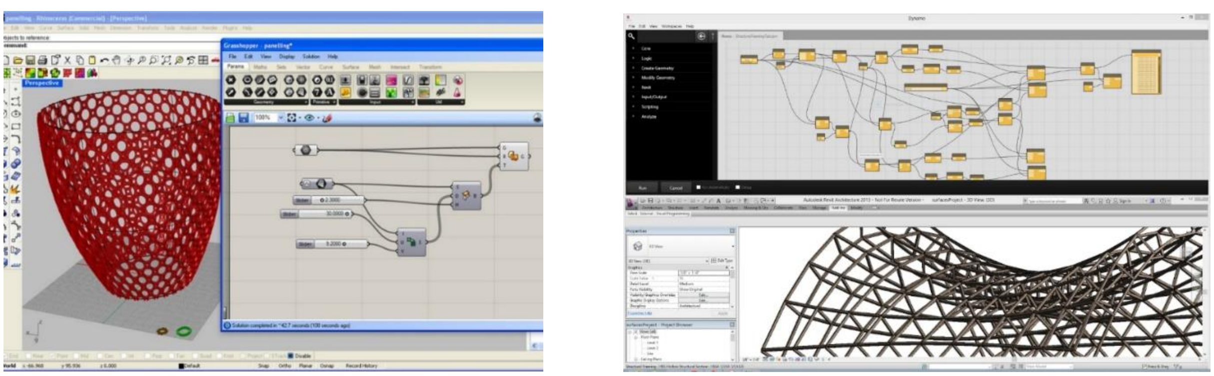
2.9.3.1 Grasshopper

Undoubtedly the most widely used Computational Design tool, Grasshopper is a highly regarded companion to Rhino 3D. Serving as a graphical algorithm editor, it offers a vast library of nodes that greatly facilitate design exploration. The seamless integration with Rhino 3D means that Grasshopper requires no additional installation, making it an accessible and convenient tool for designers (HnIn, 2022).

2.9.3.2 Dynamo

Dynamo serves as a plugin for Revit. Dynamo utilizes the Revit API to enable parametric workflows within the software. Architects and engineers widely utilize Dynamo for various purposes, including performance analysis, automation, and seamless integration with BIM processes (HnIn, 2022).

Figure 2.74. *Grasshopper Window with Rhino (Cleanpng, 2023) - Left and Dynamo + Revit (Constructionreviewonline, 2022) – Right*



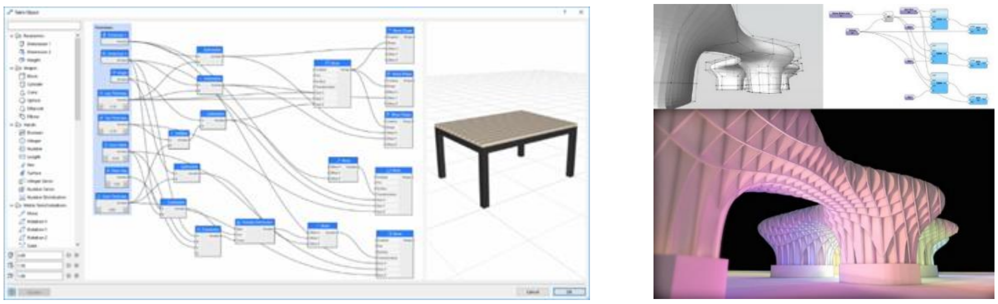
2.9.3.3 Param-O

Param-O is an integrated tool within Archicad that streamlines parametric workflows for architectural design projects. With Param-O, architects can leverage its capabilities directly within Archicad to enhance their design process and incorporate parametric design principles efficiently (HnIn, 2022).

2.9.3.4 Marionette

Marionette is a visual scripting tool integrated with Vectorworks that enables automation and algorithmic modeling. It offers a user-friendly library of nodes, simplifying the creation of complex designs through visual scripting. With Marionette, designers can seamlessly explore and implement algorithmic design principles within the Vectorworks environment. (HnIn, 2022).

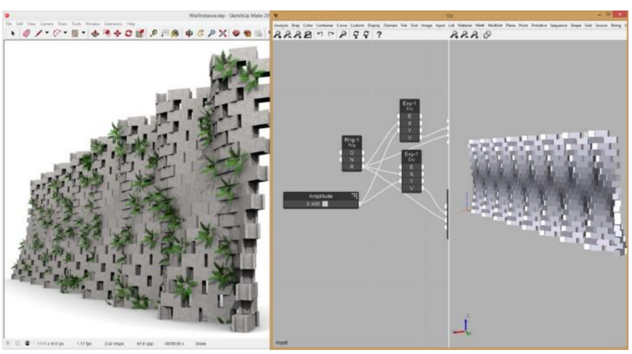
Figure 2.75. *Param-O (Graphisoft, 2023) - Left and Marionette (Vectorworks, 2016) – Right*



2.9.3.4 Viz pro

Viz Pro enhances SketchUp by incorporating parametric modeling capabilities. It includes advanced features such as intricate materials, Boolean Operations, NURBS curves and surfaces. Additionally, it seamlessly integrates with the OpenCascade CAD library (Archgyan, 20222).

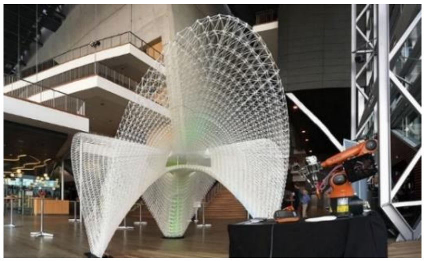
Figure 2.76. *sketch up (Archgyan, 20222) – left and Viz Pro - Right*



2.9.4 Digital fabrication methods

While digital fabrication has been in existence for several decades, its application in design is a relatively new development. Initially, digital fabrication was mainly utilized for demonstration projects like the Daedalus Pavilion. However, in recent times, it has gained traction in addressing significant challenges in society, industries, and large-scale projects, including the construction of iconic structures, such as the ongoing work on the la Sagrada Familia. Three key factors are fueling the growth of digital fabrication: advancements in computer control, a rising demand for intricate construction projects, and the necessity for agility in adapting to evolving needs (Arup, 2020).

Figure 2.77. *Daedalus Pavilion Measures 5m Wide X 5m Deep X 4.5m High, And It Consists of 48 Pieces That Are 3D Printed Using a KUKA Industrial Robot (Parametrichouse, 2023).*



2.9.4.1 Types of Digital fabrication methods

Digital fabrication originated in the late 1960s with CNC manufacturing equipment, primarily focusing on subtractive processes. Today, it encompasses additive, subtractive, and robotic techniques, working with various materials like concrete, steel, timber, composites, and biodegradable materials. Digital fabrication not only advances existing methods but also revitalizes traditional techniques lost during the industrial revolution, adding a captivating dimension to the field (Arup, 2020).

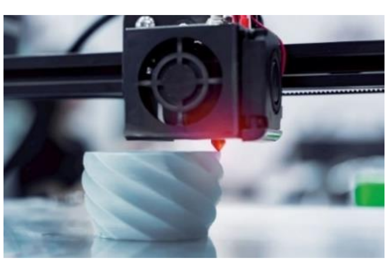
Additive and Additive concrete

An additive process involves the deposition of material, selective sintering, or layer-by-layer assembly to create a component or part. Concrete can be utilized through three primary techniques: printing formwork, extrusion of mortar, and selective powder bed bonding. These methods involve the use of concrete in various ways, such as creating formwork or false molds, extruding mortar directly, or employing selective bonding of powdered concrete layers (Arup, 2020).

Additive metal

Metal additive manufacturing, also known as 3D printing, can be broadly categorized into three main techniques: 3D printing of molds for casting, selective bonding or selective laser sintering (SLS), and an extrusion technique known as wire arc additive manufacturing (WAAM). These techniques enable the production of metal components through additive processes, providing flexibility and efficiency in metal fabrication (Arup, 2020).

Figure 2.78. *Additive manufacturing method (ABB, 2020) - left and Additive concrete construction method (Kauppila, 2023) – Middle and additive metal manufacturing method (Treatstock, 2023) – right*



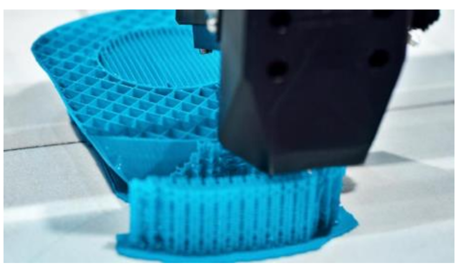
Additive thermoplastics

Fused filament fabrication is a widely used 3D printing process that involves heating thermoplastic filament and precisely extruding it layer by layer. In some cases, the extrusion process utilizes two materials: a support material that is removed after printing, and the final material used for the desired part. This technique enables the creation of complex structures and functional objects with ease and accuracy (Arup, 2020).

Subtractive

A subtractive process involves removing material using a computer-controlled tool following a designated "cutting path." This can be done using a CNC router table for 2D formats or a CNC milling center or CNC band saw for 3D formats. Subtractive techniques offer advantages such as using traditional stock materials, creating intricate geometries, and the widespread availability of CNC machines. The process starts by sculpting away excess material, like from a plywood sheet or stone block, to achieve the desired shape or form (Arup, 2020).

Figure 2.79. *In Additive Manufacturing, Thermoplastic Elastomers Are Used For Advanced 3D Printing Solutions. (Conrad, 2023) – Left and Subtractive Method (Makenica, 2020) – Right*



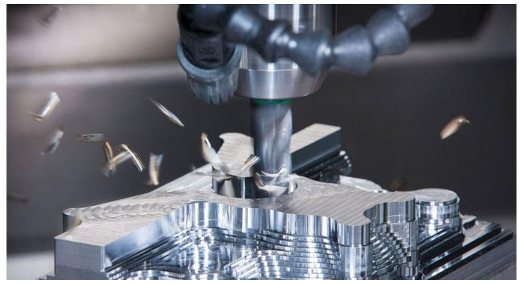
Subtractive formwork for concrete

To create complex formwork for concrete and glass fiber reinforced concrete, various subtractive techniques are employed. These techniques include CNC hotwire foam cutting, CNC foam milling, and CNC timber routing. However, it's important to note that these methods generate waste material during the process (Arup, 2020).

Subtractive metal

Computer numerically controlled (CNC) subtractive techniques are widely utilized in steel fabrication. These techniques involve the use of CNC plasma cutting, high-power laser cutting, high-pressure water jets, and CNC milling to perform various cutting operations. The specific method employed depends on factors such as cost, production rate, and required precision for the given application (Arup, 2020).

Figure 2.80. *CNC Timber Routing of Formwork (Dimar, 2014) – Left and A Machine Subtracting A Metal (Roberson MC, 2022) – Right*



Row or reused materials: Timber and Stone

Computer-controlled machining offers enhanced precision and accelerated cutting capabilities when working with natural materials. This, coupled with digital scanning techniques, empowers designers and fabricators to explore the use of non-standardized materials. By harnessing these technologies, the creative possibilities expand beyond standardized materials, enabling unique and customized design solutions (Arup, 2020).

Forming

Forming is a process that utilizes digital control to bend, stretch, or manipulate an object into a desired shape. Unlike additive and subtractive manufacturing methods, forming does not involve the addition or removal of material. Instead, existing material is reshaped and transformed using precise digital instructions. This allows for the creation of complex and customized shapes without the need for adding or subtracting material (Arup, 2020).

Figure 2.81. *The Stretch-Forming Equipment*

Note: The stretch-forming equipment located at SteelLife in Seoul, South Korea, is equipped with adjustable upper and lower faces that can be brought together to deform steel panels. This process, known as stretch-forming, allows for precise shaping and manipulation of the steel panels by applying controlled stretching forces. This technology, implemented at SteelLife, enables the production of intricate and customized steel components (Arup, 2020).

Metal forming

Various computer-controlled techniques exist for metal forming, including well-established methods like cold metal roll forming and single fabricator multi-point stretch forming. Emerging digital fabrication techniques, such as augmented pipe bending and incremental sheet metal forming, are also gaining traction. These advanced processes utilize computer control to shape metal materials with precision and efficiency, providing fabricators and manufacturers with a diverse range of options (Arup, 2020).

Forming concrete

While techniques for forming or slumping molten glass into shape are well-known, their potential application in forming concrete is often overlooked. However, these techniques can be effectively adapted for concrete forming processes as well. By leveraging the principles of glass forming, such as controlled heating and shaping, it is possible to achieve intricate and customized concrete forms. This opens up new possibilities for architects and designers to explore innovative and aesthetically pleasing concrete structures (Arup, 2020).

Figure 2.82. *Metal Forming - A Cold Forming Operation with Rolls (Voestalpine, 2022) - Left and Glass Slumping – Digital Forming of Glass: (Arzt, 2023) – Right*

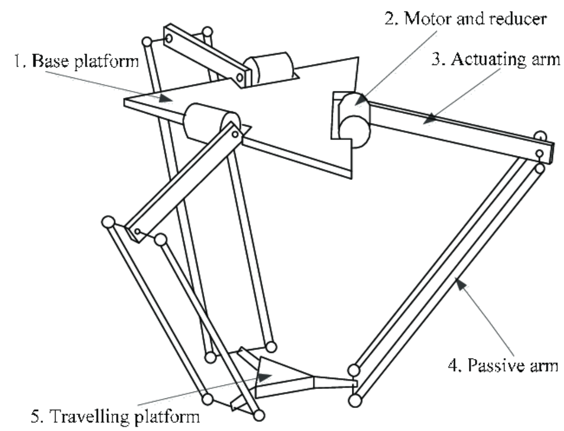
Robotic assembly

Robots are vital in construction, aiding in prefabrication and on-site assembly. They handle tasks such as brick placement and moving façade elements. Cable or delta robots offer flexibility by spanning distances of 10 to 100 meters, surpassing the reach of traditional static robots. This allows them to access larger areas where payload and precision are less crucial. Drones are being explored as assembly tools, despite limitations. Robotic assembly, along with partially learned control, has the potential to construct complex structures, leading to improved architectural and structural designs (Arup, 2020).

Cable or delta robots

The key advantage of delta and cable robots lies in their extended reach capabilities. Delta robots utilize a system of three interconnected rigid elements and joints to control their position. On the other hand, cable robots rely on cables to achieve precision positioning. Unlike traditional industrial robots, which are constrained by the length and strength of their arms, cable robots offer the ability to operate and maneuver over much larger areas, enabling more extensive and precise positioning (Arup, 2020).

Figure 2.83. *Industrial Robots At The ETH Zurich, Switzerland, Assemble Complex Out-Of-Plane Panel Frames (Arup, 2020) – Left Scheme Of The Delta Robot (Researchgate, 2016) – Right*



2.10 Contextual review

2.10.1 Overview of selected buildings

In chapter one, the research identified various problems, one of which highlights that the buildings and local practices in Addis Ababa, excluding its vernacular and ancient elements, have a limited impact on the development of geometry and new construction methods within the Ethiopia AEC industry. Despite some attempts to innovate construction methods and materials, there is still a predominant focus on conventional approaches. In response to this, the research aims to conduct a contextual review in two phases in the first phase due to the research's focus on high-rise buildings, a contextual review was conducted on certain multistory buildings constructed in the city. And in the second phase the review is conducted by exploring Ethiopia's vernacular and ancient architectural achievements. This choice is firstly motivated by the prevalence of conventional construction methods in Addis Ababa's buildings, emphasizing the importance of gaining a deeper understanding of the country's traditional architectural practices based on their geometry and construction system. Secondly due to the inclusion of all buildings in the study, such buildings are a predominant representation of low-rise structures. Additionally, due to the uniqueness of such structures in terms of their geometry material and construction techniques. Lastly it’s important to note that this thesis doesn't exclusively concentrate on high-rise buildings in Addis Ababa.

2.10.1.1 Hilton hotel

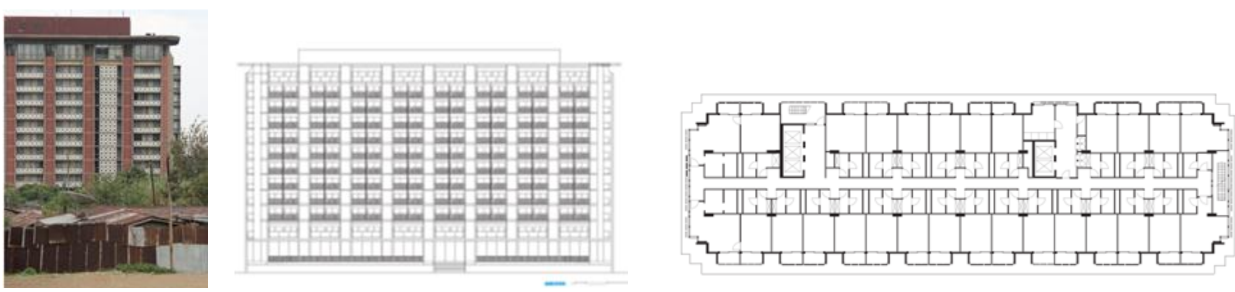
The geometry and construction method of Hilton hotel

The Hilton Hotel is characterized by a rectangular floor and roof geometry, featuring alternating rectangular façade designs. It is constructed using a combination of materials, including concrete, glass, and brick. The construction method employed involves the use of reinforced and precast concrete, along with a masonry wall construction.

Table 2.1. *Geometry and construction of hilton hotel*

Geometry	Rectangular floor and roof geometry with alternating rectangular façade pattern
Material	Concrete, glass and brick
Construction method	Reinforced and Precast concrete

Figure 2.84. *Hilton hotel*



2.10.1.2 Development bank

The geometry and construction method of Development bank building

The Development Bank building is characterized by a combination of rectangular floor, wall, and roof geometry. The primary construction materials employed include concrete, glass, and HCB (hollow concrete blocks), utilizing a construction method that involves masonry, reinforced, and precast concrete.

Table 2.2. *Geometry and construction of development bank building*

Geometry	Rectangular floor and roof geometry with rectangular façade geometry
Material	Concrete, glass and HCB
Construction method	Reinforced and Precast concrete

Figure 2.85. development bank building

2.10.1.3 Finfinne building

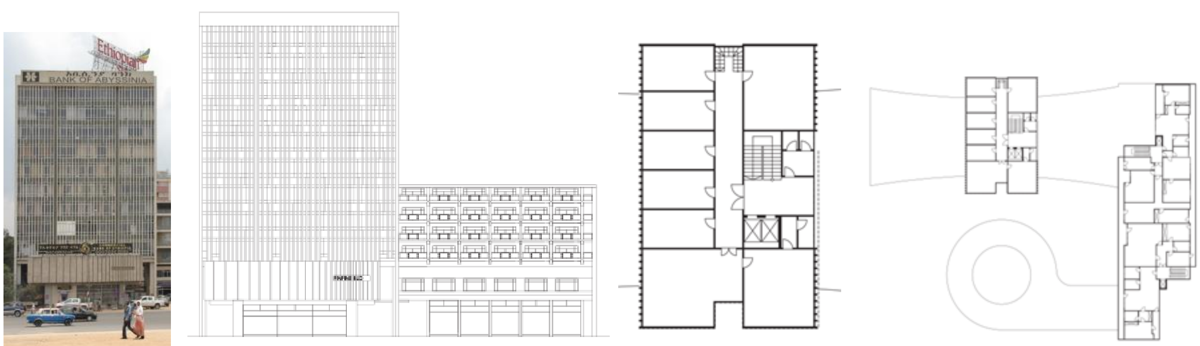
The geometry and construction method of finfine building

The Finfine Building is the outcome of a rectangular floor, façade, and roof geometry, primarily constructed using concrete, glass, and HCB (hollow concrete blocks). The construction technique employed involves the application of masonry, reinforced, and precast concrete.

Table 2.3. *Geometry and construction of finfine building*

Geometry	Rectangular floor and roof geometry with rectangular façade geometry
Material	Concrete, glass and HCB
Construction method	Reinforced and Precast concrete

Figure 2.86. *Finfine building*



2.10.1.4 General post office

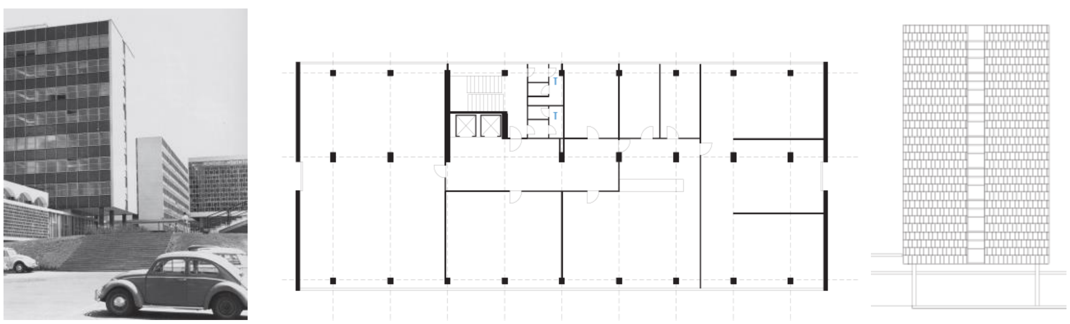
The geometry and construction method of general post office building

The General Post Office building is characterized by a rectangular floor, façade, and roof geometry, and it is constructed predominantly using concrete, glass, and metal. The construction method involves the application of reinforced concrete and curtain wall techniques.

Table 2.4. *Geometry and construction of general post office building*

Geometry	Rectangular floor and roof geometry with rectangular façade geometry
Material	Concrete, glass and metal
Construction method	Reinforced concrete and curtain wall

Figure 2.87. *General post office building*



2.10.1.5 Bedilu building

The Bedilu Building features a combination of rectilinear floor and roof geometry, complemented by a repeated subtle octagonal façade pattern. The construction of the building primarily utilizes concrete, glass, and metal as major materials. This is achieved through the application of reinforced concrete and glass wall construction methods.

Table 2.5. *Geometry and construction of bedilu building*

Geometry	Rectilinear floor and roof geometry with repeated subtle octagonal façade pattern
Material	Concrete, glass and metal
Construction method	Reinforce Concrete and glass wall

Figure 2.88. Bedilu building

2.10.1.6 Lightweight nomadic structures of Afar

The geometry and construction method of an Afar house

The Afar people's mobile houses, known as "deboita," serve as their family dwellings. These unique structures are built using bent wooden sticks anchored in the ground or secured with stones and covered with various materials. Resembling ancient armature tents, this traditional dwelling is among the oldest architectural forms. The wooden sticks are gathered or cut from trees, soaked in water for increased flexibility, and then dried in place to retain their shape. The simple framework consists of arches placed in two rotated rows, with additional stability from smaller arcs. The branches are connected using materials like lines, textiles, leather strips, or plant fiber. The house requires 20 to 30 mats made of bamboo fibers or palm leaves for covering, often obtained through trade due to their scarcity. Occasionally, materials like plastic, animal skin, or blankets are used as additional coverings (Herbig, 2017).

Figure 2.89. The Afar House (Mapio, 2023).

Table 2.1. Geometry and construction of the Afar house

Geometry	Hemispherical form with circular floor geometry
Material	Wood, bamboo, palm leaves, plastic and animal skin
Construction method	Timber stick framed and woven façade construction

2.10.1.7 Lightweight fixed and woven structures of Dorze

The geometry and construction method of the Dorze house

The unique architecture of the Dorze people predominantly utilizes split bamboo, resulting in a distinct and recognizable style. These structures exhibit remarkable dimensions, often reaching heights and diameters of up to 8 meters. The Dorze community is celebrated for their exceptional weaving skills, which are prominently showcased in their dwellings that resemble beautifully crafted round woven baskets. The construction process involves simply embedding vertical bamboo sticks into the ground, while the intricate weaving pattern is skillfully executed to achieve a graceful peaked dome shape. Complementing the main dome is an organically shaped entrance annex, seamlessly attached to the structure. The thatched roof is carefully made from plant leaves, allowing for easy repair and renewal when needed. The details of the openings, such as windows and doors, exhibit meticulous craftsmanship, utilizing rigid bundles of bamboo to ensure durability and stability. This cohesive combination of bamboo, weaving expertise, and attention to detail characterizes the unique architectural style of the Dorze people (Petra, 2021).

Figure 2.90. *The Dorze House (Habitatio, 1997)*

Table 2.6. *Geometry and construction of Dorze house*

Geometry	A conical dome and circular floor geometry
Material	Bamboo
Construction method	Woven bamboo construction

2.10.1.8 Timber structure of Konso

The geometry and construction method of the Konso house

In the Konso region, there is a communal house known as the **paffta**. It is constructed with a raised stone base, a timber platform supported by pillars, and a spacious roof area held up by a central pillar. Although the space beneath the platform is not tall enough for standing, it provides a comfortable seating area on the stone base. The roof space is accessible and serves as storage. The construction components of the platform and central pillar are precisely aligned, as depicted in plans and images (Petra, 2021).

Figure 2.91. Paffta of Konso (Petra, 2021).

Table 2.7. Geometry and construction of Paffta of Konso

Geometry	Conical form with circular floor geometry
Material	Timber, stone and thatch
Construction method	Timber frame thatched construction

2.10.1.9 Massive stone structures of northern Ethiopia

The geometry and construction method of the traditional farmhouse: Hidmo

Hidmo's walls are dry-stone masonry coated with earthen render inside. Collapsed structures reveal a dual-wall technique with an unfinished stone surface on the inner shell, filled with materials. Few openings use timber lintels adorned with ornamental white lime paint. Roofs feature layered main pillars and beams sourced from larger timber areas. In the simple rectangular house, the main beam aligns with the longer middle axis, supported by one or two pillars. Secondary beams span half the width, locally obtained from cultivated eucalyptus trees. Branch materials fill the spaces between the beams. In intricate timber structures, branches are arranged diagonally, covered with layers of soil and gravel (Petra, 2021).

Figure 2.92. Hidmo Traditional House in Inderta (Nobuhiro Shimizu1, 2019)

Table 2.4. Geometry and construction of Hidmo house

Geometry	Rectangular
Material	Stone, mud and timber
Construction method	masonry and wooden frame construction system

2.10.1.10 Hybrid structures of Axumite construction

The geometry and construction method of Debre Damo

Axum's architectural legacy can be seen in a few churches in northern Ethiopia, notably Debre Damo, the oldest church dating to the 6th century. Axumite architecture features alternating stone masonry and horizontal timber, with decorative crossbeams framing the wall openings. These crossbeams, adorned with 'monkey head' motifs, enhance the building facades in the hilly terrain of Debre Damo through a systematic arrangement. (Petra, 2021).

Figure 2.93. *Debre Damo Monastery, Ethiopia (Camelids, 2023)*

Table 2.8. *Geometry and construction of Debre damo monastery*

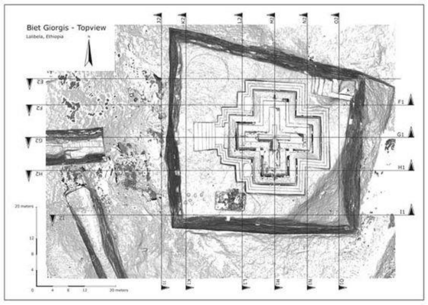
Geometry	Rectangular floor geometry with alternating rectangular façade pattern
Material	Stone and timber
Construction method	Monkey head construction system

2.10.1.11 Rock hewn structures

The geometry and construction method of Bete Geyorgis

Bete Geyorgis is one of the eleven underground churches located in Lalibela, northeastern Ethiopia. These churches are carved from monolithic structures attached to the ground and date back to the thirteenth century during the reign of King Lalibela. The churches bear symbolic crosses and are adorned with cruciform motifs. The architectural forms of these cross-shaped structures serve as significant reminders of Ethiopian history, traditions, and aesthetic practices, evoking memories and preserving cultural heritage for the devotees of Lalibela (Lieber, 2012).

__Figure 2.94.__ The Rock-Hewn Churche Of Lalibela: Bete Giyorgis (Philipp, 2022)



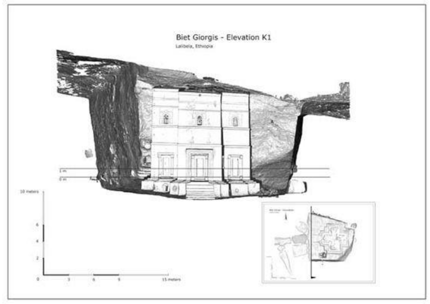


***Table 2.9.** Geometry and construction of Bete Giyorgis*

Geometry	The architectural design comprises a cruciform rectilinear floor and roof geometry, accompanied by a set of rectangular façades, resulting in an overall cubic prism form.
Material	Monolithic Stone
Construction method	The construction system is known as rock hewing or carving involves the shaping and sculpting of rock or stone to create architectural structures.

2.10.2 Buildings codes and standards about geometry of buildings

This study refers to both local and international building codes regarding the geometry of buildings. Although there is no specific, detailed guide on the subject of building geometry, the codes do touch upon various factors, with size being a key indicator. In this study, size is used as an independent variable and is analyzed in relation to the thesis. The codes do provide some guidance on the sizing of building elements, which can vary depending on the construction method and materials used.

2.10.2.1 Ethiopian building code and standards (EBCS)

The Ethiopian Building Code Standard (EBCS) provides guidelines and standards for building construction in Ethiopia. Here are some of the key provisions related to building geometry:

Building height

According to EBCS, the height of a building is determined by the width of the adjacent road and other guidelines, for instance the height of a building adjacent to a road can be increased as the width of the road increases and vice versa.

Building coverage

The EBCS specifies the amount of percentage of a property that can be covered by a building. The maximum building coverage can be higher or lower depending on the specific zoning regulations.

Floor area ratio (FAR)

The EBCS also specifies the floor area ratio (FAR) that can be achieved on a property. FAR is the ratio of the total floor area of the building to the total area of the property. FAR can be higher or lower depending on the specific zoning regulations.

2.10.2.2 International building code

The International Building Code addresses certain geometric aspects related to buildings, particularly in Chapter Five, which delves into general building heights and areas. This chapter outlines specific regulations and guidelines governing various elements. Key areas covered in the code include building height, area limitations, and the relationship between building height and the number of stories. These considerations are detailed based on factors such as Occupancy Classification, Fire-Resistance and Protection, Means of Egress, Fire Prevention, and Existing Buildings (IBC, 2021).

Table 2.10. *Allowable Building Height in Feet Above Grade Plane*[6]

Occupancy		Type of Construction											
Classification	See Footnotes	Type I		Type II		Type III		Type IV				Type V	
		A	B	A	B	A	B	A	B	C	HT	A	B
A, B, E, F, M,	NSb	UL	160	65	55	65	55	65	65	65	65	50	40
S, U	S	UL	180	85	75	85	75	270	180	85	85	70	60
H-1, H-2, H-3, H-5	NSc,d S	UL	160	65	55	65	55	120	90	65	65	50	40
H-4	NSc,d	UL	160	65	55	65	55	65	65	65	65	50	40
	S	UL	180	85	75	85	75	140	100	85	85	70	60
I-1 Condition	NSd,e	UL	160	65	55	65	55	65	65	65	65	50	40
1, I-3	S	UL	180	85	75	85	75	180	120	85	85	70	60
I-1 Condition	NSd,e,f	UL	160	65	55	65	55	65	65	65	65	50	40
2, I-2	Si	UL	180	85									
I-4	NSd,g	UL	160	65	55	65	55	65	65	65	65	50	40
	S	UL	180	85	75	85	75	270	180	85	85	70	60
Rh	NSd	UL	160	65	55	65	55	65	65	65	65	50	40
	S13D	60	60	60	60	60	60	60	60	60	60	50	40
	S13R	60	60	60	60	60	60	60	60	60	60	60	60
	S	UL	180	85	75	85	75	270	180	85	85	70	60

[6] For SI: 1 foot = 304.8 mm.
UL = Unlimited; NS = Buildings not equipped throughout with an automatic sprinkler system; S = Buildings equipped throughout with an automatic sprinkler system installed in accordance with Section 903.3.1.1; S13R = Buildings equipped throughout with an automatic sprinkler system installed in accordance with Section 903.3.1.2. (IBC, 2021).

3.0. Chapter 3: Research methodology

Research methods

The research aims to address the thesis question using two primary methods. In addition to the two main methods of the research, the literature review section involves a systematic analysis of previously collected data pertaining to the geometry of buildings, construction materials, and techniques utilized in the Architecture, Engineering, and Construction (AEC) industry. Firstly, the research conducts an in-depth analysis of existing buildings, focusing on specific parameters to uncover or discover the relationship between geometry, construction methods, and materials employed in these buildings. Secondly, a questionnaire survey is employed to investigate the impact of geometry on the construction materials and methods used in buildings, with a specific focus on the entire buildings in Addis Ababa. This method allows for the identification and examination of the correlation and interplay between geometry, construction materials and construction methods in the context of the city, besides identify the relation of geometry with specialized professionals, computational design and digital fabrication. So the former method involves an in-depth analysis of previously constructed buildings while the later method involves administering surveys to professionals actively engaged in the field.

Method Type one: Building Analysis

This method involves a comprehensive examination of already constructed buildings. This analysis centers on assessing the physical structure and shape of the main elements comprising the building's outer shell or envelope. This assessment is carried out through surveys, on-site observations, and reviews of the building's envelope. The specific elements of the building's outer shell that are considered include the floor or slab, exterior wall or façade, and the roof. These elements play a critical role in defining the overall three-dimensional representation or volume of a building.

Method Type two: questionier Survey

In this research, surveys are used to gather information from professionals who are actively involved in the field. This method aims to obtain insights into various aspects related to building construction, including the impact of envelope geometry on material and technique choices. Which is a questioner for consulting design and engineering companies

By combining these two research methods, the aim is to gain a comprehensive understanding of how the geometry of a building's envelope influences the selection of materials and techniques used in constructing its outer shell. And to know the effect of specialized professionals, computational design and digital fabrication on the geometry of buildings.

In order to ensure accurate data collection and analysis, it is important to identify the key variables of the research. By reviewing relevant literature and defining the research question, the main variables have been identified as crucial for developing a data collection and analysis strategy. These variables simplify the research process by facilitating the collection of primary or secondary data, as each variable represents a distinct piece of data.

3.1 Study area

The study focuses in the architecture, engineering and construction industry of our country specifically in Addis Ababa the capital city of Ethiopia, as a typical example of other Ethiopian urban areas due to the high population size. The reason for the selection is that the city is a major center for the construction industry that many big and mass buildings are constructed and a home of many buildings compared to other cities of Ethiopia. So the study focuses on selected high-rise and all buildings of Addis Ababa city.

3.2 Research design

This thesis employs a dual methodology, utilizing both survey-based design and building analysis-based design in its research. The primary objective of the building analysis-oriented design is to investigate the impact of geometry, the independent variable in this study, on the building materials and construction methods—both of which are considered dependent variables. This research aims to unravel the intricate relationship between geometric considerations and the choices made in terms of construction materials and methods.

On the other hand the survey based design involves employing a questionnaire survey to evaluate the influence of geometry on all buildings in Addis Ababa. Specifically, consulting architects and engineering companies are targeted to investigate the relationship between geometry, construction materials, construction methods, computational design, digital fabrication method and presence of specialized professionals utilized in buildings. Both research designs are utilized in this thesis to collectively address the research questions and objectives. These research designs work in conjunction to achieve the goals and objectives of the thesis.

3.3 Data types

The data types utilized in this research encompass a combination of qualitative and quantitative data. For example, when examining the geometrical shape of buildings, including their floor, façade, and roof geometry, qualitative data is employed. Conversely, quantitative data is employed to assess the geometrical size of building components. This includes measurements such as the length, width, and depth of floors, the length, height, and thickness of façades, and the length, width, height, or thickness of roofs. These are merely a few examples of the data types employed in this research. For a comprehensive understanding of the data types employed and the specific variables utilized, please refer to the tables within the operationalization of variables section (Table 3.2 - Table 3.18), which provide detailed information on all variables used in this research.

3.4 Source of data

Method one

The primary data sources for this research consist of an onsite building observation including identification of the geometrical shape and form of the buildings and measurements of various building components, such as floor size, exterior wall dimensions, and roof slab measurements etc. are collected along with interviews with site engineers, resident engineers, architects, and construction managers structured as a reinforcing element to fill the data required based on 24 buildings analysis parameters and capturing of required building photographs. Overall, the primary data source for this building analysis method involves sourcing data related to the 24 measuring parameters of the research variables through on-site investigations conducted on buildings. The secondary data source for this research method consists of architectural and structural drawing reviews along with other related documents of the buildings.

Method two

The primary data source for this research method type is questionnaire survey. Through this survey, valuable information is collected to address the research objectives through a structured questionier. Participants in the survey include consulting architects and engineering companies. No secondary data is used in this research method. Overall, the combination of the questionnaire survey and the building analysis method ensures a robust and multi-faceted approach to data collection, enabling the research to address its objectives effectively.

3.5 Sampling design

3.5.1 Sampling technique

The research utilized the random sampling technique in both methods. In the questionnaire survey method, a random sample of consulting architects and engineering firms was selected from the entire population in Addis Ababa. This sample was chosen to participate in the prepared survey, aiming to establish the connection between building geometry and construction techniques and materials as reported by the respective design and engineering firms.

Similarly, for the building analysis section of the research, high-rise buildings were randomly selected from the population in Addis Ababa. This sample was chosen to empirically examine the influence of geometry on construction methods and materials used in buildings.

3.5.2 Sample population

Method Type one: Building Analysis

There are approximately 47 buildings in the city that have 17 floors above their ground level. These buildings consist of both fully completed structures and those that are nearly 90% complete. For these buildings, at least three components, namely the floor/slab, exterior wall/facade, and roof, are visible.

Method Type two: Questionier Survey

The survey population includes 10,691 companies, who are a collective representation of consulting architects and engineers in the city. This encompasses architecture and engineering firms ranging from level one (1) up to level eight (8), assuming that all of which are actively operating within the city.

3.5.3 Sample size

Method Type one: Building Analysis

The research employs Slovin's Formula to determine the sample size, considering a population size of 47 buildings in the city (A.A. Construction Permit & Control Authority, 2023) and a margin of error (e) assumed as 0.6.

n = N/1+Ne2

n = 47/1+47(0.06*0.06)

n= 47/1+47(0.0036)

n= 47/ 1.1692

n= 40.19 = 40 buildings

In response to the specific requirement for distinctive design and the influence of various factors associated with the verticality of high-rise buildings, designers and architects are tasked with creating extraordinary structures that captivate the interest of individuals (Roy, 2018), so based on this rationale this research primarily concentrates on examining and analyzing high-rise buildings within the building analysis section of the thesis. But the overall building geometries and construction of buildings of the city is studied in the questioner survey method. During this analysis, the primary focus is on the tower of high-rise buildings as it constitutes the prominent component of the structure. Besides the key criterion for selecting buildings in this research is primarily based on the number of stories they possess.

To examine the relationship between envelope geometry and construction materials and techniques employed in an individual building, approximately 24 measurement parameters are utilized. These parameters encompass a range of characteristics and features related to the building's envelope. By analyzing these parameters, researchers aim to gain insights into how the specific geometric attributes of the envelope shape influence the selection and implementation of construction materials and techniques. The measurement parameters used in the analysis may include aspects such as the dimensions and proportions of the building's floor or slab, the configuration and orientation of the façade or exterior wall, the slope and design of the roof, and other relevant geometric properties. Additionally, factors like the thickness and composition of materials used in the envelope.

By carefully examining these measurement parameters, the researcher identified patterns and correlations between the envelope geometry and the chosen construction materials and techniques. This analysis helps to shed light on how specific geometric attributes impact the selection of materials and the implementation of construction methods.

Table 3.1. *The Classification of Buildings Based On Their Height (He Sijia, 2019).*[7]

Classification	Floor	Height (m)
Low rise building	1-3	≤9
Multi-story building	4-6	9-21
Middle-rise building	7-9	21-30
Small high-rise building	10-16	30-50
High-rise building	17-40	50-100
Ultra – high – rise building	>40	>100

Source: (He Sijia, 2019)

[7] In this thesis, the classification of buildings by height follows the standards set by the China National Standards. According to these standards, buildings are categorized into six types based on their height and number of stories: low-rise, multi-story, middle-rise, small high-rise, high-rise, and ultra-high-rise (China National Standard, 2005).

Method Type two: Surveys

In this research study, the researcher has used Slovin's Formula to calculate the appropriate sample size for the questioner survey research method. To do this, the research considered a population size of 10,691, which represents the total number of consulting architects and engineers firms in Addis Ababa. So it is a large population of firms and due to the challenges of voluntary to fill the questioner survey, and consequently, and to avoid problems occurring due to the unresponsiveness of the firms, the margin of error (e) was set at 0.1.

n = N/1+Ne2

n = 10,691/1+10,691(0.1*0.1)

n = 98.963

n ≈ 100

3.6 Method of data collection

This research utilizes two interlinked and unique methods: questionnaire and building survey. In both methods, the predominant approach to data collection is through the gathering of primary data.

On the building analysis method, primary data sources play a crucial role. The researchers have direct access to all selected buildings to get primary data and had a possibility to review secondary data of the buildings from respective bodies such as architectural and structural drawings and other documents which are fundamental in understanding the geometry and construction aspects of buildings. These drawings serve as a main sources of information that are directly accessed and used for analysis and interpretation.

Besides, in this study, an essential primary data collection method involves conducting onsite observations of buildings, based on the 24 building analysis parameters. These observations aim to identify and explore the relationship between the independent variable (geometry) and the dependent variables (construction method and material) in the context of building design. Through this primary data collection method, valuable insights and information are obtained to accomplish the research objectives and contribute to a comprehensive understanding of the interplay of the variables.

Furthermore, to acquire further primary data, interviews are carried out with site engineers and architects. These interviews provide an opportunity for direct communication with industry professionals who possess firsthand knowledge and experience regarding the construction of buildings. The insights and information gathered from these interviews directly contribute to the primary data collected for the research. It is important to note that these interviews are not conducted in isolation from the building analysis parameters;

instead, they are a means of to reinforce and answer required datas in the 24 building analysis parameters. These parameters serve as the foundation for the interview process, allowing for in-depth discussions and clarifications regarding the collected data. By aligning the interviews with these parameters, the research ensures that relevant and comprehensive information is obtained to address the research objectives effectively.

Similarly In the case of the questionnaire survey, primary data is collected directly from the participants. The researcher design and administer the survey to target individuals, such as consulting architects and engineering companies. Through this survey, firsthand information is obtained. The survey responses serve as primary data points that contribute to the research findings.

Overall, the data collection methods employed in this research primarily rely on the collection of primary data. The questionnaire survey gathers primary data from the participants, while the building analysis method involves an onsite accessing of existing buildings, as well as conducting interviews with relevant professionals. This focus on primary data ensures that the research findings are based on direct and firsthand information, enhancing the validity and reliability of the study.

3.7 Method of data analysis

This study utilized four distinct data analysis techniques to investigate the influence of a building's envelope geometry on its construction methods and materials. The four data analysis methods employed in this research encompass descriptive statistics, inferential statistics, statistical modeling, and data visualization.

Descriptive statistics were utilized to provide a concise summary of the data gathered from both the building analysis and questionnaire survey methods in the research. This involved calculating various measures, such as the mean, median, mode, range, standard deviation, and frequency distribution of the independent, dependent and control variables along with their related statistical outputs.

Inferential statistics were applied in this study to examine the correlation and interplay between the independent, dependent and control variables. Techniques like hypothesis testing, Sampling, confidence Intervals, regression analysis, analysis of variance (ANOVA), Significance Level, P-Value and Chi-Square Tests were utilized to identify patterns and relationships between the variables of the study.

Statistical modeling in this study encompassed the use of statistical techniques to create mathematical models that portray the connections between the variables, such as starting from the variable identification, , the research includes exploratory Data Analysis based on descriptive analysis, data collection, selection of appropriate model to analyze the data, Parameter Estimation, Model Fitting, Model Evaluation, parameter Interpretation of the model, Predictions, Inferences and finally expression of findings based on appropriate method.

To establish these relationships, methods such as descriptive statistics, correlation and multinomial logistic regression and were employed. These techniques allowed for a comprehensive understanding of how one variables behave on other variables of the study.

Finally, data visualization techniques were employed to visually represent the connections between the variables aiding in the illustration and comprehension of these relationships.

3.8 Method of data presentation

The primary techniques employed in this study for showcasing the relationship between geometry, building methods, and materials include tables, graphs, figures, diagrams, charts, info graphics, narrative explanations, and textual descriptions.

3.9 Validation and reliability

The validity of this research is ensured through a consistent way of data collection, data analysis statistical models and tests by following the scientific research writing, and the development of the whole contents of the research follows a logical and interlinked process to maximize the validity of the research. Throughout the entire research process, from inception to conclusion, reliable data was utilized at every stage. The research relied on robust data sources, starting from the introduction of the thesis, continuing through the comprehensive literature review, and extending to the collection of data in a dependable manner. This meticulous approach was adopted to ensure the research's overall reliability.

3.10. Operationalization of Variables

3.10.1 Envelope geometry - Independent variable

The study's independent variable (IV) is envelope geometry, which refers to the combined floor, wall, and roof geometry of a building. This variable can be further divided into three sub independent variables: floor geometry, façade geometry, and roof geometry.

Table 3.2. *Envelope Geometry*

Variable	Type of variable	Indicator	Description	Method	Data type	Data source
Envelope geometry	Independent	- Floor geometry - Façade geometry - Roof geometry	It is the sum of floor, size and form geometry of a building.	Primary	Both	Questioner and on site survey

3.10.1.1 Floor geometry – Independent variable

Floor or slab geometry, another independent variable in the study, is part of the overall envelope geometry of a building. It specifically pertains to the size, shape, and form of the floor or slab.

Table 3.3. *Floor Geometry*

Variable	Type of variable	Indicator	Description	Method	Data type	Data source
Floor geometry	Independent	- Shape of floor - Size of floor - Form of floor	It is the sum of the shape, size and form of a buildings' floor.	Primary	Both	Questioner and on site survey
Shape of floor	Independent	- Circular - Triangular - Rectangular	The shape of a floor is the exterior geometric outline of a buildings' floor plan	Primary	Qualitative	Questioner and on site survey
Size of floor	Independent	- Length of floor - Width of floor - Thickness of floor	The size of a floor is the measure of the length width and thickness of a buildings floor	Primary	Quantitative	Questioner and on site survey
Form of floor	Independe nt	- Cubical - Cylindrical - Other	It is the overall formal appearance of a buildings' floor	Primary	Qualitative	Questioner and on site survey

3.10.1.2 Façade or exterior wall geometry - Independent variable

Façade or exterior geometry, which is an independent variable in the study, is a component of the overall envelope geometry of a building. It specifically focuses on the size, shape, and form of the façade or exterior wall of a building.

Table 3.4. *Façade Geometry*

Variable	Type of variable	Indicator	Description	Method	Data type	Data source
Façade or exterior wall geometry	Independent	- Shape of facade - Size of facade - Form of facade	It is the sum of the shape, size and form of a buildings' floor.	Primary	Both	Questioner and on site survey

Shape of facade	Independent	- Circular - Triangular - Rectangular - Polygonal - Other	The shape of a facade is the exterior geometric outline of a buildings' exterior wall.	Primary	Qualitative	Questioner and on site survey
Size of facade	Independent	- Length of faced - Height of facade - Thickness of façade.	The size of a facade is the measure of the length width and thickness of a building's exterior wall.	Primary	Quantitative	Questioner and on site survey
Form of facade	Independe nt	- Cubical - Cylindrical - Other	It is the overall formal appearance of a buildings' floor	Primary	Qualitative	Questioner and on site survey

3.10.1.3 Roof geometry - Independent variable

Roof geometry, as an independent variable in the study, is an integral part of the overall envelope geometry of a building. Its primary focus is on the size, shape, and form of the building's roof.

Table 3.5. *Roof Geometry*

Variable	Type of variable	Indicator	Description	Method	Data type	Data source
Roof geometry	Independe nt	- Shape of roof - Size of roof - Form of roof	It is the sum of the shape, size and form of a buildings' roof.	Primary	Both	Questioner and on site survey
Shape of roof	Independent	- Circular - Triangular - Rectangular - Other	The shape of a roof is the exterior geometric outline of a buildings' roof.	Primary	Qualitative	Questioner and on site survey
Size of roof	Independent	- Length of roof - Height of roof - Width of roof.	The size of a roof is the measure of the length width and height of a building's roof.	Primary	Quantitative	Questioner and on site survey
Form of roof	Independe nt	- Cubical - Cylindrical - Conical - Pyramidal - Other	It is the overall formal appearance of a buildings' floor	Primary	Qualitative	Questioner and on site survey

3.10.2 Construction methods of envelope - Dependent variable

The construction method of the building envelope serves as the dependent variable in the research. However, this variable can be further classified into three sub-variables: the construction method of the floor, the construction method of the façade or external wall, and the construction method of the roof.

Table 3.6. *Construction Method of Envelope*

Variable	Type of variable	Indicator		Description	Method	Data type	Data source
Construction method of buildings' envelope	Dependent	- Floor construction method - Façade construction method - Roof construction method		It is the collective variable including floor, façade and roof construction method of a building	Primary	Both	Questioner survey and on site survey.

3.10.2.1 Construction methods of floor - Dependent variable

Construction method of a floor is a dependent variable in this research, which is characterized by different construction techniques. And it includes many indicators, such as flat plate concrete slab, prestressed slab, precast slab, structural steel framed floor etc. are a few to mention.

Table 3.7. *Construction Method of Floor*

Variable	Type of variable	Indicator	Description	Method	Data type	Data source
Floor construction method	Dependent	- Concrete floor/slab - One way slab - One way joist slab - Two way slab - Two way waffle slab - Two way flat plate slab - Two way flat slab - Pre-stressed concrete floor/slab - Precast concrete floor systems - Structural steel framed floor system	It is the different types of methods which are applied in the construction of floor of a buildings.	Primary	Qualitative	Questioner survey

		- One-Way Beam System - Two-Way Beam System - Triple Beam System - Wood joist framed floor - Other				

3.10.2.2 Construction methods of façade or exterior wall – Dependent variable

In this research, the construction method of a façade or exterior wall serves as a dependent variable and encompasses diverse construction techniques. These techniques include various indicators, such as concrete walls, masonry walls, precast walls, tilt-up wall construction, adobe walls, and more.

Table 3.8. *Construction Method of Façade*

Variable	Type of variable	Indicator	Description	Method	Data type	Data source
Façade construction method	Dependent	- Concrete and Masonry Bearing Walls - Metal and Wood Stud Walls - Precast concrete walls - Tilt-up façade construction - Masonry walls - Adobe wall - Rammed earth wall - Stone masonry - Structural steel framed wall - Balloon framed wall - Other	It is the different types of methods which are applied in the construction of exterior wall of buildings.	Primary	Qualitative	Questioner survey

3.10.2.3 Construction methods of roof - Dependent variable

The construction method of a roof is examined as a dependent variable in this research, encompassing a range of construction techniques. These techniques involve different indicators, such as reinforced concrete roof slabs, space frame roofs, precast concrete roof systems, rafter framing roof construction, steel trusses with metal roof covering sheets, and various others.

Table 3.9. *Construction Method of Roof*

Variable	Type of variable	Indicator	Description	Method	Data type	Data source
Façade construction method	Dependent	- Reinforced concrete roof slabs - Precast concrete roof systems - Structural steel roof framing - Steel rigid frames - Steel trusses - Space frames - Open-web joist framed roof - Metal roof decking - Cementitious roof planks - Rafter framing - Gable Roofs, Hip Roofs, Gambrel Roofs and Flat Roofs - Light-gauge roof framing - Wood rafter framing - Other	It is the different types of methods which are applied in the construction of roof of a buildings.	Primary	Qualitative	Questioner survey

3.10.3 Construction material of envelope - Dependent variable

The research focuses on the construction material of a building envelope as a dependent variable. Moreover, this dependent variable is categorized into three sub-dependent variables, namely the construction material of the floor, the construction material of the façade, and the construction material of the roof.

Table 3.10. *Construction material of envelope*

Variable	Type of variable	Indicator	Description	Method	Data type	Data source
Construction material of buildings' envelope	Dependent	- Floor construction material - Façade construction material - Roof construction material	It is the collective variable including floor, façade and roof construction material of a building	Primary	Both	Questioner survey and on site survey.

3.10.3.1 Construction material of floor - Dependent variable

The construction material of a floor, which serves as an additional dependent variable in the research, pertains to the specific type of material employed for constructing floors or slabs in building construction.

Table 3.11. *Construction Material of Floor*

Variable	Type of variable	Indicator	Description	Method	Data type	Data source
Construction material of floor	Dependent	- Metal - Glass - Concrete - Wood - Plastic - Other	It is the collective variable including a wide variety of construction materials deployed for the construction of floor.	Primary	Qualitative	Questioner survey and on site survey.

3.10.3.2 Construction material of façade or exterior wall - Dependent variable

In the research, the construction material of a façade or exterior wall is considered an additional dependent variable. It refers to the particular type of material utilized in the construction of façades or exterior walls in building projects. This variable encompasses materials such as natural stone, clay, concrete, timber, and more.

Table 3.12. *Construction Material of Façade*

Variable	Type of variable	Indicator	Description	Method	Data type	Data source
Construction material of façade or exterior wall	Dependent	- Natural stone - Clay - Concrete - Timber - Metal - Glass - Plastics - Other	It is the collective variable including a wide variety of construction materials deployed for the construction of exterior wall.	Primary	Qualitative	Questioner survey and on site survey.

3.10.3.3 Construction material of roof - Dependent variable

The research includes the construction material of a roof as an additional dependent variable. This variable specifically relates to the type of material used in the construction of roofs for building projects. It encompasses a range of materials, including metal, glass, concrete, wood, plastic, and others.

Table 3.13. *Construction Material of Roof*

Variable	Type of variable	Indicator	Description	Method	Data type	Data source
Construction material of roof	Dependent	- Metal - Glass - Concrete - Wood - Plastic - Other	It is the collective variable including a wide variety of construction materials deployed for the construction of roof.	Primary	Qualitative	Questioner survey and on site survey.

3.10.4. Computational design – Independent variable

As highlighted in earlier sections of the research, some scholars said that there is a strong correlation between computational design and the geometry of buildings. Computational design has significantly contributed to the advancement of novel architectural geometries. In this research, computational design is regarded as a dependent variable and characterized by its progression from 2D design to per - formative design and form finding.

Table 3.14. *Computational Design*

Variable	Type of variable	Indicator	Description	Method	Data type	Data source
Computational design	Independent	- 2d design - 3d modeling - BIM - Parametric design - Algorithmic design - Generative design - Per-formative design - Form finding	It is the collective variable which includes different types of computational design.	Primary	Qualitative	Questioner survey and on site survey.

3.10.5 Digital fabrication method – Independent variable

Digital fabrication methods are considered additional dependent variables in this study. They are measured or characterized based on the specific types of fabrication techniques employed to construct building components or individual elements of a building.

Table 3.15. *Digital Fabrication Method*

Variable	Type of variable	Indicator	Description	Method	Data type	Data source
Digital fabrication	Independent	- Additive digital fab method - Subtractive digital fab method - Forming digital fab method - Robotic assembly	It is the collective variable which includes different types of digital construction techniques.	Primary	Qualitative	Questioner survey and on site survey.

3.10.6 Control variables

The design and construction considerations of a building envelope, which can influence the construction process and material choices, are regarded as the control variables in this research.

3.10.6.1 Floor – control variables

The design and construction considerations of a floor, which can influence the construction process and material choices, are regarded as the control variables of floor in the research.

Table 3.16. *Control Variables of Floor*

Variable	Type of variable	Indicator	Description	Method	Data type	Data source
Load-carrying capacity	Control	- Load testing	Ability of a floor to resist imposed loads	Both – primary and secondary	Quantitative	Questioner survey.
Durability	Control	- Visual, Material testing etc.	Long lastingness of a floor	Both – primary and secondary	Qualitative	Questioner survey.

Fire-resistance	Control	-	Fire resistance rating	The ability to resist a fire in a period of time. Differs for different materials.	Both – primary and secondary	Quantitative	Questioner survey.
Dead weight	Control	-	Load testing	The self-weight of a given floor	Both – primary and secondary	Quantitative	Questioner survey.
Overall thickness	Control	-	Thickness of floor	The whole thickness of a floor	Both – primary and secondary	Quantitative	Questioner survey.
Facility for installing building utilities	Control	-	Provision of different ducts	Includes the MEP and HVAC of a building which passes or built in the floor of a building	Both – primary and secondary	Qualitative	Questioner survey.
Sound transmission	Control	-	Sound performance testing	The ability of a floor to resist the passage of sound	Both – primary and secondary	Qualitative and quantitative	Questioner survey.
Appearance	Control	-	Visual inspection	The esthetic quality of a floor	Both – primary and secondary	Qualitative	Questioner survey.
Maintenance	Control	-	Amount of time to withstand different factors.	the ease of maintaining a given floor	Both – primary and secondary	Qualitative	Questioner survey.
Construction time	Control	-	Speed of completion	Time required to finish the construction of a certain floor	Both – primary and secondary	Quantitative	Questioner survey.

3.10.6.2 Façade – control variables

The design and construction considerations of a façade, which can influence the construction process and material choices, are regarded as the control variables of façade or exterior wall in the research.

Table 3.17. *Control Variables of Façade*

Variable	Type of variable	Indicator	Description	Method	Data type	Data source
Strength and stability	Control	-	The ability of the exterior wall to maintain its shape and capacity to external force.	Both – primary and secondary.	Both Qualitative and quantitative	Questioner survey.
Thermal resistance	Control	-	The capacity of a façade to resist different heat actions.	Both – primary and secondary	Both Qualitative and quantitative	Questioner survey.
Resistance to weather	Control	-	Ability of maintaining its material and framework property in different weather actions.	Both – primary and secondary	Qualitative	Questioner survey.
Durability and freedom from maintenance	Control	-	The repair need of the façade in a certain period of time.	Both – primary and secondary.	Qualitative	Questioner survey.
Fire resistance	Control	-	The resistance level of a façade during the occurrence of fire.	Both – primary and secondary	Both Qualitative and quantitative	Questioner survey.
Ventilation	Control	-	The performance of a façade for well in and out of air for maintaining the thermal comfort of the users.	Both – primary and secondary	Both Qualitative and quantitative	Questioner survey.
Sound resistance	Control	-	The ability of a façade in excluding unwanted noise and amplifying a desired sound in a building.	Both – primary and secondary	Both Qualitative and quantitative	Questioner survey.

3.10.6.3 Roof – control variables

The design and construction considerations of a roof, which can influence the construction process and material choices of roof, are regarded as the control variables of roof in the research.

Table 3.18. *Control Variables of roof*

Variable	Type of variable	Indicator	Description	Method	Data type	Data source
Need for familiarity with roof design	Control	-	The skill and knowledge of the designer with different roof designs.	Both – primary and secondary	Qualitative	Questioner survey.
Building owners' requirements	Control	-	The clients desire on the design and construction of the roof type.	Both – primary and secondary	Qualitative	Questioner survey.
Building-code provisions for roofs	Control	-	The codes which affect the design and construction of roofs.	Both – primary and secondary	Qualitative	Questioner survey.
Effects of climate	Control	-	Different climatic conditions which decides the design and construction of roofs.	Both – primary and secondary	Qualitative	Questioner survey.
Deck suitability	Control	-	Related with the type of fastening and joining mechanism of roof components on in a roof design and construction.	Both – primary and secondary	Qualitative	Questioner survey
Effects of rooftop traffic	Control	-	The level of the roof vulnerability to on rooftop movement of people or other moving object.	Both – primary and secondary	Qualitative	Questioner survey
Esthetic considerations	Control	-	The general visual appearance of the roof to attract viewers which determines the design and	Both – primary and secondary	Qualitative	Questioner survey

			construction of a roof.			
Effects of wind on roofs	Control	-	The prevailing wind of a certain area have an effect on the design and construction of a roof of a building.	Both – primary and secondary	Qualitative	Questioner survey
Protected membrane roofs and plaza decks	Control	-	The need of protection membranes and the type of deck determines the design and construction of roof.	Both – primary and secondary	Qualitative	Questioner survey
Pre-roofing conference	Control	-	The discussion between roof design and construction professionals for better roof design and construction.	Both – primary and secondary	Qualitative	Questioner survey
Warranties	Control	-	The warranty period of roof affects the roof to be designed and constructed especially by the owners.	Both – primary and secondary	Qualitative	Questioner survey
Roof maintenance	Control	-	Future maintenance considerations may affect the design typology and construction of a certain roof.	Both – primary and secondary	Qualitative	Questioner survey
Reroofing	Control	-	Considering how to replace existing roof elements such as, roof covering may dictate the design and construction type of a roof	Both – primary and secondary	Qualitative	Questioner survey

Reroofing Procedures	Control	-	The future procedures used in the replacement or maintenance of roof falls in the design and construction type of a roof.	Both – primary and secondary	Qualitative	Questioner survey
Roof Moisture-Detection Surveys	Control	-	Roofs design and construction types which are easy for failure detection of roof may affect the roof type and its construction.	Both – primary and secondary	Qualitative	Questioner survey

4.0. Chapter 4: Results and discussion

4.1 Statistical tests for correlation

4.1.1 Correlation model

The correlation test conducted between the 24 building analysis parameters to identify the impact of geometry on the construction technique or method and material of buildings using SPSS software has yielded valuable insights into the relationships between various architectural variables. This research endeavor aimed to explore the interdependencies and associations between different aspects of a building's design and construction. The findings from this comprehensive analysis provide architects and researchers with a deeper understanding of how geometry, building construction techniques, and materials are interconnected. By examining the correlation coefficients, we were able to discern which geometric features tend to align with specific construction methods and material choices. Such knowledge can significantly impact the design process, as architects can now make informed decisions regarding geometry to optimize construction efficiency and material performance.

Moreover, the correlations between the variables with themselves added another layer of significance to the study. Analyzing the intrinsic relationships within each variable allowed for a more thorough examination of their internal consistency and reliability. This aspect of the research offered valuable insights into the underlying patterns and characteristics within each architectural parameter. For instance, exploring the correlation within the roof form variable provided valuable information on which roof shapes are frequently employed within different architectural styles or building functionalities. As a researcher, these detailed correlations have enriched our understanding of architectural design principles, providing a basis for creating buildings that encompass both aesthetical appeal and functional coherence. The results of this study contribute to the advancement of architectural knowledge and offer practical implications for designing innovative and sustainable buildings.

The table below shows the correlation coefficients between various architectural parameters of buildings. Correlation coefficients are statistical measures that provide valuable insights into the relationships between different architectural parameters in buildings. They quantify the degree of association between two variables and can help to understand how various aspects of a building's design or geometry and construction are interconnected. The correlation coefficients range from -1 to 1, with different values indicating the strength and direction of the relationship.

Table 4.1. *Correlation model of the method one study*

Correlations

		Number of stories	Floor shape	Façade shape	Roof shape	Max Length of floor in m	Max Width of floor in m	Max Thickness of floor in cm	Max Length of façade or Wall	Max. Height of façade in m	Max Thicknes of façade in mm	Max Length of Roof	Max Width of Roof
Number of stories	Pearson Correlation	1	-.336*	-.265	-.395*	.096	-.047	.196	.096	.388*	-.468**	.096	-.108
	Sig. (2-tailed)		.034	.098	.012	.555	.771	.226	.555	.013	.002	.555	.507
	N	40	40	40	40	40	40	40	40	40	40	40	40
Floor shape	Pearson Correlation	-.336*	1	.344*	.860**	.126	.394*	.059	.126	-.145	.246	.126	.423**
	Sig. (2-tailed)	.034		.030	<.001	.440	.012	.718	.440	.372	.126	.440	.007
	N	40	40	40	40	40	40	40	40	40	40	40	40
Façade shape	Pearson Correlation	-.265	.344*	1	.258	-.103	.038	.214	-.103	.139	.116	-.103	.094
	Sig. (2-tailed)	.098	.030		.109	.526	.817	.185	.526	.393	.476	.526	.564
	N	40	40	40	40	40	40	40	40	40	40	40	40
Roof shape	Pearson Correlation	-.395*	.860**	.258	1	.092	.401*	-.021	.092	-.234	.321*	.092	.429**
	Sig. (2-tailed)	.012	<.001	.109		.572	.010	.900	.572	.146	.044	.572	.006
	N	40	40	40	40	40	40	40	40	40	40	40	40
Max Length of floor in m	Pearson Correlation	.096	.126	-.103	.092	1	.379*	-.046	1.000**	-.069	-.062	1.000**	.388*
	Sig. (2-tailed)	.555	.440	.526	.572		.016	.779	.000	.672	.704	.000	.013
	N	40	40	40	40	40	40	40	40	40	40	40	40
Max Width of floor in m	Pearson Correlation	-.047	.394*	.038	.401*	.379*	1	.037	.379*	.114	.009	.379*	.933**
	Sig. (2-tailed)	.771	.012	.817	.010	.016		.822	.016	.484	.954	.016	<.001
	N	40	40	40	40	40	40	40	40	40	40	40	40
Max Thickness of floor in cm	Pearson Correlation	.196	.059	.214	-.021	-.046	.037	1	-.046	.231	-.285	-.046	.023
	Sig. (2-tailed)	.226	.718	.185	.900	.779	.822		.779	.152	.075	.779	.890
	N	40	40	40	40	40	40	40	40	40	40	40	40
Max Length of façade or Wall	Pearson Correlation	.096	.126	-.103	.092	1.000**	.379*	-.046	1	-.069	-.062	1.000**	.388*
	Sig. (2-tailed)	.555	.440	.526	.572	.000	.016	.779		.672	.704	.000	.013
	N	40	40	40	40	40	40	40	40	40	40	40	40
Max. Height of façade in m	Pearson Correlation	.388*	-.145	.139	-.234	-.069	.114	.231	-.069	1	-.232	-.069	.074
	Sig. (2-tailed)	.013	.372	.393	.146	.672	.484	.152	.672		.149	.672	.650
	N	40	40	40	40	40	40	40	40	40	40	40	40
Max Thicknes of façade in mm	Pearson Correlation	-.468**	.246	.116	.321*	-.062	.009	-.285	-.062	-.232	1	-.062	.063
	Sig. (2-tailed)	.002	.126	.476	.044	.704	.954	.075	.704	.149		.704	.700
	N	40	40	40	40	40	40	40	40	40	40	40	40
Max Length of Roof	Pearson Correlation	.096	.126	-.103	.092	1.000**	.379*	-.046	1.000**	-.069	-.062	1	.388*
	Sig. (2-tailed)	.555	.440	.526	.572	.000	.016	.779	.000	.672	.704		.013
	N	40	40	40	40	40	40	40	40	40	40	40	40
Max Width of Roof	Pearson Correlation	-.108	.423**	.094	.429**	.388*	.933**	.023	.388*	.074	.063	.388*	1
	Sig. (2-tailed)	.507	.007	.564	.006	.013	<.001	.890	.013	.650	.700	.013	
	N	40	40	40	40	40	40	40	40	40	40	40	40
Max height or thickness of Roof in cm	Pearson Correlation	-.011	.276	-.012	.225	-.176	-.100	-.125	-.176	-.106	-.035	-.176	-.086
	Sig. (2-tailed)	.945	.085	.941	.163	.278	.540	.441	.278	.514	.829	.278	.600
	N	40	40	40	40	40	40	40	40	40	40	40	40
Roof form	Pearson Correlation	-.094	.200	.235	.162	-.165	-.073	-.221	-.165	-.150	.109	-.165	-.054
	Sig. (2-tailed)	.562	.216	.145	.317	.308	.654	.171	.308	.354	.504	.308	.740
	N	40	40	40	40	40	40	40	40	40	40	40	40
Building form	Pearson Correlation	-.420**	.663**	.218	.537**	.328*	.180	-.042	.328*	-.055	.145	.328*	.234
	Sig. (2-tailed)	.007	<.001	.177	<.001	.039	.268	.796	.039	.736	.373	.039	.147
	N	40	40	40	40	40	40	40	40	40	40	40	40
Buildingheightinm	Pearson Correlation	.963**	-.323*	-.202	-.393*	.066	.008	.205	.066	.611**	-.448**	.066	-.053
	Sig. (2-tailed)	<.001	.042	.212	.012	.686	.961	.205	.686	<.001	.004	.686	.746
	N	40	40	40	40	40	40	40	40	40	40	40	40
Max Buildingwidthinm	Pearson Correlation	-.047	.394*	.038	.401*	.379*	1.000**	.037	.379*	.114	.009	.379*	.933**
	Sig. (2-tailed)	.771	.012	.817	.010	.016	.000	.822	.016	.484	.954	.016	<.001
	N	40	40	40	40	40	40	40	40	40	40	40	40
Max Buildinglengthinm	Pearson Correlation	.096	.126	-.103	.092	1.000**	.379*	-.046	1.000**	-.069	-.062	1.000**	.388*
	Sig. (2-tailed)	.555	.440	.526	.572	.000	.016	.779	.000	.672	.704	.000	.013
	N	40	40	40	40	40	40	40	40	40	40	40	40
Floor construction method	Pearson Correlation	-.187	.299	.128	.557**	-.115	.255	.224	-.115	.046	.093	-.115	.285
	Sig. (2-tailed)	.248	.061	.432	<.001	.480	.113	.164	.480	.776	.567	.480	.075
	N	40	40	40	40	40	40	40	40	40	40	40	40
Façade construction method	Pearson Correlation	-.595**	.245	.019	.309	.181	.008	-.404**	.181	-.419**	.620**	.181	.053
	Sig. (2-tailed)	<.001	.128	.906	.053	.263	.960	.010	.263	.007	<.001	.263	.746
	N	40	40	40	40	40	40	40	40	40	40	40	40
Roof construction method	Pearson Correlation	-.205	.198	.232	.445**	-.228	.080	.116	-.228	-.179	.068	-.228	.112
	Sig. (2-tailed)	.205	.220	.150	.004	.158	.623	.475	.158	.268	.679	.158	.491
	N	40	40	40	40	40	40	40	40	40	40	40	40
Floor construction material	Pearson Correlation	-.175	.038	-.057	.019	.009	-.172	.269	.009	-.091	.253	.009	-.150
	Sig. (2-tailed)	.279	.815	.727	.910	.957	.288	.093	.957	.577	.116	.957	.355
	N	40	40	40	40	40	40	40	40	40	40	40	40
façade construction material	Pearson Correlation	-.511**	.316*	-.019	.366*	.270	.191	-.374*	.270	-.357*	.560**	.270	.220
	Sig. (2-tailed)	<.001	.047	.907	.020	.092	.239	.017	.092	.024	<.001	.092	.173
	N	40	40	40	40	40	40	40	40	40	40	40	40
Roof construction material	Pearson Correlation	-.172	.099	-.103	.380*	-.097	-.013	-.063	-.097	-.187	.133	-.097	.012
	Sig. (2-tailed)	.289	.542	.528	.016	.553	.939	.699	.553	.248	.414	.553	.941
	N	40	40	40	40	40	40	40	40	40	40	40	40

		Max height or thickness of Roof in cm	Roof form	Building form	Buildingheightinm	Max. Buildingwidthinm	Max. Buildinglengthinm	Floor construction method	Façade construction method	Roof construction method	Floor construction material	façade construction material	Roof construction material
Number of stories	Pearson Correlation	-.011	-.094	-.420**	.963**	-.047	.096	-.187	-.595**	-.205	-.175	-.511**	-.172
	Sig. (2-tailed)	.945	.562	.007	<.001	.771	.555	.248	<.001	.205	.279	<.001	.289
	N	40	40	40	40	40	40	40	40	40	40	40	40
Floor shape	Pearson Correlation	.276	.200	.663**	-.323*	.394*	.126	.299	.245	.198	.038	.316*	.099
	Sig. (2-tailed)	.085	.216	<.001	.042	.012	.440	.061	.128	.220	.815	.047	.542
	N	40	40	40	40	40	40	40	40	40	40	40	40
Façade shape	Pearson Correlation	-.012	.235	.218	-.202	.038	-.103	.128	.019	.232	-.057	-.019	-.103
	Sig. (2-tailed)	.941	.145	.177	.212	.817	.526	.432	.906	.150	.727	.907	.528
	N	40	40	40	40	40	40	40	40	40	40	40	40
Roof shape	Pearson Correlation	.225	.162	.537**	-.393*	.401*	.092	.557**	.309	.445**	.019	.366*	.380*
	Sig. (2-tailed)	.163	.317	<.001	.012	.010	.572	<.001	.053	.004	.910	.020	.016
	N	40	40	40	40	40	40	40	40	40	40	40	40
Max Length of floor in m	Pearson Correlation	-.176	-.165	.328*	.066	.379*	1.000**	-.115	.181	-.228	.009	.270	-.097
	Sig. (2-tailed)	.278	.308	.039	.686	.016	.000	.480	.263	.158	.957	.092	.553
	N	40	40	40	40	40	40	40	40	40	40	40	40
Max Width of floor in m	Pearson Correlation	-.100	-.073	.180	.008	1.000**	.379*	.255	.008	.080	-.172	.191	-.013
	Sig. (2-tailed)	.540	.654	.268	.961	.000	.016	.113	.960	.623	.288	.239	.939
	N	40	40	40	40	40	40	40	40	40	40	40	40
Max Thickness of floor in cm	Pearson Correlation	-.125	-.221	-.042	.205	.037	-.046	.224	-.404**	.116	.269	-.374*	-.063
	Sig. (2-tailed)	.441	.171	.796	.205	.822	.779	.164	.010	.475	.093	.017	.699
	N	40	40	40	40	40	40	40	40	40	40	40	40
Max Length of façade or Wall	Pearson Correlation	-.176	-.165	.328*	.066	.379*	1.000**	-.115	.181	-.228	.009	.270	-.097
	Sig. (2-tailed)	.278	.308	.039	.686	.016	.000	.480	.263	.158	.957	.092	.553
	N	40	40	40	40	40	40	40	40	40	40	40	40
Max. Height of façade in m	Pearson Correlation	-.106	-.150	-.055	.611**	.114	-.069	.046	-.419**	-.179	-.091	-.357*	-.187
	Sig. (2-tailed)	.514	.354	.736	<.001	.484	.672	.776	.007	.268	.577	.024	.248
	N	40	40	40	40	40	40	40	40	40	40	40	40
Max Thicknes of façade in mm	Pearson Correlation	-.035	.109	.145	-.448**	.009	-.062	.093	.620**	.068	.253	.560**	.133
	Sig. (2-tailed)	.829	.504	.373	.004	.954	.704	.567	<.001	.679	.116	<.001	.414
	N	40	40	40	40	40	40	40	40	40	40	40	40
Max Length of Roof	Pearson Correlation	-.176	-.165	.328*	.066	.379*	1.000**	-.115	.181	-.228	.009	.270	-.097
	Sig. (2-tailed)	.278	.308	.039	.686	.016	.000	.480	.263	.158	.957	.092	.553
	N	40	40	40	40	40	40	40	40	40	40	40	40
Max Width of Roof	Pearson Correlation	-.086	-.054	.234	-.053	.933**	.388*	.285	.053	.112	-.150	.220	.012
	Sig. (2-tailed)	.600	.740	.147	.746	<.001	.013	.075	.746	.491	.355	.173	.941
	N	40	40	40	40	40	40	40	40	40	40	40	40
Max height or thickness of Roof in cm	Pearson Correlation	1	.543**	.187	-.047	-.100	-.176	.298	.070	.232	-.046	-.031	.575**
	Sig. (2-tailed)		<.001	.248	.771	.540	.278	.062	.666	.149	.778	.849	<.001
	N	40	40	40	40	40	40	40	40	40	40	40	40
Roof form	Pearson Correlation	.543**	1	.112	-.122	-.073	-.165	.210	.186	.554**	-.060	.163	.306
	Sig. (2-tailed)	<.001		.493	.454	.654	.308	.194	.251	<.001	.712	.316	.055
	N	40	40	40	40	40	40	40	40	40	40	40	40
Building form	Pearson Correlation	.187	.112	1	-.370*	.180	.328*	.211	.450**	.003	.198	.426**	.052
	Sig. (2-tailed)	.248	.493		.019	.268	.039	.192	.004	.987	.221	.006	.752
	N	40	40	40	40	40	40	40	40	40	40	40	40
Buildingheightinm	Pearson Correlation	-.047	-.122	-.370*	1	.008	.066	-.136	-.623**	-.220	-.166	-.520**	-.193
	Sig. (2-tailed)	.771	.454	.019		.961	.686	.403	<.001	.173	.307	<.001	.232
	N	40	40	40	40	40	40	40	40	40	40	40	40
Max Buildingwidthinm	Pearson Correlation	-.100	-.073	.180	.008	1	.379*	.255	.008	.080	-.172	.191	-.013
	Sig. (2-tailed)	.540	.654	.268	.961		.016	.113	.960	.623	.288	.239	.939
	N	40	40	40	40	40	40	40	40	40	40	40	40
Max Buildinglengthinm	Pearson Correlation	-.176	-.165	.328*	.066	.379*	1	-.115	.181	-.228	.009	.270	-.097
	Sig. (2-tailed)	.278	.308	.039	.686	.016		.480	.263	.158	.957	.092	.553
	N	40	40	40	40	40	40	40	40	40	40	40	40
Floor construction method	Pearson Correlation	.298	.210	.211	-.136	.255	-.115	1	.102	.682**	.321*	.159	.623**
	Sig. (2-tailed)	.062	.194	.192	.403	.113	.480		.530	<.001	.044	.327	<.001
	N	40	40	40	40	40	40	40	40	40	40	40	40
Façade construction method	Pearson Correlation	.070	.186	.450**	-.623**	.008	.181	.102	1	.084	.141	.851**	.106
	Sig. (2-tailed)	.666	.251	.004	<.001	.960	.263	.530		.608	.384	<.001	.514
	N	40	40	40	40	40	40	40	40	40	40	40	40
Roof construction method	Pearson Correlation	.232	.554**	.003	-.220	.080	-.228	.682**	.084	1	.104	.130	.629**
	Sig. (2-tailed)	.149	<.001	.987	.173	.623	.158	<.001	.608		.522	.426	<.001
	N	40	40	40	40	40	40	40	40	40	40	40	40
Floor construction material	Pearson Correlation	-.046	-.060	.198	-.166	-.172	.009	.321*	.141	.104	1	.174	.268
	Sig. (2-tailed)	.778	.712	.221	.307	.288	.957	.044	.384	.522		.284	.095
	N	40	40	40	40	40	40	40	40	40	40	40	40
façade construction material	Pearson Correlation	-.031	.163	.426**	-.520**	.191	.270	.159	.851**	.130	.174	1	.108
	Sig. (2-tailed)	.849	.316	.006	<.001	.239	.092	.327	<.001	.426	.284		.507
	N	40	40	40	40	40	40	40	40	40	40	40	40
Roof construction material	Pearson Correlation	.575**	.306	.052	-.193	-.013	-.097	.623**	.106	.629**	.268	.108	1
	Sig. (2-tailed)	<.001	.055	.752	.232	.939	.553	<.001	.514	<.001	.095	.507	
	N	40	40	40	40	40	40	40	40	40	40	40	40

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

When the correlation coefficient is close to 1, it indicates a strong positive correlation, meaning that as one variable increases, the other variable tends to increase as well. For example, a high positive correlation between the floor shape and the roof shape (0.860**) suggests that certain floor shapes are often associated with specific roof shapes.

On the other hand, when the correlation coefficient is close to -1, it shows a strong negative correlation, implying that as one variable increases, the other variable tends to decrease. For instance, the negative correlation between the number of stories and the maximum thickness of the façade in millimeters (-0.494**) indicates that buildings with more stories tend to have thinner facades. This finding could inform architects about potential design considerations when creating buildings with varying numbers of stories.

A correlation coefficient close to 0 suggests a weak or no linear relationship between the variables. For example, the correlation between the façade shape and the number of stories (0.063) and the correlation between the façade shape and the roof shape (0.019) are relatively weak, suggesting that these architectural aspects might not be strongly influenced by each other.

Summary of key correlations

- Floor shape has a moderate positive correlation with Roof shape (0.860**), meaning that certain floor shapes tend to be associated with specific roof shapes.
- Roof shape has a strong positive correlation with Number of stories (0.557**), indicating that certain roof shapes are more common in buildings with a specific number of stories.
- Number of stories has a moderate negative correlation with Max Thickness of façade in mm (-0.494**), suggesting that buildings with more stories tend to have thinner facades.
- Max Width of floor in m has a strong positive correlation with Max Width of Roof (0.933**), implying that buildings with wider floors also tend to have wider roofs.
- Building form has a strong positive correlation with Max Length of Roof (0.663**) and Roof form (0.682**), indicating that certain building forms are associated with specific roof characteristics.
- Roof construction material has a strong positive correlation with Max Thickness of façade in mm (0.575**), suggesting that buildings with specific roof materials tend to have thicker facades.
- Façade construction method has a strong positive correlation with Roof construction method (0.851**), implying that certain façade construction methods are associated with specific roof construction methods.

❖ It is important to note that correlation does not necessarily imply causation. The relationships observed in the table indicate associations between architectural parameters.

4.2 Statistical tests of regression

4.2.1 The Impact of Floor Geometry on Floor Construction Method

Table 4.2. *Floor shapes*

		Frequency	Valid Percent	Cumulative Percent
Valid	Irregular Octagon	1	2.5	2.5
	Elliptical	2	5.0	7.5
	Rectangular	7	17.5	25.0
	Rectilinear	15	37.5	62.5
	Irregular Shape	5	12.5	75.0
	Irregular Hexagon	1	2.5	77.5
	Irregular polygon	5	12.5	90.0
	Isosceles Trapezium	2	5.0	95.0
	Square	1	2.5	97.5
	Acute Trapezium	1	2.5	100.0
	Total	40	100.0	

Table 4.3. *Floor size*

	N	Minimum	Maximum	Mean	Std. Deviation
Max Length of floor in m	40	25.0	90.0	47.963	14.1296
Max Width of floor in m	40	18.0	63.0	30.418	10.0054
Max Thickness of floor in cm	40	15.0	35.0	23.887	5.2763
Valid N (listwise)	40				

Table 4.4. *Floor construction method*

		Frequency	Valid Percent	Cumulative Percent
Valid	Solid slab	17	42.5	42.5
	Flat plate slab	15	37.5	80.0
	Solid and flat plate slab	3	7.5	87.5
	Ribbed slab	2	5.0	92.5
	Solid, flat plate and Posttensioned slab	1	2.5	95.0
	Post Tension flat plate Slab	1	2.5	97.5
	Solid and ribbed slab	1	2.5	100.0
	Total	40	100.0	

Table 4.5. *MLR to explain floor construction method based on floor geometry*

```
Multinomial logistic regression                 Number of obs     =         40
                                                LR chi2(24)       =      52.70
                                                Prob > chi2       =     0.0006
Log likelihood = -27.735723                     Pseudo R2         =     0.4872
```

The likelihood ratio chi-square test - LRχ2

In the results of a multinomial logistic regression tests, a Chi- square test is a system of comparing the fit of a model which have the complete set of predictors (floor geometry) versus a null model which is characterized by the absence of any predictors. Besides a null model is just have an intercept only. So if the result of the p value of the result of the model is less than 0.05 (α) the model is statistically significant and the results are acceptable. And can decline the null hypothesis. So in this case at least one predictor among the floor geometry of the model have a meaningful effect on the floor construction method. Here ($\alpha = 0.05$) is the applied significance value in this thesis. So, based on the LR(likelihood ratio) test, we can say that the model containing the full set of predictors represents a significant improvement in fit relative to a null model, [LR $\chi^2(24) = 52.70$, $p<0.05$]. We can infer that at least one population slope is non-zero thesis (Stevens, 2016).

Pseudo R-squared

McFadden's pseudo R-square is an index of the proportionate improvement in model fit relative to the null model (Stevens, 2016). Based on McFadden's, we might say that the full model containing our predictors represents a 48.72 % improvement in fit relative to the null model.

Summary

The 'width of floor' predictor is positive and significant ($b = 0.2003$, S.E. = 0.0977, $p<0.05$). This result indicates that in the construction method of floor, a building with a higher thickness of floor are a greater risk of to be constructed by a flat plate slab relative to solid slab than those buildings with less thickness of floor.

The 'thickness of floor' predictor is positive and significant ($b = 0.3135$, S.E. = 0.1183, $p<0.05$). This result indicates that in the construction method of floor, a building with a higher thickness of floor are a greater risk of to be constructed by a flat plate slab relative to solid slab than those buildings with less thickness of floor.

The 'thickness of floor' predictor is positive and significant ($b = 0.5842$, S.E. = 0.2724, $p<0.05$). This result indicates that in the construction method of floor, a building with a higher thickness of floor are a higher likelihood of to be constructed by a combination of solid and flat plate slab relative to solid slab than those buildings with lower thickness of floor (For more details, refer to Appendix B – table B.1).

4.2.2 The impact of Floor Geometry on Floor Construction Material

Table 4.6. *Floor construction material*

		Frequency	Valid Percent	Cumulative Percent
Valid	Concrete and Steel Rebar	38	95.0	95.0
	HCB, Concrete and Steel Rebar	2	5.0	100.0
	Total	40	100.0	

```
Summary (modelfcmg)

Call:

Multinom (formula = m1ba $ Floor construction material ~ m1ba $ Floor shape + m1ba $ Max. Width of floor in m + m1ba $ Max. Length of floor in m + m1ba $ Max. Thickness of floor in cm, data = m1ba)

Residual Deviance: 9.086456

AIC: 19.08646

Baseline variable - HCB__Concrete_and_Steel_Rebar
```

Although the model is significant, since all p values of the model are above 0.05 there is no a significant impact of floor geometry on the construction material selection of floor (For more details, refer to Appendix B – table B.2).

4.2.3 The Impact of Façade Geometry on the façade Construction Method

Table 4.7. *Façade shape*

		Frequency	Valid Percent	Cumulative Percent
Valid	Diamond or Rhombus	1	2.5	2.5
	Curved & polygonal	1	2.5	5.0
	Curved & irregular polygon	1	2.5	7.5
	Rectangular	30	75.0	82.5
	Curved	1	2.5	85.0
	Rectangular & curved	2	5.0	90.0
	Irregular shape	2	5.0	95.0
	Irregular	2	5.0	100.0
	Total	40	100.0	

N.B

Irregular geometry - a combination of single or one type of shape that make a single closed polygon but hard to categorize in a known geometry type.

Irregular shaped geometry – a combination of different type of shapes to make a single closed polygon.

Table 4.8. *Façade size*

	N	Minimum	Maximum	Mean	Std. Deviation
Max. Length of façade or Wall	40	25.0	90.0	47.963	14.1296
Max. Height of façade in m	40	2.60	4.40	3.3905	.35956
Max Thickness of façade in mm	40	6.00	200.00	103.7595	88.49091
Valid N (listwise)	40				

Table 4.9. *Façade construction method*

		Frequency	Valid Percent	Cumulative Percent
Valid	Curtain wall	4	10.0	10.0
	Curtain, Shear and masonry wall	4	10.0	20.0
	Curtain and Shear wall	3	7.5	27.5
	Curtain and Masonry wall	9	22.5	50.0
	Masonry and Glass wall	2	5.0	55.0
	Masonry wall	17	42.5	97.5
	Shear wall	1	2.5	100.0
	Total	40	100.0	

Table 4.10. *MLR to explain façade construction method based on façade geometry*

```
Multinomial logistic regression                    Number of obs     =         39
                                                   LR chi2(24)       =      46.53
                                                   Prob > chi2       =     0.0038
Log likelihood = -38.153051                        Pseudo R2         =     0.3788
```

The likelihood ratio chi-square test - LR$\chi 2$

In the results of a multinomial logistic regression tests, a Chi- square test is a system of comparing the fit of a model which have the complete set of predictors versus a null model which is characterized by the absence of any predictors. Besides a null model is just have an intercept only. So if the result of the p value of the result of the model is less than 0.05 (α) the model is statistically significant and the results are acceptable. And we can decline the null hypothesis. So in this case at least one predictor element in facade geometry have a meaningful effect on the façade construction method. Here ($\alpha = 0.05$) is the applied significance value in this thesis (Stevens, 2016). So, here based on the LR(likelihood ratio) test, we can say that the model containing the full set of predictors represents a significant improvement in fit relative to a null model, [LR $\chi^2(24) = 46.53$, $p<0.05$]. We can infer that at least one population slope is non-zero.

Pseudo R-squared

McFadden's pseudo R-square is an index of the proportionate improvement in model fit relative to the null model (Stevens, 2016). Based on McFadden's, we might say that the full model containing our predictors represents a 37.88 % improvement in fit relative to the null model.

Summary

The 'height of facade' predictor is positive and significant ($b = 5.9858$, S.E. = 3.0190, $p<0.05$). This result indicates that in the construction method of facade, a building with an increased height of façade are a greater risk of to be constructed by a combination of curtain, shear and masonry wall relative to masonry wall than those buildings with shorter height of faced.

The 'thickness of facade' predictor is positive and significant ($b = -0.0199$, S.E. = 0.0082, $p<0.05$). This result indicates that in the construction method of facade, a building with an increased thickness of façade are a higher likelihood of to be constructed by a masonry wall relative to the combination of Curtain and Masonry wall than those buildings with thin thickness of faced (For more details, refer to Appendix B – table B.3).

4.2.4 The Impact of Façade Geometry on the Façade Construction Material

Table 4.11. *Façade construction material*

		Frequency	Valid Percent	Cumulative Percent
Valid	Glass and Aluminum	4	10.0	10.0
	Glass, aluminum, Mortar and HCB	10	25.0	35.0
	Glass, Aluminum, steel and Concrete	2	5.0	40.0
	Glass, Aluminum, Mortar, HCB, steel and Concrete	3	7.5	47.5
	Glass, Aluminum, plastic, steel and Concrete	1	2.5	50.0
	Glass, HCB and Mortar	2	5.0	55.0
	HCB and Mortar	17	42.5	97.5
	Concrete and Steel Rebar	1	2.5	100.0
	Total	40	100.0	

Table 4.12. *MLR to explain façade construction material based on façade geometry*

```
Multinomial logistic regression                 Number of obs     =         39
                                                LR chi2(27)       =      56.06
                                                Prob > chi2       =     0.0008
Log likelihood = -34.294652                     Pseudo R2         =     0.4497
```

The likelihood ratio chi-square test - LRχ2

In the results of a multinomial logistic regression tests, a Chi- square test is a system of comparing the fit of a model which have the complete set of predictors versus a null model which is characterized by the absence of any predictors. Besides a null model is just have an intercept only. So if the result of the p value of the result of the model is less than 0.05 (α) the model is statistically significant and the results are acceptable. And can decline the null hypothesis. So in this case at least one predictor element in facade geometry have a meaningful effect on the façade construction material. Here ($\alpha = 0.05$) is the applied significance value in this thesis (Stevens, 2016). So, here based on the LR(likelihood ratio) test, we can say that the model containing the full set of predictors represents a significant improvement in fit relative to a null model, [LR $\chi^2(27) = 56.06$, $p<0.05$]. We can infer that at least one population slope is non-zero.

Pseudo R-squared

McFadden's pseudo R-square is an index of the proportionate improvement in model fit relative to the null model (Stevens, 2016). Based on McFadden's, we might say that the full model containing our predictors represents a 44.97 % improvement in fit relative to the null model.

Summary

The ‘thickness of facade’ predictor is negative and significant (b = -0.0212, S.E. = 0.0083, $p<0.05$). This result indicates that in the construction material selection of facade, a building with a thick thickness of façade are a greater risk of to be constructed by HCB and mortar materials relative to a combination glass, aluminum, mortar and, HCB materials than those buildings with a thin thickness of façade (For more details, refer to Appendix B – table B.4).

4.2.5 The Impact of Roof Geometry on the Construction Method of Roof

Table 4.13. *Roof shape*

		Frequency	Valid Percent	Cumulative Percent
Valid	Flat Irregular Octagon	1	2.5	2.5
	Flat Elliptical	2	5.0	7.5
	Flat Rectangular	7	17.5	25.0
	Flat Rectilinear	14	35.0	60.0
	Flat Irregular shape	5	12.5	72.5
	Flat Irregular hexagon	2	5.0	77.5
	Flat Irregular polygon	4	10.0	87.5
	Flat Isosceles Trapezium	2	5.0	92.5
	Flat Square and polyhedron	1	2.5	95.0
	Flat Acute Trapezium	1	2.5	97.5
	Polyhedron	1	2.5	100.0
	Total	40	100.0	

Table 4.14. *Roof size*

	N	Minimum	Maximum	Mean	Std. Deviation
Max Length of Roof	40	25.0	90.0	47.963	14.1296
Max Width of Roof	40	9.0	63.0	29.818	10.5513
Max height or thickness of Roof in cm	40	1.0	200.0	30.563	35.5962
Valid N (listwise)	40				

Table. 4.15 *Roof construction method*

		Frequency	Valid Percent	Cumulative Percent
Valid	Solid slab	18	45.0	45.0
	Flat plate slab	14	35.0	80.0
	Light weight flat plate slab	1	2.5	82.5
	Flat plate slab and truss	1	2.5	85.0
	waffle and solid slab	1	2.5	87.5
	Ribbed slab	1	2.5	90.0
	Waffle Slab	1	2.5	92.5
	Post Tension flat plate Slab and truss	1	2.5	95.0
	Flat plate slab and dome	1	2.5	97.5
	Truss	1	2.5	100.0
	Total	40	100.0	

Table 4.16. *MLR to explain roof construction method based on roof geometry*

```
Multinomial logistic regression                 Number of obs     =         40
                                                LR chi2(26)       =      99.38
                                                Prob > chi2       =     0.0000
Log likelihood = -8.8931354                     Pseudo R2         =     0.8482
```

The likelihood ratio chi-square test - LRχ2

In the results of a multinomial logistic regression tests, a Chi- square test is a system of comparing the fit of a model which have the complete set of predictors versus a null model which is characterized by the absence of any predictors. Besides a null model is just have an intercept only. So if the result of the p value of the result of the model is less than 0.05 (α) the model is statistically significant and the results are acceptable. And can decline the null hypothesis. So in this case at least one predictor element in roof geometry have a meaningful effect on the roof construction method. Here ($\alpha = 0.05$) is the applied significance value in this thesis (Stevens, 2016). So, here based on the LR(likelihood ratio) test, we can say that the model containing the full set of predictors represents a significant improvement in fit relative to a null model, [LR $\chi^2(26) = 99.38$, $p<0.05$].

Pseudo R-squared

McFadden's pseudo R-square is an index of the proportionate improvement in model fit relative to the null model (Stevens, 2016). Based on McFadden's, we might say that the full model containing our predictors represents 84.82 % improvement in fit relative to the null model.

Summary

The 'height or thickness of roof' predictor is positive and significant ($b = 0.5407$, S.E. = 0.2645, $p<0.05$, since $p = 0.041$). This result indicates that in the construction method of roof, a building with a thick slab in the case of flat roofs and larger height of roof in the case of pitched roof are a greater risk of to be constructed by a flat plate slab relative to a solid slab than those buildings with a thin thickness and short height of roof (For more details, refer to Appendix B – table B.5).

4.2.6 The Impact of Roof Geometry on the Roof Construction Material

Table 4.17. *Roof construction material*

		Frequency	Valid Percent	Cumulative Percent
Valid	Concrete and Steel Rebar	33	82.5	82.5
	Concrete, Steel Rebar, corrugated metal sheet and steel members	1	2.5	85.0
	HCB, Concrete and Steel Rebar	2	5.0	90.0
	Concrete, Glass and Steel Rebar	1	2.5	92.5
	Concrete, Steel Rebar, corrugated metal sheet and steel members	2	5.0	97.5
	Corrugated metal sheets and steel members	1	2.5	100.0
	Total	40	100.0	

Table 4.18. *MLR to explain roof construction material based on roof geometry*

```
Multinomial logistic regression                 Number of obs     =         40
                                                LR chi2(15)       =      38.69
                                                Prob > chi2       =     0.0007
Log likelihood = -10.053815                     Pseudo R2         =     0.6580
```

The likelihood ratio chi-square test - LRχ2

In the results of a multinomial logistic regression tests, a Chi- square test is a system of comparing the fit of a model which have the complete set of predictors versus a null model which is characterized by the absence of any predictors. Besides a null model is just have an intercept only. So if the result of the p value of the result of the model is less than 0.05 (α) the model is statistically significant and the results are acceptable. And can decline the null hypothesis. So in this case at least one predictor element in roof geometry have a meaningful effect on the roof construction material of high rise buildings. Here ($\alpha = 0.05$) is the applied significance value in this thesis (Stevens, 2016). So, here based on the LR(likelihood ratio) test, we can say that the model containing the full set of predictors represents a significant improvement in fit relative to a null model, [LR $\chi^2(15) = 38.69$, $p<0.05$]. We can infer that at least one population slope is non-zero.

Pseudo R-squared

McFadden's pseudo R-square is an index of the proportionate improvement in model fit relative to the null model (Stevens, 2016). Based on McFadden's, we might say that the full model containing our predictors represents 65.8 % improvement in fit relative to the null model.

Summary

Although the model is significant, there is no statistically significant impact of roof geometry on the construction material selection of roof (For more details, refer to Appendix B – table B.6).

4.2.7. The Impact of Overall Volumetric Geometry on the Floor Construction Method

Table 4.19. *Building form*

		Frequency	Valid Percent	Cumulative Percent
Valid	Irregular octagonal prism	1	2.5	2.5
	Elliptic Cylinder	2	5.0	7.5
	Tapered rectangular prism	1	2.5	10.0
	Rectilinear prism	15	37.5	47.5
	Irregular shaped prism	5	12.5	60.0
	Irregular Hexagonal prism	1	2.5	62.5
	Irregular polygonal prism	5	12.5	75.0
	Rectangular prism	6	15.0	90.0
	Isosceles Trapezoidal Prism	2	5.0	95.0
	Square prism	1	2.5	97.5
	Acute trapezoidal prism	1	2.5	100.0
	Total	40	100.0	

Table 4.20. *Building size*

	N	Minimum	Maximum	Mean	Std. Deviation
Building height in m	40	51.00	192.00	79.5945	27.40574
Max. Building width in m	40	18.00	63.00	30.4175	10.00541
Max. Building length in m	40	25.00	90.00	47.9625	14.12961
Valid N (listwise)	40				

Table 4.21. *MLR to explain floor construction method based on volumetric geometry*

Multinomial logistic regression	Number of obs	=	40
	LR chi2(24)	=	54.61
	Prob > chi2	=	0.0004
Log likelihood = -26.780376	Pseudo R2	=	0.5049

The likelihood ratio chi-square test - LRχ2

In the results of a multinomial logistic regression tests, a Chi- square test is a system of comparing the fit of a model which have the complete set of predictors versus a null model which is characterized by the absence of any predictors. Besides a null model is just have an intercept only. So if the result of the p value of the result of the model is less than 0.05 (α) the model is statistically significant and the results are acceptable. And can decline the null hypothesis. So in this case at least one predictor element in volumetric geometry have a meaningful effect on the floor construction method. Here ($\alpha = 0.05$) is the applied significance value in this thesis (Stevens, 2016). So, here based on the LR(likelihood ratio) test, we can say that the model containing the full set of predictors represents a significant improvement in fit relative to a null model, [LR $\chi^2(24) = 54.61$, $p<0.05$]. We can infer that at least one population slope is non-zero.

Pseudo R-squared

McFadden's pseudo R-square is an index of the proportionate improvement in model fit relative to the null model (Stevens, 2016). Based on McFadden's, we might say that the full model containing our predictors represents 50.49 % improvement in fit relative to the null model.

Summary

The 'Building width' predictor is positive and significant ($b = 0.1306$, S.E. = 0.0635596, $p<0.05$, since $p = 0.040$). This result indicates that in the construction method of floor, a building with a wide building width are a greater risk of to be constructed by a flat plate slab relative to a solid slab than those buildings with a narrow building width (For more details, refer to Appendix B – table B.7).

4.2.8 The Impact of Overall Volumetric Geometry on the Construction Material of Floor

Table 4.22. *MLR to explain floor construction material based on volumetric geometry*

Multinomial logistic regression	Number of obs	=	40
	LR chi2(4)	=	15.88
	Prob > chi2	=	0.0032
Log likelihood = -.00055711	Pseudo R2	=	0.9999

The likelihood ratio chi-square test - LRχ2

In the results of a multinomial logistic regression tests, a Chi- square test is a system of comparing the fit of a model which have the complete set of predictors versus a null model which is characterized by the absence of any predictors. Besides a null model is just have an intercept only. So if the result of the p value of the result of the model is less than 0.05 (α) the model is statistically significant and the results are acceptable. And can decline the null hypothesis. Here (α = 0.05) is the applied significance value in this thesis (Stevens, 2016). So in this case at least one predictor element in volumetric geometry have a meaningful effect on the floor construction material of high rise buildings. So, here based on the LR(likelihood ratio) test, we can say that the model containing the full set of predictors represents a significant improvement in fit relative to a null model, [LR $\chi^2(4) = 15.88$, $p<0.05$].

Pseudo R-squared

McFadden's pseudo R-square is an index of the proportionate improvement in model fit relative to the null model (Stevens, 2016). Based on McFadden's, we might say that the full model containing our predictors represents 99.99 % improvement in fit relative to the null model.

Summary

Although the model is significant, there is no a significant impact of volumetric geometry of building on the construction material selection of floor or slab (For more details, refer to Appendix B – table B.8).

4.2.9 The Impact of Overall Volumetric Geometry on the Construction Method of Facade

Table 4.23. *MLR to explain façade construction method based on volumetric geometry*

Multinomial logistic regression	Number of obs	=	40
	LR chi2(24)	=	47.43
	Prob > chi2	=	0.0030
Log likelihood = -40.127145	Pseudo R2	=	0.3715

The likelihood ratio chi-square test - LRχ2

This portion of the output contains the results from a likelihood ratio chi-square test, comparing the fit of the model with the complete set of predictors with an intercept-only, or null, model (no predictors). If it is statistically significant, we can infer that at least one population regression slope is significantly different from zero, which assures a valid occurrence of the effect of a volumetric geometry on the façade construction method (Stevens, 2016). So, here based on the LR(likelihood ratio) test, we can say that the model containing the full set of predictors represents a significant improvement in fit relative to a null model, [LR $\chi^2(24) = 47.43$, $p<0.05$]. We can infer that at least one population slope is non-zero.

Pseudo R-squared

McFadden's pseudo R-square is an index of the proportionate improvement in model fit relative to the null model (Stevens, 2016). Based on McFadden's, we might say that the full model containing our predictors represents 37.15 % improvement in fit relative to the null model.

Summary

The 'building height' predictor is positive and significant ($b = 0.1693$, S.E. = 0 .0568, $p<0.05$, since $p = 0.003$). This result indicates that in the construction method of facade, a building with a higher building height are a greater risk of their facade to be constructed by a curtain wall relative to masonry wall than those buildings with a shorter building height.

The 'building height' predictor is positive and significant ($b = 0.1508$, S.E. = 0.0540, $p<0.05$, since $p = 0.005$). This result indicates that in the construction method of floor, a building with higher building height are a greater risk of their facade to be constructed by a combination Curtain, Shear, and, and masonry wall relative to masonry wall than those buildings with a shorter building height.

The 'building height' predictor is positive and significant ($b = 0.1298$, S.E. = 0.0567, $p<0.05$, since $p = 0.022$). This result indicates that in the construction method of floor, a building with higher building height are a greater risk of their façade to be constructed by a combination curtain and shear wall relative to masonry wall than those buildings with a shorter building height.

The ‘building height’ predictor is positive and significant ($b = 0.1268$, S.E. = 0.0519, $p<0.05$, since $p = 0.015$). This result indicates that in the construction method of facade, a building with higher building height are a greater risk of their facade to be constructed by a combination Curtain and Masonry wall relative to masonry wall than those buildings with a shorter building height (For more details, refer to Appendix B – table B.9).

4.2.10. The Impact of Overall Volumetric Geometry on the Construction Material of Façade

Table 4.24. *MLR to explain façade construction material based on volumetric geometry*

```
Multinomial logistic regression                 Number of obs     =         40
                                                LR chi2(28)       =      52.59
                                                Prob > chi2       =     0.0033
Log likelihood = -38.453885                     Pseudo R2         =     0.4061
```

The likelihood ratio chi-square test - LRχ2

In the results of a multinomial logistic regression tests, a Chi- square test is a system of comparing the fit of a model which have the complete set of predictors versus a null model which is characterized by the absence of any predictors. Besides a null model is just have an intercept only. So if the result of the p value of the result of the model is less than 0.05 (α) the model is statistically significant and the results are acceptable. And can decline the null hypothesis. So in this case there is at least a meaningful interplay between the dependet and predictor variables of the model. So in this case at least one predictor element in volumetric geometry have a meaningful effect on the façade construction material of high-rise buildings. Here ($\alpha = 0.05$) is the applied significance value in this thesis (Stevens, 2016). So, here based on the LR(likelihood ratio) test, we can say that the model containing the full set of predictors represents a significant improvement in fit relative to a null model, [LR $\chi^2(28) = 52.59$, $p<0.05$].

Pseudo R-squared

McFadden’s pseudo R-square is an index of the proportionate improvement in model fit relative to the null model (Stevens, 2016). Based on McFadden’s, we might say that the full model containing our predictors represents 40.61 % improvement in fit relative to the null model.

Summary

The ‘building height’ predictor is positive and significant ($b = 0.1563$, S.E. = 0.0560, $p<0.05$, since $p = 0.005$). This result indicates that in the construction material of facade, a building with higher building height are a greater risk of their façade to be constructed by a combination of glass and aluminum material relative to HCB and mortar material than those buildings with a shorter building height.

The ‘building height’ predictor is positive and significant ($b = 0.1453$, S.E. = 0.0544, $p<0.05$, since $p = 0.008$). This result indicates that in the construction material of facade, a building with higher building height are a greater risk of their faced to be constructed by a combination of glass, aluminum, mortar and HCB material relative to HCB and mortar material than those buildings with a shorter building height.

The ‘building width’ predictor is negative and significant (b = -0.2920, S.E. = 0.1468, p<0.05, since p = 0.047). This result indicates that in the construction material of facade, a building with a wider building width are a greater risk of their faced to be constructed by HCB and mortar material relative to a combination of glass, aluminum, mortar and HCB material than those buildings with a narrower building width.

The ‘building height’ predictor is positive and significant (b = 0.1343, S.E. = 0 .0531, p<0.05, since p = 0.011). This result indicates that in the construction material of facade, a building with higher building height are a greater risk of their façade to be constructed by a combination of glass, aluminum, mortar and HCB material relative to HCB and mortar material than those buildings with a shorter building height (For more details, refer to Appendix B – table B.10).

4.2.11. The Impact of Overall Volumetric Geometry on the Construction Method of Roof

Table 4.25. *MLR to explain roof construction method based on volumetric geometry*

```
Multinomial logistic regression                 Number of obs     =         40
                                                LR chi2(36)       =      72.96
                                                Prob > chi2       =     0.0003
Log likelihood = -22.101168                     Pseudo R2         =     0.6227
```

The likelihood ratio chi-square test - LRχ2

In the results of a multinomial logistic regression tests, a Chi- square test is a system of comparing the fit of a model which have the complete set of predictors versus a null model which is characterized by the absence of any predictors. Besides a null model is just have an intercept only. So if the result of the p value of the result of the model is less than 0.05 (α) the model is statistically significant and the results are acceptable. And can decline the null hypothesis. So in this case there is at least a meaningful interplay between the dependent and predictor variables of the model. So in this case at least one predictor element in volumetric geometry have a meaningful effect on the roof construction method. Here (α = 0.05) is the applied significance value in this thesis (Stevens, 2016). So, based on the LR(likelihood ratio) test, we can say that the model containing the full set of predictors represents a significant improvement in fit relative to a null model, [LR $\chi^2(36) = 72.96$, p<0.05]. We can infer that at least one population slope is non-zero.

Pseudo R-squared

McFadden's pseudo R-square is an index of the proportionate improvement in model fit relative to the null model (Stevens, 2016). Based on McFadden's, we might say that the full model containing our predictors represents 62.27 % improvement in fit relative to the null model.

Summary

The 'building width' predictor is positive and significant (b = 0.1272, S.E. = 0.0602, $p<0.05$, since p = 0.035). This result indicates that in the construction method of roof, a building with a wider building width are a greater risk of their roof be constructed by a flat plate slab roof construction method relative to Solid slab roof construction method than those buildings with a narrower building width (For more details, refer to Appendix B – table B.11).

4.2.12. The Impact of Overall Volumetric Geometry on the Construction Material of Roof

Table 4.26. *MLR to explain roof construction material based on volumetric geometry*

```
Multinomial logistic regression                 Number of obs     =         40
                                                LR chi2(20)       =      45.92
                                                Prob > chi2       =     0.0008
Log likelihood = -6.4374846                     Pseudo R2         =     0.7810
```

The likelihood ratio chi-square test - LRχ2

In the results of a multinomial logistic regression tests, a Chi- square test is a system of comparing the fit of a model which have the complete set of predictors versus a null model which is characterized by the absence of any predictors. Besides a null model is just have an intercept only. So if the result of the p value of the result of the model is less than 0.05 (α) the model is statistically significant and the results are acceptable. And can decline the null hypothesis. So in this case there is at least one meaningful interplay between the dependent and predictor variables of the model. In other words least one predictor element in volumetric geometry of buildings have a meaningful effect on the roof construction material of high rise buildings in the city. Here ($\alpha = 0.05$) is the applied significance value in this thesis (Stevens, 2016). So, here based on the LR(likelihood ratio) test, we can say that the model containing the full set of predictors represents a significant improvement in fit relative to a null model, [LR $\chi^2(20) = 45.92$, $p<0.05$].

Pseudo R-squared

McFadden's pseudo R-square is an index of the proportionate improvement in model fit relative to the null model (Stevens, 2016). Based on McFadden's, we might say that the full model containing our predictors represents 78.10 % improvement in fit relative to the null model.

Summary

Although the model is significant, there is no a significant impact of volumetric geometry of building on the construction material selection of roof (For more details, refer to Appendix B – table B.12).

4.3 Statistical Tests on Method 2 - Geometry and Construction

4.3.1. Influence of Floor geometry on Floor construction method

Figure 4.1. *Floor geometry*

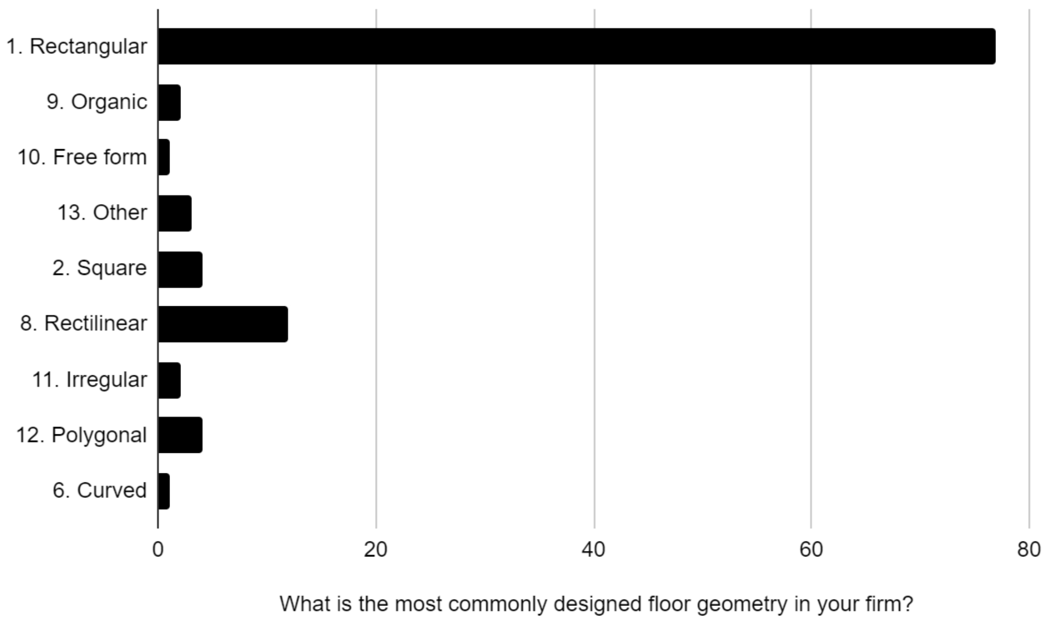
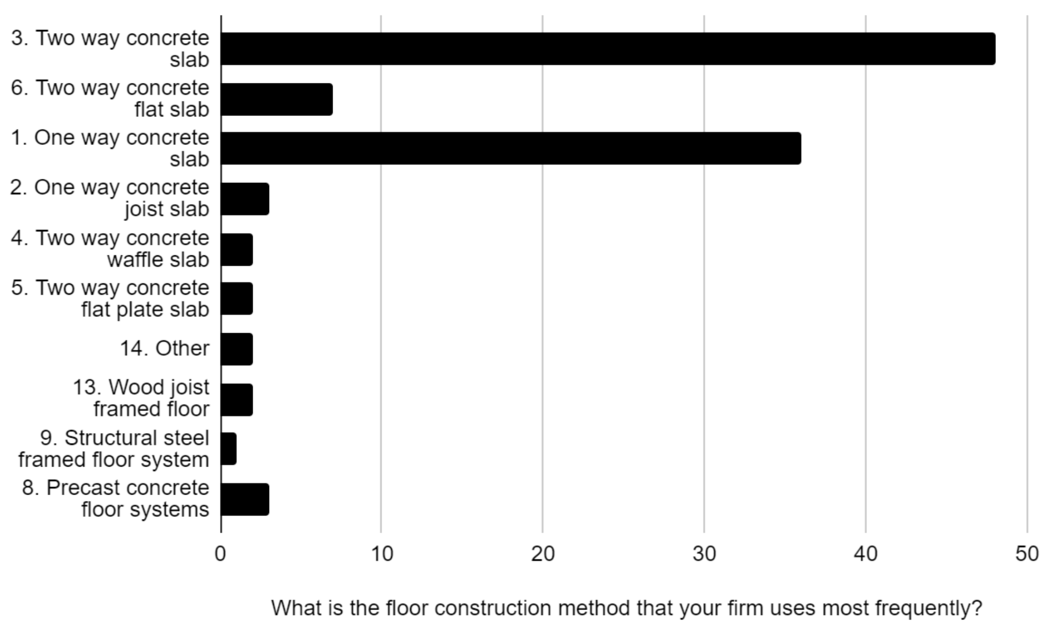


Figure 4.2. *Floor construction method*



```
> Summary (model) – from R programing software

Call: multinom (formula = QAR $ Floor construction method ~ QAR $ Floor geometry, data = QAR, ref = 1)

Residual Deviance: 288.1937

AIC: 324.1937

Baseline variable - One way concrete slab
```

Deviance residuals: measures how much probabilities estimated from our model differ from the observed proportions of successes. Bigger values indicate a bigger difference. Smaller values mean a smaller difference (Ford, 2022). Since this research focuses on identifying the effect of separate independent variable on a dependent variable, no need of comparing other models, so the precise value of residual deviance equals 288.19.

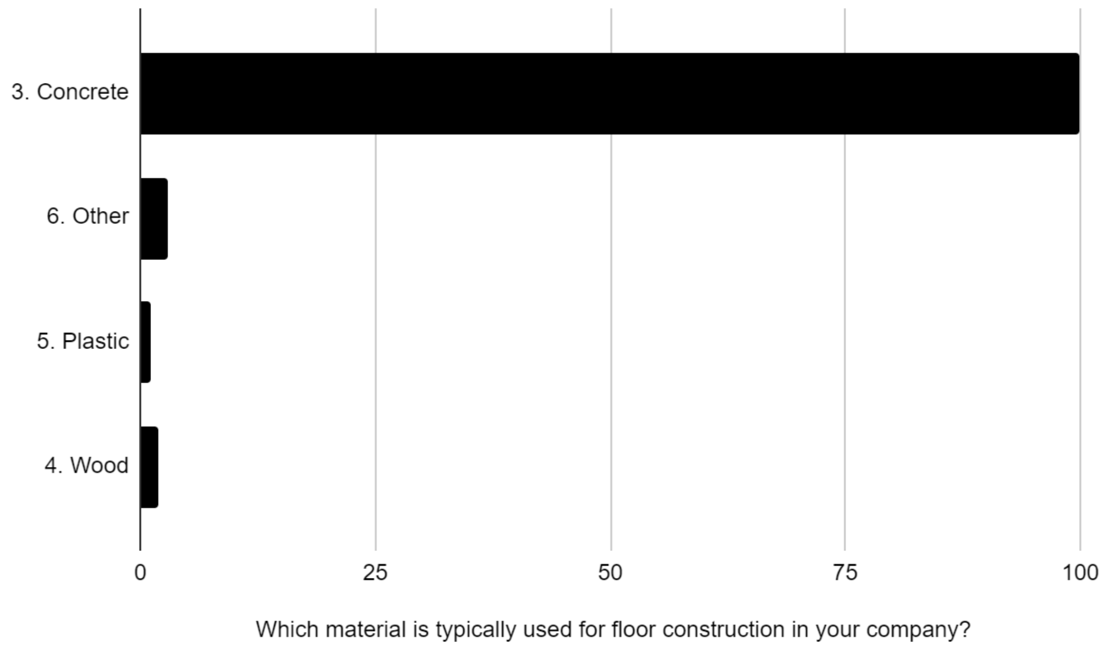
The Akaike information criterion (AIC): is a mathematical method for evaluating how well a model fits the data it was generated from. In statistics, AIC is used to compare different possible models and determine which one is the best fit for the data (Bevans, 2020). Since this research focuses on identifying the effect of separate independent variable on a dependent variable, no need of comparing other models, so the precise value of AIC equals 324.19.

Summary

A multinomial logistic regression was fitted to explain floor construction method based on floor geometry. In general the multinomial logistic regression statistical analysis results shows that most floor geometries have a substantial impact in deciding the floor construction method of buildings, in view of the fact that when their floor geometry varies, the possible floor construction methods differs accordingly, relative to the baseline construction method of floors. For instance Organic, freeform and irregular shaped floors have an effect on deciding the floor construction method of buildings, these floor geometries have relatively higher possibility of to be constructed by one way concrete slab than one way concrete joist slab. Besides rectilinear shaped floor geometries have relatively a higher possibility of to be constructed by two way concrete slab than one way concrete slab construction method. Furthermore, organic shaped floor geometries have relatively a higher possibility of to be constructed by one way concrete slab than two way concrete slab construction method. Polygonal shaped floor geometries have relatively a higher possibility of to be constructed by one way concrete slab than two way concrete slab construction method. Moreover other shaped floor geometries have relatively a higher possibility of to be constructed by two way concrete slab than one way concrete slab construction method etc. (For more details, refer to Appendix C – table C.1).

4.3.2 Influence of Floor geometry on Floor construction material

Figure 4.3. *Floor construction material*




```
> Summary (model) – from R programing software
Call:
Multinom (formula = QARF $ Floor construction material ~ QARF $ Floor g
eometry, data = QARF)
Residual Deviance: 44.04877
AIC: 98.04877
Baseline variable – Concrete
```

The Deviance residuals measure how much probabilities estimated from our model differ from the observed proportions of successes. Bigger values indicate a bigger difference. Smaller values mean a smaller difference (Ford, 2022). Since this research focuses on identifying the effect of separate independent variable on a dependent variable, no need of comparing other models, so the precise value of residual deviance equals 44.04.

The Akaike information criterion (AIC) is a mathematical method for evaluating how well a model fits the data it was generated from. In statistics, AIC is used to compare different possible models and determine which one is the best fit for the data (Bevans, 2020). Since this research focuses on identifying the effect of separate independent variable on a dependent variable, no need of comparing other models, so the precise value of AIC equals 98.04.

Summary

A multinomial logistic regression was fitted to explain floor construction material based on floor geometry. In general the multinomial logistic regression statistical analysis results shows that some floor geometries have a substantial impact in deciding the floor construction material of buildings, in view of the fact that when their floor geometry varies, the possible floor construction materials differs accordingly, relative to the baseline construction material of floors, in this case concrete. For instance, floor geometries which have a rectilinear shaped geometry have relatively higher possibility of to be constructed by concrete material than wooden material. Besides floor geometries which have square, curved, rectilinear, organic, freeform, irregular and polygonal shaped geometry also have relatively a higher possibility of to be constructed by concrete material than other types of materials which are not listed in this thesis survey form. Moreover, floor geometries which have other geometry type not listed in this thesis questioner form have relatively higher chance of to be constructed by other materials which are not listed in this thesis survey form. Bold highlighted rows are statistically significant p value results, which have a p value of less than 0.05 ($p<0.05$) (For more details, refer to Appendix C – table C.2).

4.3.3 Influence of Façade geometry on Façade construction method

Figure 4.4. *Façade geometry*

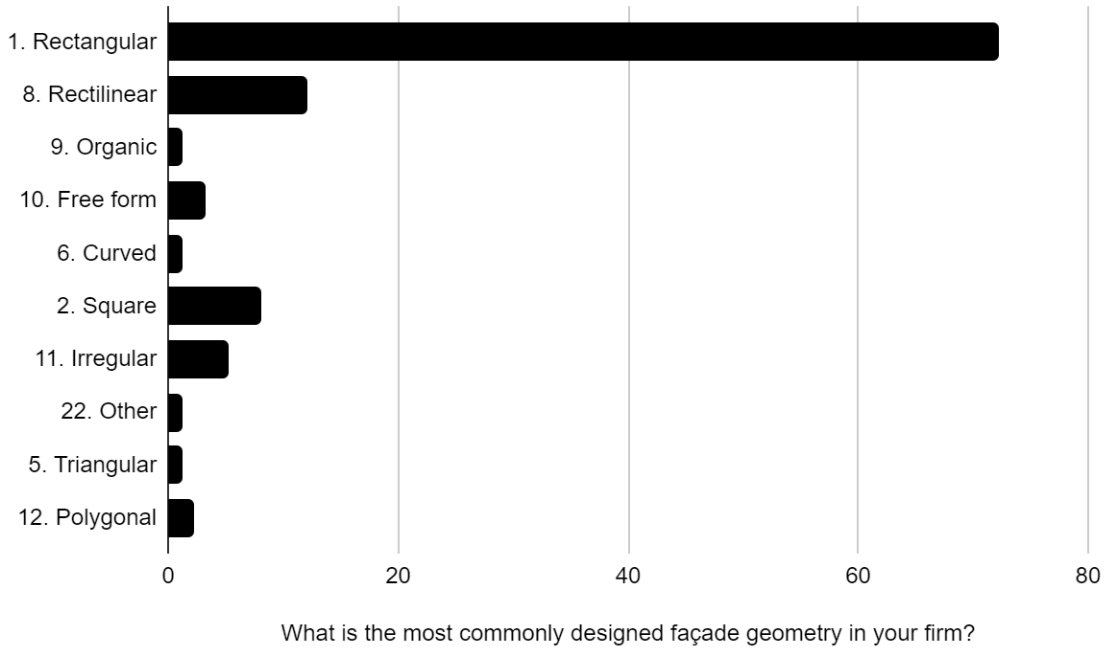
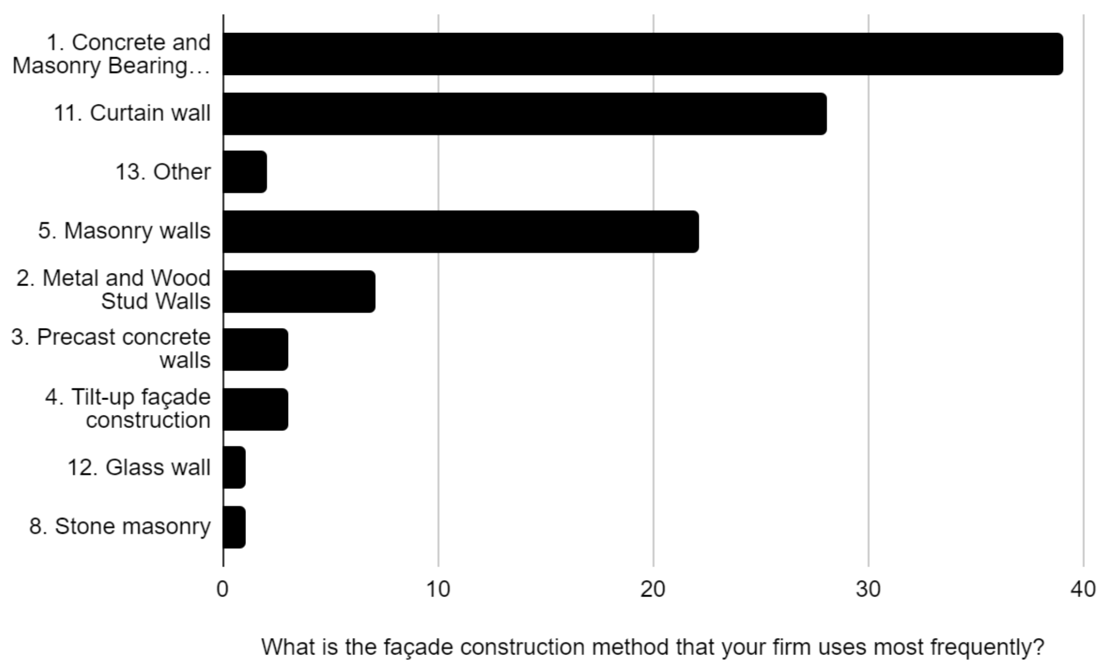


Figure 4.5. *Façade construction method*



```
> summary(model)

Call:

multinom(formula = QARF $ Façade construction method ~   QARF $ Façade
geometry, data = QARF)

Residual Deviance: 272.2638

AIC: 398.2638

Baseline variable - Concrete and Masonry Bearing Walls.
```

Deviance residuals: measure how much probabilities estimated from our model differ from the observed proportions of successes. Bigger values indicate a bigger difference. Smaller values mean a smaller difference (Ford, 2022). Due to the fact that, this research focuses on identifying the effect of separate independent variable on a dependent variable, no need of comparing other models, so the precise value of residual deviance equals 272.26.

The Akaike information criterion (AIC): is a mathematical method for evaluating how well a model fits the data it was generated from. In statistics, AIC is used to compare different possible models and determine which one is the best fit for the data (Bevans, 2020). Since this research focuses on identifying the effect of separate independent variable on a dependent variable, no need of comparing other models, so the precise value of AIC equals 398.26.

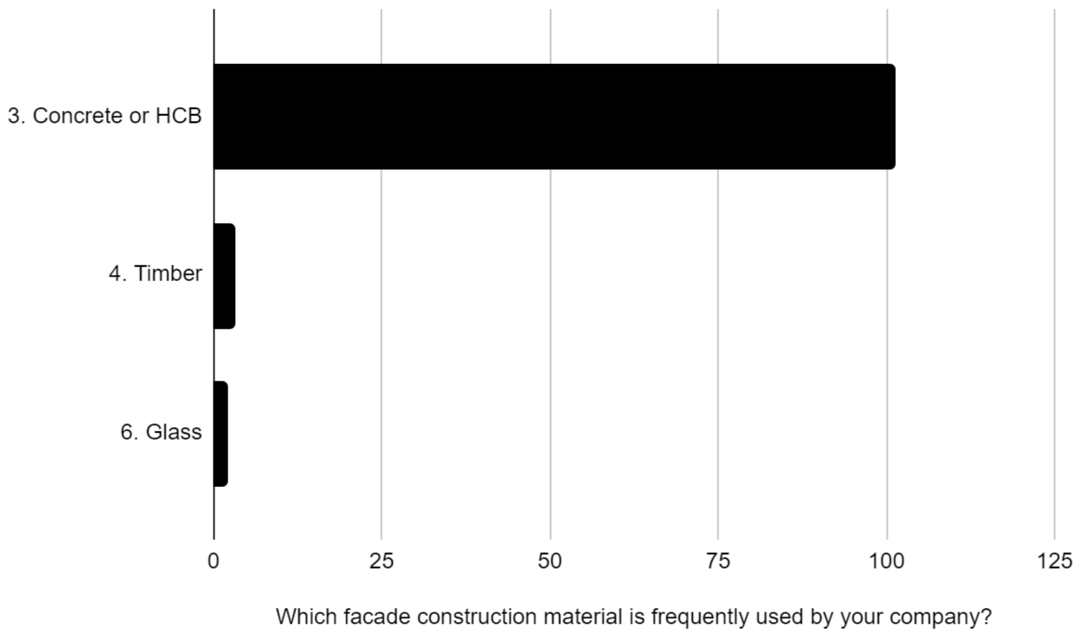
Summary

A multinomial logistic regression was fitted to explain facade construction method based on facade geometry. In general the multinomial logistic regression statistical analysis results shows that most façade geometries have a substantial impact in deciding the facade construction method of buildings, in view of the fact that when their facade geometry varies, the possible facade construction method differs accordingly, relative to the baseline construction method of façade, in this case concrete and masonry bearing walls. For instance, facade geometries which have a triangular, curved, rectilinear, irregular and polygonal shaped facade geometries have relatively higher possibility to be constructed by concrete and masonry bearing walls construction method than metal and wood stud walls. Besides, facade geometries which have a square and curved shaped façade geometries have relatively higher chance of to be constructed by concrete and masonry bearing walls than curtain wall construction method. On the other hand, façade geometries which have rectilinear, triangular, polygonal and freeform shaped façade geometries have relatively a higher chance of to be constructed by curtain wall construction method than concrete and masonry bearing walls.

Bold highlighted rows are statistically significant results, which have a p value of less than 0.05 ($p<0.05$) (For more details, refer to Appendix C– table C.3).

4.3.4 Influence of Façade geometry on Façade construction material

Figure 4.6. *Façade construction material*




```
> summary(FGonFmat)
Call:
multinom(formula = QARF $ Façade construction material ~ QARF $ Façade
geometry, data = QARF)
Residual Deviance: 31.36
AIC: 67.36
Baseline variable – Concrete or HCB.
```

Summary

A multinomial logistic regression was fitted to explain facade construction material based on facade geometry. In general the multinomial logistic regression statistical analysis results shows that most façade geometries have a substantial impact in deciding the facade construction material of buildings, in view of the fact that when their facade geometry varies, the possible facade construction material differs accordingly, relative to the baseline construction material of façade, in this case concrete or HCB material. For instance, facade geometries which have a triangular, curved, rectilinear, freeform, irregular, polygonal shaped façade geometries relatively have a higher possibility to be constructed by HCB (concrete) material than timber materials and other floor geometries not listed in this research also have a higher chance to be constructed by HCB than timber material. On the other hand facade geometries which have a square, rectilinear, freeform and irregular shaped facades have a higher probability of to be constructed by HCB material than Glass material, but polygonal façade geometries have a greater possibility to be constructed by glass material than HCB (concrete) material. Bold highlighted rows are statistically significant results, which have a p value of less than 0.05 ($p<0.05$) (For more details, refer to Appendix C – table C.4).

4.3.5 Influence of Roof geometry on Roof construction method

Figure 4.7. *Roof geometry*

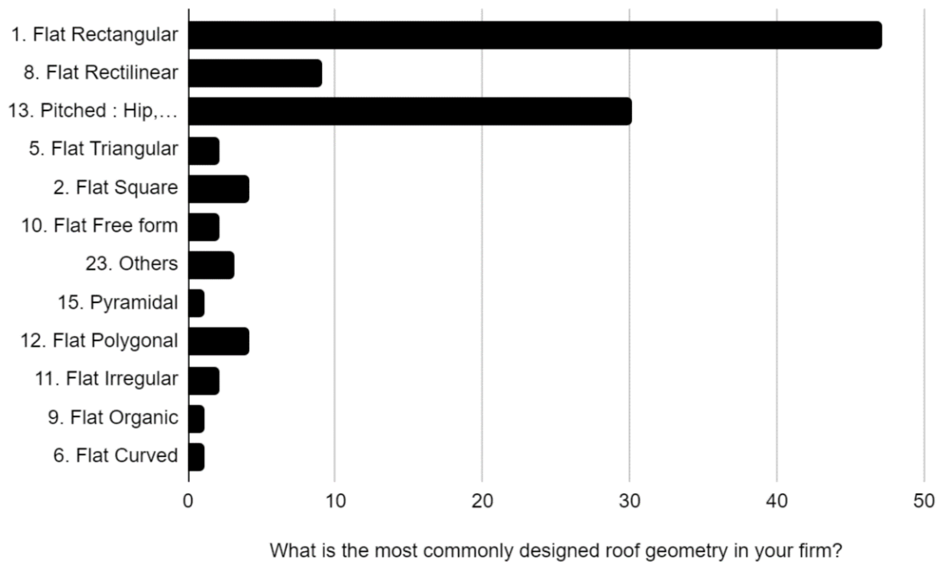
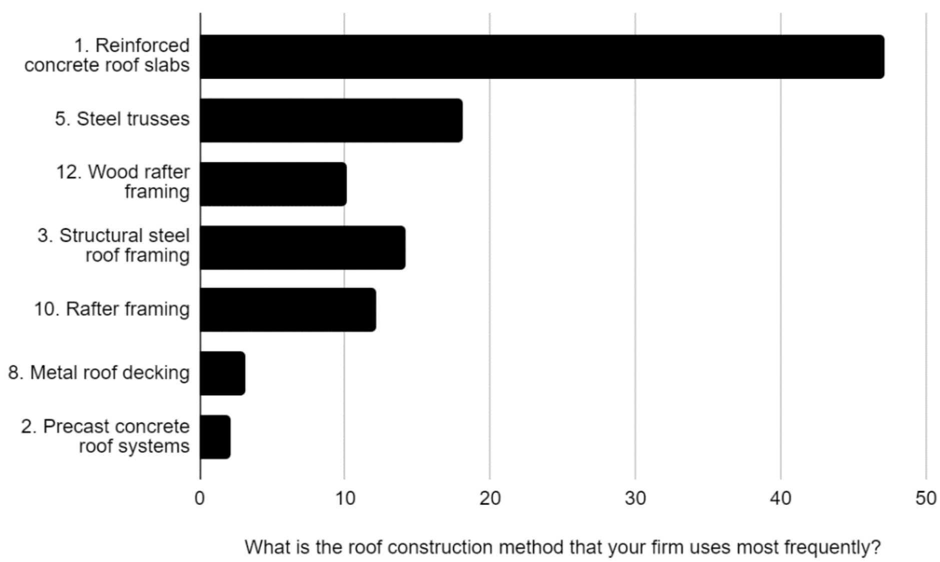


Figure 4.8. *Roof construction method*



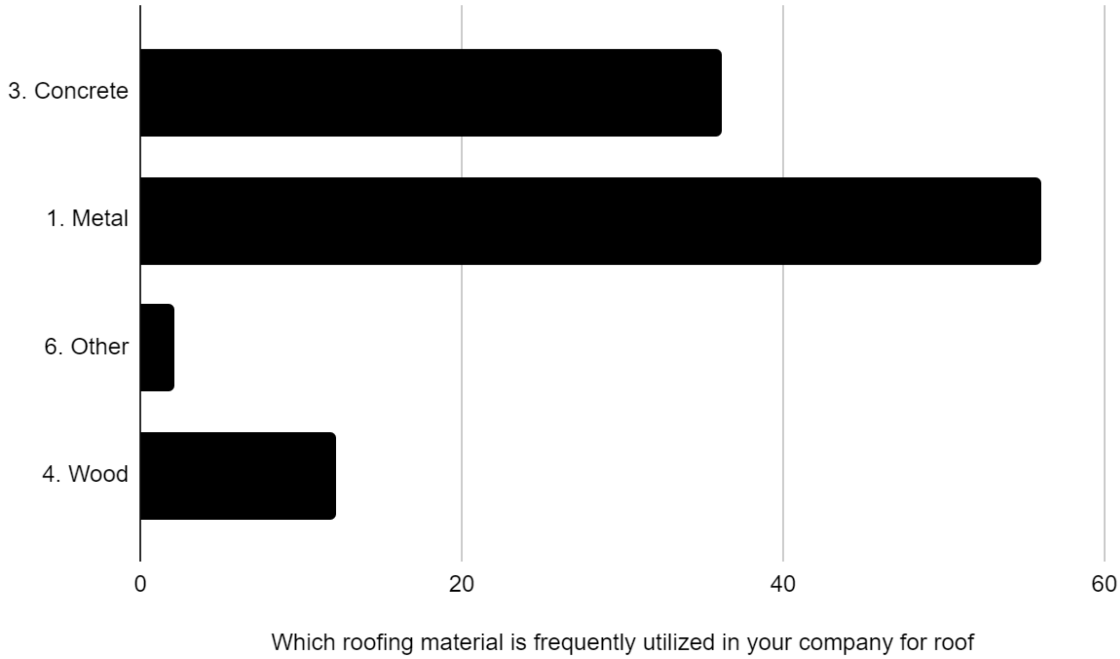
```
> Summary (ROOFGEOONROOFCONMETH)
Call:
Multinom (formula = QARF $ Roof construction method ~ QARF $Roof
geometry, data = QARF)
Residual Deviance: 214.4605
AIC: 358.4605
Baseline variable - Reinforced concrete roof slabs.
```

A multinomial logistic regression was fitted to explain roof construction method based on roof geometry. In general the multinomial logistic regression statistical analysis results shows that most roof geometries have a substantial impact in deciding the roof construction method of buildings, in view of the fact that when their roof geometry varies, the possible roof construction method differs accordingly, relative to the baseline construction method of roof, in this case Reinforced concrete roof slabs. For instance, Flat-triangular, flat-rectilinear, flat-organic, flat-irregular, flat-polygonal and other roof geometry types not listed in this thesis have a greater possibility to be constructed by reinforced concrete roof slab construction method than precast concrete roof construction method. But roofs which have pyramidal shaped geometries have relatively a higher chance to be constructed by precast concrete roof systems than reinforced concrete roof slab construction method.

Furthermore, Flat-curved, flat-organic, flat-irregular, and pyramidal shaped roof geometries have relatively a higher chance of to be constructed by Reinforced concrete roof slab construction method than steel truss roof construction method, on the contrary roof geometries which have the common Pitched roof geometry like Hip, Gable, Mansard, Gambrel butterfly etc. have relatively a higher possibility to be constructed by steel truss roof construction method than reinforced concrete roof slab construction method. Bold highlighted rows are statistically significant results, which have a p value of less than 0.05 ($p<0.05$) (For more details, refer to Appendix C – table C.5).

4.3.6 Influence of Roof geometry on Roof construction material

Figure 4.9. *Roof construction material*




```
> Summary (RofgeoonRofmat)
Call:
Multinom (formula = QARF $ Roof construction material ~ QARF $ Roof
geometry, data = QARF)
Residual Deviance: 147.3359
AIC: 219.3359
Baseline variable – Metal
```

A multinomial logistic regression was fitted to explain roof construction material based on roof geometry. In general the multinomial logistic regression statistical analysis results shows that most roof geometries have a substantial impact in deciding the roof construction material of buildings, in view of the fact that when their roof geometry varies, the possible roof construction material differs accordingly, relative to the baseline construction material of roof, in this case metal material. For instance, roof geometries which have Flat Square, flat organic, pitched (including hip, gable, mansard, butterfly etc.) and pyramidal shaped roofs have relatively a higher chance of to be constructed by metal material than concrete material. On the other hand roof geometries which have flat rectilinear shaped floors have relatively higher probability to be constructed by concrete than metal material.

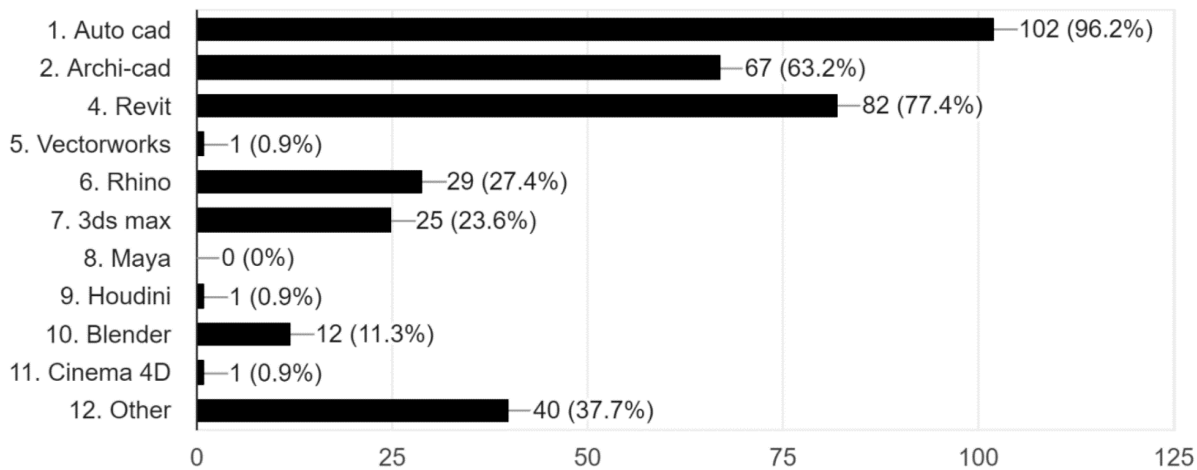
Besides Flat Square, flat triangular, flat curved, flat organic, flat freeform, flat irregular, polygonal pyramidal and other roof geometries not included in this thesis have relatively a higher possibility of to be constructed by metal material than wooden material. On the other hand flat rectilinear shaped roof geometries have relatively a higher chance of to be constructed by wood than metal materials.

Moreover roof geometries which have flat square, flat triangular, flat curved, flat organic, flat free form, flat irregular, flat polygonal, pitched(hip, gable, mansard, gambrel, butterfly etc.), pyramidal and other roof geometries which are not listed in this thesis have a higher chance of to be constructed by metal material than other materials not listed in this thesis. On the other hand roof geometries which have a rectilinear floor shapes have a higher possibility of to be constructed by other materials not included in this thesis than metal materials. Bold highlighted rows are statistically significant results, which have a p value of less than 0.05 ($p<0.05$) (For more details, refer to Appendix C – table C.6).

4.4 Geometry and computational design

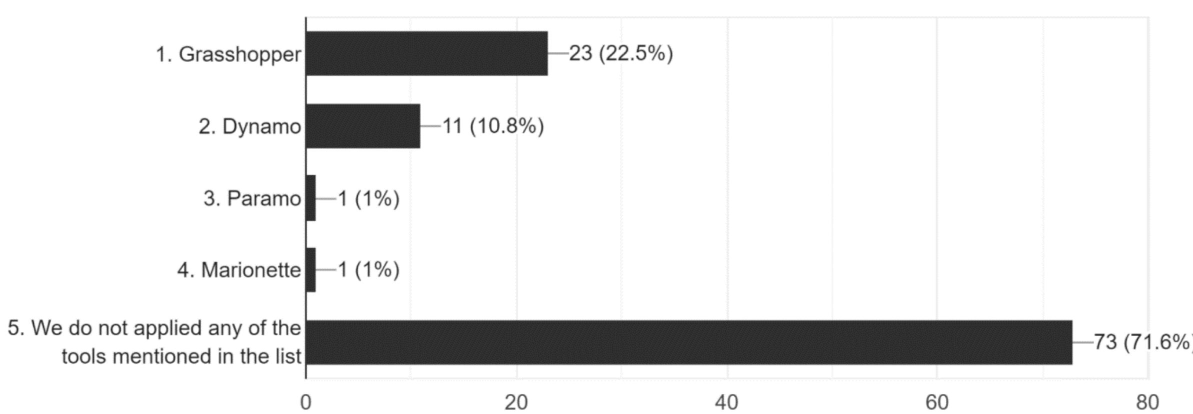
As shown on the figure below Auto CAD is the most widely used design tool in the design and engineering firms of Addis Ababa. Moreover Revit, Archicad and to some extent Rhino, 3ds max and blender are used in the firms. This indicates our level of computational design falls under 2D design and 3D modeling software tools and the extent of using these tools is moderate, for the reason that the, such software tools are applicable and have a capacity for 2D design and 3D modeling of structures.

Figure 4.10. *Extent of 2D design and 3D modeling software usage in firms*



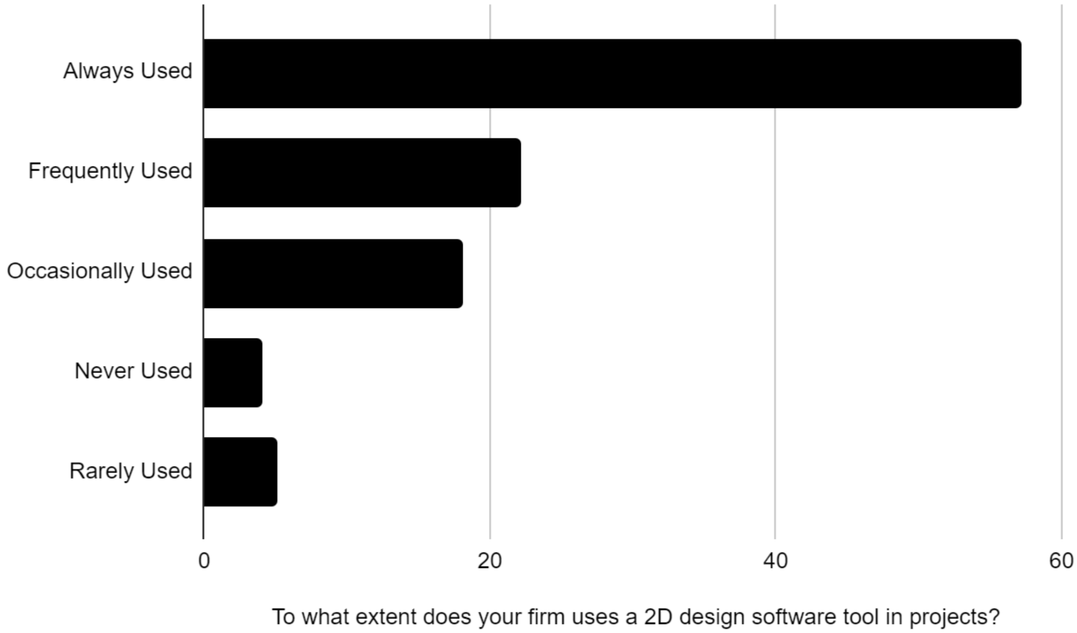
But the level of using copuational design tools in the firms is low that most firms don't apply or use such software tools in their projects, this indicates that the diversity and complexity of our buildings is in the lower level and ordiary geometrical forms are designed and constructed in the skyline of the city. Among computatinal design tools grasshoper is mostly used by the firms and dynamo is also used to some extent.

Figure 4.11. *Extent of computational software tools usage in firms*



4.4.1 The effect of 2D design software tools on the floor geometry of buildings

Figure 4.12. *Extent of 2D design software tools usage in firms*

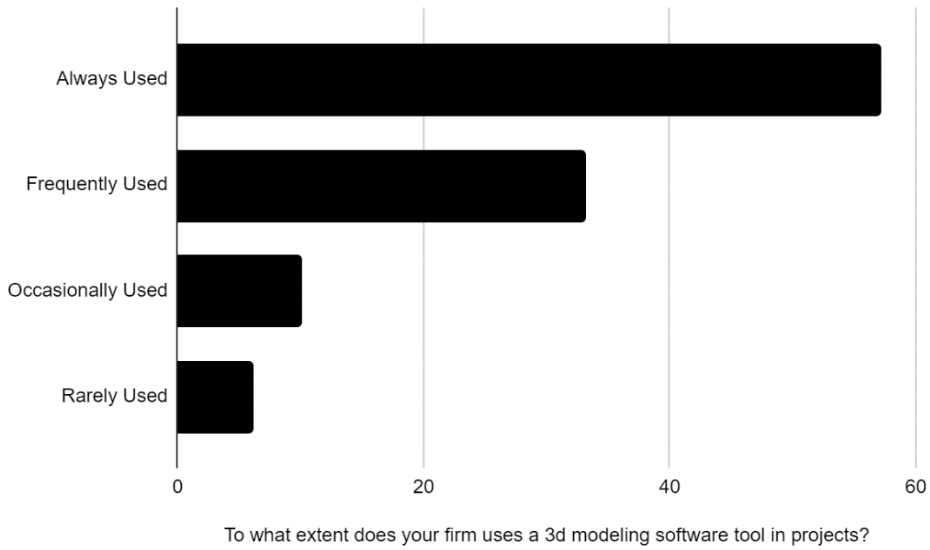



```
> Summary (model2y)

Call: multinom (formula = QARF21$Floor geometry ~ QARF21 $ `@2D design
software tool`, data = QARF21)

RD - Residual Deviance: 193.5496

AIC: 225.5496

Baseline variable – Rectangular floor geometry
```

A multinomial logistic regression was fitted to explain floor geometry of buildings based on 2D design software tools. In general the multinomial logistic regression statistical analysis results shows that there is no statistically significant interplay between floor geometry and 2d design software tools. That all p values of the model are above the significance level (α) used in this thesis (p> α). So 2d design software doesn't have an effect on floor geometries of buildings (For more details, refer to Appendix D – table D.1).

4.4.2 The effect of 3D modeling software tools on the floor geometry of buildings

Figure 4.13. *Extent of 3D modeling software tools usage in firms*

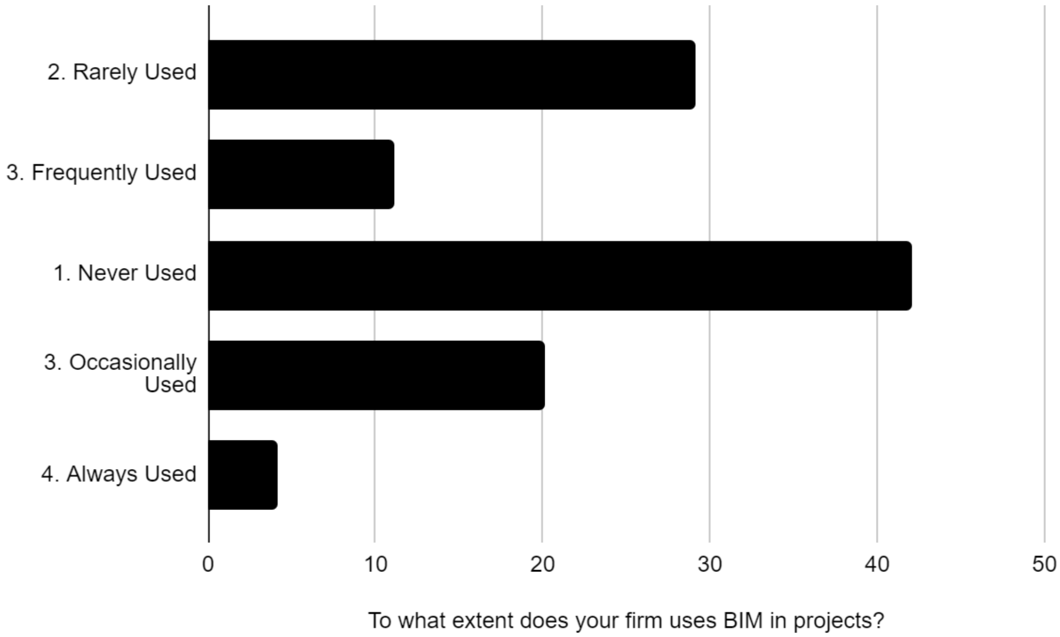



```
Summary (model2v)
Call:
Multinom (formula = QARF21 $ Floor geometry ~ QARF21$`@3d modeling sof
tware tool`, data = QARF21)
Residual Deviance: 196.408
AIC: 228.408
Baseline variable – Rectangular floor geometry
```

A multinomial logistic regression was fitted to explain floor geometry of buildings based on 3D modeling software tools. In general the multinomial logistic regression statistical analysis results shows that there is no statistically significant interplay between floor geometry and 3D modeling software tools. That all p values of the model are above the significance level (α) used in this thesis (p> α). So 3D design software tool doesn't have an effect on floor geometries of buildings (For more details, refer to Appendix D – table D.2).

4.4.3 The effect of BIM on the floor geometry of buildings

Figure 4.14 *Extent of BIM usage in firms*

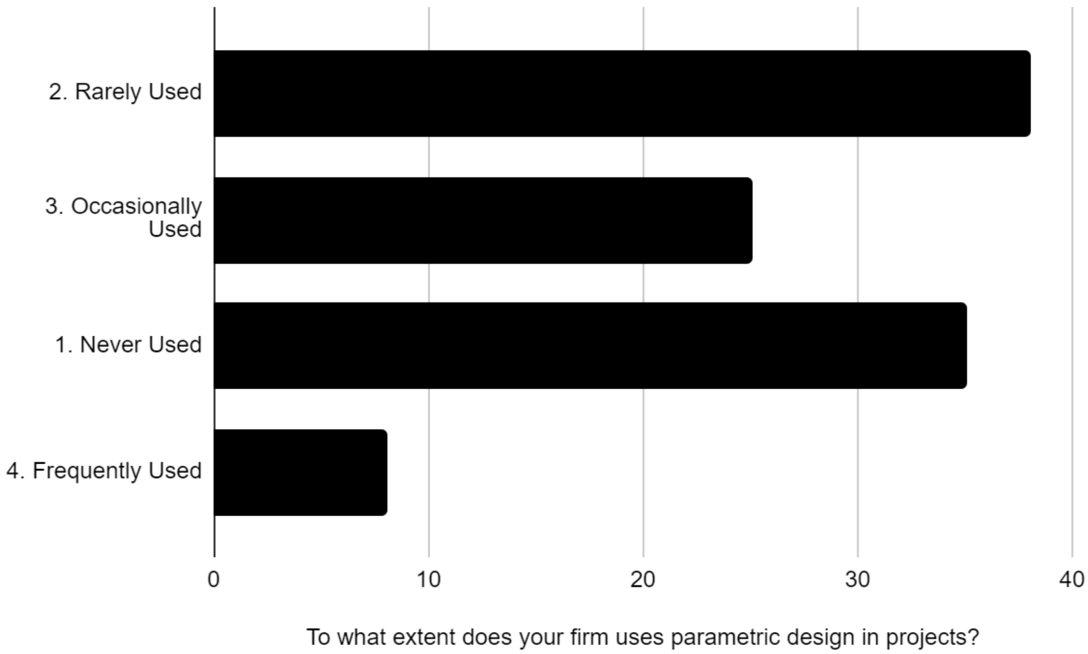



```
Summary (model2Z)
Call:
Multinom (formula = QARF21 $ Floor geometry ~ QARF21 $ BIM, data = QAR
F21)
Residual Deviance: 194.3532
AIC: 226.3532
Baseline variable – Rectangular floor geometry
```

A multinomial logistic regression was fitted to explain floor geometry of buildings based on BIM. In general the multinomial logistic regression statistical analysis results shows that there is only one statistically significant relation between floor geometry and BIM, because except one relation the remaining p values of the model are above the significance level (α) used in this thesis (p> α). so the model proves that rectangular shaped floor geometries have a higher chance of to be driven by BIM than square shaped floor geometries (For more details, refer to Appendix D – table D.3). So usage of BIM in the firms is uncommon.

4.4.4 The effect of parametric design on the floor geometry of buildings

Figure 4.15 *Extent of parametric design usage in firms*

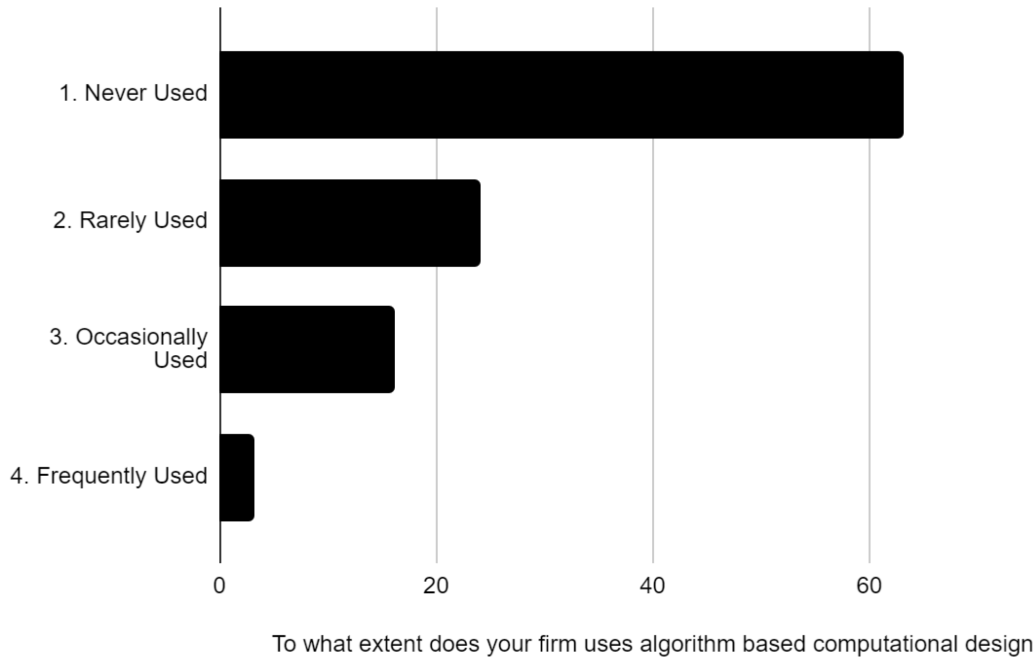



```
> summary(model2t)
Call:
multinom(formula = QARF21 $ Floor geometry ~ QARF21 $ Parametric design,
data = QARF21)
Residual Deviance: 200.3938
AIC: 232.3938
Baseline variable – Rectangular floor geometry
```

A multinomial logistic regression was fitted to explain floor geometry of buildings based on parametric design. In general the multinomial logistic regression statistical analysis results shows that there is no statistically significant interplay between floor geometry and parametric design. That all p values of the model are above the significance level (α) used in this thesis which is 0.05 (p> α). So parametric design doesn't have an effect on floor geometries of buildings (For more details, refer to Appendix D – table D.4).

4.4.5 The effect of algorithm based computational design on the floor geometry of buildings

Figure 4.16 *Extent of algorithm based computational design usage in firms*

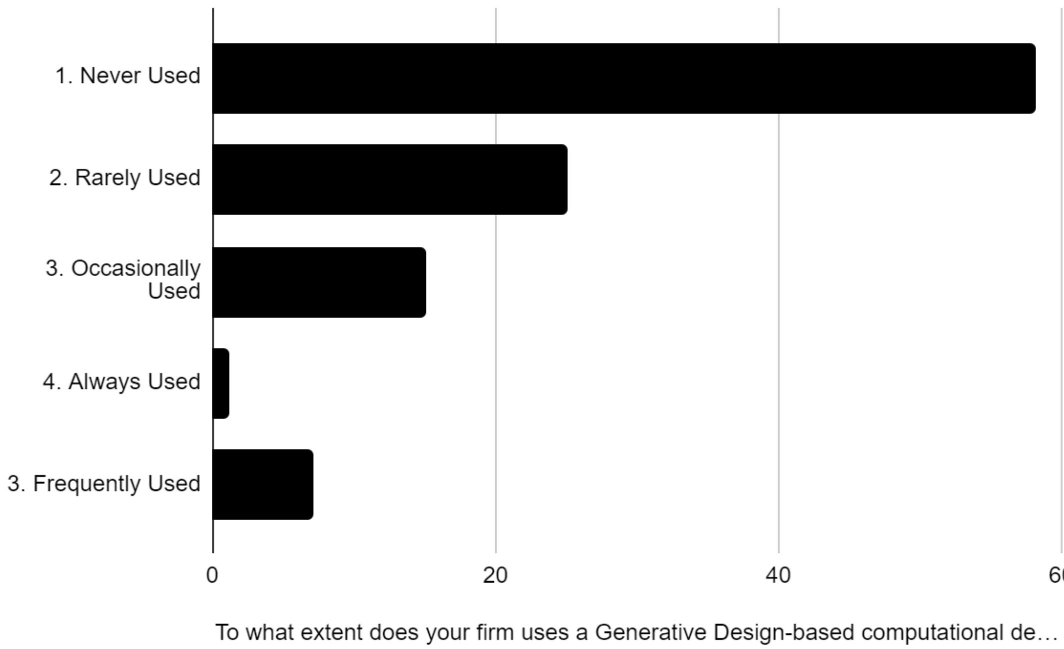



```
summary(model2n)
Call:
multinom(formula = QARF21 $ Floor geometry ~ QARF21 $ Algorithm design,
data = QARF21)
Residual Deviance: 192.1467
AIC: 224.1467
Baseline variable - Rectangular floor geometry
```

A multinomial logistic regression was fitted to explain floor geometry of buildings based on algorithm based design. In general the multinomial logistic regression statistical analysis results shows that there is no statistically significant interplay between floor geometry and algorithm based design. That all p values of the model are above the significance level (α) used in this thesis which is 0.05 (p> α). So algorithm design doesn't have an effect on floor geometries of buildings or floor geometries are not the result of algorithm based design (For more details, refer to Appendix D – table D.5).

4.4.6 The effect of generative based computational design on the floor geometry of buildings

Figure 4.17 *Extent of generative based computational design usage in firms*

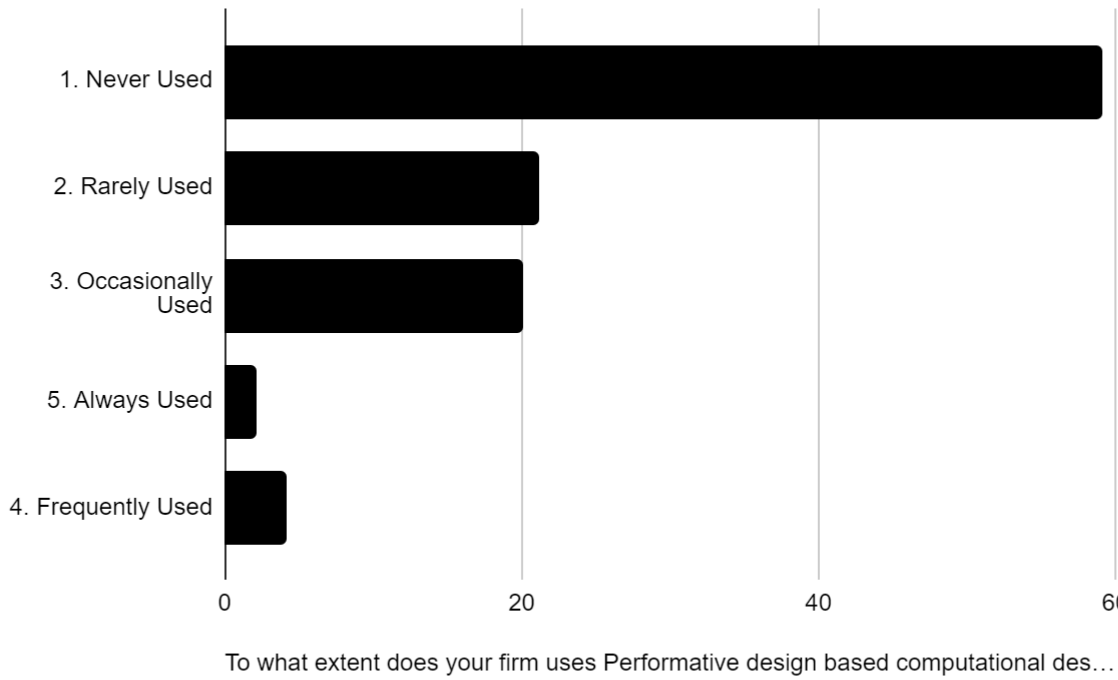



```
Summary (model2K)
Call:
Multinom (formula = QARF21 $ Floor geometry ~ QARF21 $ Generative Design,
data = QARF21)
Residual Deviance: 200.6252
AIC: 232.6252
Baseline variable - Rectangular floor geometry
```

A multinomial logistic regression was fitted to explain floor geometry of buildings based on generative design. In general the multinomial logistic regression statistical analysis results shows that there is no statistically significant interplay between floor geometry and generative design. That all p values of the model are above the significance level (α) used in this thesis which is 0.05 (p> α). So generative design doesn't have an effect on floor geometries of buildings or floor geometries are not the result of generative design (For more details, refer to Appendix D – Table D.6).

4.4.7 The effect of Per-formative design based computational design on the floor geometry of buildings

Figure 4.18. *Extent of Per-formative based computational design usage in firms*

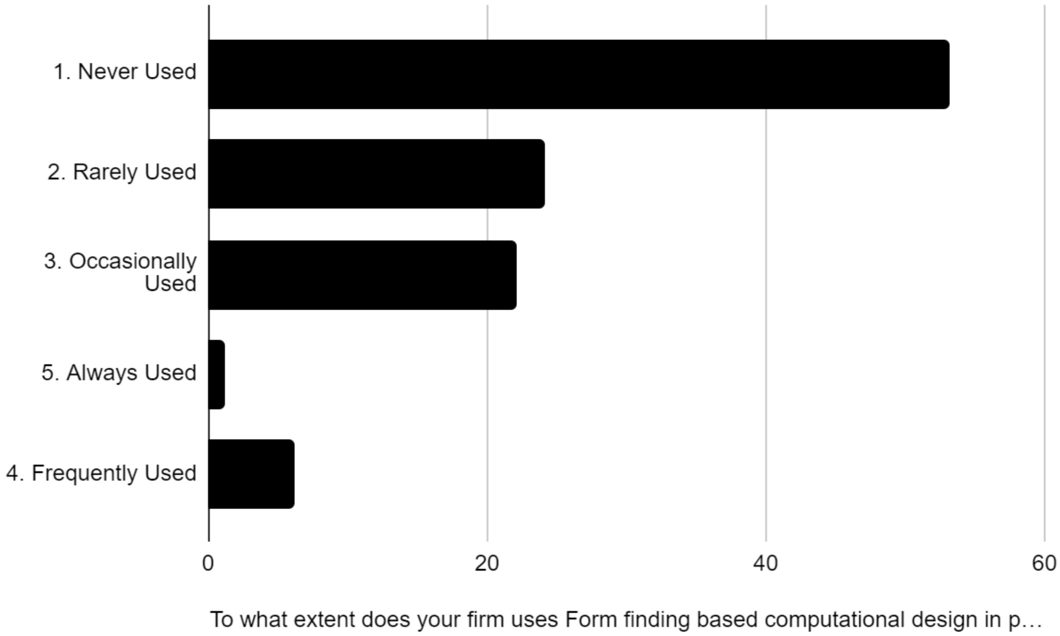



```
Summary (model2J)
Call:
Multinom (formula = QARF21 $ Floor geometry ~ QARF21$Performativedesign,
data = QARF21)
Residual Deviance: 200.2267
AIC: 232.2267
Baseline variable – Rectangular floor geometry
```

A multinomial logistic regression was fitted to explain floor geometry of buildings based on performative design. In general the multinomial logistic regression statistical analysis results shows that there is no statistically significant interplay between floor geometry and performative design. That all p values of the model are above the significance level (α) used in this thesis which is 0.05 ($p > \alpha$). So per-formative design doesn't have an effect on floor geometries of buildings or floor geometries are not the result of performative design (For more details, refer to Appendix D – Table D.7).

4.4.8 The effect of Form finding based computational design on the floor geometry of buildings

Figure 4.19. *Extent of Form finding based computational design usage in firms*

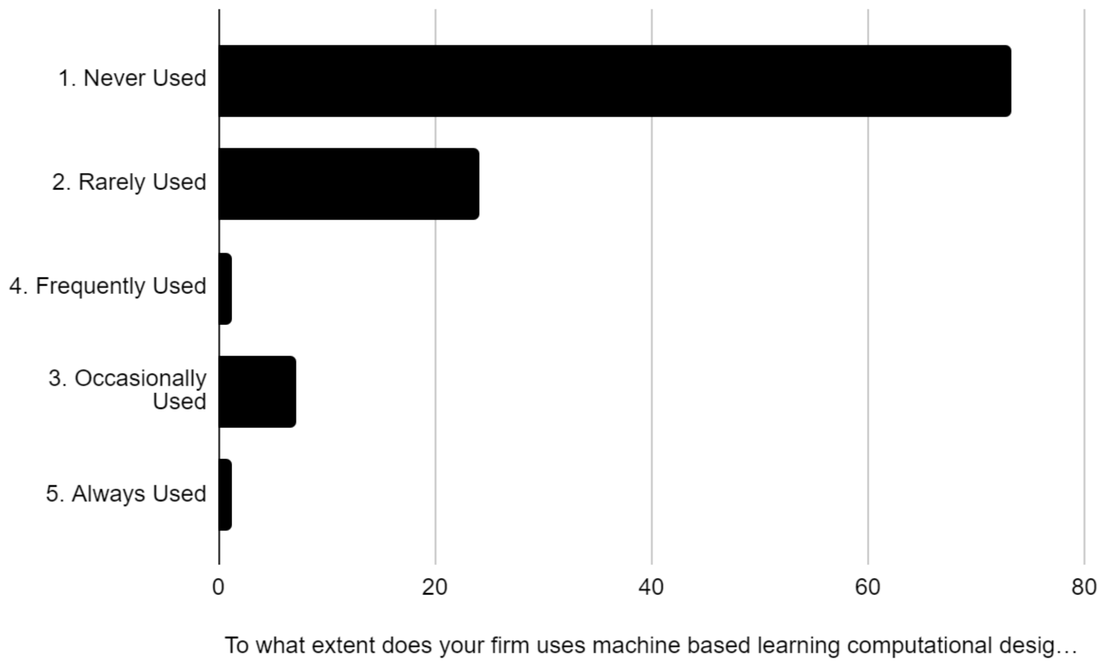



```
Summary (model21)
Call:
Multinom (formula = QARF21 $ Floor geometry ~ QARF21 $ Form finding
design, data = QARF21)
Residual Deviance: 200.3824
AIC: 232.3824
Baseline variable - Rectangular floor geometry
```

A multinomial logistic regression was fitted to explain floor geometry of buildings based on Form finding based computational design. In general the multinomial logistic regression statistical analysis results shows that there is no statistically significant interplay between floor geometry and Form finding based computational design. That all p values of the model are above the significance level (α) used in this thesis which is 0.05 ($p > \alpha$). So Form finding based computational design doesn't have an effect on floor geometries of buildings or floor geometries are not the result of form finding based computational design (For more details, refer to Appendix D – Table D.8).

4.4.9 The effect of machine based learning computational design on the floor geometry of buildings

Figure 4.20. *Extent of machine based learning computational design usage in firms*




```
Summary (model2m)
Call:
Multinom (formula = QARF21 $ Floor geometry ~ QARF21 $ Machine based learning design, data = QARF21)
Residual Deviance: 191.9588
AIC: 223.9588
Baseline variable – Rectangular floor geometry
```

A multinomial logistic regression was fitted to explain floor geometry of buildings based on machine based learning computational design. In general the multinomial logistic regression statistical analysis results shows that there is no statistically significant interplay between floor geometry and machine based learning computational design. That all p values of the model are above the significance level (α) used in this thesis which is 0.05 (p> α). So machine based learning computational design doesn't have an effect on floor geometries of buildings or floor geometries are not the result of machine based learning computational design (For more details, refer to Appendix D – Table D.9).

4.5 Effect of computational design on the facade geometry of buildings

4.5.1 The effect of 2D design software tool on the facade geometry of buildings

```
Summary (model2h)
Call:
Multinom (formula = QARF21 $ Façade geometry ~ QARF21 $ `@2Ddesign
software tool`, data = QARF21)
Residual Deviance: 224.0385
AIC: 256.0385
Baseline variable – Rectangular façade geometry
```

A multinomial logistic regression was fitted to explain facade geometry of buildings based on 2D design software tool. In general the multinomial logistic regression statistical analysis results shows that there is no statistically significant interplay between facade geometry and 2D design software tool. That all p values of the model are above the significance level (α) used in this thesis which is 0.05 (p> α). So 2D design software tool doesn't have an effect on facade geometries of buildings or façade geometries are not the result of 2D design software tool (For more details, refer to Appendix D – Table D.10).

4.5.2 The effect of 3d modeling software tool on the facade geometry of buildings

```
Summary (model2q)
Call:
Multinom (formula = QARF21 $ Façade geometry ~ QARF21 $ `@3d modeling
software tool`, data = QARF21)
Residual Deviance: 222.0143
AIC: 254.0143
Baseline variable – Rectangular façade geometry
```

A multinomial logistic regression was fitted to explain facade geometry of buildings based on 3d modeling software tool. In general the multinomial logistic regression statistical analysis results shows that there is no statistically significant interplay between facade geometry and 3d modeling software tool. That all p values of the model are above the significance level (α) used in this thesis which is 0.05 (p> α). So 3d modeling software tool doesn't have an effect on facade geometries of buildings or façade geometries are not the result of 3d modeling software tool (For more details, refer to Appendix D – Table D.11).

4.5.3 The effect of BIM on the facade geometry of buildings

```
Summary (model2a)
Call:
Multinom (formula = QARF21 $ Façade geometry ~ QARF21$BIM, data = QARF21)
```

```
Residual Deviance: 227.3733
AIC: 259.3733
Baseline variable – Rectangular façade geometry
```

A multinomial logistic regression was fitted to explain facade geometry of buildings based on BIM. In general the multinomial logistic regression statistical analysis results shows that there is no statistically significant interplay between facade geometry and BIM. That all p values of the model are above the significance level (α) used in this thesis which is 0.05 (p> α). So BIM doesn't have an effect on facade geometries of buildings or façade geometries are not the result of BIM (For more details, refer to Appendix D – Table D.12).

4.5.4 The effect of parametric design on the facade geometry of buildings

```
Summary (model2v)
Call:
Multinom (formula = QARF21 $ Façade geometry ~ QARF21 $ Parametric design, data = QARF21)
Residual Deviance: 225.6273
AIC: 257.6273
Baseline variable – Rectangular façade geometry
```

A multinomial logistic regression was fitted to explain facade geometry of buildings based on parametric design. In general the multinomial logistic regression statistical analysis results shows that there is no statistically significant interplay between facade geometry and parametric design. That all p values of the model are above the significance level (α) used in this thesis which is 0.05 (p> α). So parametric design doesn't have an effect on facade geometries of buildings or façade geometries are not the result of parametric design (For more details, refer to Appendix D – Table D.13).

4.5.5 The effect of algorithm based computational design on the facade geometry of buildings

```
Summary (model2g)
Call:
Multinom (formula = QARF21 $ Façade geometry ~ QARF21 $ Algorithm design, data = QARF21)
Residual Deviance: 228.4464
AIC: 260.4464
Baseline variable – Rectangular façade geometry
```

A multinomial logistic regression was fitted to explain facade geometry of buildings based on algorithm based computational design. In general the multinomial logistic regression statistical analysis results shows that there is only one statistically significant interplay between facade geometry and algorithm based computational design. That the remaining p values of the model are above the significance level (α) used in this thesis which is 0.05 (p> α). The result shows that rectangular shaped façade geometries have a higher risk of to be designed by algorithmic based computational design than polygonal shaped façade geometries (For more details, refer to Appendix D – Table D.14).

4.5.6 The effect of Generative Design-based computational design on the facade geometry of buildings

```
Summary (model2r)
Call:
Multinom (formula = QARF21 $ Façade geometry ~ QARF21 $ Generative Design, data = QARF21)
Residual Deviance: 227.3351
AIC: 259.3351
Baseline variable – Rectangular façade geometry
```

A multinomial logistic regression was fitted to explain facade geometry of buildings based on Generative Design-based computational design. In general the multinomial logistic regression statistical analysis results shows that there is only one statistically significant interplay between facade geometry and Generative Design-based computational design. That the remaining p values of the model are above the significance level (α) used in this thesis which is 0.05 (p> α). The result shows that irregular shaped façade geometries have a higher risk of to be designed by Generative Design-based computational design than rectangular shaped façade geometries (For more details, refer to Appendix D – Table D.15).

4.5.7 The effect of Performative design based computational design on the facade geometry of buildings

```
Summary (model2y)
Call:
Multinom (formula = QARF21 $ Façade geometry ~ QARF21 $ Performative design, data = QARF21)
Residual Deviance: 232.2034
AIC: 264.2034
Baseline variable – Rectangular façade geometry
```

A multinomial logistic regression was fitted to explain facade geometry of buildings based on Performative design based computational design. In general the multinomial logistic regression statistical analysis results shows that there is no statistically significant interplay between facade geometry and Performative design based computational design. That all p values of the model are above the significance level (α) used in this thesis which is 0.05 (p> α). So Performative design based computational design doesn't have an effect on facade geometries of buildings or façade geometries are not the result of Performative design based computational design (For more details, refer to Appendix D – Table D.16).

4.5.8 The effect of Form finding based computational design on the facade geometry of buildings

```
Summary (model2f)
Call:
Multinom (formula = QARF21 $ Façade geometry ~ QARF21 $ Form finding design, data = QARF21)
Residual Deviance: 230.9913
AIC: 262.9913
Baseline variable – Rectangular façade geometry
```

A multinomial logistic regression was fitted to explain facade geometry of buildings based on Form finding based computational design. In general the multinomial logistic regression statistical analysis results shows that there is no statistically significant interplay between facade geometry and Form finding based computational design. That all p values of the model are above the significance level (α) used in this thesis which is 0.05 (p> α). So Form finding based computational design doesn't have an effect on facade geometries of buildings or façade geometries are not the result of Form finding based computational design (For more details, refer to Appendix D – Table D.17).

4.5.9 The effect of machine based learning computational design on the facade geometry of buildings

```
Summary (model2o)
Call:
Multinom (formula = QARF21 $ Façade geometry ~ QARF21 $ Machine based learning design, data = QARF21)
Residual Deviance: 230.2565
AIC: 262.2565
Baseline variable – Rectangular façade geometry
```

A multinomial logistic regression was fitted to explain facade geometry of buildings based on machine based learning computational design. In general the multinomial logistic regression statistical analysis results shows that there is no statistically significant interplay between facade geometry and machine based learning computational design. That all p values of the model are above the significance level (α) used in this thesis which is 0.05 (p> α). So machine based learning computational design doesn't have an effect on facade geometries of buildings or façade geometries are not the result of machine based learning computational design (For more details, refer to Appendix D – Table D.18).

4.6 Effect of computational design on the roof geometry of buildings

4.6.1 The effect of 2D design software tool on the roof geometry of buildings

```
Summary (model2i)
Call:
Multinom (formula = QARF21 $ Roof geometry ~ QARF21 $ `@2D design software tool`, data = QARF21)
Residual Deviance: 320.2589
AIC: 364.2589
Baseline variable – flat rectangular roof geometry
```

A multinomial logistic regression was fitted to explain roof geometry of buildings based on 2D design software tool. The results shows that there are some statistically significant interplay between roof geometry and 2D design software tool. Flat curved, flat organic, flat free form and flat irregular shaped roof geometries have a higher chance of to be designed by 2d design software tools than flat rectangular shaped roof geometries. In the other hand the remaining roof geometries of roof are not influenced by 2D design software tools relative to the outcome variable (For more details, refer to Appendix D – Table D.19).

4.6.2 The effect of 3D modeling software tool on the roof geometry of buildings

```
Summary (model2p)
Call:
Multinom (formula = QARF21 $ Roof geometry ~ QARF21 $ `@3d modeling software tool`, data = QARF21)
Residual Deviance: 305.3048
AIC: 349.3048
Baseline variable – flat rectangular roof geometry
```

A multinomial logistic regression was fitted to explain roof geometry of buildings based on 3D modeling software tool. The results shows that there are some statistically significant interplay between roof geometry and 3D modeling software tool. Flat free form, flat irregular and flat polygonal shaped roof geometries have a higher chance of to be designed by 3D design software tools than flat rectangular shaped roof geometries. In the other hand the remaining roof geometries are not influenced by 2D design software tools relative to the outcome variable (For more details, refer to Appendix D – Table D.20).

4.6.3 The effect of BIM on the roof geometry of buildings

```
Summary (model2c)
Call:
Multinom (formula = QARF21 $ Roof geometry ~ QARF21 $BIM, data = QARF2
1)
Residual Deviance: 318.3529
AIC: 362.3529
Baseline variable – flat rectangular roof geometry
```

A multinomial logistic regression was fitted to explain roof geometry of buildings based on BIM. The results shows that there is only one statistically significant interplay between roof geometry and BIM. Flat rectangular shaped roof geometries have a higher chance of to be designed by BIM approaches than flat free form shaped roof geometries. In the other hand the remaining roof geometries are not influenced by BIM relative to the baseline variable (For more details, refer to Appendix D – Table D.21).

4.6.4 The effect of parametric design on the roof geometry of buildings

```
Summary (model2s)
Call:
Multinom (formula = QARF21 $ Roof geometry ~ QARF21 $ Parametric desig
n, data = QARF21)
Residual Deviance: 318.0037
AIC: 362.0037
Baseline variable – flat rectangular roof geometry
```

A multinomial logistic regression was fitted to explain roof geometry of buildings based on parametric design. The results shows that there is no statistically significant interplay between roof geometry and parametric design. That all p values of the model are above the significance level (α) used in this thesis which is 0.05 ($p > \alpha$). So parametric design doesn't have an effect on roof geometries of buildings or roof geometries are not the result of parametric design (For more details, refer to Appendix D – Table D.22).

4.6.5 The effect of algorithm based computational design on the roof geometry of buildings

```
Summary (model2A)
Call:
Multinom (formula = QARF21 $ Roof geometry ~ QARF21 $ Algorithm design,
data = QARF21)
Residual Deviance: 298.875
AIC: 342.875
```

```
Baseline variable – flat rectangular roof geometry
```

A multinomial logistic regression was fitted to explain roof geometry of buildings based on algorithm based computational design. The results shows that there is only one statistically significant interplay between roof geometry and algorithm based computational design. Flat rectangular shaped roof geometries have a higher chance of to be designed by algorithm based computational design than flat polygonal shaped roof geometries. In the other hand the remaining roof geometries are not influenced by algorithm based computational design relative to the outcome or baseline variable (For more details, refer to Appendix D – Table D.23).

4.6.6 The effect of Generative Design-based computational design on the roof geometry of buildings

```
Summary (model2w)
Call:
Multinom (formula = QARF21 $ Roof geometry ~ QARF21 $ Generative Design,
data = QARF21)
Residual Deviance: 315.5359
AIC: 359.5359
Baseline variable – flat rectangular roof geometry
```

A multinomial logistic regression was fitted to explain roof geometry of buildings based on Generative Design-based computational design. The results shows that there is no statistically significant interplay between roof geometry and Generative Design-based computational design. That all p values of the model are above the significance level (α) used in this thesis which is 0.05 ($p > \alpha$). So Generative Design-based computational design doesn't have an effect on roof geometries of buildings or roof geometries are not the result of Generative Design-based computational design (For more details, refer to Appendix D – Table D.24).

4.6.7 The effect of Performative design based computational design on the roof geometry of buildings

```
Summary (model2pk)
Call:
Multinom (formula = QARF21 $ Roof geometry ~ QARF21 $ Performative
design, data = QARF21)
Residual Deviance: 313.9789
AIC: 357.9789
Baseline variable – flat rectangular roof geometry
```

A multinomial logistic regression was fitted to explain roof geometry of buildings based on Performative design based computational design. The results shows that there is no statistically significant interplay between roof geometry and Performative design based computational design. That all p values of the model are above the significance level (α) used in this thesis which is 0.05 (p> α). So Performative design based computational design doesn't have an effect on roof geometries of buildings or roof geometries are not the result of Performative design based computational design (For more details, refer to Appendix D – Table D.25).

4.6.8 The effect of Form finding based computational design on the roof geometry of buildings

```
Summary (model2ff)
Call:
Multinom (formula = QARF21 $ Roof geometry ~ QARF21 $ Form finding design, data = QARF21)
Residual Deviance: 314.5803
AIC: 358.5803
Baseline variable – flat rectangular roof geometry
```

A multinomial logistic regression was fitted to explain roof geometry of buildings based on Form finding based computational design. The results shows that there is no statistically significant interplay between roof geometry and Form finding based computational design. That all p values of the model are above the significance level (α) used in this thesis which is 0.05 (p> α). So Form finding based computational design doesn't have an effect on roof geometries of buildings or roof geometries are not the result of Form finding based computational design (For more details, refer to Appendix D – Table D.26).

4.6.9 The effect of machine based learning computational design on the roof geometry of buildings

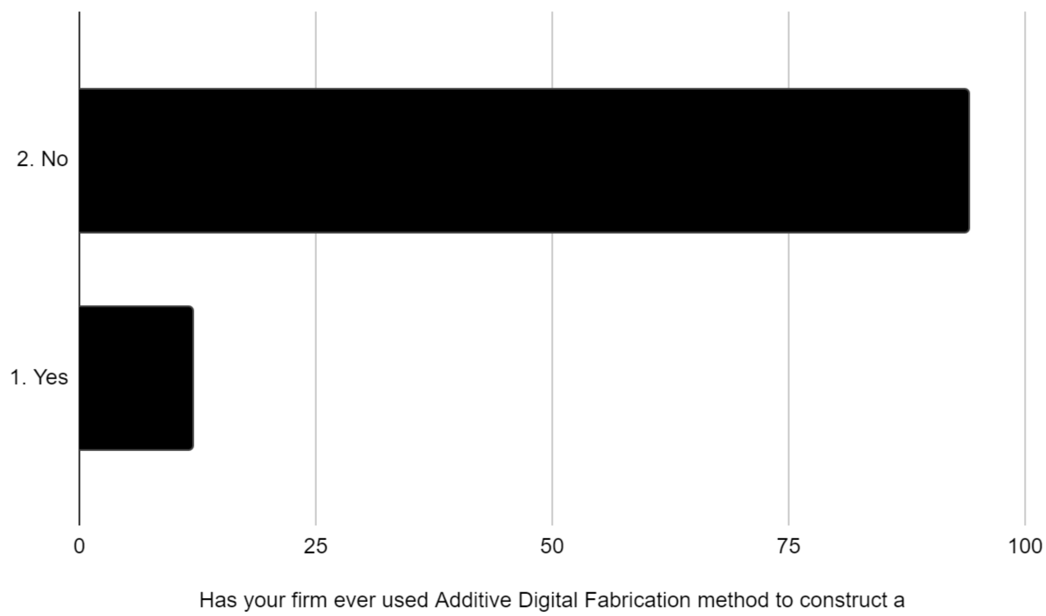
```
Summary (model2ml)
Call:
Multinom (formula = QARF21 $ Roof geometry ~ QARF21 $ Machine based learning design, data = QARF21)
Residual Deviance: 315.6639
AIC: 359.6639
Baseline variable – flat rectangular roof geometry
```

A multinomial logistic regression was fitted to explain roof geometry of buildings based on machine based learning computational design. The results shows that there is only two statistically significant interplay between roof geometry and machine based learning computational design. Flat rectangular shaped roof geometries have a higher chance of to be designed by machine based learning computational design than flat rectilinear and flat irregular shaped roof geometries. In the other hand the remaining roof geometries are not influenced by machine based learning computational design relative to the outcome variable (For more details, refer to Appendix D – Table D.27).

4.7 Effect of digital fabrication method on the floor geometry of buildings

4.7.1 The effect of Additive Digital Fabrication method on the floor geometry of buildings

Figure 4.21. *Extenet of using Additive Digital Fabrication method*

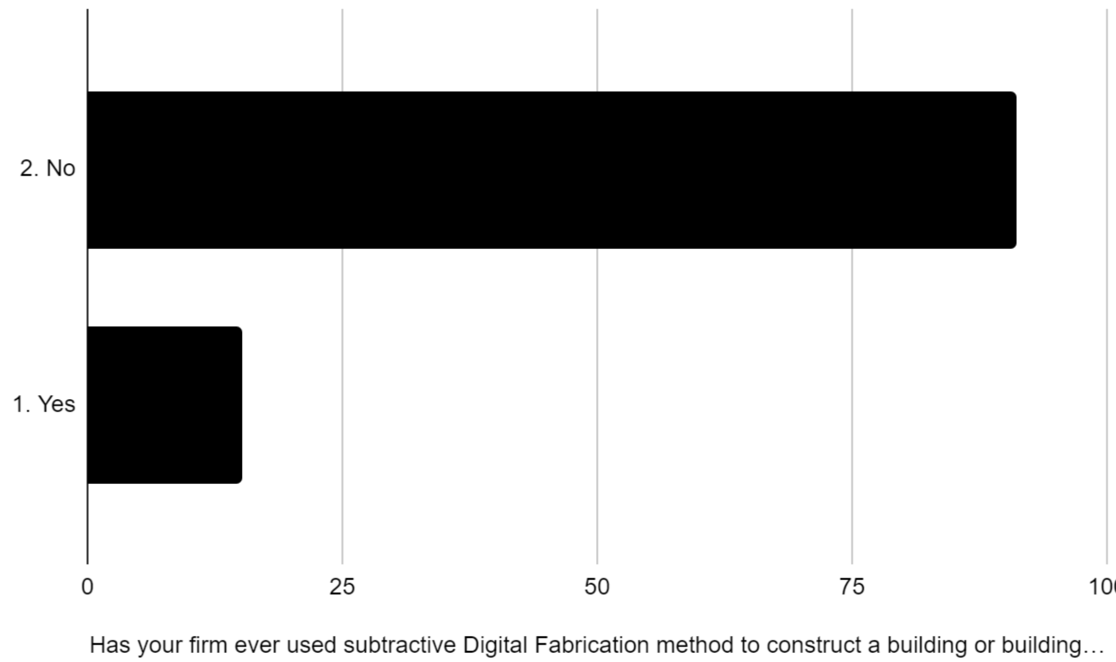



```
Summary (model2ad)
Call:
Multinom (formula = QARF21 $ Floor geometry ~ QARF21 $ Additive Digital
Fabrication, data = QARF21)
Residual Deviance: 200.7899
AIC: 232.7899
Baseline variable – Rectangular floor geometry
```

A multinomial logistic regression was fitted to explain floor geometry of buildings based on additive Digital Fabrication method. The results shows that there is only one statistically significant interplay between roof geometry and Additive digital Fabrication method. So rectilinear shaped floor geometries have a higher chance of to be constructed by Additive Digital Fabrication method than rectangular shaped floor geometries. In the other hand the remaining floor geometries doesn't have impacted by additive digital fabrication method relative to the outcome or baseline variable (For more details, refer to Appendix E – Table E.1).

4.7.2 The effect of subtractive Digital Fabrication method on the floor geometry of buildings

Figure 4.22. *Extenet of using subtractive Digital Fabrication method*

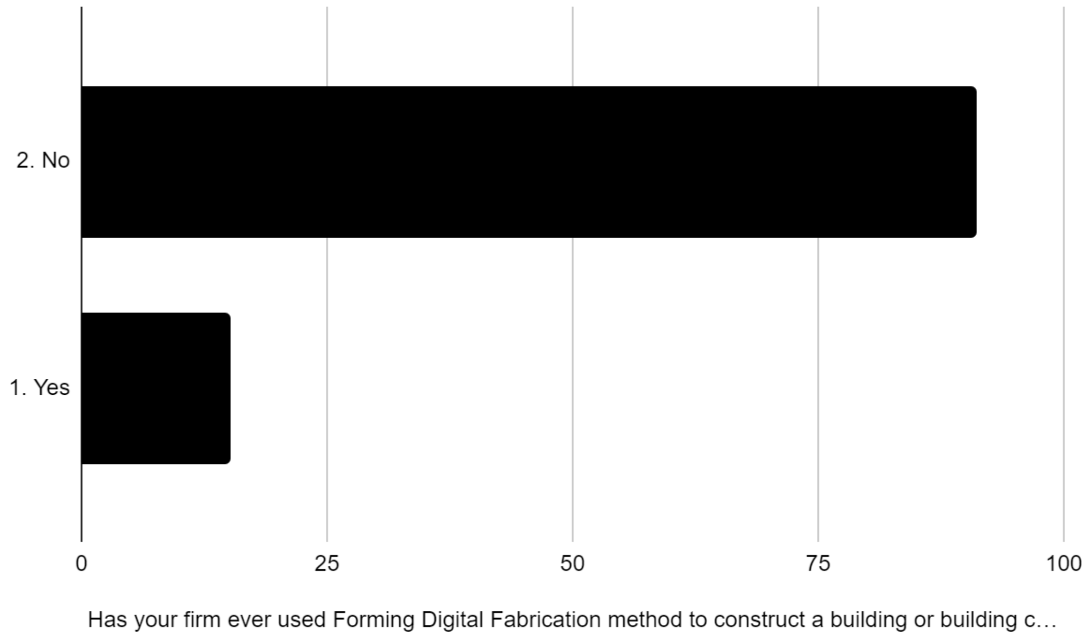



```
Summary (model2sd)
Call:
Multinom (formula = QARF21 $ Floor geometry ~QARF21 $ Subtractive Digital
Fabrication, data = QARF21)
Residual Deviance: 203.4292
AIC: 235.4292
Baseline variable – Rectangular floor geometry
```

A multinomial logistic regression was fitted to explain floor geometry of buildings based on subtractive Digital Fabrication method. The results shows that there is no statistically significant interplay between floor geometry and subtractive Digital Fabrication method. That all p values of the model are above the significance level (α) used in this thesis which is 0.05 ($p > \alpha$). So subtractive Digital Fabrication method doesn't have an effect on floor geometries of buildings or such floor geometries of buildings are not constructed by subtractive Digital Fabrication method relative to the baseline variable (For more details, refer to Appendix E – Table E.2).

4.7.3 The effect of Forming Digital Fabrication method on the floor geometry of buildings

Figure 4.23. *Extenet of using Forming Digital Fabrication method*

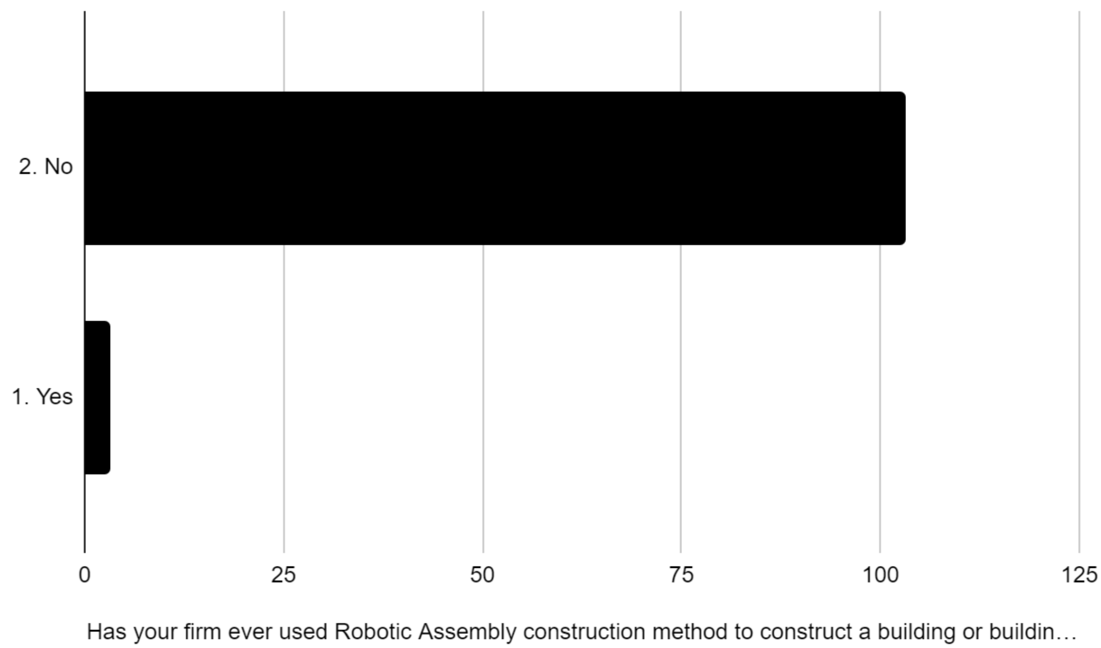



```
Summary (model2fd)
Call:
Multinom (formula = QARF21 $ Floor geometry ~ QARF21 $ Forming Digital
Fabrication, data = QARF21)
Residual Deviance: 203.6069
AIC: 235.6069
Baseline variable – Rectangular floor geometry
```

A multinomial logistic regression was fitted to explain floor geometry of buildings based on Forming Digital Fabrication method. The results shows that there is no statistically significant interplay between floor geometry and Forming Digital Fabrication method. That all p values of the model are above the significance level (α) used in this thesis which is 0.05 (p> α). So Forming Digital Fabrication method doesn't have an effect on floor geometries of buildings or such floor geometries of buildings are not constructed by Forming Digital Fabrication method (For more details, refer to Appendix E – Table E.3).

4.7.4 The effect of Robotic Assembly construction method on the floor geometry of buildings

Figure 4.24. *Extenet of using Robotic Assembly construction method*

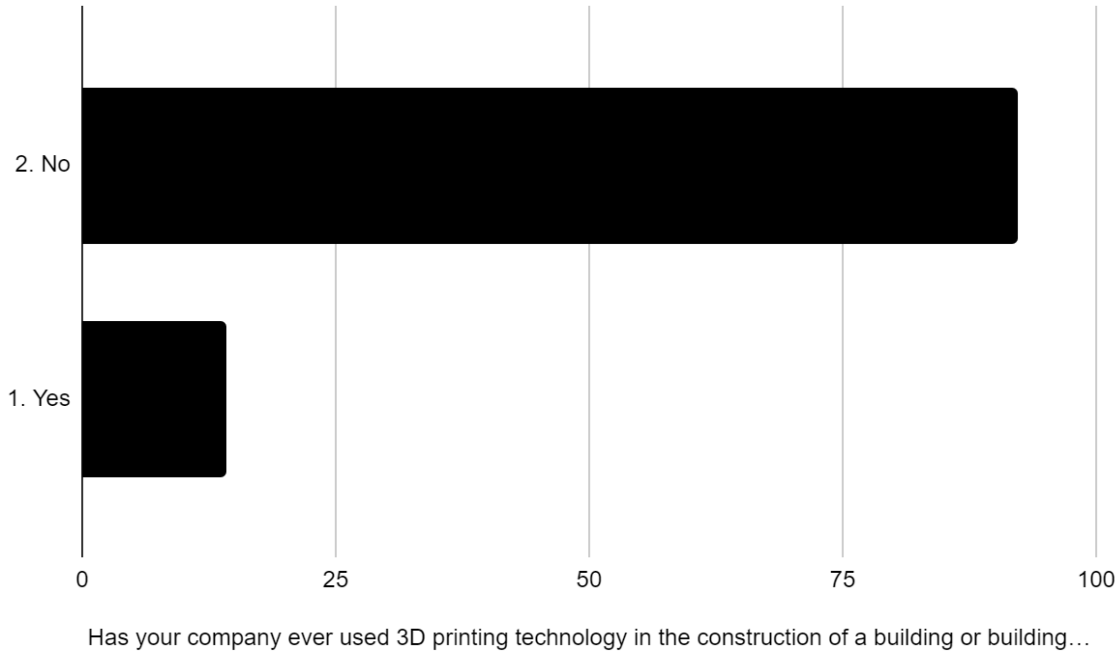



```
Summary (model2rb)
Call:
Multinom (formula = QARF21 $ Floor geometry ~ QARF21 $ Robotic Assembly
construction, data = QARF21)
Residual Deviance: 197.6057
AIC: 229.6057
Baseline variable - Rectangular floor geometry
```

A multinomial logistic regression was fitted to explain floor geometry of buildings based on Robotic Assembly construction method. The results shows that there are some statistically significant interplay between floor geometry and Robotic Assembly construction method. So rectangular shaped floor geometries have a higher risk of to be constructed by Robotic Assembly construction method than squared shaped floor geometries of buildings, in the other hand buildings which have rectilinear and polygonal shaped floors have a higher chance of to be constructed by robotic Assembly construction method than buildings which have rectangular shaped floor (For more details, refer to Appendix E – Table E.4).

4.7.5 The effect of 3D printing technology on the floor geometry of buildings

Figure 4.25. *Extenet of using 3D printing technology construction method*




```
Summary (model23dp)
Call:
Multinom (formula = QARF21 $ Floor geometry ~ QARF21 $ `@3D printing technology`, data = QARF21)
Residual Deviance: 199.121
AIC: 231.121
Baseline variable – Rectangular floor geometry
```

A multinomial logistic regression was fitted to explain floor geometry of buildings based on 3D printing construction technology. The results shows that there are some statistically significant interplay between floor geometry and 3D printing construction technology. So square, rectilinear, irregular, polygonal shaped floors and other floor geometries not listed in this thesis have a higher chance of to be constructed by 3D printing technology than rectangular shaped geometries (For more details, refer to Appendix E – Table E.5).

4.8 Effect of digital fabrication method on the façade geometry of buildings

4.8.1 The effect of Additive Digital Fabrication method on the façade geometry of buildings

```
Summary (model2gh)
Call:
Multinom (formula = QARF21 $ Façade geometry ~ QARF21 $ Additive Digital
Fabrication, data = QARF21)
Residual Deviance: 226.9123
AIC: 258.9123
Baseline variable – rectangular faced geometry
```

A multinomial logistic regression was fitted to explain façade geometry of buildings based on additive Digital Fabrication method. The results shows that there is only one statistically significant interplay between facade geometry and Additive digital Fabrication method. So rectilinear shaped facade geometries have a higher chance of to be constructed by Additive Digital Fabrication method than rectangular shaped floor geometries. In the other hand the remaining floor geometries are not impacted by additive digital fabrication method relative to the outcome or baseline variable (For more details, refer to Appendix E – Table E.6).

4.8.2 The effect of subtractive Digital Fabrication method on the façade geometry of buildings

```
Summary (model2su)
Call:
Multinom (formula = QARF21 $ Façade geometry ~ QARF21 $ Subtractive
Digital Fabrication, data = QARF21)
Residual Deviance: 226.6327
AIC: 258.6327
Baseline variable – rectangular façade geometry
```

A multinomial logistic regression was fitted to explain facade geometry of buildings based on subtractive Digital Fabrication method. The results shows that there is no statistically significant interplay between facade geometry and subtractive Digital Fabrication method. That all p values of the model are above the significance level (α) used in this thesis which is 0.05 ($p > \alpha$). So subtractive Digital Fabrication method doesn’t have an effect on facade geometries of buildings or such facade geometries of buildings are not constructed by subtractive Digital Fabrication method relative to the baseline variable (For more details, refer to Appendix E – Table E.7).

4.8.3 The effect of Forming Digital Fabrication method on the façade geometry of buildings

```
Summary (model2fo)
Call:
Multinom (formula = QARF21 $ Façade geometry ~ QARF21 $ Forming Digital
Fabrication, data = QARF21)
Residual Deviance: 227.8582
AIC: 259.8582
Baseline variable – rectangular façade geometry
```

A multinomial logistic regression was fitted to explain facade geometry of buildings based on forming digital fabrication method. The results shows that there is only one statistically significant interplay between facade geometry and Forming Digital Fabrication method. So buildings which have rectilinear shaped façade geometries have a higher chance of their floor constructed by forming digital fabrication construction method than buildings which have rectangular shaped floor geometry. The remaining p values of the model are above the significance level (α) used in this thesis which is 0.05 ($p > \alpha$) (For more details, refer to Appendix E – Table E.8).

4.8.4 The effect of Robotic Assembly construction method on the façade geometry of buildings

```
Summary (model2ro)
Call:
Multinom (formula = QARF21 $ Façade geometry ~ QARF21 $ Robotic Assembly
construction, data = QARF21)
Residual Deviance: 233.2035
AIC: 265.2035
Baseline variable – rectangular façade geometry
```

A multinomial logistic regression was fitted to explain façade geometry of buildings based on Robotic Assembly construction method. The results shows that there is a couple of statistically significant interplay between facade geometry and Robotic Assembly construction method. So rectilinear and irregular shaped facade geometries have a higher chance of to be constructed by Robotic Assembly construction method than rectangular shaped floor geometries. On the other hand the remaining floor geometries are not impacted by Robotic Assembly construction method relative to the outcome or baseline variable (For more details, refer to Appendix E – Table E.9).

4.8.5 The effect of 3D printing construction technology on the façade geometry of buildings

```
Summary (model2pp)
Call:
Multinom (formula = QARF21 $ Façade geometry ~ QARF21 $ `@3D printing technology`, data = QARF21)
Residual Deviance: 227.8581
AIC: 259.8581
Baseline variable – rectangular façade geometry
```

A multinomial logistic regression was fitted to explain façade geometry of buildings based on 3D printing construction technology. The results shows that there is only one statistically significant interplay between facade geometry and 3D printing construction technology. So rectilinear shaped facade geometries have a higher chance of to be constructed by 3D printing construction technology than rectangular shaped floor geometries. On the other hand the remaining floor geometries are not impacted by 3D printing construction technology relative to the outcome or baseline variable (For more details, refer to Appendix E – Table E.10).

4.9 Effect of digital fabrication method on the roof geometry of buildings

4.9.1 The effect of Additive Digital Fabrication method on the roof geometry of buildings

```
Summary (model2rf)
Call:
Multinom (formula = QARF21 $ Roof geometry ~ QARF21 $ Additive Digital Fabrication, data = QARF21)
Residual Deviance: 312.5245
AIC: 356.5245
Baseline variable – flat rectangular roof geometry
```

A multinomial logistic regression was fitted to explain roof geometry of buildings based on Additive Digital Fabrication method. The results shows that there are some statistically significant interplay between facade geometry and Additive Digital Fabrication method. So flat rectilinear, flat irregular and flat polygonal shaped roof geometries have a higher chance of to be constructed by Additive Digital Fabrication method than flat rectangular shaped floor geometries. On the other hand flat rectangular shaped roof geometries have a higher chance of to be constructed by additive digital fabrication method than pyramidal roof geometries (For more details, refer to Appendix E – Table E.11).

4.9.2 The effect of subtractive Digital Fabrication method on the roof geometry of buildings

```
Summary (model2so)
Call:
Multinom (formula = QARF21 $ Roof geometry ~ QARF21 $ Subtractive Digital Fabrication, data = QARF21)
Residual Deviance: 317.6006
AIC: 361.6006
Baseline variable – flat rectangular roof geometry
```

A multinomial logistic regression was fitted to explain roof geometry of buildings based on subtractive Digital Fabrication method. The results shows that there are some statistically significant interplay between roof geometry and Additive Digital Fabrication method. So flat rectilinear, flat irregular and flat polygonal shaped roof geometries have a higher chance of to be constructed by subtractive Digital Fabrication method than flat rectangular shaped floor geometries (For more details, refer to Appendix E – Table E.12).

4.9.3 The effect of Forming Digital Fabrication method on the roof geometry of buildings

```
Summary (model2fod)
Call:
```

```
Multinom (formula = QARF21 $ Roof geometry ~ QARF21 $ Forming Digital Fabrication, data = QARF21)
Residual Deviance: 306.5194
AIC: 350.5194
Baseline variable – flat rectangular roof geometry
```

A multinomial logistic regression was fitted to explain roof geometry of buildings based on Forming Digital Fabrication method. The results shows that there are some statistically significant interplay between roof geometry and Forming Digital Fabrication method. So flat rectilinear, flat irregular and flat polygonal shaped roof geometries have a higher chance of to be constructed by Forming Digital Fabrication method than flat rectangular shaped floor geometries. But roof geometries including flat free form, pyramidal and other roof geometries not included in this thesis have a lower possibility of to be constructed by forming digital fabrication than flat rectangular roof geometries (For more details, refer to Appendix E – Table E.13).

4.9.4 The effect of Robotic Assembly construction method on the roof geometry of buildings

```
Summary (model2ra)
Call:
Multinom (formula = QARF21 $ Roof geometry ~ QARF21 $ Robotic Assembly construction, data = QARF21)
Residual Deviance: 320.074
AIC: 364.074
Baseline variable – flat rectangular roof geometry
```

A multinomial logistic regression was fitted to explain roof geometry of buildings based on Forming Digital Fabrication method. The results shows that there are some statistically significant interplay between roof geometry and Forming Digital Fabrication method. So flat rectilinear, flat free form, flat irregular, flat polygonal and pitched (common hip, gable, mansard, gambrel, butterfly etc.) shaped roof geometries have a higher chance of to be constructed by Forming Digital Fabrication method than flat rectangular shaped roof geometries (For more details, refer to Appendix E – Table E.14).

4.9.5 The effect of 3D printing construction technology on the roof geometry of buildings

```
Summary (model2pc)
Call:
Multinom (formula = QARF21 $ Roof geometry ~ QARF21 $ `@3D printing technology`, data = QARF21)
Residual Deviance: 314.7493
AIC: 358.7493
```

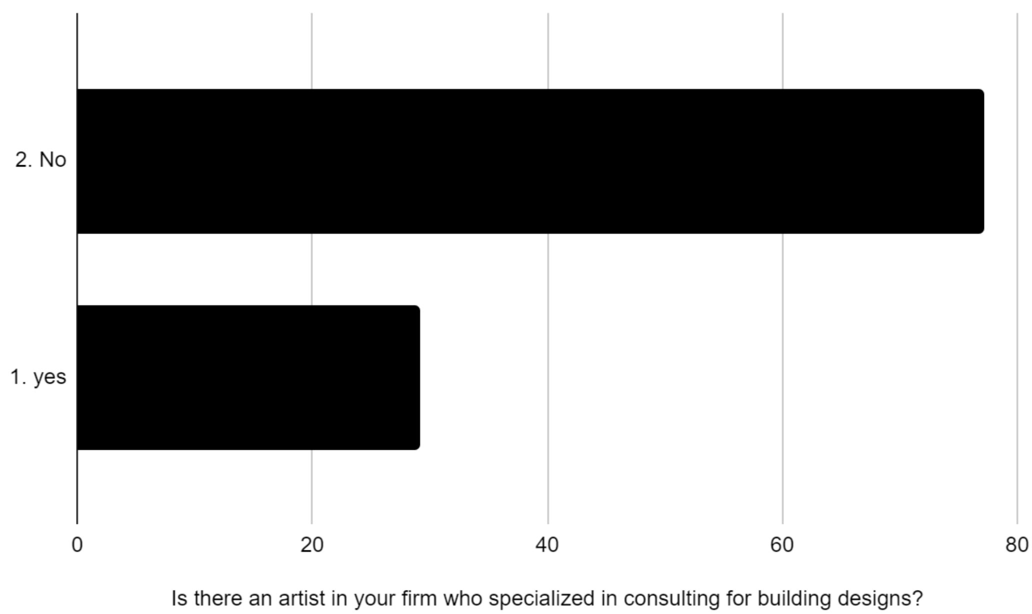
```
Baseline variable – flat rectangular roof geometry
```

A multinomial logistic regression was fitted to explain roof geometry of buildings based on 3D printing construction technology. The results shows that there are some statistically significant interplay between roof geometry and 3D printing construction technology. So flat irregular, flat polygonal and other roof geometries not listed in this thesis have a higher possibility of to be constructed by 3D printing construction technology than flat rectangular roof geometries, but flat triangular roof geometries have relatively a lower possibility of to be constructed by 3D printing construction technology than flat rectangular roof geometries (For more details, refer to Appendix E – Table E.15).

4.10 Presence of specialized professionals and floor geometry of buildings

4.10.1 Relation between presence of artist and floor geometry of buildings

Figure 4.26. *Presence of artists in the firms*

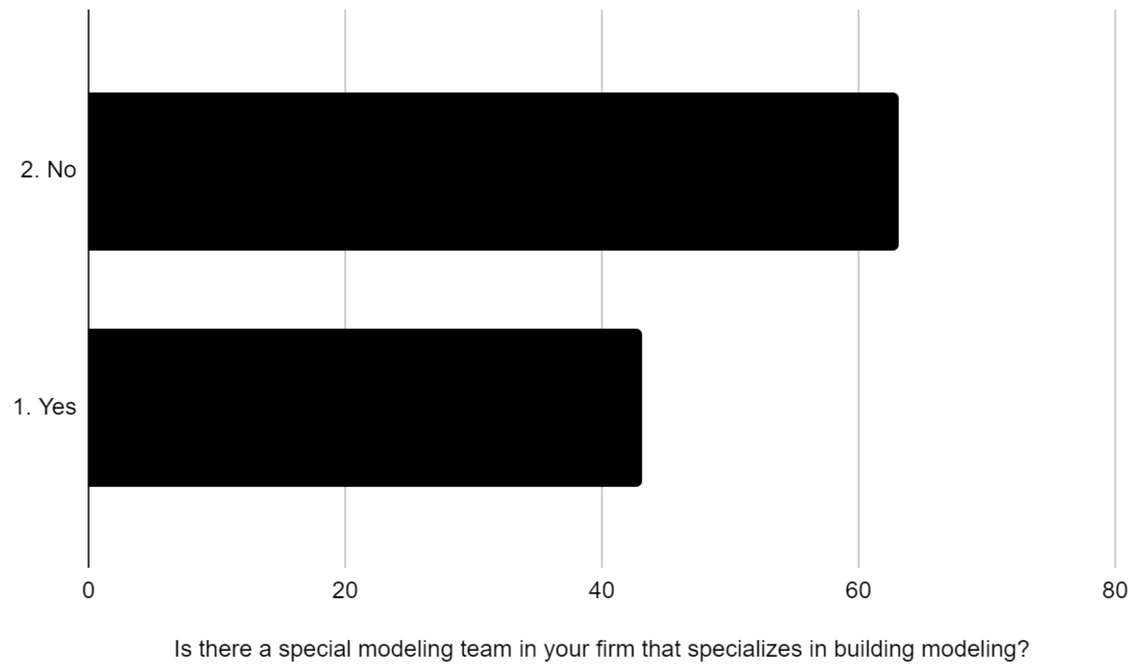



```
Summary (model2ar)
Call:
Multinom (formula = QARF21 $ Floor geometry ~ QARF21 $ Presence of
Artist, data = QARF21)
Residual Deviance: 191.3911
AIC: 223.3911
Baseline variable – rectangular floor geometry
```

A multinomial logistic regression was fitted to explain floor geometry of buildings based on presence of artist in the firm. The results shows that there is no statistically significant relation between the two variables that all p values of the model is above 0.05 significant level. So floor geometries are not the result of artists that artists have no any influence in the floor geometry of buildings. This test shows that the unavailability of artists in a design and engineering firms (For more details, refer to Appendix F – Table F.1).

4.10.2 Relation between presence of special modeling group and floor geometry of buildings

Figure 4.27. *Presence of special modeling group in the firms*

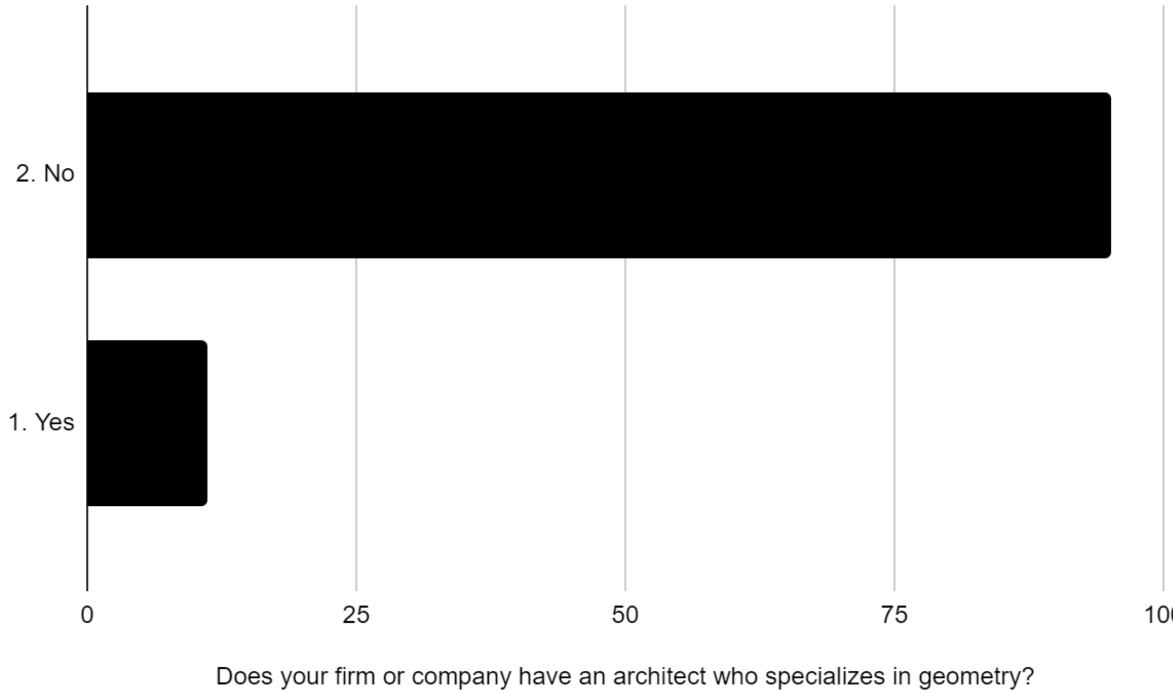



```
Summary (model2spm)
Call: multinom (formula = QARF21 $ Floor geometry ~ QARF21 $ Presence of Special modeling group, data = QARF21)
Residual Deviance: 193.6853
AIC: 225.6853
Baseline variable – rectangular floor geometry
```

A multinomial logistic regression was fitted to explain floor geometry of buildings based on a presence of special modeling group in a design and engineering firm. The results shows that there are some statistically significant interplay between floor geometry and presence of special modeling group. So floors which have a curved geometry have a higher possibility of to be designed and modeled by special modeling group than floors which have a rectangular geometry, on the other hand floors which have organic and free form geometries have a lower risk of to be designed and modeled by special modeling group than floors which have rectangular geometries. This model indicates that a small presence of special modeling group in a design and engineering firm (For more details, refer to Appendix F – Table F.2).

4.10.3 Relation between presence of specialized architect in geometry and floor geometry

Figure 4.28. *Presence of geometry architect in the firms*

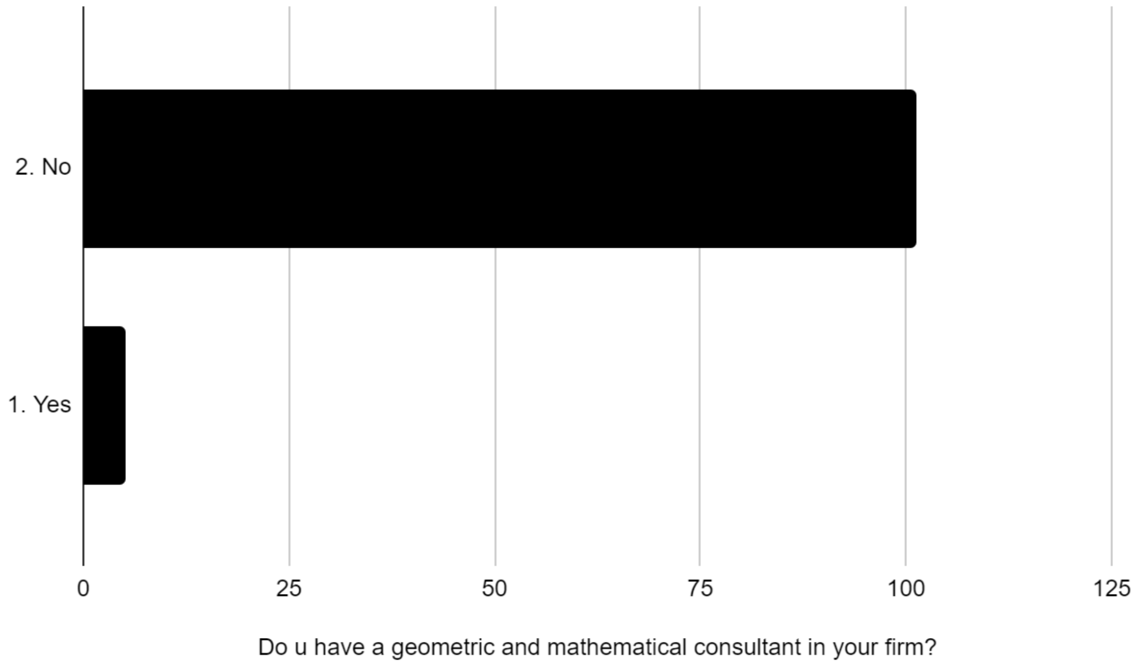



```
Summary (model2ag)
Call:
Multinom (formula = QARF21 $ Floor geometry ~ QARF21 $ Presence of
Geometry Architect, data = QARF21)
Residual Deviance: 202.1432
AIC: 234.1432
Baseline variable – rectangular floor geometry
```

A multinomial logistic regression was fitted to explain floor geometry of buildings based on a presence of specialized architect in geometry in a design and engineering firm. The results shows that there are some statistically significant interplay between floor geometry and presence of specialized architect in geometry. So floors which have square, rectilinear, irregular and other floor geometries not listed in this have higher risk of to be designed and modeled by specialized architect in geometry than floors which have a rectangular shaped geometry. This model indicates that the presence a few special modeling group in some design and engineering firm (For more details, refer to Appendix F – Table F.3).

4.10.4 Relation between presence of geometric and mathematical consultant in a firm and floor geometry of buildings

Figure 4.29. *Presence of geometric and mathematical consultant in the firms*

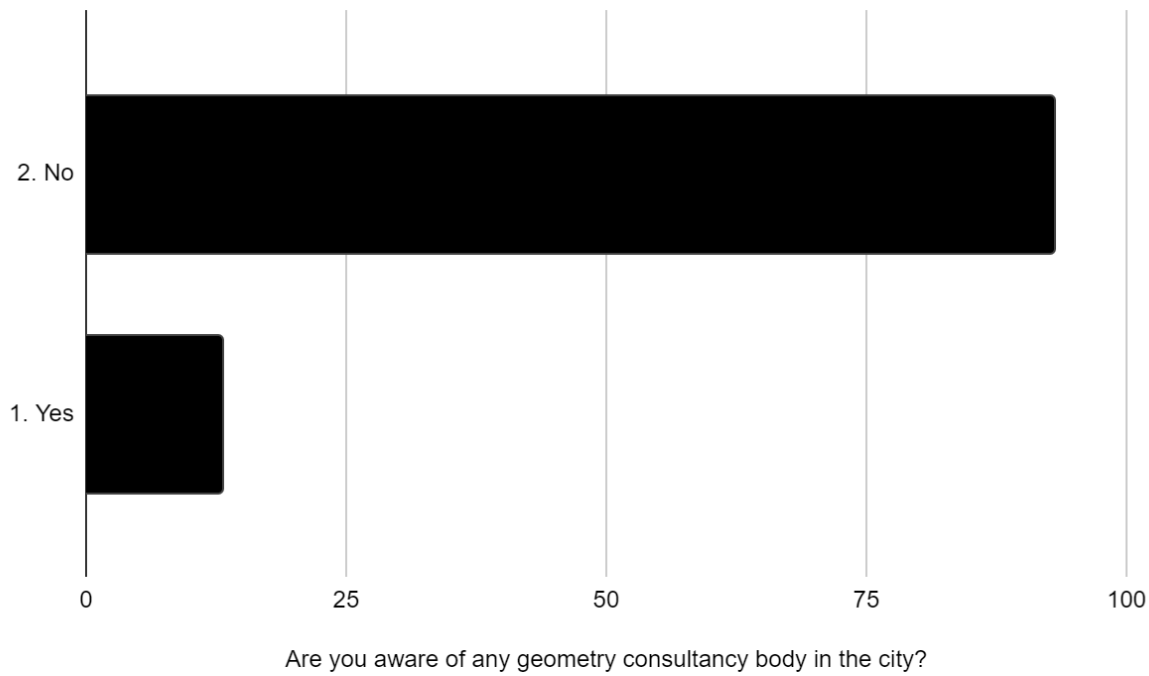



```
Summary (model2gmc)
Call:
Multinom (formula = QARF21 $ Floor geometry ~ QARF21 $ Presence of Geo.
and Mat. consultant, data = QARF21)
Residual Deviance: 204.3809
AIC: 236.3809
Baseline variable – rectangular floor geometry
```

A multinomial logistic regression was fitted to explain floor geometry of buildings based on a presence of geometric and mathematical consultant in a design and engineering firm. The results shows that there are some statistically significant interplay between floor geometry and presence of geometric and mathematical consultant. So floors which have rectilinear and polygonal shaped geometry have higher risk of to be consulted and reviewed by geometric and mathematical consultant than floors which have a rectangular shaped geometry (For more details, refer to Appendix F – Table F.4).

4.10.5 Relation between geometry consultancy body in the city and floor geometry of buildings

Figure 4.30. *Presence of building geometry consultancy body in the city*




```
Summary (model2gcs)
Call:
Multinom (formula = QARF21 $ Floor geometry ~ QARF21 $ Presence of Geometry consulting body, data = QARF21)
Residual Deviance: 205.1665
AIC: 237.1665
Baseline variable - rectangular floor geometry
```

A multinomial logistic regression was fitted to explain floor geometry of buildings based on presence of geometry consultancy body in the city. The results shows that there is no statistically significant relation between the two variables that all p values of the model is above 0.05 significant level. So floor geometries are not the result of geometry consultancy body in the city that geometry consultancy body in the city have no any influence in the floor geometry of buildings, which indicates that the non-availability of geometry consultancy body in the city (For more details, refer to Appendix F – Table F.5).

4.11 Relation between specialized professionals and façade geometry of buildings

4.11.1 Relation between presence of artist and façade geometry of buildings

```
Summary (model2fgs)
Call:
Multinom (formula = QARF21 $ Façade geometry ~ QARF21 $ Presence of Artist, data = QARF21)
Residual Deviance: 228.1181
AIC: 260.1181
Baseline variable – rectangular façade geometry
```

A multinomial logistic regression was fitted to explain facade geometry of buildings based on a presence of artist in a design and engineering firm. The results shows that there are some statistically significant interplay between facade geometry and presence of artist. So building façades which have triangular and polygonal shaped geometry have higher risk of to be consulted by artists than floors which have a rectangular shaped geometry. Besides the model shows that a few presence of design consulting artists in the design and engineering firms of the city (For more details, refer to Appendix F – Table F.6).

4.11.2 Relation between presence special modeling group and façade geometry of buildings

```
Summary (model2smg)
Call:
Multinom (formula = QARF21 $ Façade geometry ~ QARF21 $ Presence of Special modeling group, data = QARF21)
Residual Deviance: 226.6034
AIC: 258.6034
Baseline variable – rectangular façade geometry
```

A multinomial logistic regression was fitted to explain facade geometry of buildings based on presence of special modeling group in the firms. The results shows that there is no statistically significant relation between the two variables that all p values of the model is above 0.05 significant level. So façade geometries are not the result of special modeling group or special modeling group in the firm have no any influence in the floor geometry of buildings, which indicates that the unavailability of special modeling group in the firms(For more details, refer to Appendix F – Table F.7).

4.11.3 Relation between specialized architect in geometry and facade geometry of buildings

```
Summary (model2psa)
Call:
```

```
Multinom (formula = QARF21 $ Façade geometry ~ QARF21 $ Presence of Geometry Architect, data = QARF21)
Residual Deviance: 230.9897
AIC: 262.9897
Baseline variable – rectangular façade geometry
```

A multinomial logistic regression was fitted to explain facade geometry of buildings based on presence of specialized architect in geometry in the firms. The results shows that there is no statistically significant relation between the two variables that all p values of the model is above 0.05 significant level. So façade geometries are not the result of specialized architect in geometry or architect who specialized in geometry have no any influence in the floor geometry of buildings, which indicates that the unavailability of specialized architect in geometry in the firms (For more details, refer to Appendix F – Table F.8).

4.11.4 Relation between geometric and mathematical consultant and the façade geometry of buildings

```
Summary (model2gma)
Call:
Multinom (formula = QARF21 $ Façade geometry ~ QARF21 $ Presence of Geo. and Mat. consultant, data = QARF21)
Residual Deviance: 232.4054
AIC: 264.4054
Baseline variable – rectangular façade geometry
```

A multinomial logistic regression was fitted to explain facade geometry of buildings based on presence of geometric and mathematical consultant in the firms. The results shows that there is no statistically significant relation between the two variables that all p values of the model is above 0.05 significant level. So façade geometries are not the result of geometric and mathematical consultant or geometric and mathematical consultant have no any influence in the floor geometry of buildings, which indicates that the unavailability of geometric and mathematical consultant in the firms (For more details, refer to Appendix F – Table F.9).

4.11.5 Relation between geometry consultancy body in the city and façade geometry of buildings

```
Summary (model2cbo)
Call:
Multinom (formula = QARF21 $ Façade geometry ~ QARF21 $ Presence of Geometry consulting body, data = QARF21)
Residual Deviance: 232.9405
```

```
AIC: 264.9405
Baseline variable – rectangular façade geometry
```

A multinomial logistic regression was fitted to explain facade geometry of buildings based on a presence of geometry consultancy body in the city. The results shows that there is only one statistically significant interplay between facade geometry and geometry consultancy body. So building façades which have irregular shaped geometry have higher risk of to be consulted by geometry consultancy body than facades which have a rectangular shaped geometry. Besides the model indicates that presence of geometry consultancy body in the city is uncommon (For more details, refer to Appendix F – Table F.10).

4.12 Relation between specialized professionals and roof geometry of buildings

4.12.1 Relation between presence of artist and roof geometry of buildings

```
Summary (model2rfa)
Call:
Multinom (formula = QARF21 $ Roof geometry ~ QARF21 $ Presence of Artist, data = QARF21)
Residual Deviance: 312.3113
AIC: 356.3113
Baseline variable – flat rectangular roof geometry
```

A multinomial logistic regression was fitted to explain roof geometry of buildings based on a presence of artist in a design and engineering firm. The results shows that there are some statistically significant interplay between roof geometry and presence of artist. So building roofs which have flat square and flat rectilinear shaped geometry have higher risk of to be consulted by artists than façades which have a flat rectangular shaped geometry, but roofs which have flat rectangular shaped geometry have a higher risk of to be consulted by artists than flat irregular shaped roofs. Besides the model indicates that a few presence of design consulting artists in the design and engineering firms of the city (For more details, refer to Appendix F – Table F.11).

4.12.2 Relation between special modeling group and roof geometry of buildings

```
Summary (model2smm)
Call:
Multinom (formula = QARF21 $ Roof geometry ~ QARF21 $ Presence of Special modeling group, data = QARF21)
Residual Deviance: 313.0565
AIC: 357.0565
Baseline variable – flat rectangular roof geometry
```

A multinomial logistic regression was fitted to explain roof geometry of buildings based on a presence of special modeling group in a design and engineering firm. The results shows that there are some statistically significant interplay between roof geometry and presence of special modeling group. So building roofs which have pyramidal, flat curved and flat square shaped geometry have higher risk of to be consulted by special modeling group than façades which have a flat rectangular shaped geometry, but roofs which have flat rectangular shaped geometry have a higher risk of to be consulted by special modeling group than flat irregular shaped roofs. Besides the model indicates that a few presence of special modeling group in the design and engineering firms of the city (For more details, refer to Appendix F – Table F.12).

4.12.3 Relation between presence of specialized architects in geometry and roof geometry of buildings

```
Summary (modelz1)
Call:
Multinom (formula = QARF21 $ Roof geometry ~ QARF21 $ Presence of Geometry Architect, data = QARF21)
Residual Deviance: 320.7852
AIC: 364.7852
Baseline variable – flat rectangular roof geometry
```

A multinomial logistic regression was fitted to explain roof geometry of buildings based on a presence of architects specialized in geometry in a design and engineering firm. The results shows that there are some statistically significant interplay between roof geometry and presence of architects specialized in geometry. So building roofs which have Flat Square, Flat Rectilinear, Flat Free form, Flat Irregular and Others roof geometries not listed in this thesis have higher risk of to be consulted by architects specialized in geometry than roofs which have a flat rectangular shaped geometry. Besides the model indicates that few presence of architects who specialized in geometry in the design and engineering firms of the city (For more details, refer to Appendix F – Table F.13).

4.12.4 Relation between geometry and mathematical consultant and roof geometry of buildings

```
Summary (modelz2)
Call:
Multinom (formula = QARF21 $ Roof geometry ~ QARF21$PresenceofGeo.andMat.consultant, data = QARF21)
Residual Deviance: 323.0278
AIC: 367.0278
Baseline variable – flat rectangular roof geometry
```

A multinomial logistic regression was fitted to explain roof geometry of buildings based on a presence of geometric and mathematical consultant in a design and engineering firm. The results shows that there are some statistically significant interplay between roof geometry and presence of geometric and mathematical consultant in the firms. So building roofs which have Flat Rectilinear, Flat Free form, Flat Irregular, Flat Polygonal, Pitched (Hip Gable Mansard Gambrel butterfly etc.) and other roof geometries not listed in this thesis have higher risk of to be consulted by geometric and mathematical consultant than roofs which have a flat rectangular geometry. Besides the model indicates a few presence of geometric and mathematical consultant in some design and engineering firms of the city (For more details, refer to Appendix F – Table F.14).

4.12.5 Relation between geometry consultancy body and roof geometry of buildings

```
Summary (modelz3)
Call:
Multinom (formula = QARF21 $ Roof geometry ~ QARF21 $ Presence of
Geometry consulting body, data = QARF21)
Residual Deviance: 307.8448
AIC: 351.8448
Baseline variable – flat rectangular roof geometry
```

A multinomial logistic regression was fitted to explain roof geometry of buildings based on a presence of geometry consultancy body in the city. The results shows that there are some statistically significant interplay between roof geometry and presence of geometry consultancy body. So building roofs which have Flat Free form, Flat Irregular and flat Polygonal shape have higher risk of to be consulted by geometry consultancy body than roofs which have a flat rectangular geometry, but roofs which have flat rectangular geometry have a greater likelihood of to be consulted by geometry consultancy body than pyramidal roofs. Besides, the model suggests that the presence of geometry consulting body in the city is uncommon (For more details, refer to Appendix F – Table F.15).

4.13 Geometry and control variables

4.13.1 Floor geometry and its control variables

Table 4.27. *Design and Construction Consideration of Floor or Slab*

Control variable	Given consideration (%)
Floor Geometry CV	12.82
Floor Load carrying capacity CV	13.55
Floor Durability CV	12.96
Floor Fire and sound resistance CV	11.35
Floor Facility for installing systems CV	12.46
Floor Maintenance Issues CV	10.76
Floor Construction time CV	12.18
Floor Cost CV	13.85

The floor geometry of buildings accounts 12.8% impact on the design and construction of floors. When compared to other control variables it is one of the most responsible element in the construction consideration of façade.

4.13.2 Façade geometry and its control variables

Table 4.28. *Design and Construction Consideration of Façade or Exterior Wall*

Control variable	Given consideration (%)
Façade Geometry CV	14.49
Façade Strength and stability CV	14.96
Façade Resistance to weather CV	14.88
Façade Durability CV	13.82
Façade Fire and sound resistance CV	12.21
Façade Ventilation capability CV	14.33
Façade Cost CV	15.27

The facade geometry of buildings accounts 14.49 % impact on the design and construction of facades. When compared to other control variables it is one of the most responsible element in the construction consideration of façade.

4.13.3 Roof geometry and its control variables

Table 4.29. *Design and Construction Consideration of Roof*

Control variable	Given consideration (%)
Roof Geometry CV	8.20
Roof design familiarity CV	8.41
Roof owner requirements CV	9.25
Roof Building-code CV	8.80
Roof Effects of climate CV	8.46
Roof Deck suitability CV	7.81
Roof Rooftop traffic CV	7.01
Roof Esthetic consideration CV	8.99
Roof Pre-roofing conference CV	6.69
Roof Warranties CV	7.69
Roof maintenance CV	8.50
Roof Cost of construction CV	8.92

The roof geometry of buildings accounts 8.2 % impact on the design and construction of facades. When compared to other control variables it is one of the main responsible element in the construction consideration of roofs.

Generally In the three main sections of the building, the corresponding geometry of such building sections plays a substantial role in determining the construction material and method used in Addis Ababa's buildings.

5.0 Chapter 5: Conclusion and Recommendation

5.1 Conclusion

In conclusion, this thesis successfully identified the impact of geometry on the construction methods and materials used in buildings. Furthermore it also identified the current level of practices in using geometry related approaches including, computational design, digital fabrication and presence of specialized professionals and their current effect on the geometry of our buildings. The study was focused on three main building components: the floor or slab, the façade or exterior wall, and the roof. It also considered the overall volumetric geometry of buildings. Through a comprehensive building analysis method, the research identified how geometric design choices influence the construction of high-rise buildings under method type one approach of the research. The findings provide a valuable knowledge in understanding the relation between building design and construction to decide in creating a geometric architecture in the creation of efficient buildings and to decide on the sensitive issues of geometry and construction easily. Overall this thesis contributes to a deeper understanding of the significant role that geometry plays in determining construction practices and materials in the construction industry. Especially on method type two study approach the thesis deeply explored the interplay of geometry with construction and identified the impact of advanced design and construction approaches on the geometry of our buildings to realize how much our AEC firm is applying such advanced approaches in design and construction of buildings.

Based on method one building survey or analysis approach the research proofs that the floor geometry of a building have an impact on the floor construction method of buildings. For instance, a Buildings with a greater thickness of floor pose a higher chance of being constructed with a flat plate slab compared to those with a lesser thickness, relative to solid slab construction. Rectilinear shape is the dominant floor geometry and solid slab is the most used floor construction method in high-rise buildings.

But, floor geometry doesn't have an impact in deciding the floor construction material of buildings. Besides concrete and steel rebar which are the major constituents of reinforced concrete slab are the major construction materials used for floor construction of high-rise buildings in the city.

The facade geometry of building have an impact on the facade construction method of buildings. For instance, in the construction method of facade, a building with an increased thickness of façade are a greater likelihood of to be constructed by a masonry wall relative to the combination of Curtain and Masonry wall than those buildings with lesser thickness of façade. Rectangular shape is the most dominant façade geometry of high-rise buildings of the city and Masonry wall construction is the major construction method used on the façade construction of these buildings.

Besides, façade geometry also have an impact on the selection of façade construction material of buildings, for instance buildings which have a thick thickness of façade are a greater risk of to be constructed by HCB and mortar materials relative to a combination of glass, aluminum, mortar and, HCB materials than those buildings with a thin thickness of façade. Hollow concrete block (HCB) and mortar are the most commonly used material for the façade construction of high-rise buildings.

Roof geometry have an impact in deciding the construction method of roofs. For instance in the research it is found that in the construction method of roof, A building featuring a thick slab in the context of flat roofs is at a higher likelihood of being constructed with a flat plate slab than a solid slab, compared to buildings with a thinner roof thickness. So if a thick flat slab roof is designed the architect or engineer can be informed that the construction method of the designed flat roof might be flat plate slab by referring this thesis. So this research can be a guide to identify which roof geometry goes with which roof construction method. Flat Rectilinear slab roof geometry is the most constructed roof geometry and solid slab is the major roof construction method in the construction of high-rise buildings.

On the other hand roof geometry doesn't have any impact in deciding the roof construction material of buildings. Concrete and Steel rebar are the most widely used roof construction materials.

Volumetric geometry of buildings have an impact in deciding the floor construction method of buildings, that the research indicate that in the construction method of floor, A building with a wide width has a higher possibility of being constructed with a flat plate slab compared to a solid slab, relative to buildings with a narrower width. So width of buildings affects the floor construction method of buildings. Rectilinear prism is the most widely designed and constructed building's volumetric geometry in high-rise buildings of the city.

On the other hand, volumetric geometry of buildings doesn't have any impact in deciding the floor construction material of high rise buildings.

Volumetric geometry of buildings have an impact in deciding the façade construction method of buildings, for instance the research proofs that in the construction method of facade, A building with increased height is more likely to have its façade constructed with a curtain wall rather than a masonry wall, relative to buildings of shorter height.

Besides, volumetric geometry of a building also have an impact in deciding the construction material of a façade or exterior wall, for example the result indicates that in the construction material of facade, a building with increased building height have a greater possibility of their façade to be constructed by a combination of glass and aluminum material relative to HCB and mortar material than those buildings with a shorter building height. Which shows that taller buildings have a higher tendency of their façade material be a combination of glass and aluminum than HCB and mortar. Moreover a building with a wider building width have a greater possibility of their faced to be constructed by HCB and mortar material relative to a combination of glass, aluminum, mortar and HCB material than those buildings with a narrower building width.

Volumetric geometry of buildings have an impact in deciding the roof construction method of buildings. For instance, a building with a wider building width are a greater risk of their roof be constructed by a flat plate slab roof construction method relative to Solid slab roof construction method than those buildings with a narrower building width.

On the other hand, volumetric geometry of buildings doesn't have any impact in deciding the roof construction material of high rise buildings.

In general, geometry has a substantial impact on the construction of high-rise buildings in Addis Ababa. In contrast, relative to construction method, most construction materials used in high-rise buildings are not significantly affected by architectural geometry.

Considering all buildings in the city Floor geometry of buildings have an impact in deciding the floor construction method. For instance certain geometrical floor shapes have an influence on deciding the floor construction method of buildings, these floor geometries have relatively higher possibility of to be constructed by one way concrete slab than one way concrete joist slab. Rectangular shaped floors are the most designed and constructed floor geometries of the city. Besides, two way concrete slab is the major commonly used floor construction methods in the city.

Like the effect of floor geometry on floor construction method, floor geometry also have an impact on the floor construction material of buildings in the city, For example, floor geometries which have a certain geometrical shape have relatively higher possibility of to be constructed by concrete material than wooden material. The research reveals that concrete is the most commonly used floor construction material in the city.

Façade construction method of buildings is also determined by the façade geometry of buildings, that certain façade geometries are constructed by a specific type of façade construction method, for instance facade geometries which have a particular shape have relatively higher possibility to be constructed by concrete and masonry bearing walls construction method than metal and wood stud wall construction method. Besides, facade geometries which have a specific geometrical shape have relatively higher chance of to be constructed by concrete and masonry bearing walls than curtain wall construction method.

Rectangular shaped façades are the most widely used façade geometry in the buildings of the city and concrete and bearing masonry walls are the major façade construction method.

The research revealed that most façade geometries have a substantial impact in deciding the facade construction material of buildings, in view of the fact that when their facade geometry varies, the possible facade construction material differs accordingly. For instance, facade geometries which have a certain geometrical shape have relatively a higher possibility to be constructed by HCB (concrete) material than timber materials. On the other hand facade geometries which have a specific geometrical façade shape have a higher probability of to be constructed by HCB material than Glass material, in the other hand particular façade geometries have a greater possibility to be constructed by glass material than HCB (concrete) material. Concrete or HCB are the commonly used façade construction material in the city.

The most designed and constructed roof geometry in the city is flat rectangular roof. Common pitched roof geometry and flat rectilinear roof follow as the second and the third most designed and constructed roof in the city respectively. Here roof geometry have a substantial impact on the type of roof construction method of buildings, for example roofs which have particular roof geometrical shaped and other roof geometry types not listed in this thesis have a greater possibility to be constructed by reinforced concrete roof slab construction method than precast concrete roof construction method. But roofs which have particular geometrical shapes have relatively a higher chance to be constructed by precast concrete roof systems than reinforced concrete roof slab construction method. Flat rectangular shaped roofs are the major roof geometry and reinforced concrete slabs are the dominant construction method of roofs in the city.

The most widely used roof construction material in the city is metal, besides concrete and wooden materials follows it as second and third ranked material respectively used in the construction industry of the city. This shows that the usage of metal material as a reinforcing material for flat concrete roofs and using it as a metal member in a steel framed truss construction of roofs is a common practice. According to the interplay of geometry and construction material roof geometry have a substantial impact on the type of roof construction material of buildings. For instance roof geometries which have particular roof shapes have relatively a higher chance of to be constructed by metal material than concrete material. On the other hand roof geometries which have certain floor shape have relatively higher likelihood of to be constructed by concrete than metal materials. Metal is the major material used for the construction of roofs in the city.

In general geometry has a significant impact on both the construction techniques and materials used in all buildings in Addis Ababa. Based on the findings, the geometry of a building influences both the choice of materials and construction methods for the entire structure. Therefore, it can be concluded that the construction trends in Addis Ababa are predominantly driven by architectural geometry.

Among the elements of computational design levels 2d design software tools, 3d modeling software tool, parametric design, algorithm based computational design, generative based computational design, Per-formative design based computational design, Form finding based computational design and machine based learning computational design doesn't have any impact on the floor geometry of buildings. Only BIM have extremely small effect on the floor geometry of buildings. 2d design software tools and 3D modeling software tools are widely used in the firms. But using BIM, parametric design, algorithm based computational design, generative based computational design, Per-formative design based computational design, Form finding based computational design and machine based learning computational design in the firms are uncommon.

In general computational design has a minor and negligible impact on the floor geometry of buildings, and the primary indicators or predictors of it do not affect the floor geometry of all the city's buildings.

Among the elements or levels of computational design, 2D design software tool, 3d modeling software tool, BIM, parametric design, Performative design based computational design, Form finding based computational design and machine based learning computational design doesn't have an impact on the façade geometry of buildings, however algorithm based computational design and generative design-based computational design are rarely affect the façade geometry of buildings. 2d design software tools and 3D modeling software tools are widely used in the firms. But using BIM, parametric design, algorithm based computational design, generative based computational design, Per-formative design based computational design, Form finding based computational design and machine based learning computational design in the firms are uncommon.

In general computational design has a nearly insignificant and negligible impact on the façade geometry of all the city's buildings, as the major predictor elements of computational design do not influence the façade geometry.

Among the elements or levels of computational design 2D design software tool, 3D modeling software tool, BIM, algorithm based computational design and machine based learning computational design have an effect on the roof geometry of buildings but parametric design, generative Design-based computational design, performative design based computational design and Form finding based computational design doesn't have an effect on the roof geometry of buildings. 2d design software tools and 3D modeling software tools are widely used in the firms. But using BIM, parametric design, algorithm based computational design, generative based computational design, Per-formative design based computational design, Form finding based computational design and machine based learning computational design in the firms are uncommon.

In general computational design has a moderate impact on the roof geometry of all the city's buildings, with nearly half of the predictors influencing the roof geometry of these structures.

Among the elements of digital fabrication methods, additive digital fabrication method have an impact on the floor geometry of buildings, for instance the research revealed that specific floor geometries have a higher chance of to be constructed by Additive Digital Fabrication method than rectangular shaped floor geometries. And Robotic Assembly construction method also have an impact, that specific floor geometries have a higher chance of to be constructed by Robotic Assembly construction method than squared shaped floor geometries of buildings, in the other hand buildings which have particular floors geometrical shapes have a higher chance of to be constructed by robotic Assembly construction method than buildings which have rectangular shaped floor. But subtractive Digital Fabrication method, Forming Digital Fabrication method and 3D printing technology doesn't have any impact on the floor geometry of buildings. The research also indicates that Additive Digital Fabrication method, subtractive Digital Fabrication method, Forming Digital Fabrication method, Robotic Assembly construction method and 3D printing construction technologies are uncommon in the building construction practice of the city.

In general digital fabrication has a minor impact on the floor geometry of buildings, and the major elements in digital fabrication do not affect the floor geometry.

Among the elements of digital fabrication methods, additive Digital Fabrication method, forming Digital Fabrication method Robotic Assembly construction method and 3D printing construction technology have an effect on the facade geometry of buildings but subtractive Digital Fabrication method doesn't have an impact on the façade geometry of buildings. The research also indicates that Additive Digital Fabrication method, subtractive Digital Fabrication method, Forming Digital Fabrication method, Robotic Assembly construction method and 3D printing construction technologies are uncommon in the building construction practice of the city.

In general digital fabrication has a significant impact on the façade geometry of buildings, and the façade geometry of these buildings is influenced by digital fabrication, as the major predictors have an impact on the façade geometry of the buildings.

Among the elements of digital fabrication methods, additive Digital Fabrication method, subtractive Digital Fabrication method, Forming Digital Fabrication method Robotic Assembly construction method and 3D printing construction technology have an effect on the roof geometry of buildings. For instance certain roof geometries have a higher chance of to be constructed by Forming Digital Fabrication method than flat rectangular shaped roof geometries. The research also indicates that Additive Digital Fabrication method, subtractive Digital Fabrication method, Forming Digital Fabrication method, Robotic Assembly construction method and 3D printing construction technologies are uncommon in the roof construction practice of the city.

In general digital fabrication has a substantial impact on the roof geometry of buildings because all indicator elements of digital fabrication influence the roof geometry.

Among the elements of specialized professionals special modeling group have an impact on the floor geometry of buildings for instance floors which have a certain geometric shape have a higher possibility of to be designed and modeled by special modeling group than floors which have a rectangular floor geometry. Furthermore specialized architect in geometry, geometric and mathematical consultant also have an effect on the floor geometry of buildings. But Artists and geometry consultancy body in the city doesn't have an impact on the floor geometry of buildings. It is visible that the presence of artists, presence of specialized architect in geometry, presence of geometric and mathematical consultant in the firms and presence geometry consultancy body in the city is uncommon but presence of special modeling group are the most common specialized professionals in the firms of the city.

In general specialized professionals have a moderate impact on the floor geometry of buildings, as the floor geometry of these buildings is influenced by certain specialized professionals.

Among the elements of specialized professionals, artists and geometry consultancy body in the city have an impact on the façade geometry of buildings. The research uncovers that building façades which have certain geometrical shape have higher likelihood of to be consulted by artists than floors which have a rectangular shaped geometry and building façades which have certain geometric shapes have higher risk of to be consulted by geometry consultancy body than facades which have a rectangular shaped geometry. On the other hand special modeling group, specialized architect in geometry, geometric and mathematical consultant in a firm doesn't have an impact on the façade geometry of buildings. It is visible that the presence of artists, presence of specialized architect in geometry, presence of geometric and mathematical consultant in the firms and presence geometry consultancy body in the city is uncommon but presence of special modeling groups are the most common specialized professionals in the firms of the city.

In general specialized professionals have a minor impact on the façade geometry of buildings. The major indicators of specialized professionals do not affect the façade geometry of buildings, indicating that the façade geometry of the buildings are not significantly influenced by specialized professionals.

Among the elements of specialized professionals artists, special modeling group, specialized architects in geometry, geometry and mathematical consultancy body have an impact on the roof geometry of buildings. The research indicates roofs which have certain geometrical shape have higher possibility of to be consulted by artists than roofs which have a flat rectangular shaped geometry. Besides, roofs which have certain geometrical shape have higher likelihood of to be consulted by special modeling group than roofs which have a flat rectangular shaped geometry. It is visible that the presence of artists, presence of specialized architect in geometry, presence of geometric and mathematical consultant in the firms and presence geometry consultancy body in the city is uncommon but presence of special modeling group are the most common specialized professionals in the firms of the city.

In general specialized professionals have a significant influence on the roof geometry of buildings, as all indicators related to them have a tangible impact on the roof geometry of city buildings. Therefore, it can be said that the roof geometry of the city's buildings is strongly driven by certain specialized professionals.

5.1 Recommendation

Based on the findings of the thesis the research recommends a logical use of materials and construction methods especially in this research there are some elements of a building in which their material or construction technique is not driven by their geometry, so for such scenarios the research recommends that the professionals to focus on other construction determining parameters which may affect the material and construction method of specific building components rather than focusing on the geometric aspect of the buildings.

The research also recommends designers and constructors to be informed about the relation between geometry and building construction to decide quickly on what factors should they have to focus. Although, most components of a buildings is affected by geometry of respective components, there are other design and construction consideration which affect construction method and material of building.

The research also recommends that the professionals to think and propose another effective and appropriate material and construction method rather than sticking with conventional or commonly used material and construction techniques In the case of non-linkage, there is an absence of both relationship and effect between building geometry and construction, designers and constructors are not obliged to use a conventional and common construction technique and material.

Over and above that, the research recommends the AEC professionals to design and propose strongly linked geometry and construction material and method in the implementation of new projects. This helps to produce structural safe buildings and ease the construction process. Design building geometries which are strongly related to local construction material and method is much recommended, as importing construction materials is among the major problems of the construction industry.

As discussed earlier on the results and conclusion section of the thesis the research uncovers the level of using computational design in the design and engineering firms is very weak, which is among the main cause for the poor development of geometry in the construction industry. Most buildings of the city don't even need 2D design software tools to be designed, since they don’t differ from ancient architectural geometries that were designed and constructed before the introduction of 2D CAD tools. So the research recommends concerned bodies of the AEC sector to provide platforms for the development of using computational design tools and approaches to the professionals.

The research also revealed that the presence of specialized professionals, such as artists, special modeling groups, geometry architects, building geometry consultants are uncommon in the AEC firms. That is why most buildings in the city have almost similar ordinary form and shape. So based on these findings the research recommends the integration and adoption of such specialized professionals and companies are crucial in the industry.

In addition flourishing the three elements of advanced design and construction approaches. Growing the number of specialized professionals, usage of computational design tools and producing buildings by digital fabrication methods can improve our level of using geometry as a means for generating new and better construction material, technique and also software tools. These things can be practical in a specific time period by making design and construction professional familiar with these design and construction approaches. Educating the AEC professionals to use advanced design approaches and construction methods. As this research shows the level of using advanced design and construction approaches in the AEC firms is very low and uncommon, this research recommends the application and integration of such design and construction approaches in the AEC firms through education and practice can help to change, improve or sustain the ongoing geometry and construction habit of the industry.

Over and above that the research also recommends developing a culture of participating geometers mathematicians, artists and other related professionals to the industry in design and construction of building is also vital for producing geometrically sound architecture through collaboration of professionals.

On top of that, the research recommends architects and engineers to break the common conventional design and construction trends through new geometrical revolution or practice because geometry is one of the reason for the creation of new material and construction techniques.

Finally due to the fact that, there are no sufficient researches on geometry related cases. Extra researches are entertained. Especially on how can we shift, sustain and improve the current architectural geometry practice and construction through considering the skill and knowledge of our AEC professionals.

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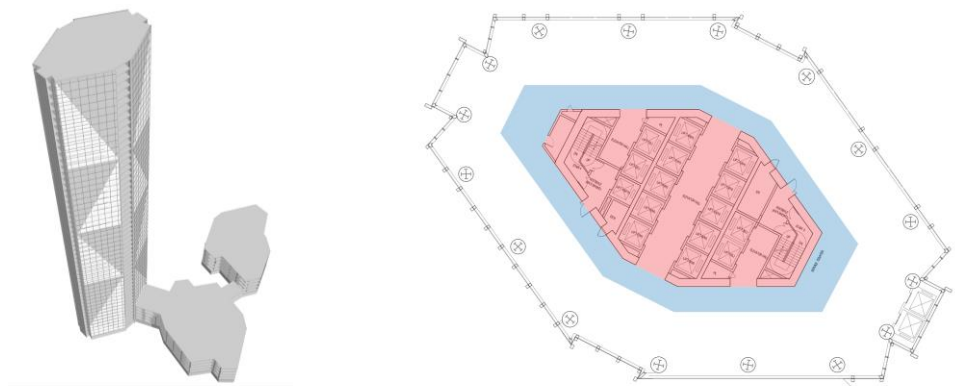
Appendices

Appendix A.0: Detailed data of the analyzed buildings

1. Commercial bank of Ethiopia - headquarter building

The headquarter building of Commercial bank of Ethiopia have an irregular octagonal floor and roof geometry with diamond or rhombus shaped façade geometry. Besides the overall volumetric geometry of the building is irregular octagonal prism mainly an extrusion of its floor geometry. This shape is the product of the two similar floor and roof geometry with its façade surface geometry.

Figure A.1. *Geometry of CBE headquarter*



Note: The available information includes the depiction of the overall volumetric form (on the left) and floor geometry (on the right) of the CBE building. The volumetric representation is based on a self-created 3D model, while the architectural drawings used for the floor geometry are sourced from Helawi S. in the CBE drawing document.

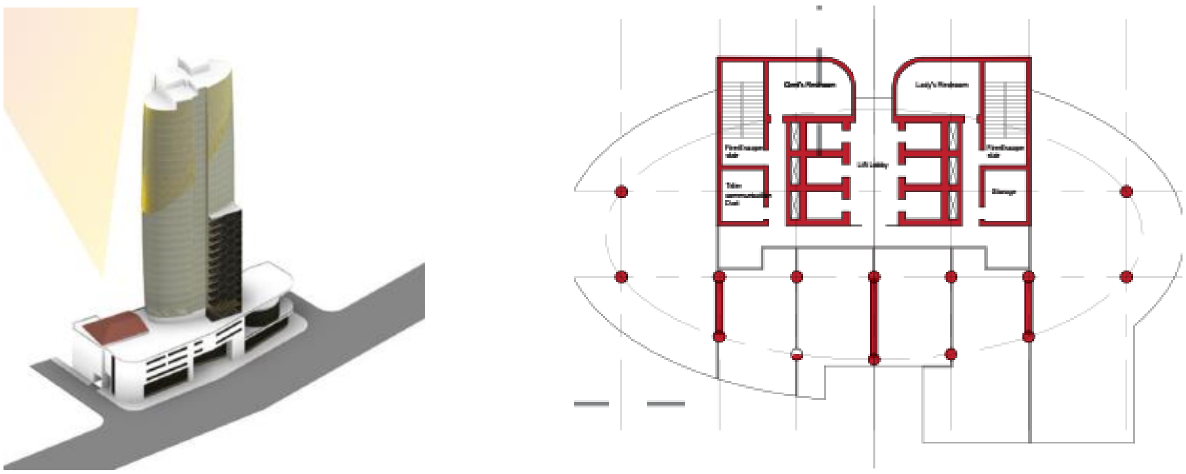
Table A.1. *The details of CBE high-rise building*

Main variables	Sub variables		**Number of stories**	**48**
Geometry	**Shape**		Floor shape	Irregular octagon
			Façade shape	Diamond or Rhombus
			Roof shape	Irregular octagon
	Size	Floor size	Maximum length of floor (m)	54
			Maximum width of floor (m)	35
			Maximum thickness of floor (cm)	18
		Façade size	Maximum length of façade or exterior wall (m)	54
			Maximum height of façade (m)	4
			Maximum thickness of façade (mm)	24
		Roof size	Maximum length of roof (m)	54
			Maximum width of roof (m)	35
			Max height or thickness of roof (m)	18
	Form		Form of roof	No form/ flat shape
			Form of building	Irregular octagonal prism
Construction method			Floor construction method	Solid slab
			Façade construction method	Curtain wall
			Roof construction method	Solid slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	Glass and aluminum
			Roof construction material	Concrete and Steel rebar

2. Nib bank headquarter building

The headquarter building of Nib bank have elliptical floor and roof geometry with curved and polygonal shaped façade geometry. Besides the overall volumetric geometry of the building is mainly elliptical cylinder mainly an extrusion of its floor geometry. This shape is the product of the two similar floor and roof geometry with its façade surface geometry.

Figure A.2. *Geometry of Nib bank headquarter*



Overall volumetric form (left) and floor geometry (right) of Nib Bank Building (Helawi S, 2023)

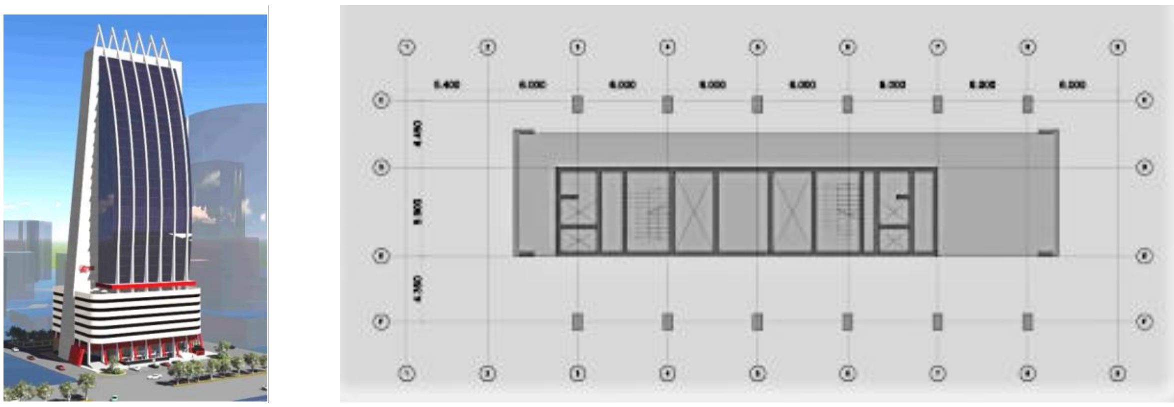
Table A.2. *The details of Nib bank high-rise building (Own table, 2023)*

Main variables	Sub variables		**Number of stories**	**35**
Geometry	**Shape**		Floor shape	Elliptical
			Façade shape	Curved and polygonal
			Roof shape	Elliptical
	Size	Floor size	Maximum length of floor (m)	44
			Maximum width of floor (m)	22
			Maximum thickness of floor (cm)	35
		Façade size	Maximum length of façade or exterior wall (m)	44
			Maximum height of façade (m)	3.6
			Maximum thickness of façade (mm)	22
		Roof size	Maximum length of roof (m)	44
			Maximum width of roof (m)	22
			Max height or thickness of roof (m)	35
	Form		Form of roof	No form/ flat shape
			Form of building	Elliptical cylinder
Construction method			Floor construction method	Flat plate slab
			Façade construction method	Curtain shear and masonry wall
			Roof construction method	Flat plate slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	Glass, aluminum, cement and HCB
			Roof construction material	Concrete and Steel rebar

3. Zemen bank headquarter building

The headquarter building of zemen bank have rectangular floor and roof geometry with curved, angled and planer shaped façade geometry. Besides the overall volumetric geometry of the building is dominantly a tapered rectangular prism, which have a tapering consecutive slabs in each floor level of the building. This shape is the product of the two similar floor and roof geometry with its curved and planer façade surface geometry.

Figure A.3. *Geometry of Zemen bank headquarter*



Overall volumetric form (left) and floor geometry (right) of Zemen Bank Building (Helawi S, 2023)

Table A.3. *The details of Zemen bank high-rise building*

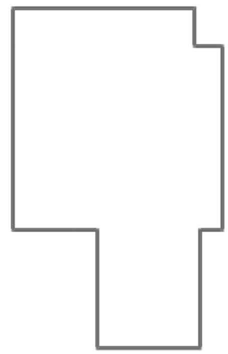
Main variables	Sub variables		**Number of stories**	**32**
Geometry	**Shape**		Floor shape	Rectangular
			Façade shape	Curved & irregular polygon
			Roof shape	Rectangular
	Size	Floor size	Maximum length of floor (m)	41
			Maximum width of floor (m)	33
			Maximum thickness of floor (cm)	25
		Façade size	Maximum length of façade or exterior wall (m)	41
			Max. height of façade (m)	3.6
			Maximum thickness of façade (mm)	22
		Roof size	Maximum length of roof (m)	41
			Maximum width of roof (m)	9
			Max height or thickness of roof (m)	25
	Form		Form of roof	No form/ flat shape
			Form of building	Tapered rectangular prism
Construction method			Floor construction method	Flat plate slab
			Façade construction method	Stick Curtain & shear wall
			Roof construction method	Flat plate slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	Glass, aluminum, cement and steel rebar
			Roof construction material	Concrete and Steel rebar

(Own table, 2023)

4. Wegagen bank headquarter building

The headquarter building of wegagen bank have rectilinear floor and roof geometry with rectangular shaped façade geometry. Besides the overall volumetric geometry of the building is dominantly a rectilinear prism. The form is the product of the two similar floor and roof geometry with its rectangular shaped façade geometry.

Figure A.4. *Geometry of Wegagen bank headquarter*



The overall volumetric form (on the left) and floor geometry (on the right) of the Wegagen Bank building. The volumetric form information is sourced from Wikipedia, while the floor plan illustration is drawn by the author and reflects the state of the building, 2023)

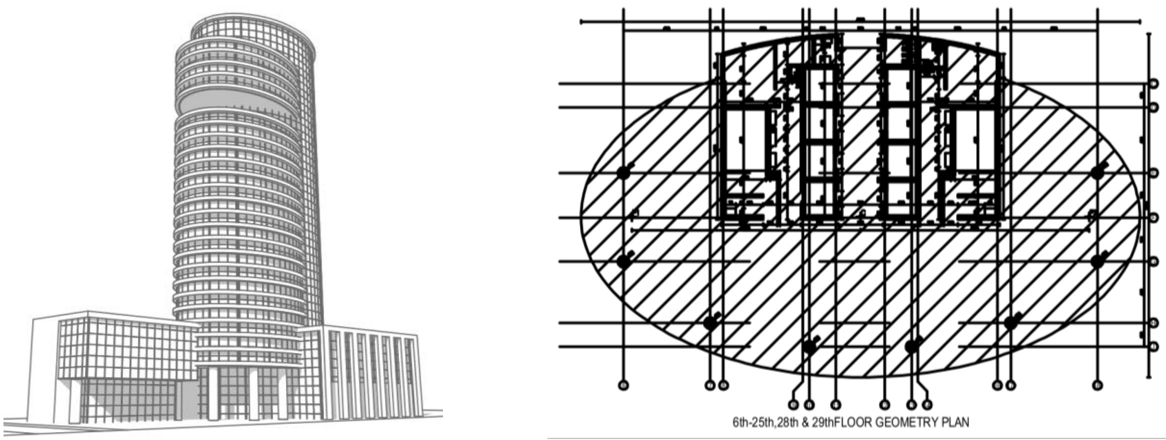
Table A.4. *The details of Wegagen bank high-rise building*

Main variables	Sub variables		**Number of stories**	**23**
Geometry	**Shape**		Floor shape	Rectilinear
			Façade shape	Rectangular
			Roof shape	Rectilinear
	Size	Floor size	Maximum length of floor (m)	52
			Maximum width of floor (m)	40
			Maximum thickness of floor (cm)	20
		Façade size	Maximum length of façade or exterior wall (m)	52
			Max. height of façade (m)	3.4
			Maximum thickness of façade (mm)	6
		Roof size	Maximum length of roof (m)	52
			Maximum width of roof (m)	40
			Max height or thickness of roof (m)	20
	Form		Form of roof	No form/ flat shape
			Form of building	Rectilinear prism
Construction method			Floor construction method	Flat plate slab
			Façade construction method	Curtain, shear & masonry wall
			Roof construction method	Flat plate slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	Glass, aluminum, concrete, steel rebar and HCB
			Roof construction material	Concrete and Steel rebar

5. Hibret bank headquarter building

The headquarters of Hibret Bank showcases an architectural design featuring elliptical floor and roof geometry, along with a gracefully curved façade. The overall volumetric form of the building is predominantly characterized by an elliptic cylinder, which is a result of combining the similar floor and roof geometry with the curved façade. This integration creates a harmonious and visually appealing composition for the building, emphasizing its elegant and modern architectural style.

Figure A.5. *Geometry of Hibret bank headquarter*



The overall volumetric form (on the left) and floor geometry (on the right) of the Hibret Bank building. The volumetric representation is by the author, while the floor plan is sourced from the engineering department of Hibret Bank (Own model, 2023).

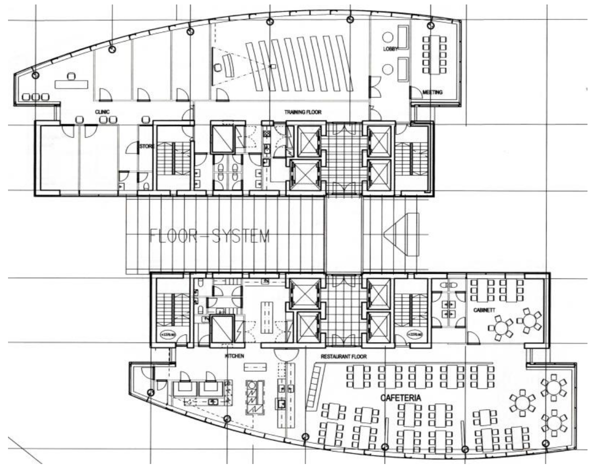
Table A.5. *The details of Hibret bank high-rise building*

Main variables	Sub variables		**Number of stories**	**31**
Geometry	**Shape**		Floor shape	Elliptical
			Façade shape	Curved
			Roof shape	Elliptical
	Size	Floor size	Maximum length of floor (m)	50
			Maximum width of floor (m)	23
			Maximum thickness of floor (cm)	30
		Façade size	Maximum length of façade or exterior wall (m)	50
			Max. height of façade (m)	3
			Maximum thickness of façade (mm)	12
		Roof size	Maximum length of roof (m)	50
			Maximum width of roof (m)	23
			Max height or thickness of roof (m)	30
	Form		Form of roof	No form/ flat shape
			Form of building	Elliptical cylinder
Construction method			Floor construction method	Solid slab
			Façade construction method	Curtain wall
			Roof construction method	Flat plate slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	Glass & aluminum
			Roof construction material	Concrete and Steel rebar

6. Awash bank headquarter building

The headquarter building of Awash bank have irregular floor and roof geometry which is a result of the curved and linear shape of the two envelopes, since it is difficult to categorize such shapes these shapes are categorized as an irregular shape. And it have both curved and rectangular shaped façade geometry. Besides the overall volumetric geometry of the building is categorized as irregular prism. This shape is the product of the two similar floor and roof geometry with its curved and rectangular shaped façade geometry.

Figure A.6. *Geometry of Awash bank headquarter*



Overall volumetric form (left) and floor geometry (right) of awash bank building photo from (Independent-travellers.com, 2023) & floor plan from engineering department of awash bank)

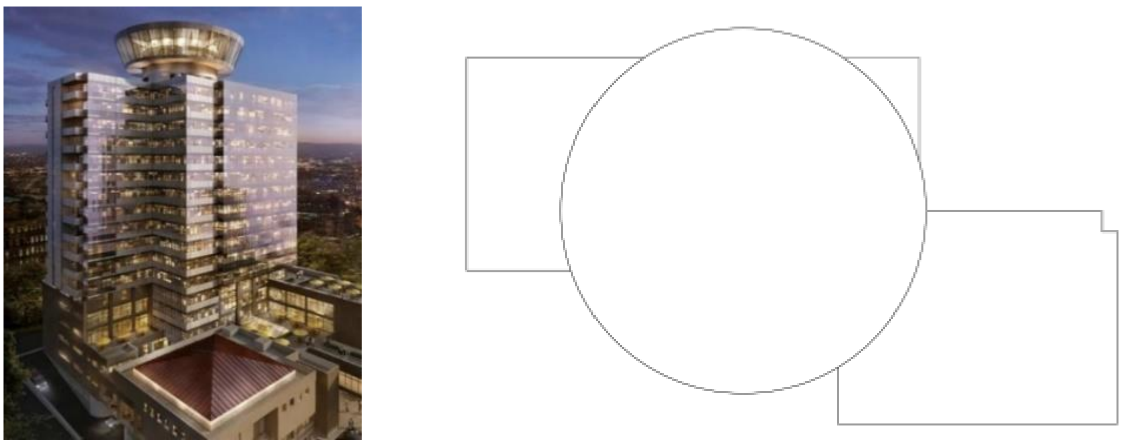
Table A.6. *The details of Awash bank high-rise building*

Main variables	Sub variables		Number of stories	18
Geometry	**Shape**		Floor shape	Irregular
			Façade shape	Rectangular and Curved
			Roof shape	Irregular
	Size	Floor size	Maximum length of floor (m)	34
			Maximum width of floor (m)	34
			Maximum thickness of floor (cm)	30
		Façade size	Maximum length of façade or exterior wall (m)	34
			Max. height of façade (m)	4.2
			Maximum thickness of façade (mm)	10
		Roof size	Maximum length of roof (m)	34
			Maximum width of roof (m)	34
			Max height or thickness of roof (m)	30
	Form		Form of roof	No form/ flat shape
			Form of building	Irregular prism
Construction method			Floor construction method	Flat plate slab
			Façade construction method	Curtain & masonry wall
			Roof construction method	Flat plate slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	Glass, aluminum, concrete & HCB
			Roof construction material	Concrete and Steel rebar

7. Maritime Transit Shipping Enterprise Headquarter Building – MTSE Building

The headquarter building of Maritime transit enterprise have a combination of rectilinear and circular shaped floor and roof geometry which is a result of the circular and linear shape of the two envelopes, since it is difficult to categorize such shapes these shapes are categorized as an irregular shape. And it have both curved and rectangular shaped façade geometry. Besides the overall volumetric geometry of the building is categorized as irregular form or a mix of rectilinear prism and tapered truncated cone. This shape is the product of the two similar floor and roof geometry with its curved and rectangular shaped façade geometry.

Figure A.7. *Geometry of MTSE building*



Overall volumetric form (left) and floor geometry (right) of MTSE HQ building (ZIAS Architecture & Engineering PLC and own floor plan illustration, 2023).

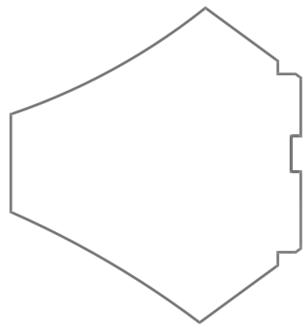
Table A.7. *The details of MTSE high-rise building*

Main variables	Sub variables		Number of stories	19
Geometry	**Shape**		Floor shape	Rectilinear & Circular
			Façade shape	Rectangular & Curved
			Roof shape	Rectilinear & Circular
	Size	Floor size	Maximum length of floor (m)	51
			Maximum width of floor (m)	32
			Maximum thickness of floor (cm)	20
		Façade size	Maximum length of façade or exterior wall (m)	51
			Max. height of façade (m)	3
			Maximum thickness of façade (mm)	10
		Roof size	Maximum length of roof (m)	51
			Maximum width of roof (m)	32
			Max height or thickness of roof (m)	20
	Form		Form of roof	No form/ flat shape
			Form of building	Irregular (rectilinear prism with tapered truncated cone)
Construction method			Floor construction method	Flat plate slab
			Façade construction method	Curtain & shear wall
			Roof construction method	Flat plate slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	Glass, aluminum, steel & concrete
			Roof construction material	Concrete and Steel rebar

8. Nani tower

The distinctive architectural design of the Nani Tower is defined by its irregular hexagonal floor and roof geometry, which adds a unique visual element to the structure. Additionally, the building exhibits a rectangular-shaped façade, further contributing to its overall aesthetic appeal. The dominant volumetric form of the tower takes the form of an irregular hexagonal prism, resulting from the harmonious integration of the similar floor and roof geometry with the rectangular façade. This combination creates an intriguing and visually captivating architectural composition for the Nani Tower.

Figure A.8. *Geometry of Nani tower*



Overall volumetric form (left) and floor geometry (right) of Nani Tower (Own photo and floor plan illustration, 2023)

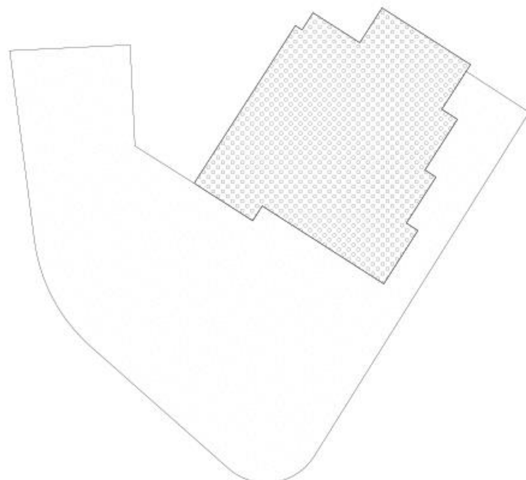
Table A.8. *The details of Nani tower high-rise building*

Main variables	Sub variables		Number of stories	**23**
Geometry	**Shape**		Floor shape	Irregular Hexagon
			Façade shape	Rectangular
			Roof shape	Irregular Hexagon
	Size	Floor size	Maximum length of floor (m)	35
			Maximum width of floor (m)	32
			Maximum thickness of floor (cm)	26
		Façade size	Maximum length of façade or exterior wall (m)	35
			Max. height of façade (m)	3.8
			Maximum thickness of façade (mm)	24
		Roof size	Maximum length of roof (m)	35
			Maximum width of roof (m)	32
			Max height or thickness of roof (m)	26
	Form		Form of roof	No form/ flat shape
			Form of building	Irregular hexagonal prism
Construction method			Floor construction method	Flat plate slab
			Façade construction method	Curtain & shear wall
			Roof construction method	Flat plate slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	Glass, aluminum, plastic, steel & concrete
			Roof construction material	Concrete and Steel rebar

9. KK TOWER

The KK Tower showcases a distinctive architectural style characterized by its rectilinear floor and roof layouts, complemented by a rectangular façade design. The dominant volumetric shape of the building can be described as a rectilinear prism, which results from the harmonious combination of the similar floor and roof geometries with the rectangular façade. This architectural composition gives the KK Tower a visually striking presence and adds to its overall aesthetic appeal.

Figure A.9. *Geometry of KK tower*



Overall volumetric form (left) and floor geometry (right) of KK Tower. (KKplcethiopia, 2023) And own floor plan illustration)

Table A.9. *The details of KK TOWER high-rise building*

Main variables	Sub variables		Number of stories	22
Geometry	**Shape**		Floor shape	Rectilinear
			Façade shape	Rectangular
			Roof shape	Rectilinear
	Size	Floor size	Maximum length of floor (m)	34
			Maximum width of floor (m)	32
			Maximum thickness of floor (cm)	30
		Façade size	Maximum length of façade or exterior wall (m)	34
			Max. height of façade (m)	3.75
			Maximum thickness of façade (mm)	30
		Roof size	Maximum length of roof (m)	34
			Maximum width of roof (m)	32
			Max height or thickness of roof (cm)	30
	Form		Form of roof	No form/ flat shape
			Form of building	Rectilinear prism
Construction method			Floor construction method	Solid and Flat plate slab
			Façade construction method	Curtain wall
			Roof construction method	Light weight Flat plate slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	Glass and aluminum
			Roof construction material	Concrete and Steel rebar

10. KKare Center Building

The KKare Center building, situated near Mexico Square, boasts an exceptional architectural design. It stands out due to its unconventional arrangement of floors and roofs, which are non-uniform in shape, and its rectangular façade. The building's overall form can be best described as an irregular polygonal prism, resulting from the combination of similar floor and roof layouts and the rectangular façade design.

Figure A.10. *Geometry of KKare center*

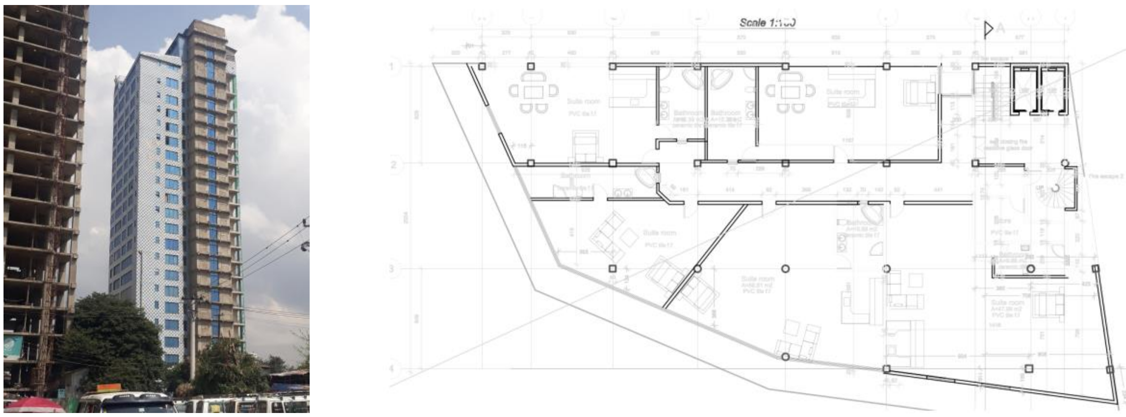


Fig. Overall volumetric form (left) and floor geometry (right) of KKare center building (Photo and floor plan of KKare Building, 2023 Own image and KKare engineering department respectively).

Table A.10. *The details of KKare Center high-rise building*

Main variables	Sub variables		Number of stories	**22**
Geometry	**Shape**		Floor shape	Irregular Polygon
			Façade shape	Rectangular
			Roof shape	Irregular Polygon
	Size	Floor size	Maximum length of floor (m)	50
			Maximum width of floor (m)	23
			Maximum thickness of floor (cm)	30
		Façade size	Maximum length of façade or exterior wall (m)	50
			Max. height of façade (m)	3.1
			Maximum thickness of façade (mm)	200
		Roof size	Maximum length of roof (m)	50
			Maximum width of roof (m)	23
			Max height or thickness of roof (cm)	30
	Form		Form of roof	No form
			Form of building	Irregular polygonal prism
Construction method			Floor construction method	Solid slab
			Façade construction method	Masonry and Glass wall
			Roof construction method	Solid slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	Glass, aluminum, Concrete and HCB
			Roof construction material	Concrete and Steel rebar

11. Nile Insurance Headquarter Building

The Nile Insurance headquarters building is characterized by a rectangular floor and roof geometry, complemented by a rectangular-shaped façade. The overall volumetric form of the building can be described as a rectangular prism. This shape is achieved through the integration of similar floor and roof geometries, combined with the rectangular façade. The resulting design creates a cohesive and visually appealing structure for the Nile Insurance headquarters.

Figure A.11. *Geometry of Nile insurance headquarter*

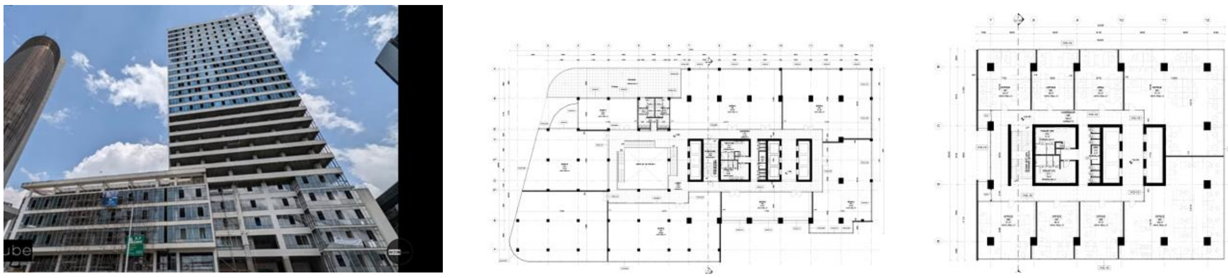


Fig. Photo and floor geometry of Nile Insurance HQ, 2023 (Own image, Jekale CM Consultancy and Wosen architects). The details provided shows a photograph depicting the overall volumetric form (on the left) and floor geometry (on the right) of the Nile Insurance headquarters.

Table A.11. *The details of Nile Insurance high-rise building*

Main variables	Sub variables		Number of stories	**25**
Geometry	**Shape**		Floor shape	Rectangular
			Façade shape	Rectangular
			Roof shape	Rectangular
	Size	Floor size	Maximum length of floor (m)	34
			Maximum width of floor (m)	27
			Maximum thickness of floor (cm)	25
		Façade size	Maximum length of façade or exterior wall (m)	34
			Max. height of façade (m)	3.5
			Maximum thickness of façade (mm)	24
		Roof size	Maximum length of roof (m)	34
			Maximum width of roof (m)	27
			Max height or thickness of roof (cm)	25
	Form		Form of roof	No form
			Form of building	Rectangular prism
Construction method			Floor construction method	Solid Slab
			Façade construction method	Curtain And masonry wall
			Roof construction method	Solid Slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	Glass, aluminum, Concrete and HCB
			Roof construction material	Concrete and Steel rebar

12. Dashen bank Headquarter Building

Dashen bank headquarter building have an irregular shaped floor and roof geometry with irregular shaped façade geometry too, because the shape is composed from a straight and curved lines which is difficult to categorize in a distinct geometry type, so in this thesis such types of shapes are classified as irregular shapes. Besides the overall volumetric geometry of the building is irregular shaped prism. This shape is the result of the two similar floor and roof geometry and its irregular shaped façade geometry.

Figure A.12. *Geometry of Dashen bank headquarter*

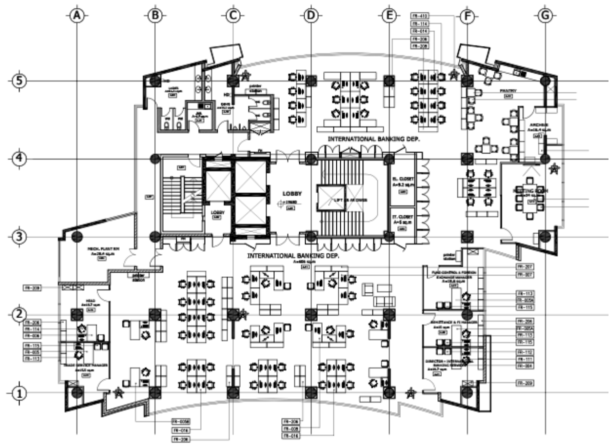


Fig. The provided image showcases the overall volumetric form (on the left) and floor geometry (on the right) of the Dashen Bank HQ. This photo was taken by the author and the floor plan drawing is a part of the documentation from the Engineering department of Dashen Bank in 2023).

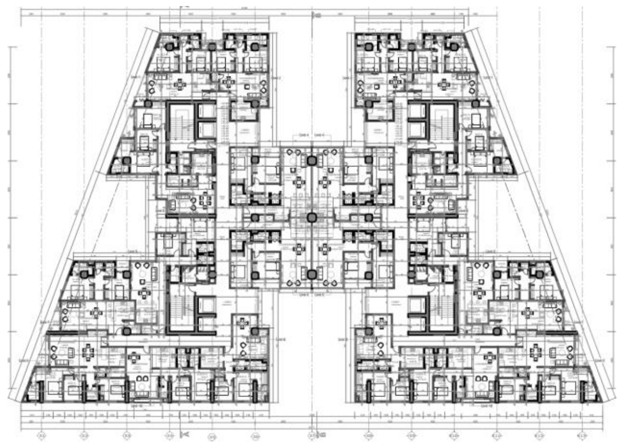
Table A.12. *The details Dashen bank HQ high-rise building*

Main variables	Sub variables		Number of stories	**21**
Geometry	**Shape**		Floor shape	Irregular Shape
			Façade shape	Irregular Shape
			Roof shape	Irregular Shape
	Size	Floor size	Maximum length of floor (m)	45
			Maximum width of floor (m)	26
			Maximum thickness of floor (cm)	26
		Façade size	Maximum length of façade or exterior wall (m)	45
			Max. height of façade (m)	3.3
			Maximum thickness of façade (mm)	25
		Roof size	Maximum length of roof (m)	45
			Maximum width of roof (m)	26
			Max height or thickness of roof (cm)	25
	Form		Form of roof	No form
			Form of building	Irregular shaped prism
Construction method			Floor construction method	Solid Slab
			Façade construction method	Curtain wall
			Roof construction method	Solid Slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	Glass and aluminum
			Roof construction material	Concrete and Steel rebar

13. Chelelek Al-Sam Tower

The Chelelek Al-Sam Tower features a floor and roof design that resembles an isosceles trapezium, while its exterior facade has a rectangular shape. The building's overall volumetric structure can be described as an isosceles trapezoidal prism, which is formed by the similarity between the floor and roof geometry, as well as the rectangular facade shape.

Figure A.13. *Geometry of Chelelek Al sam tower*



Overall volumetric form (left) and floor geometry (right) of Al-Sam Tower (Photo from (Alsam.carrd.co, 2023) and floor plan from construction department of Alsam properties, 2023)

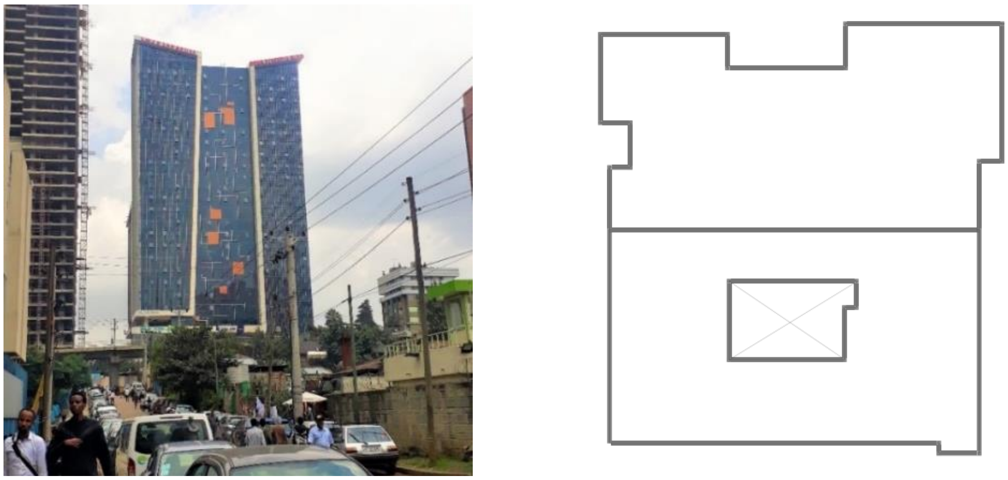
Table A.13. *The details of Chelelek Al-Sam Tower*

Main variables	Sub variables		Number of stories	**21**
Geometry	**Shape**		Floor shape	Isosceles Trapezium
			Façade shape	Rectangular
			Roof shape	Isosceles Trapezium
	Size	Floor size	Maximum length of floor (m)	80
			Maximum width of floor (m)	55
			Maximum thickness of floor (cm)	26
		Façade size	Maximum length of façade or exterior wall (m)	80
			Max. height of façade (m)	2.6
			Maximum thickness of façade (mm)	200
		Roof size	Maximum length of roof (m)	80
			Maximum width of roof (m)	55
			Max height or thickness of roof (cm)	26
	Form		Form of roof	No form
			Form of building	Isosceles Trapezoidal Prism
Construction method			Floor construction method	Flat Plate Slab
			Façade construction method	Masonry wall
			Roof construction method	Flat Plate Slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	HCB and cement or concrete
			Roof construction material	Concrete and Steel rebar

14. ORDA Ethiopia Headquarters

ORDA Headquarters building have a rectilinear floor and roof geometry with rectangular shaped façade geometry. Besides the overall volumetric geometry of the building is rectilinear prism. This building form is the result of the two similar floor and roof geometry and its rectangular shaped façade geometry.

Figure A.14. *Geometry of ORDA Ethiopia headquarter*



The image representing the overall volumetric form (on the left) and floor geometry (on the right) of the ORDA Ethiopia Tower (Own photo and floor plan illustration, 2023)

Table A.14. The details of ORDA Ethiopia Headquarters

Main variables	Sub variables		Number of stories	**27**
Geometry	**Shape**		Floor shape	Rectilinear
			Façade shape	Rectangular
			Roof shape	Rectilinear
	Size	Floor size	Maximum length of floor (m)	51
			Maximum width of floor (m)	25
			Maximum thickness of floor (cm)	25
		Façade size	Maximum length of façade or exterior wall (m)	51
			Max. height of façade (m)	3.52
			Maximum thickness of façade (mm)	22
		Roof size	Maximum length of roof (m)	51
			Maximum width of roof (m)	25
			Max height or thickness of roof (cm)	25
	Form		Form of roof	No form
			Form of building	Rectilinear prism
Construction method			Floor construction method	Flat Plate Slab
			Façade construction method	Curtain and Masonry wall
			Roof construction method	Flat Plate Slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	Glass, Aluminum HCB and cement or concrete
			Roof construction material	Concrete and Steel rebar

15. Tsedey Bank (ACSI) HQ

The Tsedey Bank (ACSI) headquarters building features an unconventional floor plan that consists of irregular polygon shapes. The roof has an irregular hexagonal design, while the façade is composed of polygonal shapes. The overall structure of the building can be described as an irregular polygonal prism. This unique architectural form arises from the combination of distinct floor and roof geometries, as well as the polygonal design of the façade.

Figure A.15. *Geometry of Tsedey bank (ACSI) headquarter*

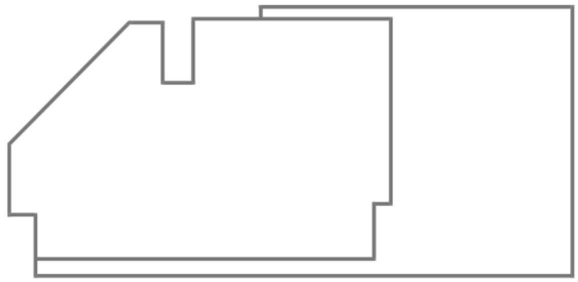


Fig. Overall volumetric form (left) and floor geometry (right) of Tsedey bank (own photo and drawing, 2023)

Table A.15. *The details of Tsedey Bank (ACSI) HQ*

Main variables	Sub variables		Number of stories	**36**
Geometry	**Shape**		Floor shape	Irregular polygon
			Façade shape	Polygonal
			Roof shape	Irregular Hexagon
	Size	Floor size	Maximum length of floor (m)	53
			Maximum width of floor (m)	34
			Maximum thickness of floor (cm)	30
		Façade size	Maximum length of façade or exterior wall (m)	53
			Max. height of façade (m)	3.84
			Maximum thickness of façade (mm)	28
		Roof size	Maximum length of roof (m)	53
			Maximum width of roof (m)	34
			Max height or thickness of roof (cm)	30
	Form		Form of roof	No form
			Form of building	Irregular polygonal prism
Construction method			Floor construction method	Flat Plate Slab
			Façade construction method	Curtain, Shear and Masonry wall
			Roof construction method	Flat Plate Slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	Glass, Aluminum HCB, steel and cement or concrete
			Roof construction material	Concrete and Steel rebar

16. CMC High-rise building

The CMC high-rise building showcases a rectangular floor plan and roof design, complemented by a rectangular façade. The overall structure of the building can be described as a rectangular prism. This architectural form is achieved through the consistent use of rectangular floor and roof geometries, as well as the rectangular design of the façade.

Figure A.16. *Geometry of CMC High-rise building*

Overall volumetric form (left) and floor geometry (right) of CMC high-rise building (own photo and drawing, 2023)

Table A.16. *The details of CMC High-rise building*

Main variables	Sub variables		Number of stories	**36**
Geometry	**Shape**		Floor shape	Rectangular
			Façade shape	Rectangular
			Roof shape	Rectangular
	Size	Floor size	Maximum length of floor (m)	90
			Maximum width of floor (m)	18
			Maximum thickness of floor (cm)	20
		Façade size	Maximum length of façade or exterior wall (m)	90
			Max. height of façade (m)	3.52
			Maximum thickness of façade (mm)	200
		Roof size	Maximum length of roof (m)	90
			Maximum width of roof (m)	18
			Max height or thickness of roof (cm)	20
	Form		Form of roof	No form
			Form of building	Rectangular prism
Construction method			Floor construction method	Solid Slab
			Façade construction method	Masonry wall
			Roof construction method	Solid Slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	HCB and concrete
			Roof construction material	Concrete and Steel rebar

17. Senga Tera Traders SC. Building

The Senga Tera Traders SC building features a rectilinear floor plan and roof design, accompanied by a rectangular façade. The overall structure of the building can be described as a rectilinear prism. This architectural form is a result of the consistent use of similar rectangular floor and roof geometries, as well as the rectangular design of the façade.

Figure A.17. *Geometry of Senga Tera Traders SC. Building*

Overall volumetric form (left) and floor geometry (right) of CMC Senga Tera Traders SC. Building (Asrat, 2020) & Own photo with floor plan illustration, 2023).

Table A.17. *The details of Senga Tera Traders SC. Building*

Main variables	Sub variables		Number of stories	**27**
Geometry	**Shape**		Floor shape	Rectilinear
			Façade shape	Rectangular
			Roof shape	Rectilinear
	Size	Floor size	Maximum length of floor (m)	38
			Maximum width of floor (m)	20
			Maximum thickness of floor (cm)	27
		Façade size	Maximum length of façade or exterior wall (m)	38
			Max. height of façade (m)	3.2
			Maximum thickness of façade (mm)	14
		Roof size	Maximum length of roof (m)	38
			Maximum width of roof (m)	20
			Max height or thickness of roof (cm)	27
	Form		Form of roof	No form
			Form of building	Rectilinear prism
Construction method			Floor construction method	Flat plate Slab
			Façade construction method	Curtain and Masonry wall
			Roof construction method	Flat plate slab and steel truss
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	Glass, Aluminum HCB and concrete
			Roof construction material	Concrete and Steel rebar

18. Eleli Building – Kazanchise

The Eleli building exhibits an irregular floor and roof design, accompanied by an irregularly shaped façade. Additionally, the overall volumetric geometry of the building can be described as an irregular prism. This unique architectural form arises from the use of similar floor and roof geometries, as well as the irregular shape of the façade.

Figure A.18. *Geometry of Eleli Building*

Overall volumetric form (left) and floor geometry (right) of Eleli building (Own photo and drawing, 2023)

Table A.18. *The details of Eleli Building*

Main variables	Sub variables		Number of stories	**21**
Geometry	**Shape**		Floor shape	Irregular Shape
			Façade shape	Irregular
			Roof shape	Irregular Shape
	Size	Floor size	Maximum length of floor (m)	30
			Maximum width of floor (m)	23
			Maximum thickness of floor (cm)	30
		Façade size	Maximum length of façade or exterior wall (m)	30
			Max. height of façade (m)	3.6
			Maximum thickness of façade (mm)	200
		Roof size	Maximum length of roof (m)	30
			Maximum width of roof (m)	23
			Max height or thickness of roof (cm)	30
	Form		Form of roof	No form
			Form of building	Irregular prism
Construction method			Floor construction method	Solid and Flat plate Slab
			Façade construction method	Curtain and Masonry wall
			Roof construction method	Waffle and solid slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	Glass, Aluminum HCB and mortar
			Roof construction material	Concrete and Steel rebar

19. Keen real estate – mixed-use building (Bole Rwanda)

The KEEN real estate mixed-use building showcases an irregular polygonal floor and roof design, complemented by a rectangular façade geometry. Moreover, the building's overall volumetric shape can be described as an irregular polygonal prism. This unique architectural form is a result of combining similar floor and roof geometries with a rectangular façade design.

Figure A.19. *Geometry of Keen real estate – mixed-use building (Bole Rwanda)*

Overall volumetric form (left) and floor geometry (right) of Keen real estate – mixed-use building (Own photo) and (Keen real-estate Engineer Ashagre.)

Table A.19. *The details of Keen real estate – mixed-use building*

Main variables	Sub variables		Number of stories	**19**
Geometry	**Shape**		Floor shape	Irregular Polygon
			Façade shape	Rectangular
			Roof shape	Irregular Polygon
	Size	Floor size	Maximum length of floor (m)	41
			Maximum width of floor (m)	23
			Maximum thickness of floor (cm)	30
		Façade size	Maximum length of façade or exterior wall (m)	41
			Max. height of façade (m)	3.1
			Maximum thickness of façade (mm)	200
		Roof size	Maximum length of roof (m)	41
			Maximum width of roof (m)	23
			Max height or thickness of roof (cm)	30
	Form		Form of roof	No form
			Form of building	Irregular polygonal prism
Construction method			Floor construction method	Ribbed Slab
			Façade construction method	Masonry and Glass wall
			Roof construction method	Ribbed slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	Glass, HCB and Mortar
			Roof construction material	Concrete and Steel rebar

20. The place luxury living – Bole Atlas

The Z PLACE Luxury living building, situated near Bole Atlas, features a distinct rectangular floor and roof design, accompanied by a rectangular façade geometry. Moreover, the overall volumetric shape of the building can be described as a rectangular prism. This architectural form is achieved through the consistent use of similar rectangular floor, façade, and roof geometries, resulting in a cohesive rectangular prism structure. An interesting aspect of this building is that all of its exterior walls consist of a shear wall construction, incorporating intermediate foam material.

Figure A.20. *Geometry of Z PLACE Luxury living*

Overall volumetric form (left) and floor geometry (right) of the place luxury living (Own photo and Drawing, 2023)

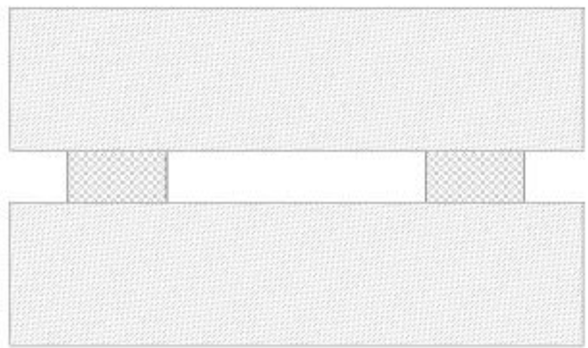
Table A.20. *The details of Z PLACE Luxury living*

Main variables	Sub variables		Number of stories	22
Geometry	**Shape**		Floor shape	Rectangular
			Façade shape	Rectangular
			Roof shape	Rectangular
	Size	Floor size	Maximum length of floor (m)	65
			Maximum width of floor (m)	24
			Maximum thickness of floor (cm)	18
		Façade size	Maximum length of façade or exterior wall (m)	65
			Max. height of façade (m)	3.6
			Maximum thickness of façade (mm)	450
		Roof size	Maximum length of roof (m)	65
			Maximum width of roof (m)	24
			Max height or thickness of roof (cm)	18
	Form		Form of roof	No form
			Form of building	Rectangular prism
Construction method			Floor construction method	Solid Slab
			Façade construction method	Shear wall
			Roof construction method	Solid slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	Concrete and Steel rebar
			Roof construction material	Concrete and Steel rebar

21. Noah Real estate – Centrum building

The Noah Real Estate building features a rectilinear floor plan and roof design, complemented by a rectangular façade. Furthermore, the overall volumetric shape of the building can be described as a rectilinear prism. This architectural form is achieved through the consistent use of similar rectilinear floor and roof geometries, along with a rectangular-shaped façade.

Figure A.21. *Geometry of Centrum building*



Overall volumetric form (left) and floor geometry (right) of Centrum building of Noah Real estate – ATLAS (Own photo and Drawing, 2023)

Table A.21. *The details of Noah Real estate – Centrum building*

Main variables	Sub variables		Number of stories	22
Geometry	**Shape**		Floor shape	Rectilinear
			Façade shape	Rectangular
			Roof shape	Rectilinear
	Size	Floor size	Maximum length of floor (m)	67
			Maximum width of floor (m)	31
			Maximum thickness of floor (cm)	17
		Façade size	Maximum length of façade or exterior wall (m)	67
			Max. height of façade (m)	3.05
			Maximum thickness of façade (mm)	200
		Roof size	Maximum length of roof (m)	67
			Maximum width of roof (m)	31
			Max height or thickness of roof (cm)	17
	Form		Form of roof	No form
			Form of building	Rectilinear prism
Construction method			Floor construction method	Solid slab
			Façade construction method	Masonry wall
			Roof construction method	Solid slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	HCB and Mortar
			Roof construction material	Concrete and Steel rebar

22. Elilta real-estate - Sar Bet

The Elilta real-estate building exhibits an isosceles trapezium floor and roof design, accompanied by a combination of rectangular and curved façade geometry. Moreover, the overall volumetric shape of the building can be described as an isosceles trapezoidal prism. This distinctive architectural form is achieved through the use of similar floor and roof geometries, as well as the incorporation of both rectangular and curved elements in the irregular façade geometry.

Figure A.22. *Geometry of Elilta real estate*

Overall volumetric form (left) and floor geometry (right) of Elilta Real-estate (Own photo and Drawing from the site engineer, 2023)

Table A.22. *The details of Elilta real-estate*

Main variables	Sub variables		Number of stories	**21**
Geometry	**Shape**		Floor shape	Isosceles Trapezium
			Façade shape	Rectangular & curved
			Roof shape	Isosceles Trapezium
	Size	Floor size	Maximum length of floor (m)	64
			Maximum width of floor (m)	58
			Maximum thickness of floor (cm)	25
		Façade size	Maximum length of façade or exterior wall (m)	64
			Max. height of façade (m)	4.4
			Maximum thickness of façade (mm)	200
		Roof size	Maximum length of roof (m)	64
			Maximum width of roof (m)	58
			Max height or thickness of roof (cm)	25
	Form		Form of roof	No form
			Form of building	Isosceles Trapezoidal Prism
Construction method			Floor construction method	Solid, flat plate and Posttensioned slab
			Façade construction method	Masonry wall
			Roof construction method	Flat plate slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	HCB and mortar
			Roof construction material	Concrete and Steel rebar

23. Yadot Tower – Megenagna

The Yadot Tower building possesses a floor and roof design that is characterized by straight lines and right angles, and its façade has a rectangular shape. The overall shape of the building can be described as a rectilinear prism. This particular architectural structure is achieved by employing similar floor and roof designs, as well as a rectangular façade design.

Figure A.23. *Geometry of Yadot tower*

Overall volumetric form (left) and floor geometry (right) of Yadot tower (Arch. Bruk. @ Yadot and own Drawing, 2023)

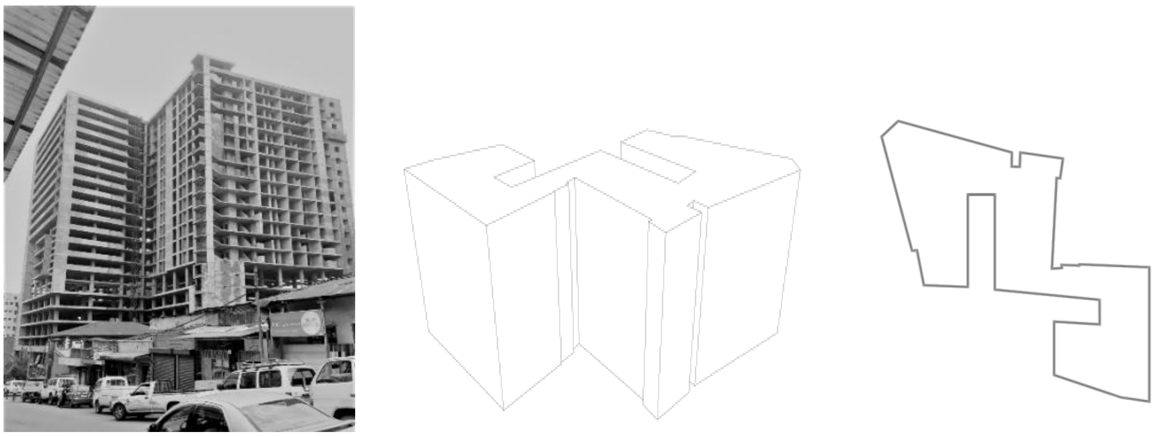
Table A.23. *The details of Yadot Tower*

Main variables	Sub variables		Number of stories	**24**
Geometry	**Shape**		Floor shape	Rectilinear
			Façade shape	Rectangular
			Roof shape	Rectilinear
	Size	Floor size	Maximum length of floor (m)	51
			Maximum width of floor (m)	24
			Maximum thickness of floor (cm)	17
		Façade size	Maximum length of façade or exterior wall (m)	51
			Max. height of façade (m)	3.4
			Maximum thickness of façade (mm)	200
		Roof size	Maximum length of roof (m)	51
			Maximum width of roof (m)	24
			Max height or thickness of roof (cm)	160
	Form		Form of roof	Hip and Flat
			Form of building	Rectilinear prism
Construction method			Floor construction method	Solid slab
			Façade construction method	Curtain and Masonry wall
			Roof construction method	Solid slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	Glass, aluminum, Mortar and HCB
			Roof construction material	Concrete and Steel rebar

24. Gong Real estate – Piazza

The Gong Real Estate building features an irregular polygon as its floor and roof geometry, while its façade is rectangular in shape. The building's overall form can be described as that of an irregular polygonal prism. This distinctive architectural design is achieved by maintaining consistent floor and roof geometries, combined with a rectangular façade shape.

Figure A.24. *Geometry of Gong real estate*



Overall volumetric form (left) and floor geometry (right) of Gong realestate building (Own photo and floor plan illustration, 2023)

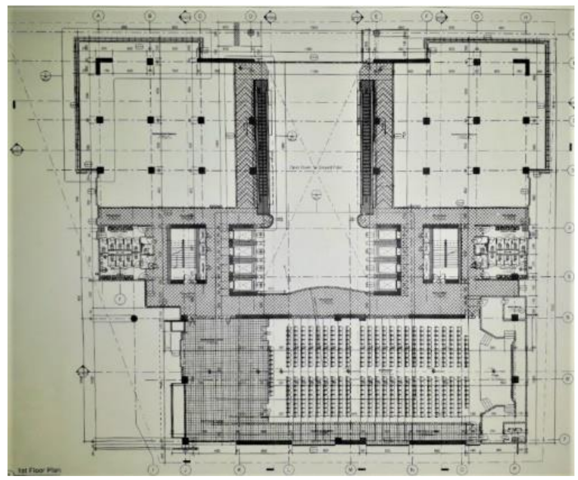
Table A.24. *The details of Gong Real estate*

Main variables	Sub variables		Number of stories	**20**
Geometry	**Shape**		Floor shape	Irregular polygon
			Façade shape	Rectangular
			Roof shape	Irregular polygon
	Size	Floor size	Maximum length of floor (m)	67
			Maximum width of floor (m)	63
			Maximum thickness of floor (cm)	25
		Façade size	Maximum length of façade or exterior wall (m)	67
			Max. height of façade (m)	3.15
			Maximum thickness of façade (mm)	200
		Roof size	Maximum length of roof (m)	67
			Maximum width of roof (m)	63
			Max height or thickness of roof (cm)	25
	Form		Form of roof	No form
			Form of building	Irregular polygonal prism
Construction method			Floor construction method	Flat plate slab
			Façade construction method	Masonry wall
			Roof construction method	Flat plate slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	Mortar and HCB
			Roof construction material	Concrete and Steel rebar

25. Mahiberawi Wastna Building – Piazza

The Mahiberawi Wastna Building exhibits a floor and roof design that follows straight lines and right angles, while its façade takes on a rectangular shape. Moreover, the overall volumetric shape of the building can be described as a rectilinear prism. This particular architectural form is achieved through the implementation of similar floor and roof designs, as well as a rectangular façade design.

Figure A.25. *Geometry of Mahiberawi wastna building*



Overall volumetric form (left) and floor geometry (right) of Mahiberawi Wastna Building (Own photo and resident Eng. Gebyhu – YACAE, 2023)

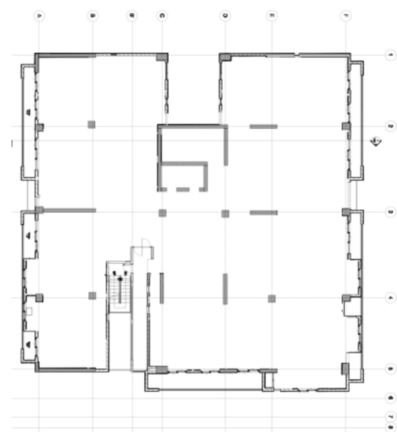
Table A.25. *The details of Mahiberawi Wastna Building*

Main variables	Sub variables		Number of stories	**24**
Geometry	**Shape**		Floor shape	Rectilinear
			Façade shape	Rectangular
			Roof shape	Rectilinear
	Size	Floor size	Maximum length of floor (m)	54
			Maximum width of floor (m)	42
			Maximum thickness of floor (cm)	30
		Façade size	Maximum length of façade or exterior wall (m)	54
			Max. height of façade (m)	3.6
			Maximum thickness of façade (mm)	24
		Roof size	Maximum length of roof (m)	54
			Maximum width of roof (m)	42
			Max height or thickness of roof (cm)	1
	Form		Form of roof	No form
			Form of building	Rectilinear prism
Construction method			Floor construction method	Flat plate slab
			Façade construction method	Curtain, Shear and Masonry wall
			Roof construction method	Waffle slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	Glass, Aluminum, Mortar, HCB, steel and Concrete
			Roof construction material	Concrete and Steel rebar

26. Betopia properties Building (KAZADIS TOWER) - Saint Uriel

The KAZADIS TOWER features a square-shaped floor and roof, accompanied by a rectangular façade geometry. The overall volumetric structure of the building can be described as a square prism, which is achieved through the consistent use of similar floor and roof geometries, combined with the rectangular shape of the building's façade.

Figure A.26. *Geometry of Kazadis tower*



Overall volumetric form (left) and floor geometry (right) of KAZADIS TOWER (Betopia properties, 2023)**.**

Table A.26. *The details of kazadis tower*

Main variables	Sub variables		Number of stories	**21**
Geometry	**Shape**		Floor shape	Square
			Façade shape	Rectangular
			Roof shape	Square
	Size	Floor size	Maximum length of floor (m)	29
			Maximum width of floor (m)	29
			Maximum thickness of floor (cm)	20
		Façade size	Maximum length of façade or exterior wall (m)	29
			Max. height of façade (m)	3.06
			Maximum thickness of façade (mm)	200
		Roof size	Maximum length of roof (m)	29
			Maximum width of roof (m)	29
			Max height or thickness of roof (cm)	200
	Form		Form of roof	Gable and Flat shape
			Form of building	Square prism
Construction method			Floor construction method	Post Tension flat plate Slab
			Façade construction method	Masonry wall
			Roof construction method	Post Tension flat plate Slab and steel truss with EGA
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	HCB and Mortar
			Roof construction material	Concrete, Steel Rebar, sheet and members

27. Amdeyhon building - Around AU

The Amdeyhon building features an irregular polygonal shape for both its floors and roof, giving it the appearance of a rectangle with a rectangular façade. Furthermore, the overall volume of the building can be described as an irregular polygonal prism. This unique architectural form is a result of the consistent floor and roof geometry, combined with the rectangular façade shape.

Figure A.27. *Geometry of Z Amdeyhon building*

The Amdeyhon building's overall volumetric shape (on the left) and floor layout (on the right) 3D rendering YACAE and own photo and floor plan illustration, 2023).

Table A.27. *The details of Amdeyhon building*

Main variables	Sub variables		Number of stories	**20**
Geometry	**Shape**		Floor shape	Irregular polygon
			Façade shape	Rectangular
			Roof shape	Irregular polygon
	Size	Floor size	Maximum length of floor (m)	36
			Maximum width of floor (m)	22
			Maximum thickness of floor (cm)	18
		Façade size	Maximum length of façade or exterior wall (m)	36
			Max. height of façade (m)	3.4
			Maximum thickness of façade (mm)	200
		Roof size	Maximum length of roof (m)	36
			Maximum width of roof (m)	22
			Max height or thickness of roof (cm)	18
	Form		Form of roof	No form
			Form of building	Irregular polygonal prism
Construction method			Floor construction method	Solid Slab
			Façade construction method	Curtain and masonry wall
			Roof construction method	Solid slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	Glass, Aluminum, HCB and Mortar
			Roof construction material	Concrete and Steel Rebar

28. Noah real estate - Aware site

The Noah real estate company constructs Abware site building that feature straight lines in both their floors and roofs, as well as rectangular facades. The building as a whole takes the shape of a rectangular prism due to the consistent use of these rectilinear elements in the floors, roofs, and facades. This building design is achieved by employing similar floor and roof geometries, along with rectangular facades.

Figure A.28. *Geometry of Noah realestate aware*

Noah realestate Aware site building's overall volumetric shape (on the left) and floor layout (on the right) - (Own photo and floor plan from site engineers, 2023)

Table A.28. *The details of Noah real estate - Aware site*

Main variables	Sub variables		Number of stories	**20**
Geometry	**Shape**		Floor shape	Rectilinear
			Façade shape	Rectangular
			Roof shape	Rectilinear
	Size	Floor size	Maximum length of floor (m)	49
			Maximum width of floor (m)	36
			Maximum thickness of floor (cm)	16
		Façade size	Maximum length of façade or exterior wall (m)	49
			Max. height of façade (m)	3.24
			Maximum thickness of façade (mm)	200
		Roof size	Maximum length of roof (m)	49
			Maximum width of roof (m)	36
			Max height or thickness of roof (cm)	16
	Form		Form of roof	No form
			Form of building	Rectilinear prism
Construction method			Floor construction method	Solid slab
			Façade construction method	Masonry wall
			Roof construction method	Solid slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	HCB and Mortar
			Roof construction material	Concrete and Steel Rebar

29. Century real estate – Bole Brass site

The Century real estate building, located close to Bole Brass, features a floor and roof layout that adopts a rectilinear shape, accompanied by rectangular facades. The building's overall volumetric structure can be characterized as a rectangular prism. This geometric shape is achieved by employing matching floor and roof designs, along with rectangular facades.

Figure A.29. *Geometry of Century realestate bole brass*

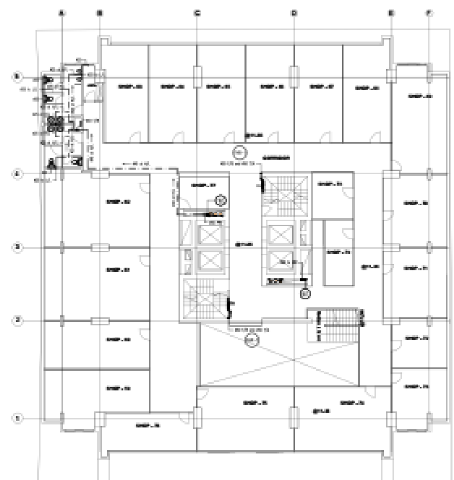


Fig. Overall volumetric form (left) and floor geometry (right) of Century real estate – Bole Ras building (Own photo and Century realestate engineer, 2023)**.**

Table A.29. *The details of Century real estate – Bole Brass site*

Main variables	Sub variables		Number of stories	**20**
Geometry	**Shape**		Floor shape	Rectilinear
			Façade shape	Rectangular
			Roof shape	Rectilinear
	Size	Floor size	Maximum length of floor (m)	35
			Maximum width of floor (m)	32
			Maximum thickness of floor (cm)	26
		Façade size	Maximum length of façade or exterior wall (m)	35
			Max. height of façade (m)	3.2
			Maximum thickness of façade (mm)	200
		Roof size	Maximum length of roof (m)	35
			Maximum width of roof (m)	32
			Max height or thickness of roof (cm)	26
	Form		Form of roof	No form
			Form of building	Rectilinear prism
Construction method			Floor construction method	Flat plate slab
			Façade construction method	Masonry wall
			Roof construction method	Flat plate slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	HCB and Mortar
			Roof construction material	Concrete and Steel Rebar

30. Century real estate - Bole Medhanialem

The Century real estate building, situated near Bole Medhanialem, possesses a floor and roof design that follows a rectangular shape, along with rectangular facades. The building's overall volumetric structure can be described as a rectangular prism. This geometric form is achieved through the use of similar floor and roof geometries, as well as rectangular facades.

Figure A.30. *Geometry of century realestate bole medhanialem*

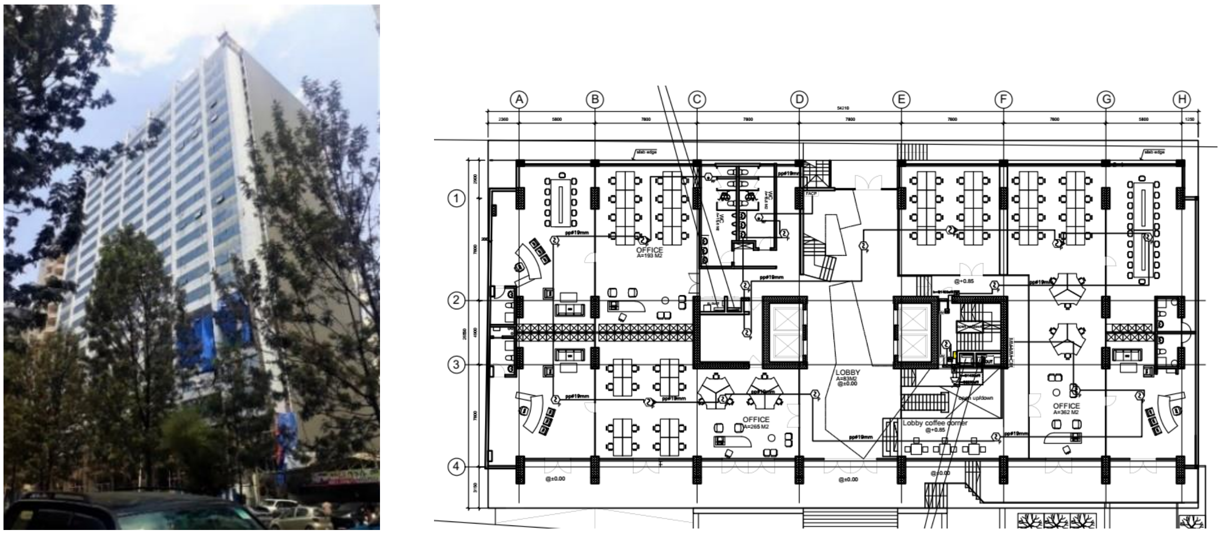


Fig. Overall volumetric form (left) and floor geometry (right) of Century real estate – Bole Atlas building (Own photo and century realestate engineering department, 2023)**.**

Table A.30. *The details of Century real estate – Bole Medhanialem*

Main variables	Sub variables		Number of stories	**19**
Geometry	**Shape**		Floor shape	Rectangular
			Façade shape	Rectangular
			Roof shape	Rectangular
	Size	Floor size	Maximum length of floor (m)	51
			Maximum width of floor (m)	25
			Maximum thickness of floor (cm)	25
		Façade size	Maximum length of façade or exterior wall (m)	51
			Max. height of façade (m)	3.23
			Maximum thickness of façade (mm)	24.38
		Roof size	Maximum length of roof (m)	51
			Maximum width of roof (m)	25
			Max height or thickness of roof (cm)	25
	Form		Form of roof	No form
			Form of building	Rectangular prism
Construction method			Floor construction method	Flat plate slab
			Façade construction method	Curtain and Masonry wall
			Roof construction method	Flat plate slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	Glass, Aluminum HCB and Mortar
			Roof construction material	Concrete and Steel Rebar

31. Edge plaza - Bole to 22 road

The Edge Plaza building is located in close proximity to the Adey Abeba stadium, specifically along the Bole to 22 road. Showcases an unconventional layout and design. Both the floors and roof exhibit irregular shapes, and the building's façade features a combination of rectangular and horizontally curved walls, giving it an irregular appearance. The overall structure of the building can be described as an irregular-shaped prism, which is achieved by combining the similar irregular floor and roof geometry with the distinctive façade design.

Figure A.31. *Geometry of Edge plaza*

Fig. Edge Plaza – Bole to 22 road (Own photo and floor plan illustration, 2023): Overall form (left) and floor geometry (right) respectively.

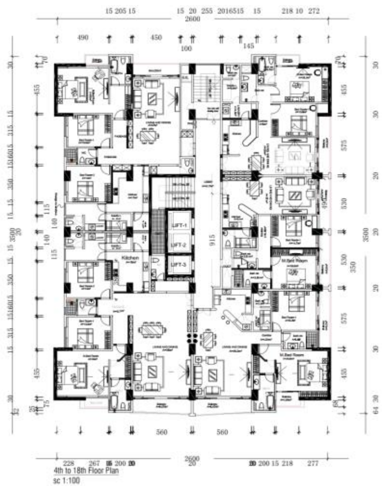
Table A.31. *The details of Edge plaza*

Main variables	Sub variables		Number of stories	**20**
Geometry	**Shape**		Floor shape	Irregular shape
			Façade shape	Irregular shape
			Roof shape	Irregular shape
	Size	Floor size	Maximum length of floor (m)	42
			Maximum width of floor (m)	28
			Maximum thickness of floor (cm)	20
		Façade size	Maximum length of façade or exterior wall (m)	42
			Max. height of façade (m)	3.2
			Maximum thickness of façade (mm)	200
		Roof size	Maximum length of roof (m)	42
			Maximum width of roof (m)	28
			Max height or thickness of roof (cm)	20
	Form		Form of roof	Flat shape and domical form
			Form of building	Irregular shaped prism
Construction method			Floor construction method	Flat plate slab
			Façade construction method	Masonry wall
			Roof construction method	Flat plate slab and concrete dome
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	HCB and Mortar
			Roof construction material	Concrete and Steel Rebar

32. Addis - life realestate Apartment - AU

The Addis - life real estate Apartment building, situated in front of the African Union, features a straightforward layout and design. Both the floors and roof have a rectilinear shape, and the building's exterior is a rectangular in appearance. The overall structure of the building resembles a rectilinear prism, which is achieved by combining the similar rectilinear floor and roof geometry with the rectangular façade design.

Figure A.32. *Geometry of Addis life realestate apartment*



Addis - life realestate – in front of African union (Own photo and floor plan from the realestate engineering department, 2023): Overall form (left) and floor geometry (right) respectively.

Table A.32. *The details of Addis - life realestate Apartment -AU*

Main variables	Sub variables		Number of stories	**20**
Geometry	**Shape**		Floor shape	Rectilinear
			Façade shape	Rectangular
			Roof shape	Rectilinear
	Size	Floor size	Maximum length of floor (m)	35
			Maximum width of floor (m)	27
			Maximum thickness of floor (cm)	15
		Façade size	Maximum length of façade or exterior wall (m)	35
			Max. height of façade (m)	3.3
			Maximum thickness of façade (mm)	200
		Roof size	Maximum length of roof (m)	35
			Maximum width of roof (m)	27
			Max height or thickness of roof (cm)	15
	Form		Form of roof	No form
			Form of building	Rectilinear prism
Construction method			Floor construction method	Solid slab
			Façade construction method	Masonry wall
			Roof construction method	Solid slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	HCB and Mortar
			Roof construction material	Concrete and Steel Rebar

33. Noah Eagle points – Adjacent to እግዚአብሔር አብ ቤተ ክርስቲያን

The Noah Eagle points building, possesses a floor and roof design that follows a rectilinear shape, along with rectangular facades. The building's overall volumetric structure can be described as a rectilinear prism. This geometric form is achieved through the application of similar floor and roof geometries, as well as rectangular facades.

Figure A.33. *Geometry of Noah eagle points*

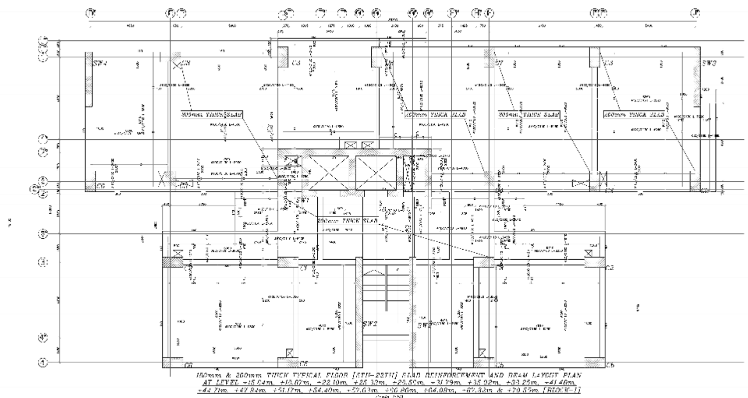


Fig. Overall volumetric form (left) and floor geometry (right) of Noah Eagle points building (Own photo and floor plan from Noah realestate site engineer, 2023) – 6 identical blocks.

Table A.33. *The details of Noah Eagle points*

Main variables	Sub variables		Number of stories	**23**
Geometry	**Shape**		Floor shape	Rectilinear
			Façade shape	Rectangular
			Roof shape	Rectilinear
	Size	Floor size	Maximum length of floor (m)	35
			Maximum width of floor (m)	18.7
			Maximum thickness of floor (cm)	20
		Façade size	Maximum length of façade or exterior wall (m)	35
			Max. height of façade (m)	3.23
			Maximum thickness of façade (mm)	150
		Roof size	Maximum length of roof (m)	35
			Maximum width of roof (m)	18.7
			Max height or thickness of roof (cm)	20
	Form		Form of roof	No form
			Form of building	Rectilinear prism
Construction method			Floor construction method	Solid slab
			Façade construction method	Masonry wall
			Roof construction method	Solid slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	HCB and Mortar
			Roof construction material	Concrete and Steel Rebar

34. Noah La Gare high-rise building

Figure A.34. *Noah La Gare High-rise building (own photo and floor plan illustration, 2023)*

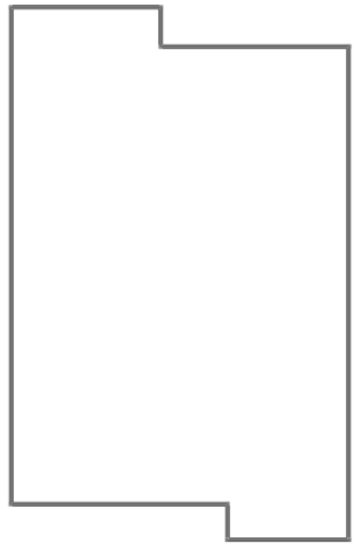


Table A.34. *The details of Noah La Gare high-rise building*

Main variables	Sub variables		Number of stories	**35**
Geometry	**Shape**		Floor shape	Rectilinear
			Façade shape	Rectangular
			Roof shape	Rectilinear
	Size	Floor size	Maximum length of floor (m)	51
			Maximum width of floor (m)	33
			Maximum thickness of floor (cm)	18
		Façade size	Maximum length of façade or exterior wall (m)	54
			Max. height of façade (m)	3.74
			Maximum thickness of façade (mm)	24
		Roof size	Maximum length of roof (m)	51
			Maximum width of roof (m)	33
			Max height or thickness of roof (cm)	12
	Form		Form of roof	No form
			Form of building	Rectilinear prism
Construction method			Floor construction method	Solid and flat plate slab
			Façade construction method	Curtain wall
			Roof construction method	Solid slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	Glass and aluminum
			Roof construction material	Concrete and Steel Rebar

35. Noah Gibson Apartment

Figure A.35. *Noah Gibson Apartment (own photo and floor plan illustration, 2023)*

Table A.35. *The details of Noah Gibson Apartment*

Main variables	Sub variables		Number of stories	**22**
Geometry	**Shape**		Floor shape	Acute Trapezium
			Façade shape	Rectangular
			Roof shape	Acute Trapezium
	Size	Floor size	Maximum length of floor (m)	70.5
			Maximum width of floor (m)	33
			Maximum thickness of floor (cm)	22
		Façade size	Maximum length of façade or exterior wall (m)	70.5
			Max. height of façade (m)	3.2
			Maximum thickness of façade (mm)	200
		Roof size	Maximum length of roof (m)	70.5
			Maximum width of roof (m)	33
			Max height or thickness of roof (cm)	22
	Form		Form of roof	No form
			Form of building	Acute Trapezoidal prism
Construction method			Floor construction method	Solid slab
			Façade construction method	Masonry wall
			Roof construction method	Solid slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	HCB and Mortar
			Roof construction material	Concrete and Steel Rebar

36. Judges apartment – Megenagna

Figure A.36. *Geometry of Judges Apartment*

The Judges apartment building, situated in the vicinity of Megenagna, features a straightforward layout and design. Both the floors and roof have a rectilinear shape, and the building's façade is rectangular in appearance. The overall structure of the building can be described as a rectilinear prism, achieved by combining the similar rectilinear floor and roof geometry with the rectangular-shaped façade design.

Fig. Overall volumetric form (left) and floor geometry (right) of Judges apartment building (Own photo and floor plan from site engineers, 2023) – 4- identical blocks.

Table A.36. *The details of Judges apartment – Megenagna*

Main variables	Sub variables		Number of stories	**18**
Geometry	**Shape**		Floor shape	Rectilinear
			Façade shape	Rectangular
			Roof shape	Flat Rectilinear
	Size	Floor size	Maximum length of floor (m)	25
			Maximum width of floor (m)	24
			Maximum thickness of floor (cm)	15
		Façade size	Maximum length of façade or exterior wall (m)	25
			Max. height of façade (m)	3.0
			Maximum thickness of façade (mm)	200
		Roof size	Maximum length of roof (m)	25
			Maximum width of roof (m)	24
			Max height or thickness of roof (cm)	15
	Form		Form of roof	No form
			Form of building	Rectilinear prism
Construction method			Floor construction method	Solid slab
			Façade construction method	Masonry wall
			Roof construction method	Solid slab
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	HCB and Mortar
			Roof construction material	Concrete and Steel Rebar

37. 40 – 60 Condominium – Megenagna

The 40-60 Condominium building, located near Megenagna, showcases a combination of rectilinear, rectangular and polyhedron design elements. The floors have a straightforward rectilinear shape, while the roof exhibits a complex pitched geometry resembling a polyhedron. The façade of the building features rectangular shapes. Overall, the building's volumetric geometry can be described as a rectilinear prism. This architectural form is achieved by incorporating the rectilinear floor shape, a base polyhedron roof with rectilinear characteristics, and the rectangular-shaped façade geometry.

Figure A.37. *Geometry of 40 – 60 Condominium*

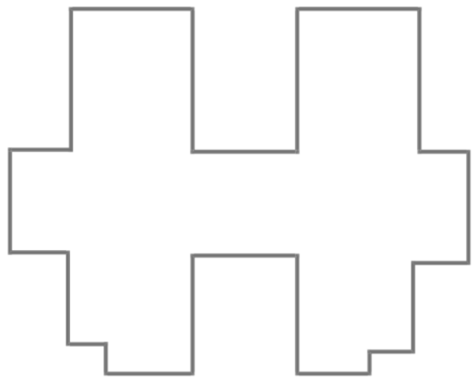


Fig. Overall volumetric form (left) and floor geometry (right) of 40 – 60 Condominium building (Own photo and floor plan illustration, 2023) – 11 Identical blocks.

Table A.37. *The details of 40 – 60 Condominium – Megenagna*

Main variables	Sub variables		Number of stories	**18**
Geometry	**Shape**		Floor shape	Rectilinear
			Façade shape	Rectangular
			Roof shape	Polyhedron
	Size	Floor size	Maximum length of floor (m)	45
			Maximum width of floor (m)	36.5
			Maximum thickness of floor (cm)	20
		Façade size	Maximum length of façade or exterior wall (m)	45
			Max. height of façade (m)	3.0
			Maximum thickness of façade (mm)	200
		Roof size	Maximum length of roof (m)	45
			Maximum width of roof (m)	36.5
			Max height or thickness of roof (cm)	15
	Form		Form of roof	No form
			Form of building	Rectilinear prism
Construction method			Floor construction method	Solid and Ribbed slab
			Façade construction method	Masonry wall
			Roof construction method	Rafter framed pitched roof
Construction material			Floor construction material	Concrete and Steel rebar
			Façade construction material	HCB and Mortar
			Roof construction material	Corrugated metal sheets

38. High lander high end residence - Kazan – chis

Figure A.38. *Geometry of Highlander high end residence*

Fig. Overall volumetric form (left) and floor geometry (right) of High lander high end residence – located at Kazan - chis (Own photo and floor plan illustration, 2023).

Table A.38. *The details of High lander high end residence*

Main variables	Sub variables		Number of stories	**18**
Geometry	**Shape**		Floor shape	Rectangular
			Façade shape	Rectangular
			Roof shape	Rectangular
	Size	Floor size	Maximum length of floor (m)	38
			Maximum width of floor (m)	26.5
			Maximum thickness of floor (cm)	17
		Façade size	Maximum length of façade or exterior wall (m)	38
			Max. height of façade (m)	3.6
			Maximum thickness of façade (mm)	200
		Roof size	Maximum length of roof (m)	38
			Maximum width of roof (m)	26.5
			Max height or thickness of roof (cm)	17
	Form		Form of roof	No form
			Form of building	Rectangular prism
Construction method			Floor construction method	Solid slab
			Façade construction method	Masonry wall
			Roof construction method	Solid slab
Construction material			Floor construction material	Concrete and Steel Rebar
			Façade construction material	HCB and Mortar
			Roof construction material	Concrete and Steel Rebar

39. GIANT EAGLE – Around federal police

Figure A.39. *Geometry of Giant eagle building*

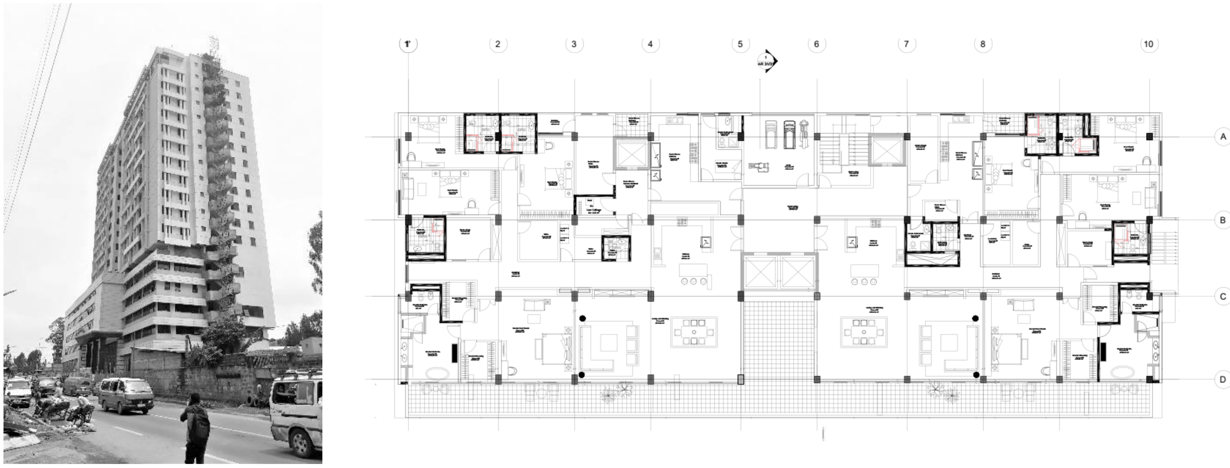


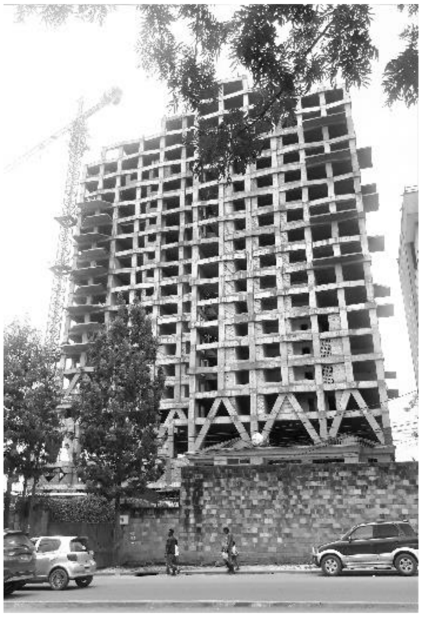
Fig. Overall volumetric form (left) and floor geometry (right) of GIANT EAGLE building – Around federal police (Own photo and floor plans from site Eng. Ephrem, 2023).

Table A.39. *The details of Giant Eagle building*

Main variables	Sub variables		Number of stories	**18**
Geometry	**Shape**		Floor shape	Rectangular
			Façade shape	Rectangular
			Roof shape	Rectangular
	Size	Floor size	Maximum length of floor (m)	56
			Maximum width of floor (m)	23
			Maximum thickness of floor (cm)	30
		Façade size	Maximum length of façade or exterior wall (m)	56
			Max. height of façade (m)	3.4
			Maximum thickness of façade (mm)	200
		Roof size	Maximum length of roof (m)	56
			Maximum width of roof (m)	23
			Max height or thickness of roof (cm)	17
	Form		Form of roof	No form
			Form of building	Rectangular prism
Construction method			Floor construction method	Ribbed slab
			Façade construction method	Masonry wall
			Roof construction method	Solid slab
Construction material			Floor construction material	HCB, Concrete and Steel Rebar
			Façade construction material	HCB and Mortar
			Roof construction material	Concrete and Steel Rebar

40. Rock stone realestate – Balderas

Figure A.40. *Geometry of Rock stone realestate building*



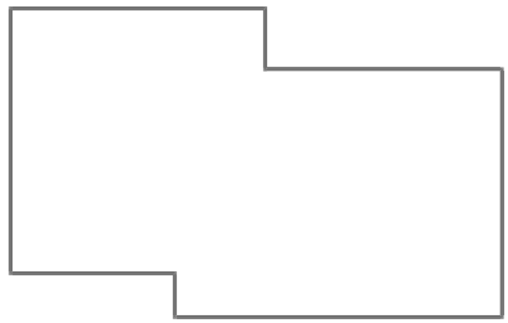


Fig. Overall volumetric form (left) and floor geometry (right) of Rock stone realestate - Balderas (Own photo and floor plan illustration, 2023).

Table A.40. *The details of Rock stone realestate - Balderas*

Main variables	Sub variables		Number of stories	**19**
Geometry	**Shape**		Floor shape	Rectilinear
			Façade shape	Rectangular
			Roof shape	Rectilinear
	Size	Floor size	Maximum length of floor (m)	46
			Maximum width of floor (m)	24
			Maximum thickness of floor (cm)	27.5
		Façade size	Maximum length of façade or exterior wall (m)	46
			Max. height of façade (m)	3.2
			Maximum thickness of façade (mm)	200
		Roof size	Maximum length of roof (m)	46
			Maximum width of roof (m)	24
			Max height or thickness of roof (cm)	27.5
	Form		Form of roof	No form
			Form of building	Rectilinear prism
Construction method			Floor construction method	Flat plate slab
			Façade construction method	Masonry wall
			Roof construction method	Flat plate slab
Construction material			Floor construction material	Concrete and Steel Rebar
			Façade construction material	HCB and Mortar
			Roof construction material	Concrete and Steel Rebar

Appendix A.2 – Survey Questions

The questionnaire questions used in the second research method of the thesis are available at the following link.

- ***https://forms.gle/A7N56aZpCRthQ6yN7***

- 1.0 - . Statistical Models

Note - These models are crucial for understanding the thesis and must be included in the main body. However, due to their length, they are presented separately in the document. The complexity and intensity of the analysis have resulted in the models being large, as the research employs a deep approach to address the research questions. It's important to note that the decision to provide these models separately from the main document is not due to their relevance but rather because they occupy many pages. These models are an integral part of the main body of the research, not supplementary documents.

Appendix B - Statistical models on method 1 (Geometry and construction)

Table B.1. *Multinomial logistic regression to identify the impact of floor geometry on the floor construction method of buildings.*

```
Multinomial logistic regression                 Number of obs     =         40
                                                LR chi2(24)       =      52.70
                                                Prob > chi2       =     0.0006
Log likelihood = -27.735723                     Pseudo R2         =     0.4872
```

Floorconstructionmethod	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Solid_slab	(base outcome)					
Flat_plate_slab						
Floorshape	.0255212	.2700506	0.09	0.925	-.5037682	.5548107
MaxLengthoffloorinm	-.0425117	.0540054	-0.79	0.431	-.1483602	.0633369
MaxWidthoffloorinm	.2003594	.0977764	2.05	0.040	.0087211	.3919977
MaxThicknessoffloorincm	.3135516	.1183386	2.65	0.008	.0816123	.5454909
_cons	-11.44485	4.937786	-2.32	0.020	-21.12273	-1.766966
Solid_and_flat_plate_slab						
Floorshape	-.0352359	.5678997	-0.06	0.951	-1.148299	1.077827
MaxLengthoffloorinm	-.1553976	.1029248	-1.51	0.131	-.3571265	.0463313
MaxWidthoffloorinm	.2371051	.1528821	1.55	0.121	-.0625382	.5367484
MaxThicknessoffloorincm	.5842155	.2724962	2.14	0.032	.0501329	1.118298
_cons	-16.68625	10.20382	-1.64	0.102	-36.68536	3.312867
Ribbed_slab						
Floorshape	.4868312	.5096132	0.96	0.339	-.5119922	1.485655
MaxLengthoffloorinm	.062538	.105073	0.60	0.552	-.1434012	.2684773
MaxWidthoffloorinm	-.2385498	.3739731	-0.64	0.524	-.9715237	.4944241
MaxThicknessoffloorincm	.6139285	.3640342	1.69	0.092	-.0995654	1.327422
_cons	-17.9866	16.71872	-1.08	0.282	-50.75468	14.78148
Solid__flat_plate_and_Posttensio						
Floorshape	39.03786	18454.95	0.00	0.998	-36131.99	36210.07
MaxLengthoffloorinm	-4.374306	4664.099	-0.00	0.999	-9145.84	9137.091
MaxWidthoffloorinm	3.462772	3454.31	0.00	0.999	-6766.86	6773.786
MaxThicknessoffloorincm	.7308575	34076.64	0.00	1.000	-66788.25	66789.71
_cons	-229.8068	907652.8	-0.00	1.000	-1779197	1778737
Post_Tension_flat_plate_Slab						
Floorshape	35.39926	550290.2	0.00	1.000	-1078514	1078584
MaxLengthoffloorinm	-7.057358	93357.15	-0.00	1.000	-182983.7	182969.6
MaxWidthoffloorinm	5.817765	136059.9	0.00	1.000	-266666.6	266678.3
MaxThicknessoffloorincm	-3.424152	249666.2	-0.00	1.000	-489340.1	489333.2
_cons	-83.45146	8661444	-0.00	1.000	-1.70e+07	1.70e+07
Solid_and_ribbed_slab						
Floorshape	-.6144262	1.531017	-0.40	0.688	-3.615164	2.386312
MaxLengthoffloorinm	-.2454056	.3318371	-0.74	0.460	-.8957944	.4049832
MaxWidthoffloorinm	.485154	.4860373	1.00	0.318	-.4674615	1.43777
MaxThicknessoffloorincm	-.0612497	.3284005	-0.19	0.852	-.7049029	.5824036
_cons	-3.855282	7.783072	-0.50	0.620	-19.10982	11.39926

Note: 2 observations completely determined. Standard errors questionable.

Table B.2. *Multinomial logistic regression to identify the impact of floor geometry on the floor construction material of buildings.*

"y.level" – floor construction material	**"term" – floor geometry**	**"estimate"**	**"std. error"**	**"statistic"**	**"p. value"**
" Concrete and Steel Rebar"	"(Intercept)"	-13.0304041591575	14.9299356912943	-0.872770280367353	0.38278830170227
" Concrete and Steel Rebar "	"m1ba$Floorshape"	0.538384696057382	0.476080623633703	1.1308687422482	0.258110341265584
" Concrete and Steel Rebar "	"m1ba$MaxWidthofflooringm"	-0.311662880779922	0.304363772280589	-1.02398152856577	0.305843999586168
" Concrete and Steel Rebar "	"m1ba$MaxLengthoffloorinm"	0.0678331561441959	0.0912164937128068	0.74365011614859	0.45708817549762
" Concrete and Steel Rebar "	"m1ba$MaxThicknessoffloorincm"	0.439345980959099	0.325576916692873	1.34943836136131	0.177196206127701

Table B.3. *Multinomial logistic regression to identify the impact of façade geometry on the façade construction method of buildings.*

Multinomial logistic regression	Number of obs = 39
	LR chi2(24) = 46.53
	Prob > chi2 = 0.0038
Log likelihood = -38.153051	Pseudo R2 = 0.3788

Façadeconstructionmethod	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Curtain_wall						
Façadeshape	.4915885	.6458885	0.76	0.447	-.7743297	1.757507
Max_LengthoffaçadeorWall	-.1077462	.0831795	-1.30	0.195	-.2707749	.0552826
Max_Heightoffaçadeinm	4.481719	2.836415	1.58	0.114	-1.077552	10.04099
MaxThicknesoffaçadeinmm	-.0398606	.0234647	-1.70	0.089	-.0858506	.0061294
_cons	-11.09704	9.531725	-1.16	0.244	-29.77888	7.584795
Curtain__Shear_and_masonry_wall						
Façadeshape	.1612306	.669975	0.24	0.810	-1.151896	1.474357
Max_LengthoffaçadeorWall	-.0254994	.0551936	-0.46	0.644	-.1336768	.082678
Max_Heightoffaçadeinm	5.985895	3.019063	1.98	0.047	.0686401	11.90315
MaxThicknesoffaçadeinmm	-.0999416	.0785714	-1.27	0.203	-.2539386	.0540554
_cons	-17.17458	10.03571	-1.71	0.087	-36.84421	2.49505
Curtain_and_Shear_wall						
Façadeshape	-.6008049	.9695331	-0.62	0.535	-2.501055	1.299445
Max_LengthoffaçadeorWall	-.1257128	.1000344	-1.26	0.209	-.3217765	.070351
Max_Heightoffaçadeinm	4.278195	3.150996	1.36	0.175	-1.897643	10.45403
MaxThicknesoffaçadeinmm	-.1380573	.1260436	-1.10	0.273	-.3850983	.1089836
_cons	-3.102823	11.3791	-0.27	0.785	-25.40544	19.1998
Curtain_and_Masonry_wall						
Façadeshape	.303327	.4796176	0.63	0.527	-.6367062	1.24336
Max_LengthoffaçadeorWall	-.1025446	.0552545	-1.86	0.063	-.2108415	.0057522
Max_Heightoffaçadeinm	2.969254	1.977539	1.50	0.133	-.9066515	6.845159
MaxThicknesoffaçadeinmm	-.0199991	.0082207	-2.43	0.015	-.0361113	-.0038869
_cons	-4.86094	5.423331	-0.90	0.370	-15.49047	5.768594
Masonry_and_Glass_wall						
Façadeshape	-5.682179	4219.738	-0.00	0.999	-8276.216	8264.852
Max_LengthoffaçadeorWall	-.0823524	.1026086	-0.80	0.422	-.2834615	.1187567
Max_Heightoffaçadeinm	-9.35401	8.454985	-1.11	0.269	-25.92548	7.217456
MaxThicknesoffaçadeinmm	.3329401	47.14114	0.01	0.994	-92.062	92.72788
_cons	-12.11735	19333.67	-0.00	0.999	-37905.41	37881.18
Masonry_wall	(base outcome)					
Shear_wall						
Façadeshape	-.6353693	1.749981	-0.36	0.717	-4.065269	2.79453
Max_LengthoffaçadeorWall	.0195772	.0735309	0.27	0.790	-.1245406	.163695
Max_Heightoffaçadeinm	4.719041	4.883284	0.97	0.334	-4.852021	14.2901
MaxThicknesoffaçadeinmm	-.0237195	.0294439	-0.81	0.420	-.0814285	.0339895
_cons	-15.37272	16.84529	-0.91	0.361	-48.38889	17.64345

Table B.4. *Multinomial logistic regression to identify the impact of façade geometry on the façade construction material of buildings.*

```
Multinomial logistic regression                  Number of obs     =         39
                                                 LR chi2(27)       =      56.06
                                                 Prob > chi2       =     0.0008
Log likelihood = -34.294652                      Pseudo R2         =     0.4497
```

façadeconstructionmaterial	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Glass_and_Aluminium						
Façadeshape	.634836	.6824849	0.93	0.352	-.7028098	1.972482
Max_LengthoffaçadeorWall	-.1152161	.084211	-1.37	0.171	-.2802666	.0498345
Max_Heightoffaçadeinm	4.822374	2.886187	1.67	0.095	-.8344493	10.4792
MaxThicknesoffaçadeinmm	-.0417761	.0224892	-1.86	0.063	-.0858541	.002302
_cons	-12.44505	9.742921	-1.28	0.201	-31.54082	6.650729
Glass__aluminium_Mortar_and_HCB						
Façadeshape	.2118705	.4942344	0.43	0.668	-.7568111	1.180552
Max_LengthoffaçadeorWall	-.1111397	.057115	-1.95	0.052	-.223083	.0008036
Max_Heightoffaçadeinm	3.542049	2.03554	1.74	0.082	-.447537	7.531635
MaxThicknesoffaçadeinmm	-.0212326	.0083583	-2.54	0.011	-.0376146	-.0048506
_cons	-5.810303	5.48705	-1.06	0.290	-16.56472	4.944118
Glass__Aluminium__steel_and_Cocr						
Façadeshape	-1.440928	1.522951	-0.95	0.344	-4.425856	1.544001
Max_LengthoffaçadeorWall	-.0774005	.0976755	-0.79	0.428	-.2688411	.11404
Max_Heightoffaçadeinm	.3575833	4.560685	0.08	0.938	-8.581195	9.296361
MaxThicknesoffaçadeinmm	-.1545315	.1621162	-0.95	0.340	-.4722735	.1632104
_cons	10.7679	19.54615	0.55	0.582	-27.54185	49.07766
Glass__Aluminium__Mortar__HCB__s						
Façadeshape	.8569674	.7411065	1.16	0.248	-.5955747	2.30951
Max_LengthoffaçadeorWall	-.0087902	.0602052	-0.15	0.884	-.1267903	.1092099
Max_Heightoffaçadeinm	5.473595	3.080203	1.78	0.076	-.5634908	11.51068
MaxThicknesoffaçadeinmm	-.1247618	.0964807	-1.29	0.196	-.3138606	.064337
_cons	-19.27825	10.72906	-1.80	0.072	-40.30682	1.750317
Glass__Aluminium_plastic__steel						
Façadeshape	-159.2647	20057.52	-0.01	0.994	-39471.28	39152.76
Max_LengthoffaçadeorWall	-33.04351	4150.889	-0.01	0.994	-8168.637	8102.55
Max_Heightoffaçadeinm	360.6313	46059.96	0.01	0.994	-89915.23	90636.49
MaxThicknesoffaçadeinmm	-7.951652	1097.878	-0.01	0.994	-2159.754	2143.851
_cons	634.5378	106878.9	0.01	0.995	-208844.3	210113.4
Glass__HCB_and_Mortar						
Façadeshape	-6.35958	4232.093	-0.00	0.999	-8301.108	8288.389
Max_LengthoffaçadeorWall	-.0822267	.1025745	-0.80	0.423	-.2832691	.1188156
Max_Heightoffaçadeinm	-9.314287	8.465168	-1.10	0.271	-25.90571	7.277137
MaxThicknesoffaçadeinmm	.35911	84.64182	0.00	0.997	-165.5358	166.254
_cons	-14.77564	.	.	.	.	.
HCB_and_Mortar	(base outcome)					
Concrete_and_Steel_Rebar						
Façadeshape	-.5686629	1.841399	-0.31	0.757	-4.177738	3.040412
Max_LengthoffaçadeorWall	.0190029	.0748367	0.25	0.800	-.1276743	.1656802
Max_Heightoffaçadeinm	4.654283	4.969073	0.94	0.349	-5.084921	14.39349
MaxThicknesoffaçadeinmm	-.0232633	.0299266	-0.78	0.437	-.0819184	.0353917
_cons	-15.46102	17.1196	-0.90	0.366	-49.01482	18.09277

Note: 1 observation completely determined. Standard errors questionable.

Table B.5. *Multinomial logistic regression to identify the impact of roof geometry on the construction method of buildings.*

```
Multinomial logistic regression                 Number of obs     =         40
                                                LR chi2(26)       =      99.38
                                                Prob > chi2       =     0.0000
Log likelihood = -8.8931354                     Pseudo R2         =     0.8482

---------------------------------------------------------------------------------------------------
         Roofconstructionmethod |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
--------------------------------+------------------------------------------------------------------
Solid_slab                      |  (base outcome)
--------------------------------+------------------------------------------------------------------
Flat_plate_slab                 |
                      Roofshape |  -.4649794   .3753647    -1.24   0.215    -1.200681     .270722
                MaxLengthofRoof |   .0233866   .0796926     0.29   0.769     -.132808    .1795811
                 MaxWidthofRoof |   .3204684   .1831209     1.75   0.080    -.0384419    .6793787
  MaxheightorthicknessofRoofincm |   .5407514   .2645321     2.04   0.041     .0222781    1.059225
                       Roofform |   -87.5339    2098.63    -0.04   0.967    -4200.773    4025.705
                          _cons |   66.22577   2098.469     0.03   0.975    -4046.698    4179.149
--------------------------------+------------------------------------------------------------------
Light_weight_flat_plate_slab    |
                      Roofshape |  -79.75208    1290450    -0.00   1.000     -2529315     2529156
                MaxLengthofRoof |  -12.64383    1507622    -0.00   1.000     -2954897     2954872
                 MaxWidthofRoof |   17.63733   636688.4     0.00   1.000     -1247869     1247904
  MaxheightorthicknessofRoofincm |   8.125645   377437.2     0.00   1.000    -739755.2    739771.4
                       Roofform |  -750.8565   7.97e+07    -0.00   1.000    -1.56e+08    1.56e+08
                          _cons |   717.1263   3.24e+07     0.00   1.000    -6.36e+07    6.36e+07
--------------------------------+------------------------------------------------------------------
Flat_plate_slab_and_truss       |
                      Roofshape |   183.1419   231.1525     0.79   0.428    -269.9087    636.1925
                MaxLengthofRoof |    -52.211   65.25644    -0.80   0.424    -180.1113    75.68926
                 MaxWidthofRoof |  -41.98625   52.84386    -0.79   0.427    -145.5583    61.58582
  MaxheightorthicknessofRoofincm |   64.38444   80.44109     0.80   0.423    -93.27719    222.0461
                       Roofform |   -7729.96    9645.24    -0.80   0.423    -26634.28    11174.36
                          _cons |   8085.908   10085.42     0.80   0.423    -11681.14    27852.96
--------------------------------+------------------------------------------------------------------
waffle_and_solid_slab           |
                      Roofshape |   179.5794   1.58e+09     0.00   1.000    -3.11e+09    3.11e+09
                MaxLengthofRoof |  -72.05631   3.95e+08    -0.00   1.000    -7.74e+08    7.74e+08
                 MaxWidthofRoof |  -41.41988   8.38e+07    -0.00   1.000    -1.64e+08    1.64e+08
  MaxheightorthicknessofRoofincm |    59.5672   7.52e+07     0.00   1.000    -1.47e+08    1.47e+08
                       Roofform |  -6753.591          .        .       .            .           .
                          _cons |   7890.036          .        .       .            .           .
--------------------------------+------------------------------------------------------------------
Ribbed_slab                     |
                      Roofshape |   284.7439   3.32e+07     0.00   1.000    -6.52e+07    6.52e+07
                MaxLengthofRoof |  -59.06775    3215195    -0.00   1.000     -6301725     6301607
                 MaxWidthofRoof |  -35.11942    9530251    -0.00   1.000    -1.87e+07    1.87e+07
  MaxheightorthicknessofRoofincm |   71.88862   993987.6     0.00   1.000     -1948108     1948252
                       Roofform |  -8398.796          .        .       .            .           .
                          _cons |   7976.629          .        .       .            .           .
--------------------------------+------------------------------------------------------------------
Waffle_Slab                     |
                      Roofshape |   1.823884          .        .       .            .           .
                MaxLengthofRoof |   -.206549    5593738    -0.00   1.000    -1.10e+07    1.10e+07
                 MaxWidthofRoof |    .531727          .        .       .            .           .
  MaxheightorthicknessofRoofincm |   -6.95223   2.93e+08    -0.00   1.000    -5.75e+08    5.75e+08
                       Roofform |   85.46793          .        .       .            .           .
                          _cons |   -60.1406          .        .       .            .           .
--------------------------------+------------------------------------------------------------------
Post_Tension_flat_plate_Slab_and |
                      Roofshape |   63.84269          .        .       .            .           .
                MaxLengthofRoof |  -15.16989    1886158    -0.00   1.000     -3696818     3696787
                 MaxWidthofRoof |   5.114269    2948057     0.00   1.000     -5778081     5778092
  MaxheightorthicknessofRoofincm |  -4.414684   169487.8    -0.00   1.000    -332194.3    332185.5
                       Roofform |   298.5513          .        .       .            .           .
                          _cons |  -265.1524          .        .       .            .           .
--------------------------------+------------------------------------------------------------------
Flat_plate_slab_and_dome        |
                      Roofshape |  -15.12943          .        .       .            .           .
                MaxLengthofRoof |  -5.455542   5.33e+08    -0.00   1.000    -1.04e+09    1.04e+09
                 MaxWidthofRoof |  -1.048262          .        .       .            .           .
  MaxheightorthicknessofRoofincm |  -6.019719          .        .       .            .           .
                       Roofform |   299.2616          .        .       .            .           .
                          _cons |  -33.52089          .        .       .            .           .
--------------------------------+------------------------------------------------------------------
Truss_10                        |
                      Roofshape |   71.27689          .        .       .            .           .
                MaxLengthofRoof |  -6.967739   1.37e+07    -0.00   1.000    -2.68e+07    2.68e+07
                 MaxWidthofRoof |   5.259671    9218948     0.00   1.000    -1.81e+07    1.81e+07
  MaxheightorthicknessofRoofincm |  -7.746591   4.73e+07    -0.00   1.000    -9.27e+07    9.27e+07
                       Roofform |  -173.2877          .        .       .            .           .
                          _cons |  -89.45758          .        .       .            .           .
---------------------------------------------------------------------------------------------------
Note: 7 observations completely determined.  Standard errors questionable.
```

Table B.6. *Multinomial logistic regression to identify the impact of roof geometry on the roof construction material of buildings.*

```
Multinomial logistic regression                 Number of obs     =         40
                                                LR chi2(15)       =      38.69
                                                Prob > chi2       =     0.0007
Log likelihood = -10.053815                     Pseudo R2         =     0.6580
```

Roofconstructionmaterial	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Concrete_and_Steel_Rebar	(base outcome)					
Concrete__Steel_Rebar__corrugate						
Roofshape	.010167	.8398076	0.01	0.990	-1.635826	1.65616
MaxLengthofRoof	-.1160951	.1891508	-0.61	0.539	-.4868238	.2546336
MaxWidthofRoof	-.1883092	.1822909	-1.03	0.302	-.5455928	.1689744
MaxheightorthicknessofRoofincm	.1460199	.2417967	0.60	0.546	-.3278929	.6199327
Roofform	-8.22739	9.59357	-0.86	0.391	-27.03044	10.57566
_cons	10.18969	.	.	.	.	.
HCB__Concrete_and_Steel_Rebar						
Roofshape	.3547113	.4049155	0.88	0.381	-.4389085	1.148331
MaxLengthofRoof	.0098817	.0475039	0.21	0.835	-.0832243	.1029876
MaxWidthofRoof	-.1496252	.1291651	-1.16	0.247	-.4027841	.1035337
MaxheightorthicknessofRoofincm	-.0197119	.1477898	-0.13	0.894	-.3093746	.2699508
Roofform	-5.60689	6647.6	-0.00	0.999	-13034.66	13023.45
_cons	5.02147	6647.602	0.00	0.999	-13024.04	13034.08
Concrete__Glass_and_Steel_Rebar						
Roofshape	-.3156755	.	.	.	.	.
MaxLengthofRoof	-.3214855	.	.	.	.	.
MaxWidthofRoof	1.216584	.	.	.	.	.
MaxheightorthicknessofRoofincm	-7.66538	.	.	.	.	.
Roofform	9.673991	.	.	.	.	.
_cons	5.242797	.	.	.	.	.
_eq_5						
Roofshape	-.5138051	2.17e+08	-0.00	1.000	-4.26e+08	4.26e+08
MaxLengthofRoof	-.1951457	5.76e+07	-0.00	1.000	-1.13e+08	1.13e+08
MaxWidthofRoof	-.2935918	6.99e+07	-0.00	1.000	-1.37e+08	1.37e+08
MaxheightorthicknessofRoofincm	.6655612	9.12e+07	0.00	1.000	-1.79e+08	1.79e+08
Roofform	1.458252	2.37e+09	0.00	1.000	-4.64e+09	4.64e+09
_cons	-45.71586	.	.	.	.	.
Corrugated_metal_sheets_and_stee						
Roofshape	17.36791	6531892	0.00	1.000	-1.28e+07	1.28e+07
MaxLengthofRoof	-1.748538	1787987	-0.00	1.000	-3504392	3504388
MaxWidthofRoof	1.085556	1710733	0.00	1.000	-3352973	3352976
MaxheightorthicknessofRoofincm	-1.255903	5519396	-0.00	1.000	-1.08e+07	1.08e+07
Roofform	-23.81502	.	.	.	.	.
_cons	-69.59791	.	.	.	.	.

Note: 5 observations completely determined. Standard errors questionable.

Table B.7. *Multinomial logistic regression to identify the impact of building's volumetric geometry on the floor construction method of buildings.*

Multinomial logistic regression	Number of obs = 40
	LR chi2(24) = 54.61
	Prob > chi2 = 0.0004
Log likelihood = -26.780376	Pseudo R2 = 0.5049

Floorconstructionmethod	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Solid_slab	(base outcome)					
Flat_plate_slab						
Buildingform	-.0738349	.209792	-0.35	0.725	-.4850197	.3373498
Buildingheightinm	-.0038614	.0154213	-0.25	0.802	-.0340867	.0263638
Max_Buildingwidthinm	.1306687	.0635596	2.06	0.040	.0060941	.2552433
Max_Buildinglengthinm	-.0284295	.0378803	-0.75	0.453	-.1026735	.0458145
_cons	-1.925227	2.406769	-0.80	0.424	-6.642408	2.791953
Solid_and_flat_plate_slab						
Buildingform	-.0687887	.4300124	-0.16	0.873	-.9115976	.7740201
Buildingheightinm	.0327644	.0332043	0.99	0.324	-.0323148	.0978436
Max_Buildingwidthinm	.140337	.1485898	0.94	0.345	-.1508936	.4315676
Max_Buildinglengthinm	-.1991159	.1381693	-1.44	0.150	-.4699226	.0716909
_cons	-.0720969	5.085993	-0.01	0.989	-10.04046	9.896266
Ribbed_slab						
Buildingform	21.2527	5420.433	0.00	0.997	-10602.6	10645.11
Buildingheightinm	-6.109115	1267.109	-0.00	0.996	-2489.598	2477.379
Max_Buildingwidthinm	-20.1825	4447.752	-0.00	0.996	-8737.616	8697.251
Max_Buildinglengthinm	-.0723798	554.1988	-0.00	1.000	-1086.282	1086.137
_cons	695.6639	147952.3	0.00	0.996	-289285.5	290676.9
Solid__flat_plate_and_Posttensio						
Buildingform	13.9036	7842.629	0.00	0.999	-15357.37	15385.17
Buildingheightinm	.5425943	587.2239	0.00	0.999	-1150.395	1151.48
Max_Buildingwidthinm	2.078813	2504.158	0.00	0.999	-4905.981	4910.139
Max_Buildinglengthinm	-1.185588	2719.13	-0.00	1.000	-5330.582	5328.211
_cons	-198.718	109794.3	-0.00	0.999	-215391.6	214994.2
Post_Tension_flat_plate_Slab						
Buildingform	8.147476	19566.22	0.00	1.000	-38340.95	38357.24
Buildingheightinm	-.4408082	1376.268	-0.00	1.000	-2697.877	2696.995
Max_Buildingwidthinm	1.917994	3891.863	0.00	1.000	-7625.994	7629.83
Max_Buildinglengthinm	-2.153659	4293.005	-0.00	1.000	-8416.29	8411.982
_cons	-24.73307	271998.1	-0.00	1.000	-533131.2	533081.8
Solid_and_ribbed_slab						
Buildingform	-56.26346	107750.3	-0.00	1.000	-211242.9	211130.4
Buildingheightinm	-3.256896	9709.341	-0.00	1.000	-19033.21	19026.7
Max_Buildingwidthinm	8.290418	19745.36	0.00	1.000	-38691.9	38708.48
Max_Buildinglengthinm	-2.749475	13613.99	-0.00	1.000	-26685.69	26680.19
_cons	241.929	256120.2	0.00	0.999	-501744.4	502228.2

Note: 5 observations completely determined. Standard errors questionable.

Table B.8. *Multinomial logistic regression to identify the impact of building's volumetric geometry on the floor construction material of buildings.*

Multinomial logistic regression — Number of obs = 40; LR chi2(4) = 15.88; Prob > chi2 = 0.0032; Pseudo R2 = 0.9999

Log likelihood = -.00055711

Floorconstructionmaterial	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Concrete_and_Steel_Rebar						
Buildingform	-15.59154	825.131	-0.02	0.985	-1632.819	1601.635
Buildingheightinm	3.554474	57.40787	0.06	0.951	-108.9629	116.0718
Max_Buildingwidthinm	12.31729	195.4442	0.06	0.950	-370.7463	395.3809
Max_Buildinglengthinm	.3883352	68.17164	0.01	0.995	-133.2256	134.0023
_cons	-409.9429	5115.964	-0.08	0.936	-10437.05	9617.161
HCB__Concrete_and_Steel_Rebar	(base outcome)					

Table B.9. *Multinomial logistic regression to identify the impact of building's volumetric geometry on the façade construction method of buildings.*

Multinomial logistic regression	Number of obs	=	40
	LR chi2(24)	=	47.43
	Prob > chi2	=	0.0030
Log likelihood = -40.127145	Pseudo R2	=	0.3715

Façadeconstructionmethod	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Curtain_wall						
Buildingform	-.839504	.5398661	-1.56	0.120	-1.897622	.2186142
Buildingheightinm	.1693638	.0568798	2.98	0.003	.0578815	.280846
Max_Buildingwidthinm	.073307	.1292457	0.57	0.571	-.1800099	.326624
Max_Buildinglengthinm	-.1009292	.105634	-0.96	0.339	-.307968	.1061097
_cons	-8.343877	5.287179	-1.58	0.115	-18.70656	2.018803
Curtain__Shear_and_masonry_wall						
Buildingform	-.8342524	.491791	-1.70	0.090	-1.798145	.1296403
Buildingheightinm	.1508226	.0540113	2.79	0.005	.0449623	.2566829
Max_Buildingwidthinm	.06622	.0902753	0.73	0.463	-.1107163	.2431562
Max_Buildinglengthinm	.0139987	.0858695	0.16	0.871	-.1543025	.1822999
_cons	-11.57096	4.975191	-2.33	0.020	-21.32216	-1.819769
Curtain_and_Shear_wall						
Buildingform	-.5602741	.4974688	-1.13	0.260	-1.535295	.4147468
Buildingheightinm	.1298769	.0567859	2.29	0.022	.0185786	.2411752
Max_Buildingwidthinm	.0599002	.1109187	0.54	0.589	-.1574964	.2772968
Max_Buildinglengthinm	-.0893414	.0905771	-0.99	0.324	-.2668692	.0881865
_cons	-6.067574	4.558019	-1.33	0.183	-15.00113	2.865979
Curtain_and_Masonry_wall						
Buildingform	-.1420896	.2876701	-0.49	0.621	-.7059126	.4217333
Buildingheightinm	.1268349	.0519975	2.44	0.015	.0249218	.2287481
Max_Buildingwidthinm	-.1910337	.1168593	-1.63	0.102	-.4200737	.0380062
Max_Buildinglengthinm	-.0667788	.0457245	-1.46	0.144	-.1563972	.0228395
_cons	-.6769733	4.624827	-0.15	0.884	-9.741468	8.387521
Masonry_and_Glass_wall						
Buildingform	.6667278	.8540754	0.78	0.435	-1.007229	2.340685
Buildingheightinm	-.1087311	.1559381	-0.70	0.486	-.4143642	.196902
Max_Buildingwidthinm	-.7396516	.6326264	-1.17	0.242	-1.979576	.5002733
Max_Buildinglengthinm	-.0523752	.0910213	-0.58	0.565	-.2307736	.1260232
_cons	20.93705	19.2681	1.09	0.277	-16.82773	58.70183
Masonry_wall	(base outcome)					
Shear_wall						
Buildingform	.4794191	.8301739	0.58	0.564	-1.147692	2.10653
Buildingheightinm	.1161654	.0994759	1.17	0.243	-.0788037	.3111346
Max_Buildingwidthinm	-.1472933	.2430313	-0.61	0.544	-.6236258	.3290392
Max_Buildinglengthinm	-.0064327	.0734601	-0.09	0.930	-.150412	.1375465
_cons	-10.32899	10.16351	-1.02	0.309	-30.24909	9.591118

Table B.10. *Multinomial logistic regression to identify the impact of building's volumetric geometry on the façade construction material of buildings.*

```
Multinomial logistic regression                 Number of obs     =         40
                                                LR chi2(28)       =      52.59
                                                Prob > chi2       =     0.0033
Log likelihood = -38.453885                     Pseudo R2         =     0.4061
```

façadeconstructionmaterial	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Glass_and_Aluminium						
Buildingform	-.80427	.53338	-1.51	0.132	-1.849676	.2411356
Buildingheightinm	.1563613	.0560122	2.79	0.005	.0465794	.2661433
Max_Buildingwidthinm	.0066608	.1400733	0.05	0.962	-.2678777	.2811994
Max_Buildinglengthinm	-.0806453	.1012763	-0.80	0.426	-.2791432	.1178527
_cons	-6.180785	5.816244	-1.06	0.288	-17.58041	5.218844
Glass__aluminium_Mortar_and_HCB						
Buildingform	-.2229777	.3231459	-0.69	0.490	-.8563319	.4103766
Buildingheightinm	.1453436	.0544153	2.67	0.008	.0386916	.2519956
Max_Buildingwidthinm	-.2920364	.1468454	-1.99	0.047	-.5798481	-.0042247
Max_Buildinglengthinm	-.084258	.0519477	-1.62	0.105	-.1860736	.0175576
_cons	1.771495	5.011694	0.35	0.724	-8.051245	11.59424
Glass__Aluminium__steel_and_Cocr						
Buildingform	-.9738478	.7629952	-1.28	0.202	-2.469291	.5215953
Buildingheightinm	.1101267	.0589232	1.87	0.062	-.0053607	.2256141
Max_Buildingwidthinm	.0380614	.1265405	0.30	0.764	-.2099535	.2860763
Max_Buildinglengthinm	-.0207965	.0942463	-0.22	0.825	-.2055157	.1639228
_cons	-5.428489	6.3775	-0.85	0.395	-17.92816	7.071182
Glass__Aluminium__Mortar__HCB__s						
Buildingform	-.7445388	.4990303	-1.49	0.136	-1.72262	.2335426
Buildingheightinm	.1343614	.0531321	2.53	0.011	.0302244	.2384985
Max_Buildingwidthinm	.0732333	.0840854	0.87	0.384	-.0915711	.2380377
Max_Buildinglengthinm	.0288766	.0858644	0.34	0.737	-.1394145	.1971676
_cons	-11.85337	5.123859	-2.31	0.021	-21.89595	-1.81079
Glass__Aluminium_plastic__steel						
Buildingform	.3553736	.8866289	0.40	0.689	-1.382387	2.093134
Buildingheightinm	.3303047	.2427642	1.36	0.174	-.1455045	.8061138
Max_Buildingwidthinm	.8050263	1.194794	0.67	0.500	-1.536727	3.146779
Max_Buildinglengthinm	-1.043812	1.277076	-0.82	0.414	-3.546834	1.459211
_cons	-19.10854	26.84504	-0.71	0.477	-71.72385	33.50677
Glass__HCB_and_Mortar						
Buildingform	.6530292	.8557669	0.76	0.445	-1.024243	2.330301
Buildingheightinm	-.0933139	.1584219	-0.59	0.556	-.4038152	.2171874
Max_Buildingwidthinm	-.7744474	.6366769	-1.22	0.224	-2.022311	.4734164
Max_Buildinglengthinm	-.0629745	.0932386	-0.68	0.499	-.2457188	.1197699
_cons	21.38584	19.29569	1.11	0.268	-16.43301	59.20469
HCB_and_Mortar	(base outcome)					
Concrete_and_Steel_Rebar						
Buildingform	.4694969	.8502411	0.55	0.581	-1.196945	2.135939
Buildingheightinm	.1114188	.0950896	1.17	0.241	-.0749533	.297791
Max_Buildingwidthinm	-.1557809	.2605181	-0.60	0.550	-.666387	.3548252
Max_Buildinglengthinm	-.0075672	.0766361	-0.10	0.921	-.1577711	.1426367
_cons	-9.598749	10.13165	-0.95	0.343	-29.45641	10.25892

Table B.11. *Multinomial logistic regression to identify the impact of building's volumetric geometry on the roof construction method of buildings.*

Multinomial logistic regression	Number of obs	=	40
	LR chi2(36)	=	72.96
	Prob > chi2	=	0.0003
Log likelihood = -22.101168	Pseudo R2	=	0.6227

Roofconstructionmethod	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Solid_slab	(base outcome)					
Flat_plate_slab						
Buildingform	-.1730662	.211098	-0.82	0.412	-.5868106	.2406783
Buildingheightinm	-.0074273	.0144786	-0.51	0.608	-.0358049	.0209502
Max_Buildingwidthinm	.1272257	.0602605	2.11	0.035	.0091173	.245334
Max_Buildinglengthinm	-.0116978	.0377432	-0.31	0.757	-.085673	.0622775
_cons	-1.982269	2.325334	-0.85	0.394	-6.53984	2.575301
Light_weight_flat_plate_slab						
Buildingform	-108.0971	327706.7	-0.00	1.000	-642401.4	642185.3
Buildingheightinm	1.710353	14794.94	0.00	1.000	-28995.85	28999.27
Max_Buildingwidthinm	36.94241	100501.6	0.00	1.000	-196942.6	197016.5
Max_Buildinglengthinm	-33.5667	95544.43	-0.00	1.000	-187297.2	187230.1
_cons	274.3885	991166.5	0.00	1.000	-1942376	1942925
Flat_plate_slab_and_truss						
Buildingform	2124.53	441919.1	0.00	0.996	-864021	868270.1
Buildingheightinm	212.4674	44187.86	0.00	0.996	-86394.15	86819.08
Max_Buildingwidthinm	-1462.003	303572.2	-0.00	0.996	-596452.6	593528.6
Max_Buildinglengthinm	-212.5723	44247	-0.00	0.996	-86935.1	86509.96
_cons	10480.26	2172568	0.00	0.996	-4247675	4268635
waffle_and_solid_slab						
Buildingform	11.19119	84981.24	0.00	1.000	-166549	166571.4
Buildingheightinm	4.745194	21582.18	0.00	1.000	-42295.54	42305.03
Max_Buildingwidthinm	-14.89	73436.95	-0.00	1.000	-143948.7	143918.9
Max_Buildinglengthinm	-19.21369	83191.13	-0.00	1.000	-163070.8	163032.4
_cons	527.5975	1634058	0.00	1.000	-3202167	3203222
Ribbed_slab						
Buildingform	64.79683	174878.7	0.00	1.000	-342691.1	342820.7
Buildingheightinm	-12.23406	36596.58	-0.00	1.000	-71740.21	71715.74
Max_Buildingwidthinm	-36.46065	104153.4	-0.00	1.000	-204173.3	204100.4
Max_Buildinglengthinm	-5.489532	14517.07	-0.00	1.000	-28458.43	28447.45
_cons	1354.051	3787557	0.00	1.000	-7422122	7424830
Waffle_Slab						
Buildingform	-161.1412	983855.8	-0.00	1.000	-1928483	1928161
Buildingheightinm	-3.90634	17832.42	-0.00	1.000	-34954.81	34947
Max_Buildingwidthinm	15.42013	117670.5	0.00	1.000	-230614.6	230645.4
Max_Buildinglengthinm	2.908354	117690.7	0.00	1.000	-230666.7	230672.5
_cons	160.8052	5084243	0.00	1.000	-9964773	9965095
Post_Tension_flat_plate_Slab_and						
Buildingform	9.804488	342616.9	0.00	1.000	-671507.1	671526.7
Buildingheightinm	-.5709473	24363.94	-0.00	1.000	-47753.02	47751.88
Max_Buildingwidthinm	2.254089	62018.73	0.00	1.000	-121552.2	121556.7
Max_Buildinglengthinm	-2.517483	68600.56	-0.00	1.000	-134457.2	134452.1
_cons	-30.15968	3989149	-0.00	1.000	-7818619	7818559
Flat_plate_slab_and_dome						
Buildingform	-.2098555	.6902129	-0.30	0.761	-1.562648	1.142937
Buildingheightinm	-.0645238	.0982154	-0.66	0.511	-.2570224	.1279748
Max_Buildingwidthinm	.0550227	.1830413	0.30	0.764	-.3037316	.413777
Max_Buildinglengthinm	-.0287332	.1046518	-0.27	0.784	-.233847	.1763806
_cons	2.592002	8.135567	0.32	0.750	-13.35342	18.53742
Truss_10						
Buildingform	-39.59231	4358978	-0.00	1.000	-8543479	8543400
Buildingheightinm	-7.469644	418719.1	-0.00	1.000	-820681.8	820666.9
Max_Buildingwidthinm	4.438957	834273.9	0.00	1.000	-1635142	1635151
Max_Buildinglengthinm	.8787614	583715.7	0.00	1.000	-1144061	1144063
_cons	385.3058	9577189	0.00	1.000	-1.88e+07	1.88e+07

Note: 7 observations completely determined. Standard errors questionable.

Table B.12. *Multinomial logistic regression to identify the impact of building's volumetric geometry on the roof construction method of buildings.*

```
Multinomial logistic regression                 Number of obs     =         40
                                                LR chi2(20)       =      45.92
                                                Prob > chi2       =     0.0008
Log likelihood = -6.4374846                     Pseudo R2         =     0.7810
```

Roofconstructionmaterial	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Concrete_and_Steel_Rebar	(base outcome)					
Concrete__Steel_Rebar__corrugate						
Buildingform	2123.866	425422.4	0.00	0.996	-831688.7	835936.4
Buildingheightinm	212.395	42536.7	0.00	0.996	-83158	83582.79
Max_Buildingwidthinm	-1461.49	292046.7	-0.01	0.996	-573862.6	570939.6
Max_Buildinglengthinm	-212.5022	42618.35	-0.00	0.996	-83742.92	83317.92
_cons	10475.84	2087975	0.01	0.996	-4081880	4102832
HCB__Concrete_and_Steel_Rebar						
Buildingform	28.78358	163012.9	0.00	1.000	-319470.7	319528.2
Buildingheightinm	-8.163316	32464.98	-0.00	1.000	-63638.36	63622.03
Max_Buildingwidthinm	-26.54164	75397.31	-0.00	1.000	-147802.6	147749.5
Max_Buildinglengthinm	-.0533247	19977.25	-0.00	1.000	-39154.75	39154.64
_cons	914.4569	2607785	0.00	1.000	-5110250	5112079
Concrete__Glass_and_Steel_Rebar						
Buildingform	-165.0651	1210125	-0.00	1.000	-2371967	2371637
Buildingheightinm	-3.891468	19825.74	-0.00	1.000	-38861.63	38853.85
Max_Buildingwidthinm	15.88656	152452.7	0.00	1.000	-298785.9	298817.7
Max_Buildinglengthinm	2.191085	153398.6	0.00	1.000	-300653.5	300657.8
_cons	191.7381	6543224	0.00	1.000	-1.28e+07	1.28e+07
_eq_5						
Buildingform	.4076084	.3681963	1.11	0.268	-.314043	1.12926
Buildingheightinm	.0012004	.0511153	0.02	0.981	-.0989837	.1013846
Max_Buildingwidthinm	-.0940077	.1760434	-0.53	0.593	-.4390463	.251031
Max_Buildinglengthinm	-.0497312	.0611741	-0.81	0.416	-.1696302	.0701679
_cons	-.5924533	5.763201	-0.10	0.918	-11.88812	10.70321
Corrugated_metal_sheets_and_stee						
Buildingform	-42.97195	3194579	-0.00	1.000	-6261304	6261218
Buildingheightinm	-7.794735	290966.5	-0.00	1.000	-570291.7	570276.1
Max_Buildingwidthinm	4.587546	567810.5	0.00	1.000	-1112884	1112893
Max_Buildinglengthinm	.9869731	394876.4	0.00	1.000	-773942.6	773944.5
_cons	406.8356	8423451	0.00	1.000	-1.65e+07	1.65e+07

Note: 5 observations completely determined. Standard errors questionable.

Appendix C statistical models on method 2 (Geometry and Construction)

Table C.1. *Multinomial logistic regression to identify the impact of floor geometry on the floor construction method of buildings.*

Y – Levels – Dependent Variable Floor construction method	"term" – Predictors	"estimate"	"std.error"	"statistic"	"p.value"
"One way concrete joist slab"	"(Intercept)"	-2.1972141251403	0.608579343404889	-3.61039879015166	0.000305726583453931
"One way concrete joist slab"	"QAR$FloorgeometrySquare"	-38.1912804523178	NA	NA	NA
"One way concrete joist slab"	"QAR$FloorgeometryCurved"	-5.75660072855074	NA	NA	NA
"One way concrete joist slab"	"QAR$FloorgeometryRectilinear"	-13.163549475558	NA	NA	NA
"One way concrete joist slab"	"QAR$FloorgeometryOrganic"	-26.2431906249644	1.2550548864826e-13	-209099943816109	0
"One way concrete joist slab"	"QAR$FloorgeometryFree form"	-26.2431906249644	1.25528019014998e-13	-209062413562258	0
"One way concrete joist slab"	"QAR$FloorgeometryIrregular"	-26.7901819384689	3.95796844632034e-13	-67686699128122.7	0
"One way concrete joist slab"	"QAR$FloorgeometryPolygonal"	-36.9509339454591	NA	NA	NA
"One way concrete joist slab"	"QAR$FloorgeometryOther"	-8.74396817640794	NA	NA	NA
"Two way concrete slab"	"(Intercept)"	0.200677414905634	0.259499930707834	0.773323577999616	0.439330905254276
"Two way concrete slab"	"QAR$FloorgeometrySquare"	-0.200683102798477	1.03312158724836	-0.194249259017983	0.845980714230749
"Two way concrete slab"	"QAR$FloorgeometryCurved"	-31.0244204192254	NA	NA	NA
"Two way concrete slab"	"QAR$FloorgeometryRectilinear"	86.7030160317997	0.674200101157865	128.601309734153	0
"Two way concrete slab"	"QAR$FloorgeometryOrganic"	-62.6414715282936	3.08248400476795e-17	-2032175071513771776	0
"Two way concrete slab"	"QAR$FloorgeometryFree form"	-62.6414715282936	NA	NA	NA
"Two way concrete slab"	"QAR$FloorgeometryIrregular"	-0.200762848063389	1.43782481761705	-0.1396295609893	0.888952683123264
"Two way concrete slab"	"QAR$FloorgeometryPolygonal"	-51.8198736772036	7.54240503574817e-23	-6.8704708155551e+23	0
"Two way concrete slab"	"QAR$FloorgeometryOther"	81.2278592614172	0.87038280476813	93.3242922728193	0
"Two way concrete waffle slab"	"(Intercept)"	-3.29570799606707	1.01828943683625	-3.23651397809506	0.00120999300246729
"Two way concrete waffle slab"	"QAR$FloorgeometrySquare"	-21.0554878308071	1.11629160194355e-10	-188619960896.847	0
"Two way concrete waffle slab"	"QAR$FloorgeometryCurved"	-2.84307748401698	2.09634544441065e-57	-1.35620657921494e+57	0
"Two way concrete waffle slab"	"QAR$FloorgeometryRectilinear"	88.0026449401451	1.17624151564757	74.8168159085051	0
"Two way concrete waffle slab"	"QAR$FloorgeometryOrganic"	-13.131553232107	1.47919637887648e-07	-88774914.6741491	0
"Two way concrete waffle slab"	"QAR$FloorgeometryFree form"	-13.131553232108	1.47919637887052e-07	-88774914.6745138	0

"Two way concrete waffle slab"	"QAR$FloorgeometryIrregular"	-13.6265231212094	1.12957593617959e-07	-120633971.429105	0
"Two way concrete waffle slab"	"QAR$FloorgeometryPolygonal"	-21.7884782672629	5.61423500031598e-11	-388093449348.603	0
"Two way concrete waffle slab"	"QAR$FloorgeometryOther"	-4.4029472427865	4.19276654974065e-39	-1.05012935744272e+39	0
"Two way concrete flat plate slab"	"(Intercept)"	-3.29620427074913	1.0185331185318	-3.23622689412453	0.00121121066934598
"Two way concrete flat plate slab"	"QAR$FloorgeometrySquare"	-21.0554878308073	1.11648752390934e-10	-188586861741.924	0
"Two way concrete flat plate slab"	"QAR$FloorgeometryCurved"	-2.84307748401695	2.09611780564298e-57	-1.35635386349139e+57	0
"Two way concrete flat plate slab"	"QAR$FloorgeometryRectilinear"	88.0023382102867	1.17651763608802	74.7989962164091	0
"Two way concrete flat plate slab"	"QAR$FloorgeometryOrganic"	-13.1315532321243	1.47953937581349e-07	-88754334.2663942	0
"Two way concrete flat plate slab"	"QAR$FloorgeometryFree form"	-13.1315532321247	1.47953937581981e-07	-88754334.266018	0
"Two way concrete flat plate slab"	"QAR$FloorgeometryIrregular"	-13.6265231212183	1.12954223548098e-07	-120637570.629804	0
"Two way concrete flat plate slab"	"QAR$FloorgeometryPolygonal"	-21.7884782672637	5.61489337026479e-11	-388047943753.493	0
"Two way concrete flat plate slab"	"QAR$FloorgeometryOther"	-4.40294724278665	4.19333674803226e-39	-1.04998656376756e+39	0
" Two way concrete flat slab"	"(Intercept)"	-1.50405573301766	0.451332643050971	-3.33247717880623	0.000860765296251733
" Two way concrete flat slab"	"QAR$FloorgeometrySquare"	-44.8367851845232	1.01146507718916e-20	-4.43285548811273e+21	0
" Two way concrete flat slab"	"QAR$FloorgeometryCurved"	-9.56508494756191	9.53005652622744e-60	-1.00367557330201e+60	0
" Two way concrete flat slab"	"QAR$FloorgeometryRectilinear"	-18.8316519997519	1.74431143162458e-46	-1.07960377134104e+47	0
" Two way concrete flat slab"	"QAR$FloorgeometryOrganic"	-37.7902289306094	2.99723876513807e-18	-1.2608347846745e+19	0
" Two way concrete flat slab"	"QAR$FloorgeometryFree form"	-37.7902289306094	2.99723876513804e-18	-12608347846745176064	0
" Two way concrete flat slab"	"QAR$FloorgeometryIrregular"	-36.1563197526781	6.82767331604637e-17	-529555502717209152	0
" Two way concrete flat slab"	"QAR$FloorgeometryPolygonal"	0.810865206951482	1.30526633473251	0.621225864311939	0.534451024024135
" Two way concrete flat slab"	"QAR$FloorgeometryOther"	-13.9895848504764	6.91203836764393e-43	-2.02394490689799e+43	0
"Precast concrete floor systems"	"(Intercept)"	-3.29561123048952	1.01824199818011	-3.23656973134059	0.00120975665620016
"Precast concrete floor systems"	"QAR$FloorgeometrySquare"	-22.6268296408209	2.31929288115459e-11	-975591734216.715	0
"Precast concrete floor systems"	"QAR$FloorgeometryCurved"	128.815013835915	6.24835362889588e-55	2.06158328235782e+56	0
"Precast concrete floor systems"	"QAR$FloorgeometryRectilinear"	88.0019812603332	1.17634144652148	74.8098959877344	0
"Precast concrete floor systems"	"QAR$FloorgeometryOrganic"	-14.2288848567082	4.9369704407812e-08	-288210857.800005	0

"Precast concrete floor systems"	"QAR$FloorgeometryFree form"	-14.2288848567076	4.93697044078808e-08	-288210857.799592	0
"Precast concrete floor systems"	"QAR$FloorgeometryIrregular"	-14.8217243019736	3.41870051603551e-08	-433548485.234431	0
"Precast concrete floor systems"	"QAR$FloorgeometryPolygonal"	-23.9047159593822	6.76435861747578e-12	-3533922033291.4	0
"Precast concrete floor systems"	"QAR$FloorgeometryOther"	-5.87312443474289	9.63866399646724e-40	-6.09329720062397e+39	0
"Structural steel framed floor system"	"(Intercept)"	-72.1358452057358	0.612371853663564	-117.797453906768	0
"Structural steel framed floor system"	"QAR$FloorgeometrySquare"	-5.28579396970041	3.8892699413813e-34	-1.35907099516551e+34	0
"Structural steel framed floor system"	"QAR$FloorgeometryCurved"	-0.949574065098918	1.1906448985222e-86	-7.97529193025985e+85	0
"Structural steel framed floor system"	"QAR$FloorgeometryRectilinear"	-3.0156595929286	3.91397018008085e-70	-7.70486093194075e+69	0
"Structural steel framed floor system"	"QAR$FloorgeometryOrganic"	-2.36692770913099	2.82399091762901e-33	-8.38149901387869e+32	0
"Structural steel framed floor system"	"QAR$FloorgeometryFree form"	-2.36692770913099	2.82399091762901e-33	-8.38149901387869e+32	0
"Structural steel framed floor system"	"QAR$FloorgeometryIrregular"	-2.84177666159369	4.29636992681348e-33	-6.61436680267747e+32	0
"Structural steel framed floor system"	"QAR$FloorgeometryPolygonal"	71.4426765805834	0.612371853663564	116.665513206023	0
"Structural steel framed floor system"	"QAR$FloorgeometryOther"	-1.5441642084272	4.85151387896261e-68	-3.18285023386841e+67	0
"Wood joist framed floor"	"(Intercept)"	-2.60270076231266	0.732833798138557	-3.55155666799713	0.000382959517382258
"Wood joist framed floor"	"QAR$FloorgeometrySquare"	-31.1495950481108	3.19379198144139e-15	-9753169658235738	0
"Wood joist framed floor"	"QAR$FloorgeometryCurved"	-3.88426686084154	9.38094116274298e-58	-4.14059399100398e+57	0
"Wood joist framed floor"	"QAR$FloorgeometryRectilinear"	-9.71417820963402	5.59413441917424e-43	-1.73649352728066e+43	0
"Wood joist framed floor"	"QAR$FloorgeometryOrganic"	-20.3536733985827	4.64925557153529e-11	-437783492118.534	0
"Wood joist framed floor"	"QAR$FloorgeometryFree form"	-20.3536733985807	4.64925557154433e-11	-437783492117.64	0
"Wood joist framed floor"	"QAR$FloorgeometryIrregular"	-20.9157396223206	9.61800038950623e-11	-217464532909.988	0
"Wood joist framed floor"	"QAR$FloorgeometryPolygonal"	-30.789700275695	6.11337875209731e-15	-5036445724082121	0
"Wood joist framed floor"	"QAR$FloorgeometryOther"	-6.1008504429778	6.40453264386132e-40	-9.52583237876913e+39	0
"Other"	"(Intercept)"	-3.29579380060532	1.01833154430746	-3.23646440987615	0.00121020316530681
"Other"	"QAR$FloorgeometrySquare"	-20.8013963005838	1.24392122973486e-10	-167224385301.452	0
"Other"	"QAR$FloorgeometryCurved"	-2.94306172860403	1.54494257764931e-57	-1.90496512374072e+57	0
"Other"	"QAR$FloorgeometryRectilinear"	-7.47284748070864	6.16804851750853e-42	-1.21154161798441e+42	0

"Other"	"QAR$FloorgeometryOrganic"	-12.9468386004388	1.5170742974482e-07	-85340834.1451444	0
"Other"	"QAR$FloorgeometryFree form"	-12.9468386004387	1.51707429744883e-07	-85340834.1451084	0
"Other"	"QAR$FloorgeometryIrregular"	-13.4614660131594	1.20906231217146e-07	-111338066.513568	0
"Other"	"QAR$FloorgeometryPolygonal"	-21.5462295938159	6.27955092942287e-11	-343117363581.859	0
"Other"	"QAR$FloorgeometryOther"	84.7242912871322	0.87038280476813	97.3414121039567	0

Table C.2. *Multinomial logistic regression to identify the impact of floor geometry on the floor construction material of buildings.*

"y.level(Floor construction material)"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Wood"	"(Intercept)"	-3.56951059797907	0.716989142275198	-4.9784723191931	6.40881068655428e-07
"Wood"	"QARF$FloorgeometrySquare"	-590.675002268067	NA	NA	NA
"Wood"	"QARF$FloorgeometryCurved"	-450.29700993285	NA	NA	NA
"Wood"	**"QARF$FloorgeometryRectilinear"**	**-363.026057496018**	**1.41030785037027e-06**	**-257409087.952469**	**0**
"Wood"	"QARF$FloorgeometryOrganic"	-450.29700993285	NA	NA	NA
"Wood"	"QARF$FloorgeometryFree form"	-450.297009932848	NA	NA	NA
"Wood"	"QARF$FloorgeometryIrregular"	-639.388572216285	NA	NA	NA
"Wood"	**"QARF$FloorgeometryPolygonal"**	**-738.942986635663**	**0**	**-Inf**	**0**
"Wood"	**"QARF$FloorgeometryOther"**	**-384.151548889506**	**0**	**-Inf**	**0**
"Plastic"	"(Intercept)"	-19.761259721142	2244.38451896268	-0.00880475674029125	0.99297491130394
"Plastic"	"QARF$FloorgeometrySquare"	18.662642824954	2244.38481562346	0.00831525979637755	0.993365459045441
"Plastic"	"QARF$FloorgeometryCurved"	-0.389392531705061	40.8690141664623	-0.00952781807065465	0.992398016080612
"Plastic"	"QARF$FloorgeometryRectilinear"	-3.94878126888762	13.7903632209059	-0.286343528856539	0.774615021967062
"Plastic"	"QARF$FloorgeometryOrganic"	-0.389392531705061	40.8690141664623	-0.00952781807065465	0.992398016080612

"Plastic"	"QARF$FloorgeometryFree form"	-0.389392531705061	40.8690141664623	-0.00952781807065465	0.992398016080612
"Plastic"	"QARF$FloorgeometryIrregular"	-0.750638875227555	57.3668340205238	-0.0130848928312656	0.98956006394229
"Plastic"	"QARF$FloorgeometryPolygonal"	-1.42205948749033	58.6597892221386	-0.0242424922821516	0.980659184139101
"Plastic"	"QARF$FloorgeometryOther"	-0.700707885253504	29.7914959186017	-0.0235203994847397	0.981235166549552
"Other"	"(Intercept)"	-3.56955691417667	0.717005291655935	-4.978424783913	6.41038457017e-07
"Other"	**"QARF$FloorgeometrySquare"**	**-552.850033544502**	**0**	**-Inf**	**0**
"Other"	**"QARF$FloorgeometryCurved"**	**-441.48465387151**	**0**	**-Inf**	**0**
"Other"	**"QARF$FloorgeometryRectilinear"**	**-358.519845885978**	**3.88533157325725e-155**	**-9.22752251966528e+156**	**0**
"Other"	**"QARF$FloorgeometryOrganic"**	**-441.48465387151**	**0**	**-Inf**	**0**
"Other"	**"QARF$FloorgeometryFree form"**	**-441.48465387151**	**0**	**-Inf**	**0**
"Other"	**"QARF$FloorgeometryIrregular"**	**-616.631922227554**	**0**	**-Inf**	**0**
"Other"	**"QARF$FloorgeometryPolygonal"**	**-705.569329863802**	**0**	**-Inf**	**0**
"Other"	**"QARF$FloorgeometryOther"**	**3.56950624348328**	**1.58559029686753**	**2.25121599856857**	**0.0243718600872482**

Table C.3. *Multinomial logistic regression to identify the impact of facade geometry on the façade construction method of buildings.*

"y.leve – Façade constrution method"	**"term - Indicator"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Metal and Wood Stud Walls"	"(Intercept)"	-1.90952244829166	0.535756475204004	-3.56416121254447	0.000365021570472172
"Metal and Wood Stud Walls"	"QARF$FaçadegeometrySquare"	1.21635433287208	1.01834994473236	1.19443648930698	0.232307270393398
"Metal and Wood Stud Walls"	**"QARF$FaçadegeometryTriangular"**	**-3.37648863976358**	**3.43312244689052e-15**	**-983503703114861**	**0**
"Metal and Wood Stud Walls"	**"QARF$FaçadegeometryCurved"**	**-29.782192189835**	**1.12400458845913e-14**	**-2649650410294381**	**0**
"Metal and Wood Stud Walls"	**"QARF$FaçadegeometryRectilinear"**	**-19.0240974384278**	**5.79026812714809e-09**	**-3285529619.81707**	**0**
"Metal and Wood Stud Walls"	**"QARF$FaçadegeometryFree form"**	**48.9800772671123**	**0.946724955851861**	**51.736332674404**	**0**

"Metal and Wood Stud Walls"	**"QARF$FaçadegeometryIrregular"**	**-22.3801891081839**	**7.85040245146408e-11**	**-285083334855.146**	**0**
"Metal and Wood Stud Walls"	**"QARF$FaçadegeometryPolygonal"**	**-3.14465903100447**	**8.39517883023464e-16**	**-3745791596099427**	**0**
"Metal and Wood Stud Walls"	**"QARF$FaçadegeometryOther"**	**-29.7821921898344**	**1.07148118766176e-14**	**-2779534772311466**	**0**
"Precast concrete walls"	"(Intercept)"	-3.29582858383465	1.01835128215595	-3.23643583661726	0.00121032432755036
"Precast concrete walls"	**"QARF$FaçadegeometrySquare"**	**-23.0045238919843**	**5.93351095044719e-11**	**-387705088675.206**	**0**
"Precast concrete walls"	**"QARF$FaçadegeometryTriangular"**	**-1.37724236303604**	**1.67470944071263e-15**	**-822376902855453**	**0**
"Precast concrete walls"	**"QARF$FaçadegeometryCurved"**	**-12.985321588404**	**3.28962965915091e-07**	**-39473505.9379166**	**0**
"Precast concrete walls"	"QARF$FaçadegeometryRectilinear"	3.29575911936	1.74268861190368	1.89119220545073	0.0585986914659037
"Precast concrete walls"	"QARF$FaçadegeometryFree form"	-4.40260691418272	NA	NA	NA
"Precast concrete walls"	"QARF$FaçadegeometryIrregular"	3.29567997804721	1.74270478467384	1.89112924175739	0.0586070939086838
"Precast concrete walls"	**"QARF$FaçadegeometryPolygonal"**	**-1.61528645703604**	**1.4833775119341e-16**	**-10889247302461524**	**0**
"Precast concrete walls"	**"QARF$FaçadegeometryOther"**	**-12.9853215884042**	**3.28962966517293e-07**	**-39473505.8656567**	**0**
"Tilt-up façade construction "	"(Intercept)"	-3.29575674470632	1.01831599369545	-3.23647744424211	0.0012101478980131
"Tilt-up façade construction "	**"QARF$FaçadegeometrySquare"**	**-23.8862095594967**	**2.11244298451388e-11**	**-1130738662988.98**	**0**
"Tilt-up façade construction "	**"QARF$FaçadegeometryTriangular"**	**-1.45425816687745**	**1.6986615974721e-21**	**-8.5612000002922e+20**	**0**
"Tilt-up façade construction "	**"QARF$FaçadegeometryCurved"**	**-13.4199938617621**	**1.82962153686741e-07**	**-73348469.0212994**	**0**
"Tilt-up façade construction "	"QARF$FaçadegeometryRectilinear"	3.29567033787377	1.74267285215968	1.89115836273543	0.0586032076185231
"Tilt-up façade construction "	**"QARF$FaçadegeometryFree form"**	**50.366302174798**	**1.0706394183092**	**47.0431980305178**	**0**
"Tilt-up façade construction "	**"QARF$FaçadegeometryIrregular"**	**-12.9088047811852**	**3.95437938424608e-07**	**-32644325.5106296**	**0**
"Tilt-up façade construction "	**"QARF$FaçadegeometryPolygonal"**	**-1.65851646551656**	**1.28814277008793e-17**	**-128752534581500080**	**0**
"Tilt-up façade construction "	**"QARF$FaçadegeometryOther"**	**-13.4199938617621**	**1.82962153686758e-07**	**-73348469.021292**	**0**

"Masonry walls"	"(Intercept)"	-0.300090814865102	0.295020762686783	-1.01718540801043	0.309065236312556
"Masonry walls"	"QARF$FaçadegeometrySquare"	-1.0862443543684	1.15631453126362	-0.939402147944429	0.347524310625851
"Masonry walls"	**"QARF$FaçadegeometryTriangular"**	**-8.9593720046477**	**8.64318930619211e-25**	**-1.0365817162224e+25**	**0**
"Masonry walls"	**"QARF$FaçadegeometryCurved"**	**-44.0165335630573**	**2.29409964342451e-20**	**-1.9186844690561e+21**	**0**
"Masonry walls"	"QARF$FaçadegeometryRectilinear"	0.300017195948257	1.44463340299339	0.207677044796693	0.835481142492374
"Masonry walls"	**"QARF$FaçadegeometryFree form"**	**-14.837700576256**	**9.72609767856692e-28**	**-1.52555537345192e+28**	**0**
"Masonry walls"	**"QARF$FaçadegeometryIrregular"**	**-26.6840648159774**	**5.21529719000166e-12**	**-5116499375555.04**	**0**
"Masonry walls"	**"QARF$FaçadegeometryPolygonal"**	**-6.63042466609471**	**8.25445466541839e-20**	**-80325411366937755658**	**0**
"Masonry walls"	**"QARF$FaçadegeometryOther"**	**-44.0165335630576**	**2.29409964342375e-20**	**-1.91868446905674e+21**	**0**
"Curtain wall"	"(Intercept)"	-0.587772583954386	0.322030806293278	-1.82520607490916	0.0679699374238777
"Curtain wall"	**"QARF$FaçadegeometrySquare"**	**-33.2518831284024**	**5.42878839838491e-15**	**-6125102083237396**	**0**
"Curtain wall"	**"QARF$FaçadegeometryTriangular"**	**44.8128202179723**	**2.36092720980541e-20**	**1.89810257732028e+21**	**0**
"Curtain wall"	**"QARF$FaçadegeometryCurved"**	**-41.0038865510249**	**3.71486212019573e-19**	**-1.10377950040483e+20**	**0**
"Curtain wall"	**"QARF$FaçadegeometryRectilinear"**	**2.37945772703039**	**1.12707506188695**	**2.11117946576397**	**0.0347568891201132**
"Curtain wall"	**"QARF$FaçadegeometryFree form"**	**47.6583432705101**	**0.91387770843404**	**52.1495850382151**	**0**
"Curtain wall"	"QARF$FaçadegeometryIrregular"	1.68629455551523	1.19873066737897	1.40673347350188	0.159506435988654
"Curtain wall"	**"QARF$FaçadegeometryPolygonal"**	**36.3680079054138**	**2.24701453045145e-16**	**161850345925920608**	**0**
"Curtain wall"	**"QARF$FaçadegeometryOther"**	**-41.0038865510249**	**3.71486212019568e-19**	**-1.10377950040485e+20**	**0**
"Glass wall"	"(Intercept)"	-3.29576851314104	1.01832177867912	-3.23647061483456	0.00121017685523925
"Glass wall"	**"QARF$FaçadegeometrySquare"**	**-24.7326237152053**	**7.36662142213676e-12**	**-3357390355486.93**	**0**
"Glass wall"	**"QARF$FaçadegeometryTriangular"**	**-1.26667959996476**	**1.58888139773976e-21**	**-7.97214695676252e+20**	**0**
"Glass wall"	**"QARF$FaçadegeometryCurved"**	**-13.3583694650801**	**1.56645295478852e-07**	**-85277820.9792044**	**0**
"Glass wall"	"QARF$FaçadegeometryRectilinear"	3.29572382350929	1.74266426332327	1.89119837531088	0.0585978681579759
"Glass wall"	**"QARF$FaçadegeometryFree form"**	**-4.14561933914896**	**5.34029398193132e-24**	**-7.76290472617332e+23**	**0**
"Glass wall"	**"QARF$FaçadegeometryIrregular"**	**-13.1581821092183**	**2.74397698657235e-07**	**-47952960.8798026**	**0**
"Glass wall"	**"QARF$FaçadegeometryPolygonal"**	**-1.43610082451111**	**1.24760802964643e-17**	**-115108334539823200**	**0**
"Glass wall"	**"QARF$FaçadegeometryOther"**	**-13.35836946508**	**1.56645295479285e-07**	**-85277820.9789677**	**0**
"Other"	"(Intercept)"	-3.29583414937046	1.0183540049993	-3.23643264836253	0.00121033784774253
"Other"	**"QARF$FaçadegeometrySquare"**	**-24.7326237152064**	**7.36675973251596e-12**	**-3357327320726.86**	**0**
"Other"	**"QARF$FaçadegeometryTriangular"**	**-1.26667959996474**	**1.58893127051107e-21**	**-7.97189673004119e+20**	**0**
"Other"	**"QARF$FaçadegeometryCurved"**	**-13.358369465895**	**1.56648810262968e-07**	**-85275907.576126**	**0**
"Other"	"QARF$FaçadegeometryRectilinear"	3.2956830667868	1.74271362101525	1.89112142525566	0.0586081370829453
"Other"	**"QARF$FaçadegeometryFree form"**	**-4.14561933914897**	**5.34041369864624e-24**	**-7.76273070417721e+23**	**0**
"Other"	**"QARF$FaçadegeometryIrregular"**	**-13.1581821100369**	**2.74391625560184e-07**	**-47954022.2234328**	**0**
"Other"	**"QARF$FaçadegeometryPolygonal"**	**-1.43610082451111**	**1.24764719032261e-17**	**-115104721563134400**	**0**
"Other"	**"QARF$FaçadegeometryOther"**	**-13.358369465895**	**1.5664881026338e-07**	**-85275907.5759016**	**0**

Table C.4. *Multinomial logistic regression to identify the impact of facade geometry on the façade construction material of buildings.*

"y.level" –Façade construction material	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Timber"	"(Intercept)"	–3.51153768615778	0.717580394561683	–4.89358086253558	9.90176026546476e-07
"Timber"	"QARF$FaçadegeometrySquare"	–43.0899429600758	NA	NA	NA
"Timber"	**"QARF$FaçadegeometryTriangular"**	**–22.5538467662764**	**2.62791942524661e-08**	**–858239660.988079**	**0**
"Timber"	**"QARF$FaçadegeometryCurved"**	**–22.5538467662764**	**2.62797032738098e-08**	**–858223037.424986**	**0**
"Timber"	**"QARF$FaçadegeometryRectilinear"**	**–35.9956364227167**	**2.0857805750721e-14**	**–1725763335458832**	**0**
"Timber"	**"QARF$FaçadegeometryFree form"**	**–38.6788220125097**	**1.95025154739735e-13**	**–198327349434114**	**0**
"Timber"	**"QARF$FaçadegeometryIrregular"**	**–43.0406120646347**	**1.18143854989147e-13**	**–364306819585231**	**0**
"Timber"	**"QARF$FaçadegeometryPolygonal"**	**–20.4006042581863**	**5.77044738415889e-09**	**–3535359201.81689**	**0**
"Timber"	**"QARF$FaçadegeometryOther"**	**–22.5538467662764**	**2.62790664678361e-08**	**–858243834.265606**	**0**
"Glass"	"(Intercept)"	–4.20469101482809	1.00743437334536	–4.17366244995762	2.99741756604674e-05
"Glass"	**"QARF$FaçadegeometrySquare"**	**–27.8292034660028**	**8.1475160074597e-10**	**–34156672341.0215**	**0**
"Glass"	"QARF$FaçadegeometryTriangular"	-12.986756794704	5408.48316462207	–0.00240118280845412	0.998084135150513
"Glass"	"QARF$FaçadegeometryCurved"	-12.986756794704	5408.48316462203	–0.00240118280845413	0.998084135150513
"Glass"	**"QARF$FaçadegeometryRectilinear"**	**–22.0410001460015**	**4.56564065414308e-07**	**–48275810.1560194**	**0**
"Glass"	**"QARF$FaçadegeometryFree form"**	**–24.2392787280061**	**1.26516962833782e-08**	**–1915891607.34531**	**0**
"Glass"	**"QARF$FaçadegeometryIrregular"**	**–27.7640222244798**	**6.21161860401263e-10**	**–44696920391.3205**	**0**
"Glass"	**"QARF$FaçadegeometryPolygonal"**	**4.20471628488316**	**1.73635365548491**	**2.42157827214578**	**0.0154532726971521**
"Glass"	"QARF$FaçadegeometryOther"	-12.986756794704	5408.48316462203	–0.00240118280845413	0.998084135150513

Table C.5. *Multinomial logistic regression to identify the impact of roof geometry on the roof construction method of buildings.*

"y.level" – Roof construction method	"term" – predictors(Roof geometry)	"estimate"	"std.error"	"statistic"	"p.value"
"Precast concrete roof systems"	"(Intercept)"	-3.49641579882783	1.01499241390994	-3.44477037553315	0.000571544703778617
"Precast concrete roof systems"	"QARF$RoofgeometryFlat Square"	-92.8326581267114	NA	NA	NA

"Precast concrete roof systems"	**"QARF$RoofgeometryFlat Triangular"**	**-109.941244351707**	**6.23334545559295e-08**	**-1763759848.30202**	**0**
"Precast concrete roof systems"	"QARF$RoofgeometryFlat Curved"	-12.9947127770569	NA	NA	NA
"Precast concrete roof systems"	**"QARF$RoofgeometryFlat Rectilinear"**	**-207.360305878456**	**2.02483666107819e-08**	**-10240841143.6032**	**0**
"Precast concrete roof systems"	**"QARF$RoofgeometryFlat Organic"**	**-12.9947127770569**	**2.25990703861403e-08**	**-575010943.150403**	**0**
"Precast concrete roof systems"	"QARF$RoofgeometryFlat Free form"	-109.672112816329	NA	NA	NA
"Precast concrete roof systems"	**"QARF$RoofgeometryFlat Irregular"**	**-5.66011175029383**	**1.41590483793264e-08**	**-399752271.385564**	**0**
"Precast concrete roof systems"	**"QARF$RoofgeometryFlat Polygonal"**	**-191.519358457224**	**2.12423214765819e-08**	**-9015933530.06922**	**0**
"Precast concrete roof systems"	"QARF$RoofgeometryPitched : Hip Gable Mansard Gambrel butterfly etc."	-11.1272243536993	1059.05759523403	-0.0105067225840918	0.991617002500684
"Precast concrete roof systems"	**"QARF$RoofgeometryPyramidal"**	**733.711562713482**	**2.50218332198002e-09**	**293228540158.634**	**0**
"Precast concrete roof systems"	**"QARF$Roofgeometry Others"**	**-102.263879359492**	**1.12606641363886e-08**	**-9081514031.57732**	**0**
"Structural steel roof framing"	"(Intercept)"	-2.39791733234074	0.60302829690195	-3.97645905616703	6.99490357282164e-05
"Structural steel roof framing"	"QARF$RoofgeometryFlat Square"	-152.802748598461	NA	NA	NA
"Structural steel roof framing"	"QARF$RoofgeometryFlat Triangular"	-194.298069240656	NA	NA	NA
"Structural steel roof framing"	**"QARF$RoofgeometryFlat Curved"**	**637.859144023254**	**7.34661233318049e-10**	**868235746076.331**	**0**
"Structural steel roof framing"	**"QARF$RoofgeometryFlat Rectilinear"**	**-234.258233242398**	**1.83980889486624e-10**	**-1273274816183.72**	**0**
"Structural steel roof framing"	**"QARF$RoofgeometryFlat Organic"**	**637.859144022686**	**0**	**Inf**	**0**
"Structural steel roof framing"	"QARF$RoofgeometryFlat Free form"	-179.479572992231	NA	NA	NA
"Structural steel roof framing"	**"QARF$RoofgeometryFlat Irregular"**	**563.04469439668**	**0**	**Inf**	**0**
"Structural steel roof framing"	"QARF$RoofgeometryFlat Polygonal"	-248.497517125702	NA	NA	NA
"Structural steel roof framing"	**"QARF$RoofgeometryPitched : Hip Gable Mansard Gambrel butterfly etc."**	**3.31397188694173**	**1.03127734506891**	**3.21346328685257**	**0.00131144562820828**
"Structural steel roof framing"	**"QARF$RoofgeometryPyramidal"**	**-48.5508919533289**	**0**	**-Inf**	**0**
"Structural steel roof framing"	"QARF$Roofgeometry Others"	-162.941182384733	NA	NA	NA
"Steel trusses"	"(Intercept)"	-1.70478417023528	0.44381909656155	-3.84116903360613	0.000122449754297491
"Steel trusses"	"QARF$RoofgeometryFlat Square"	2.39828997139461	1.30277345453404	1.84091099112271	0.0656346034590115
"Steel trusses"	"QARF$RoofgeometryFlat Triangular"	-269.822120182802	NA	NA	NA
"Steel trusses"	**"QARF$RoofgeometryFlat Curved"**	**-62.3147363183899**	**0**	**-Inf**	**0**
"Steel trusses"	"QARF$RoofgeometryFlat Rectilinear"	-281.263281830098	NA	NA	NA
"Steel trusses"	**"QARF$RoofgeometryFlat Organic"**	**-62.3147363183303**	**0**	**-Inf**	**0**
"Steel trusses"	"QARF$RoofgeometryFlat Free form"	-244.442795767369	NA	NA	NA
"Steel trusses"	**"QARF$RoofgeometryFlat Irregular"**	**-52.5247957387477**	**0**	**-Inf**	**0**
"Steel trusses"	"QARF$RoofgeometryFlat Polygonal"	0.606285184822613	1.23702594704043	0.490115172016516	0.624052402566218

"Steel trusses"	**"QARF$RoofgeometryPitched : Hip Gable Mansard Gambrel butterfly etc."**	**2.95731458543893**	**0.916363031420997**	**3.22723034871131**	**0.0012499479125786**
"Steel trusses"	**"QARF$RoofgeometryPyramidal"**	**-63.7676208990111**	**0**	**-Inf**	**0**
"Steel trusses"	"QARF$Roofgeometry Others"	-216.067762843352	NA	NA	NA
"Metal roof decking"	"(Intercept)"	-562.236791815618	0.586295746381234	-958.964473622547	0
"Metal roof decking"	**"QARF$RoofgeometryFlat Square"**	**-35.5261970574477**	**0**	**-Inf**	**0**
"Metal roof decking"	**"QARF$RoofgeometryFlat Triangular"**	**-39.3614657888963**	**0**	**-Inf**	**0**
"Metal roof decking"	**"QARF$RoofgeometryFlat Curved"**	**-9.89016986052562**	**0**	**-Inf**	**0**
"Metal roof decking"	**"QARF$RoofgeometryFlat Rectilinear"**	**-93.0143474514876**	**0**	**-Inf**	**0**
"Metal roof decking"	**"QARF$RoofgeometryFlat Organic"**	**-9.89016986052637**	**0**	**-Inf**	**0**
"Metal roof decking"	**"QARF$RoofgeometryFlat Free form"**	**562.237004539646**	**1.15919916905492**	**485.021918190325**	**0**
"Metal roof decking"	**"QARF$RoofgeometryFlat Irregular"**	**-5.93978052492365**	**0**	**-Inf**	**0**
"Metal roof decking"	**"QARF$RoofgeometryFlat Polygonal"**	**-82.6785787698108**	**0**	**-Inf**	**0**
"Metal roof decking"	**"QARF$RoofgeometryPitched : Hip Gable Mansard Gambrel butterfly etc."**	**561.543358930412**	**1.04580921085731**	**536.946273852456**	**0**
"Metal roof decking"	"QARF$RoofgeometryPyramidal"	-12.3277254487592	0	-Inf	0
"Metal roof decking"	"QARF$Roofgeometry Others"	562.236652073906	1.15918510402748	485.027499163393	0
"Rafter framing"	"(Intercept)"	-465.560969956459	0.454914420129995	-1023.40341249992	0
"Rafter framing"	**"QARF$RoofgeometryFlat Square"**	**465.561379468181**	**1.09864648516968**	**423.759039648026**	**0**
"Rafter framing"	**"QARF$RoofgeometryFlat Triangular"**	**-31.5691893496763**	**0**	**-Inf**	**0**
"Rafter framing"	**"QARF$RoofgeometryFlat Curved"**	**-12.0411651190801**	**0**	**-Inf**	**0**
"Rafter framing"	**"QARF$RoofgeometryFlat Rectilinear"**	**464.644675305589**	**0.746288691985381**	**622.60714961321**	**0**
"Rafter framing"	**"QARF$RoofgeometryFlat Organic"**	**-12.0411651190724**	**0**	**-Inf**	**0**
"Rafter framing"	**"QARF$RoofgeometryFlat Free form"**	**-37.5668754821647**	**0**	**-Inf**	**0**
"Rafter framing"	**"QARF$RoofgeometryFlat Irregular"**	**-15.176434282785**	**0**	**-Inf**	**0**
"Rafter framing"	**"QARF$RoofgeometryFlat Polygonal"**	**-65.0194137829625**	**0**	**-Inf**	**0**
"Rafter framing"	**"QARF$RoofgeometryPitched : Hip Gable Mansard Gambrel butterfly etc."**	**467.064803719419**	**0.715854395066943**	**652.457827929857**	**0**
"Rafter framing"	**"QARF$RoofgeometryPyramidal"**	**-12.8427371913824**	**0**	**-Inf**	**0**
"Rafter framing"	**"QARF$Roofgeometry Others"**	**-40.3299040813569**	**0**	**-Inf**	**0**
"Wood rafter framing"	"(Intercept)"	-2.80330145268317	0.728198260543598	-3.84964041329968	0.000118291356748627
"Wood rafter framing"	"QARF$RoofgeometryFlat Square"	-126.978307302033	NA	NA	NA
"Wood rafter framing"	"QARF$RoofgeometryFlat Triangular"	-151.656411148579	NA	NA	NA
"Wood rafter framing"	**"QARF$RoofgeometryFlat Curved"**	**-29.6063794585245**	**0**	**-Inf**	**0**
"Wood rafter framing"	"QARF$RoofgeometryFlat Rectilinear"	1.19384171846262	1.31540491092046	0.907584963801921	0.364097541422731
"Wood rafter framing"	**"QARF$RoofgeometryFlat Organic"**	**-29.6063794585255**	**0**	**-Inf**	**0**
"Wood rafter framing"	"QARF$RoofgeometryFlat Free form"	-145.491897797929	NA	NA	NA
"Wood rafter framing"	**"QARF$RoofgeometryFlat Irregular"**	**-28.3554106690547**	**0**	**-Inf**	**0**
"Wood rafter framing"	"QARF$RoofgeometryFlat Polygonal"	-217.648752006519	NA	NA	NA

"Wood rafter framing"	**"QARF$RoofgeometryPitched : Hip Gable Mansard Gambrel butterfly etc."**	**3.90167040308014**	**1.09399726950626**	**3.56643522962452**	**0.000361870196140682**
"Wood rafter framing"	**"QARF$RoofgeometryPyramidal"**	**-33.1159117023937**	**0**	**-Inf**	**0**
"Wood rafter framing"	"QARF$Roofgeometry Others"	2.80313377436315	1.59067138373943	1.76223310673598	0.0780299206452628

Table C.6. *Multinomial logistic regression to identify the impact of roof geometry on the roof construction material of buildings.*

"y.level" -	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Concrete"	**"(Intercept)"**	**0.485479755559387**	**0.317743549953576**	**1.52789806631895**	**0.126537848396215**
"Concrete"	**"QARF$RoofgeometryFlat Square"**	**-45.7955499325161**	**2.43694008877683e-15**	**-18792234632038992**	**0**
"Concrete"	"QARF$RoofgeometryFlat Triangular"	-42.0763349553624	NA	NA	NA
"Concrete"	"QARF$RoofgeometryFlat Curved"	-42.0763349553625	NA	NA	NA
"Concrete"	**"QARF$RoofgeometryFlat Rectilinear"**	**51.5526486372576**	**0.626845375397273**	**82.2414117749298**	**0**
"Concrete"	**"QARF$RoofgeometryFlat Organic"**	**-42.0763349553625**	**3.58750019736055e-16**	**-117285944642789120**	**0**
"Concrete"	**"QARF$RoofgeometryFlat Free form"**	**-0.485338338272142**	**1.4494691965027**	**-0.334838670213325**	**0.737746788018777**
"Concrete"	**"QARF$RoofgeometryFlat Irregular"**	**-44.6861635706618**	**NA**	**NA**	**NA**
"Concrete"	**"QARF$RoofgeometryFlat Polygonal"**	**-0.485483437381089**	**1.04926686936189**	**-0.462688236479186**	**0.643587851424759**
"Concrete"	**"QARF$RoofgeometryPitched : Hip Gable Mansard Gambrel butterfly etc."**	**-3.52999462554389**	**1.07171487511401**	**-3.29378149684484**	**0.000988493074194362**
"Concrete"	**"QARF$RoofgeometryPyramidal"**	**-42.0763349553624**	**2.89267986086868e-19**	**-1.45457973156859e+20**	**0**

"Concrete"	"QARF$Roofgeometry Others"	-1.17862783111156	1.26529103827932	-0.931507293937991	0.351591213361309
"Wood"	"(Intercept)"	-2.77255227156473	1.03074994360896	-2.68983984792394	0.00714863169088856
"Wood"	"QARF$RoofgeometryFlat Square"	-22.5471734053263	1.11526472911709e-10	-202168801869.812	0
"Wood"	"QARF$RoofgeometryFlat Triangular"	-13.2176066669604	3.14121285765742e-07	-42078035.6693736	0
"Wood"	"QARF$RoofgeometryFlat Curved"	-13.2176066669604	3.14121285765719e-07	-42078035.6693768	0
"Wood"	"QARF$RoofgeometryFlat Rectilinear"	54.2998653489025	0.626845375397273	86.6240184263769	0
"Wood"	"QARF$RoofgeometryFlat Organic"	-13.2176066669604	3.14121285765724e-07	-42078035.6693762	0
"Wood"	"QARF$RoofgeometryFlat Free form"	-12.7856812087204	5.61435430612811e-07	-22773199.7511535	0
"Wood"	"QARF$RoofgeometryFlat Irregular"	-18.3515219763605	3.70250996884629e-09	-4956508457.98503	0
"Wood"	"QARF$RoofgeometryFlat Polygonal"	-16.7876590469766	1.8242611101377e-08	-920244308.979943	0
"Wood"	"QARF$RoofgeometryPitched : Hip Gable Mansard Gambrel butterfly etc."	1.80747161114791	1.11133456654895	1.62639736543127	0.103865150933941
"Wood"	"QARF$RoofgeometryPyramidal"	-13.2176066669604	3.14121285765726e-07	-42078035.6693758	0
"Wood"	"QARF$Roofgeometry Others"	-17.630872339605	7.92536079636269e-09	-2224614474.04346	0
"Other"	"(Intercept)"	-2.07946307349213	0.750001040664029	-2.77261358417721	0.00556081091404309
"Other"	"QARF$RoofgeometryFlat Square"	-33.284959024123	8.98045013069675e-16	-37063798072158112	0

"Other"	"QARF$RoofgeometryFlat Triangular"	-20.480973689936	8.16466069 45407e-11	-250849048799.182	0
"Other"	"QARF$RoofgeometryFlat Curved"	-20.480973689936	8.16466069 454082e-11	-250849048799.178	0
"Other"	"QARF$RoofgeometryFlat Rectilinear"	3.73274164530726	8.94261053 018512e-22	4.17410736239453e+2 1	0
"Other"	"QARF$RoofgeometryFlat Organic"	-20.4809736899361	8.16466069 454031e-11	-250849048799.195	0
"Other"	"QARF$RoofgeometryFlat Free form"	-20.4070349380327	2.85040631 923703e-10	-71593424419.2074	0
"Other"	"QARF$RoofgeometryFlat Irregular"	-27.8500908167064	1.02944081 096344e-13	-270536105816923	0
"Other"	"QARF$RoofgeometryFlat Polygonal"	-26.71137811045	5.15224716 301589e-13	-51844131823082.7	0
"Other"	"QARF$RoofgeometryPitch ed : Hip Gable Mansard Gambrel butterfly etc."	-43.0144846310147	3.00469372 753869e-19	- 1.43157634459637e+2 0	0
"Other"	"QARF$RoofgeometryPyram idal"	-20.4809736899361	8.16466069 453964e-11	-250849048799.216	0
"Other"	"QARF$Roofgeometry Others"	-27.3361846694719	3.06095395 90316e-13	-89306095535394.1	0

Appendix D - Statistical models on Geometry and computational design

Table D.1. *Multinomial logistic regression to identify the impact of 2D design software tools on the floor geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Square"	"(Intercept)"	-0.368495763609484	1.31489687701594	-0.28024689239947	0.77928809248159
"Square"	"QARF21$`@2Ddesignsoftwaretool`"	-0.707158943511336	0.385271480802639	-1.83548219566656	0.0664342747586282
"Curved"	"(Intercept)"	-39.0891984668607	259.650208983818	-0.1505456075689	0.880334171077696
"Curved"	"QARF21$`@2Ddesignsoftwaretool`"	7.08747080148939	51.9335835866256	0.136471822508983	0.891448298502197
"Rectilinear"	"(Intercept)"	-4.95533365061387	2.13843399418957	-2.31727220203112	0.020488908569291
"Rectilinear"	"QARF21$`@2Ddesignsoftwaretool`"	0.702041891041513	0.456620490350502	1.53747347277961	0.124177406249656
"Organic"	"(Intercept)"	-39.0866611155949	259.583920107692	-0.150574277094588	0.880311553910348
"Organic"	"QARF21$`@2Ddesignsoftwaretool`"	7.08696382045556	51.9203267046258	0.136496903433856	0.891428472342774
"Free form"	"(Intercept)"	-39.0879445987418	259.616206261422	-0.150560495285036	0.880322426261256
"Free form"	"QARF21$`@2Ddesignsoftwaretool`"	7.08722266499657	51.9267834590211	0.136484915738899	0.891437948458195
"Irregular"	"(Intercept)"	-45.1625042705593	361.49090080687	-0.124934000191302	0.900575800978497
"Irregular"	"QARF21$`@2Ddesignsoftwaretool`"	8.44080111502675	72.2994820603978	0.116747739741419	0.907059958075478
"Polygonal"	"(Intercept)"	-3.3340730812339	2.21933219552616	-1.50228662836275	0.133023100483729
"Polygonal"	"QARF21$`@2Ddesignsoftwaretool`"	0.0959344788340542	0.508588618932893	0.188628835295885	0.8503837312029
"Other"	"(Intercept)"	-1.061225386411	1.76982436417238	-0.599621865250601	0.548758271687568
"Other"	"QARF21$`@2Ddesignsoftwaretool`"	-0.707266445037303	0.52595771198368	-1.34472112286329	0.178715310680485

Table D.2. *Multinomial logistic regression to identify the impact of 3D modeling software tools on the floor geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Square"	"(Intercept)"	0.276194867567469	1.81222060856571	0.152406868270892	0.878866040264706
"Square"	"QARF21$`@3dmodelingsoftwaretool`"	-0.813189483656919	0.48440535995988	-1.67873758400252	0.093203197696628
"Curved"	"(Intercept)"	-44.6914920262778	382.901636110446	-0.116717944797151	0.907083569580468
"Curved"	"QARF21$`@3dmodelingsoftwaretool`"	8.20438333998181	76.5827303419082	0.107130985058287	0.914685066092344
"Rectilinear"	"(Intercept)"	-1.43713649931588	1.52622321054408	-0.941629303883769	0.346382461354309
"Rectilinear"	"QARF21$`@3dmodelingsoftwaretool`"	-0.0922382015994205	0.350736355805777	-0.262984432815679	0.792562577731092

"Organic"	"(Intercept)"	-44.6887618718266	382.797556702635	-0.116742547305603	0.907064072902713
"Organic"	"QARF21$`@3dmodelingsoftwaretool`"	8.20383669927895	76.5619151206385	0.107152971374242	0.914667623950844
"Free form"	"(Intercept)"	-44.6839304331047	382.612354079064	-0.116786428761971	0.907029298432635
"Free form"	"QARF21$`@3dmodelingsoftwaretool`"	8.20287075349565	76.5248757549854	0.107192212631084	0.914636493255256
"Irregular"	"(Intercept)"	-4.88893960357636	4.43693934779839	-1.10187208351231	0.270517286711166
"Irregular"	"QARF21$`@3dmodelingsoftwaretool`"	0.286386791268405	0.973702536712802	0.294121439012822	0.768665109093691
"Polygonal"	"(Intercept)"	-50.6407799892607	398.736360098046	-0.127003165642603	0.898937893020401
"Polygonal"	"QARF21$`@3dmodelingsoftwaretool`"	9.67148656975254	79.7478871305765	0.121275771907496	0.903472609573287
"Other"	"(Intercept)"	-2.08477819618219	2.97773553778387	-0.700122012089007	0.483851110190777
"Other"	"QARF21$`@3dmodelingsoftwaretool`"	-0.369339275603543	0.720326631555048	-0.512738609714053	0.608134177947736

Table D.3. *Multinomial logistic regression to identify the impact of BIM on the floor geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Square"	"(Intercept)"	23.7603528765898	0.26700296686276	88.9890968470126	0
"Square"	**"QARF21$BIM"**	**-25.6665079003363**	**0.26700296686599**	**-96.1281749098259**	**0**
"Curved"	"(Intercept)"	-4.02399034687018	2.12920866406733	-1.88989947992384	0.0587714051321688
"Curved"	"QARF21$BIM"	-0.140816838034528	0.93699637108032	-0.150285361161188	0.880539481921063
"Rectilinear"	"(Intercept)"	-1.53858618403092	0.659618224317412	-2.33254044128797	0.0196722779964922
"Rectilinear"	"QARF21$BIM"	-0.141018196809948	0.287646410610808	-0.490248414748163	0.62395812511285
"Organic"	"(Intercept)"	-4.02405311093067	2.12930116244281	-1.88984685769585	0.0587784446309121
"Organic"	"QARF21$BIM"	-0.140830560138431	0.937044195365909	-0.150292335019949	0.880533980073402
"Free form"	"(Intercept)"	10.1911510289387	0.50870868801501	20.0333732626126	2.81900474228103e-89
"Free form"	"QARF21$BIM"	-13.4835792696604	0.508709603274968	-26.5054545517834	8.3860418641901e-155
"Irregular"	"(Intercept)"	-2.32143201923135	1.5737557455851	-1.47509041713984	0.140188236448241
"Irregular"	"QARF21$BIM"	-0.726755449737525	0.926884344825834	-0.784084286021775	0.432990655283291
"Polygonal"	"(Intercept)"	-3.88973299111129	1.22660925865764	-3.17112639062262	0.00151849058581988
"Polygonal"	"QARF21$BIM"	0.390919899417391	0.410287553594941	0.95279492636847	0.340693985463089
"Other"	"(Intercept)"	-6.06666516734168	2.19790762448456	-2.76020024670709	0.00577659418462984
"Other"	"QARF21$BIM"	0.864951201181909	0.602133528364454	1.43647739319771	0.150866544643861

Table D.4. *Multinomial logistic regression to identify the impact of Parametric design on the floor geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Square"	"(Intercept)"	-2.18347290770863	1.20557792292454	-1.81114208064783	0.0701188610855212
"Square"	"QARF21$Parametricdesign"	-0.394306938975441	0.618342285267824	-0.637683930680326	0.523679448025903
"Curved"	"(Intercept)"	-4.18906441687993	2.43820789003288	-1.71809156799318	0.0857799145900309
"Curved"	"QARF21$Parametricdesign"	-0.0635371830304474	1.10974432515799	-0.0572538931626455	0.954342947993714
"Rectilinear"	"(Intercept)"	-1.08457263727378	0.735717075981372	-1.47417080924358	0.140435607228459
"Rectilinear"	"QARF21$Parametricdesign"	-0.394409081231258	0.37278295056255	-1.05801266027878	0.29004967057211

"Organic"	"(Intercept)"	-7.04148348312293	3.56638508714982	-1.97440357983056	0.0483358713247282
"Organic"	"QARF21$Parametricdesign"	1.07524739736525	1.14605992326993	0.938212196005735	0.348135371989063
"Free form"	"(Intercept)"	-7.04147848254154	3.56593866297024	-1.97464935548733	0.0483079539170773
"Free form"	"QARF21$Parametricdesign"	1.07536888359174	1.14588841404009	0.938458640837707	0.34800876216178
"Irregular"	"(Intercept)"	-3.49461302100837	1.73518753638631	-2.01396848912725	0.0440128419239545
"Irregular"	"QARF21$Parametricdesign"	-0.0639909645562229	0.789658639888446	-0.0810362368291986	0.935413134434924
"Polygonal"	"(Intercept)"	-5.65557141691909	1.82271444044454	-3.10282910555083	0.0019168029186234
"Polygonal"	"QARF21$Parametricdesign"	1.07545289131965	0.593930111188776	1.81073980096259	0.0701811387408074
"Other"	"(Intercept)"	-4.75654790338138	1.99941340943426	-2.37897169286629	0.0173610091049702
"Other"	"QARF21$Parametricdesign"	0.497955541162643	0.750405534203087	0.663581914666262	0.506957935614563

Table D.5. *Multinomial logistic regression to identify the impact of Algorithm design on the floor geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Square"	"(Intercept)"	-3.81060788642332	1.19231111989194	-3.19598452354338	0.00139354586425731
"Square"	"QARF21$Algorithmdesign"	0.490635233488701	0.544251889077479	0.901485586610164	0.367330193897102
"Curved"	"(Intercept)"	-7.8858599724605	3.59165760349919	-2.19560460461979	0.0281202563834582
"Curved"	"QARF21$Algorithmdesign"	1.55892665316544	1.16603644829051	1.33694504614409	0.181240575434933
"Rectilinear"	"(Intercept)"	-0.294472153548831	0.872891016944976	-0.337352713949849	0.735851026217245
"Rectilinear"	"QARF21$Algorithmdesign"	-1.14210506457703	0.683451830059256	-1.67108348291058	0.0947051893575299
"Organic"	"(Intercept)"	-7.88569907690275	3.58876293465206	-2.19733072941673	0.0279968345301334
"Organic"	"QARF21$Algorithmdesign"	1.55971245185674	1.16494356264619	1.33887383206258	0.180611749828884
"Free form"	"(Intercept)"	-5.15483225086279	2.32536718157292	-2.21678205993084	0.0266379880245163
"Free form"	"QARF21$Algorithmdesign"	0.470553585661974	1.05968413665583	0.444050797199774	0.65700585843882
"Irregular"	"(Intercept)"	-4.47214951095864	1.6603072216329	-2.69356746311102	0.00706918375388333
"Irregular"	"QARF21$Algorithmdesign"	0.473389704198856	0.758165134493547	0.624388649202498	0.532372377678138
"Polygonal"	"(Intercept)"	4.51928235827465	23.9596890147737	0.188620242753904	0.850390466174914
"Polygonal"	"QARF21$Algorithmdesign"	-6.90378718014578	23.9426693167637	-0.288346595310992	0.773081443096132
"Other"	"(Intercept)"	-5.72406773706576	1.98245358816668	-2.88736531903338	0.00388482882763778
"Other"	"QARF21$Algorithmdesign"	1.02895996662706	0.744067822964467	1.3828846442083	0.166700239468782

Table D.6. *Multinomial logistic regression to identify the impact of Generative Design on the floor geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Square"	"(Intercept)"	-3.71678718816351	1.11551027264438	-3.33191659396615	0.000862501014547206
"Square"	"QARF21$Generative Design"	0.391595778300769	0.446254633587608	0.877516442020072	0.380206192217644
"Curved"	"(Intercept)"	-6.44767522949946	2.70318598266737	-2.38521332636432	0.0170692200640859

"Curved"	"QARF21$Generative Design"	0.904687133101251	0.844587196777125	1.07115894789012	0.28409796667255
"Rectilinear "	"(Intercept)"	-0.522230465096337	0.755013024421389	-0.691684048095134	0.489135766840715
"Rectilinear "	"QARF21$Generative Design"	-0.892603344988343	0.534941704050798	-1.66859928517292	0.0951968206488681
"Organic"	"(Intercept)"	-6.44767052914591	2.70312582242402	-2.38526467235032	0.0170668376533966
"Organic"	"QARF21$Generative Design"	0.904708772355226	0.844561954609997	1.07121658442808	0.284072056290534
"Free form"	"(Intercept)"	-4.68781092401622	2.1034569859324	-2.22862219449581	0.0258390530456967
"Free form"	"QARF21$Generative Design"	0.195953872632534	0.924989951663853	0.211844325746519	0.832228486289311
"Irregular"	"(Intercept)"	-3.04806893654459	1.51353413523633	-2.01387525103201	0.0440226325400381
"Irregular"	"QARF21$Generative Design"	-0.352800121567834	0.885496325202533	-0.398420763053015	0.690320055381801
"Polygonal"	"(Intercept)"	-2.86412571823882	1.05543064074552	-2.71370339998438	0.00665357082557793
"Polygonal"	"QARF21$Generative Design"	-0.0379186651229439	0.526482579369245	-0.0720226397013412	0.942583890760179
"Other"	"(Intercept)"	-3.9944028394017	1.49704931214214	-2.6681838781156	0.00762625076727473
"Other"	"QARF21$Generative Design"	0.195832217889184	0.659400512377144	0.296985237671725	0.766477779593275

Table D.7. *Multinomial logistic regression to identify the impact of Performative design on the floor geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Square"	"(Intercept)"	-2.76869907286485	1.05660998727578	-2.62036049839288	0.00878368590325306
"Square"	"QARF21$Performativ edesign"	-0.0905660474438404	0.526502120301456	-0.172014592062774	0.863426057183688
"Curved"	"(Intercept)"	-4.59140317013172	2.09693672659779	-2.18957640061038	0.0285549720855693
"Curved"	"QARF21$Performativ edesign"	0.142826444473713	0.920873389892961	0.155098894203376	0.876743353935008
"Rectilinear"	"(Intercept)"	-0.430977257593539	0.750997021682118	-0.573873457751159	0.566053435342105
"Rectilinear"	"QARF21$Performativ edesign"	-0.941786731094927	0.529971993347125	-1.77705000059893	0.0755600135444739
"Organic"	"(Intercept)"	-6.24738243651189	2.56001705227137	-2.44036750886832	0.0146723269062804
"Organic"	"QARF21$Performativ edesign"	0.812561864976612	0.793076830368144	1.02456891168971	0.305566639649504
"Free form"	"(Intercept)"	8.61480232001141	701.240749732586	0.0122850851484267	0.990198166786739
"Free form"	"QARF21$Performativ edesign"	-12.2616018601342	701.238559607456	-0.0174856355118265	0.986049192296888
"Irregular "	"(Intercept)"	-2.95132787902716	1.5148119105515	-1.94831309317648	0.0513775114358138
"Irregular "	"QARF21$Performativ edesign"	-0.406325504850841	0.885876636763194	-0.458670528139751	0.646470781159635
"Polygonal "	"(Intercept)"	-3.61328611754637	1.10431589516321	-3.27196786116382	0.00106801716045477
"Polygonal "	"QARF21$Performativ edesign"	0.335207758815998	0.439825844940558	0.762137474802785	0.445977958582741
"Other"	"(Intercept)"	-2.95128642590586	1.51469277144315	-1.94843897161665	0.0513624604912925
"Other"	"QARF21$Performativ edesign"	-0.40625938630297	0.885778888046888	-0.458646499465299	0.646488039106362

Table D.8. *Multinomial logistic regression to identify the impact of Form finding design on the floor geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Square"	"(Intercept)"	-2.65461499172032	1.08705138060185	-2.44203267581574	0.0146048246555808
"Square"	"QARF21$Formfindingdesign"	-0.151963298096457	0.545463913370338	-0.278594595117208	0.78055596102508
"Curved"	"(Intercept)"	-4.51603142297864	2.18142639037982	-2.07021948707255	0.0384317951974177
"Curved"	"QARF21$Formfindingdesign"	0.101990855027696	0.968489166195537	0.105309236889392	0.916130433755078
"Rectilinear"	"(Intercept)"	-0.555696496464198	0.71539783999755	-0.776765689516342	0.437297022904501
"Rectilinear"	"QARF21$Formfindingdesign"	-0.811727635872775	0.466874177140737	-1.73864324826019	0.0820975342552479
"Organic"	"(Intercept)"	-6.48911952571251	2.84692083024648	-2.27934667405229	0.022646465567527
"Organic"	"QARF21$Formfindingdesign"	0.89594059559143	0.895157495468402	1.00087481826046	0.316887332228163
"Free form"	"(Intercept)"	8.04557604573529	469.944200567313	0.0171202794630144	0.986340660610854
"Free form"	"QARF21$Formfindingdesign"	-11.6155032542491	469.940927584271	-0.0247169432846773	0.980280740422311
"Irregular"	"(Intercept)"	-3.82246879825431	1.55217580469187	-2.46265196680677	0.0137913714461516
"Irregular"	"QARF21$Formfindingdesign"	0.10193857362727	0.689609854065622	0.147820645291373	0.882484315745342
"Polygonal"	"(Intercept)"	-3.58974008131702	1.16303248247634	-3.08653467156284	0.00202504328737346
"Polygonal"	"QARF21$Formfindingdesign"	0.31874021749826	0.468211658444958	0.680760958744325	0.496022757310589
"Other"	"(Intercept)"	-4.75104099443818	1.72678453777897	-2.75138032018116	0.00593447000814767
"Other"	"QARF21$Formfindingdesign"	0.51597974474927	0.633688139313652	0.814248701748036	0.415502490603237

Table D.9. *Multinomial logistic regression to identify the impact of Machine based learning design on the floor geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Square"	"(Intercept)"	-2.26770281856827	1.36187928043011	-1.66512762999969	0.0958872953969618
"Square"	"QARF21$Machinebasedlearningdesign"	-0.500517300053922	1.00453380890856	-0.498258292170116	0.618302000862287
"Curved"	"(Intercept)"	9.6474947206821	0.504898472541021	19.1077914578129	2.17480148335439e-81
"Curved"	"QARF21$Machinebasedlearningdesign"	-13.5594021917032	0.504898860502778	-26.8556799240956	7.23989894116893e-159
"Rectilinear"	"(Intercept)"	-0.696914848969113	0.909771196091499	-0.766033099270624	0.443656607885765
"Rectilinear"	"QARF21$Machinebasedlearningdesign"	-0.892197202565586	0.721370953634879	-1.23680777285243	0.21615845570766
"Organic"	"(Intercept)"	9.64738982094901	0.504950407823242	19.1056184359516	2.26725487165463e-81
"Organic"	"QARF21$Machinebasedlearningdesign"	-13.55950708974	0.504950795779193	-26.8531254987255	7.75470437070407e-159

"Free form"	"(Intercept)"	-128.318371518115	281.313139417453	-0.456140697103015	0.648288806630186
"Free form"	"QARF21$Machinebasedlearningdesign"	36.8360965457179	863.458869660365	0.0426610899951808	0.965971696999255
"Irregular"	"(Intercept)"	9.28948993385869	596.752873997091	0.015566728437581	0.987580049326158
"Irregular"	"QARF21$Machinebasedlearningdesign"	-12.5083341883666	596.751568746486	-0.0209607060013955	0.983277000851871
"Polygonal"	"(Intercept)"	-3.22126755425243	1.23813521182389	-2.60170902457996	0.00927605180969408
"Polygonal"	"QARF21$Machinebasedlearningdesign"	0.199258219016181	0.753653367307182	0.264389741570631	0.791479615423329
"Other"	"(Intercept)"	-3.91367070119603	1.7278531777273	-2.26504818328592	0.0235097228748504
"Other"	"QARF21$Machinebasedlearningdesign"	0.198819948368681	1.05010290824706	0.189333775582596	0.849831224944908

Table D.10. *Multinomial logistic regression to identify the impact of 2D design software tool` on the facade geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Square"	"(Intercept)"	-0.952759800885822	1.26540195717755	-0.752930557347115	0.451491644490822
"Square"	"QARF21$`@2Ddesignsoftwaretool`"	-0.340424339270771	0.317810017322952	-1.07115673111348	0.28409896325168
"Triangular"	"(Intercept)"	-41.2322637974698	331.596464223502	-0.124344702812267	0.901042354196631
"Triangular"	"QARF21$`@2Ddesignsoftwaretool`"	7.52253654755639	66.3220654150407	0.113424340760208	0.909694143094997
"Curved"	"(Intercept)"	-41.2220870223332	331.257341448684	-0.124441278318715	0.900965891959128
"Curved"	"QARF21$`@2Ddesignsoftwaretool`"	7.52050319909588	66.2542436659171	0.113509758514753	0.909626426908747
"Rectilinear"	"(Intercept)"	-0.912268771878622	1.10199836664671	-0.827831328511478	0.407766029809521
"Rectilinear"	"QARF21$`@2Ddesignsoftwaretool`"	-0.209844478501017	0.266354819952899	-0.787838112102215	0.430791404987475
"Free form"	"(Intercept)"	-6.07648407827124	4.1415515117404	-1.46719992762271	0.142321676626897
"Free form"	"QARF21$`@2Ddesignsoftwaretool`"	0.655704837593262	0.880077432776875	0.745053575029576	0.456239332813507
"Irregular"	"(Intercept)"	-47.8597947644563	338.136089704871	-0.141540037344813	0.887443333164646
"Irregular"	"QARF21$`@2Ddesignsoftwaretool`"	9.16996080031546	67.6278095386145	0.135594526318046	0.892141832852919
"Polygonal"	"(Intercept)"	-5.09642805375461	3.94781540307423	-1.29094892577448	0.196721388428491
"Polygonal"	"QARF21$`@2Ddesignsoftwaretool`"	0.353817875420202	0.863779527016197	0.409615954481365	0.682087691426198
"Other"	"(Intercept)"	-1.61307532318313	2.41407383701793	-0.66819634861531	0.504008265933499
"Other"	"QARF21$`@2Ddesignsoftwaretool`"	-0.722039379269712	0.720409300475395	-1.00226271203501	0.316216726578506

Table D.11. *Multinomial logistic regression to identify the impact of 3D modeling software tool on the facade geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Square"	"(Intercept)"	-2.09522689107251	1.80332287330292	-1.16187008000123	0.245288242223236
"Square"	"QARF21$`@3dmodelingsoftwaretool`"	-0.0497954521117455	0.424220163235159	-0.11738115353122	0.906558018124245
"Triangular"	"(Intercept)"	-42.1878577908362	274.736448985824	-0.153557556511233	0.877958604911894
"Triangular"	"QARF21$`@3dmodelingsoftwaretool`"	7.74495633131329	54.950658201316	0.140943831881668	0.88791431490963
"Curved"	"(Intercept)"	-42.2015295743464	275.095065698114	-0.153407075722172	0.878077265315758
"Curved"	"QARF21$`@3dmodelingsoftwaretool`"	7.74772230495472	55.0223766388565	0.140810389849342	0.888019734937437
"Rectilinear"	"(Intercept)"	-6.87666487252707	2.83369731891659	-2.42674643710932	0.0152348995073801
"Rectilinear"	"QARF21$`@3dmodelingsoftwaretool`"	1.13034939073977	0.597209787373459	1.89271745814996	0.0583954534601646
"Free form"	"(Intercept)"	-3.97311911963876	3.09658021311605	-1.28306675306197	0.199468690452644
"Free form"	"QARF21$`@3dmodelingsoftwaretool`"	0.193088926124692	0.702192181321287	0.274980171042868	0.783331472496914
"Irregular"	"(Intercept)"	-8.75685247878303	4.83601664496165	-1.81075730744357	0.0701784275860927
"Irregular"	"QARF21$`@3dmodelingsoftwaretool`"	1.34082127221955	1.00604565035483	1.33276384798906	0.182609313048191
"Polygonal"	"(Intercept)"	-41.7768799376273	199.815984152632	-0.209076766880248	0.834388311240954
"Polygonal"	"QARF21$`@3dmodelingsoftwaretool`"	7.80142880011621	39.9655754541286	0.195203714983923	0.845233470869073
"Other"	"(Intercept)"	-42.1988918771822	275.023258440915	-0.153437538760919	0.878053243712781
"Other"	"QARF21$`@3dmodelingsoftwaretool`"	7.74719336222962	55.0080160879267	0.140837534475816	0.887998290354708

Table D.12. *Multinomial logistic regression to identify the impact of BIM on the facade geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Square"	"(Intercept)"	-1.38474611883332	0.84987408811412	-1.62935443991013	0.103238007687281
"Square"	"QARF21$BIM"	-0.512319620465376	0.46875488781158	-1.09293712724188	0.274421405702321
"Triangular"	"(Intercept)"	-5.83778416011893	2.57918393071545	-2.26342297290119	0.0236096279292422
"Triangular"	"QARF21$BIM"	0.633804161313176	0.796080632665432	0.796155735118284	0.425941522243242
"Curved"	"(Intercept)"	-4.15111436346402	2.11706278148263	-1.96078944836813	0.0499035894402044

"Curved"	"QARF21$BIM"	-0.0480025396031705	0.930851314644152	-0.0515684286501986	0.958872576141626
"Rectilinear"	"(Intercept)"	-2.90718658204516	0.74525769553276	-3.90091454200539	9.58299777658167e-05
"Rectilinear"	"QARF21$BIM"	0.478926963770885	0.257591079666776	1.85925290732285	0.0629912986849954
"Free form"	"(Intercept)"	-3.05266538814418	1.2395540863131	-2.46271253658964	0.0137890420644973
"Free form"	"QARF21$BIM"	-0.0478980438898895	0.544602145404999	-0.0879505236878375	0.92991600005777
"Irregular"	"(Intercept)"	-2.87599026286784	0.992967317913369	-2.89635943800394	0.00377519722795784
"Irregular"	"QARF21$BIM"	0.111353199971963	0.401146166433789	0.277587595967572	0.781328955057032
"Polygonal"	"(Intercept)"	-2.46886497294252	1.55941176125231	-1.58320273983303	0.11337526219843
"Polygonal"	"QARF21$BIM"	-0.622272729331744	0.916820400330963	-0.678729148159345	0.497309493845778
"Other"	"(Intercept)"	-8.36304402617371	4.05139649040772	-2.06423736752857	0.038995216162173
"Other"	"QARF21$BIM"	1.34821489849037	0.991751483893454	1.35942816359347	0.174010951658703

Table D.13. *Multinomial logistic regression to identify the impact of parametric design on the facade geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Square"	"(Intercept)"	-2.47848916858716	0.962883829323458	-2.57402720152503	0.01005223698192
"Square"	"QARF21$Parametricdesign"	0.0892173032948096	0.440192289558945	0.202678023697784	0.839386701218381
"Triangular"	"(Intercept)"	-4.4274993083642	2.44632634714095	-1.80985636423312	0.0703180644928704
"Triangular"	"QARF21$Parametricdesign"	0.0921386506754413	1.11423436140033	0.0826923436104093	0.934096172936374
"Curved"	"(Intercept)"	-38.0583276512336	187.958988076468	-0.202482084207381	0.839539863066914
"Curved"	"QARF21$Parametricdesign"	9.21433140792566	46.9952318292276	0.196069495760951	0.844555771684548
"Rectilinear"	"(Intercept)"	-2.99152746004047	0.848842624986996	-3.52424274179952	0.000424694989513119
"Rectilinear"	"QARF21$Parametricdesign"	0.566550971003507	0.337605127789653	1.67814681818607	0.0933184408475142
"Free form"	"(Intercept)"	-4.16308776873702	1.56422805978682	-2.66143273846166	0.00778088850124903
"Free form"	"QARF21$Parametricdesign"	0.475676083530496	0.625512406338216	0.760458271827301	0.446980702975202
"Irregular"	"(Intercept)"	-4.37451369908874	1.35478783565227	-3.22892897616151	0.00124254749485247
"Irregular"	"QARF21$Parametricdesign"	0.76789565571278	0.499931641344523	1.5360013093942	0.124538059205349
"Polygonal"	"(Intercept)"	-5.00425773471485	2.01320034778481	-2.48572266551673	0.0129288677582765
"Polygonal"	"QARF21$Parametricdesign"	0.657440460332503	0.75846489031024	0.866804078516522	0.386049367052493
"Other"	"(Intercept)"	-4.42850228349523	2.45175594522242	-1.80625738549743	0.0708781449463
"Other"	"QARF21$Parametricdesign"	0.0900474789369708	1.11756493801813	0.0805747172926336	0.935780173490838

Table D.14. *Multinomial logistic regression to identify the impact of Algorithm design on the facade geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"

"Square"	"(Intercept)"	-2.7358427976919	0.867957952273175	-3.15204531570538	0.00162131109458776
"Square"	"QARF21$Algorithmdesign"	0.267794508424917	0.455782386485701	0.5875490505233	0.556835017734101
"Triangular"	"(Intercept)"	5.42218170280904	168.337222497277	0.0322102362292258	0.974304393085472
"Triangular"	"QARF21$Algorithmdesign"	-9.21547785560522	168.328112535946	-0.0547471109654205	0.956339936493715
"Curved"	"(Intercept)"	-5.28961811864922	2.29410755949281	-2.30574111347189	0.021125102356719
"Curved"	"QARF21$Algorithmdesign"	0.595366746963551	1.03549637855197	0.574957826309452	0.565319819825334
"Rectilinear"	"(Intercept)"	-2.80335703164912	0.715472463186096	-3.91818997360904	8.92163821505937e-05
"Rectilinear"	"QARF21$Algorithmdesign"	0.595011181410291	0.337862358930382	1.76110527166743	0.0782205869488198
"Free form"	"(Intercept)"	-2.5931961140545	1.37763419509945	-1.88235463614294	0.0597878808449358
"Free form"	"QARF21$Algorithmdesign"	-0.391194635642282	0.929669368717806	-0.420788991017113	0.673909171309538
"Irregular"	"(Intercept)"	-3.67851676375823	1.05620919278108	-3.48275397421265	0.000496284223954328
"Irregular"	"QARF21$Algorithmdesign"	0.59510997993563	0.485708539014054	1.22524092564576	0.220484458846911
"Polygonal"	"(Intercept)"	11.6517789878845	0.36138202109427	32.2422763384928	4.51398315198102e-228
"Polygonal"	**"QARF21$Algorithmdesign"**	**-14.7504776357418**	**0.361382105690413**	**-40.8168456696584**	**0**
"Other"	"(Intercept)"	-5.28963591839795	2.29420055448527	-2.30565540926946	0.0211298945503795
"Other"	"QARF21$Algorithmdesign"	0.595326089522897	1.03555551566154	0.574885730913794	0.565368580849235

Table D.15. *Multinomial logistic regression to identify the impact of Generative Design on the facade geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Square"	"(Intercept)"	-3.24616454828661	0.851715630480834	-3.81132438118342	0.000138224240171737
"Square"	"QARF21$GenerativeDesign"	0.508117336401195	0.363787516177075	1.39674209203448	0.162491141610954
"Triangular"	"(Intercept)"	5.04449551498579	133.293989355924	0.0378448836242413	0.969811358028817
"Triangular"	"QARF21$GenerativeDesign"	-8.79300399853781	133.282494618978	-0.0659726847375933	0.947399572485298
"Curved"	"(Intercept)"	-4.95205754539142	2.11200595073761	-2.34471761012886	0.0190414952702903
"Curved"	"QARF21$GenerativeDesign"	0.392239739742293	0.931954366800833	0.420878697192819	0.673843661643814
"Rectilinear"	"(Intercept)"	-2.46793989315259	0.658170462940745	-3.74969712576539	0.000177048276031329
"Rectilinear"	"QARF21$GenerativeDesign"	0.39235627270514	0.300878286057747	1.30403651870656	0.192221131366148
"Free form"	"(Intercept)"	-3.25461076482068	1.21857922520157	-2.67082410196376	0.0075665285778311
"Free form"	"QARF21$GenerativeDesign"	0.0638737979225734	0.640738684490512	0.0996877501993859	0.920592226019845
"Irregular"	"(Intercept)"	-4.72577847805109	1.18055699810096	-4.00300746652043	6.25423275643372e-05
"Irregular"	**"QARF21$GenerativeDesign"**	**0.972334782671873**	**0.40962645499218**	**2.37371090373163**	**0.0176103326281916**
"Polygonal"	"(Intercept)"	-4.25760975819137	1.50416224497552	-2.83055220433396	0.00464677273420545
"Polygonal"	"QARF21$GenerativeDesign"	0.391795059318564	0.666427761469806	0.58790326869706	0.556597222329855
"Other"	"(Intercept)"	-4.95210267320869	2.11227526314187	-2.34444002617479	0.0190556749108039
"Other"	"QARF21$GenerativeDesign"	0.392114829354011	0.932134400525707	0.420663403402842	0.67400088824238

Table D.16. *Multinomial logistic regression to identify the impact of performative Design on the facade geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Square"	"(Intercept)"	-2.61020852208208	0.811562245718977	-3.21627642962821	0.00129865675917597
"Square"	"QARF21$Performativedesign"	0.173899384825534	0.385038285412495	0.451641801384073	0.651527050979879
"Triangular"	"(Intercept)"	4.15909229807146	86.1124041526202	0.0482984111174059	0.961478420822441
"Triangular"	"QARF21$Performativedesign"	-7.86919715315178	86.0945898631588	-0.0914017613146111	0.927173362282817
"Curved"	"(Intercept)"	-4.79661714587823	2.08100358392176	-2.30495381312066	0.0211691602758341
"Curved"	"QARF21$Performativedesign"	0.298349758394243	0.912691287717167	0.326890113239142	0.743750999158787
"Rectilinear"	"(Intercept)"	-2.30946598864706	0.647373451195778	-3.56744006783287	0.000360485793325326
"Rectilinear"	"QARF21$Performativedesign"	0.297508381809569	0.29188653974783	1.01926036762982	0.308079374001142
"Free form"	"(Intercept)"	-3.11308878084772	1.20768473008961	-2.57773299875766	0.00994508090668253
"Free form"	"QARF21$Performativedesign"	-0.0218639669258	0.632203739935736	-0.0345837355027708	0.972411670930469
"Irregular"	"(Intercept)"	-3.50497181011284	0.982014608201567	-3.56916463445665	0.000358121331750682
"Irregular"	"QARF21$Performativedesign"	0.450167440181408	0.40279951635005	1.11759677434715	0.263739247062829
"Polygonal"	"(Intercept)"	-4.89404897809529	1.60188076252781	-3.05518930783111	0.00224918504443035
"Polygonal"	"QARF21$Performativedesign"	0.65140270577831	0.58216714435881	1.11892729105445	0.263171159068427
"Other"	"(Intercept)"	-4.79654566941131	2.08102002840945	-2.30490125223704	0.0211721044706371
"Other"	"QARF21$Performativedesign"	0.298300368776553	0.912723952351778	0.32682430214298	0.743800777465894

Table D.17. *Multinomial logistic regression to identify the impact of Form finding design on the facade geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Square"	"(Intercept)"	-3.0460158569592	0.875145239084135	-3.48058324598434	0.000500323318946559
"Square"	"QARF21$Formfindingdesign"	0.384529286805971	0.371928416139188	1.03387982773026	0.301192346505848
"Triangular"	"(Intercept)"	4.65525880953598	97.8203545145748	0.0475898787388096	0.962043098487634
"Triangular"	"QARF21$Formfindingdesign"	-8.29331551241848	97.8046580446909	-0.0847946884966249	0.932424616298922
"Curved"	"(Intercept)"	-4.73213148002647	2.17119576393756	-2.17950474969817	0.0292941922099308
"Curved"	"QARF21$Formfindingdesign"	0.259281063115828	0.963920960338723	0.268985812928808	0.787940600102339
"Rectilinear"	"(Intercept)"	-2.54972038263835	0.692908817409326	-3.6797343583696	0.000233477036128151
"Rectilinear"	"QARF21$Formfindingdesign"	0.404477851626097	0.295862235016311	1.36711551443461	0.171589101109001

"Free form"	"(Intercept)"	-2.9970853806711	1.24187088405855	-2.4133631113698	0.0158060639738049
"Free form"	"QARF21$Formfindingdesign"	-0.0895639995732617	0.654492899503908	-0.136844875843801	0.891153411485811
"Irregular"	"(Intercept)"	-3.48640198062979	1.03359539570426	-3.37308195752389	0.00074331823895762
"Irregular"	"QARF21$Formfindingdesign"	0.432376722135567	0.427603314864749	1.01116316713384	0.311938341455954
"Polygonal"	"(Intercept)"	-4.95049314050814	1.71786539177251	-2.88177011087008	0.00395448132607728
"Polygonal"	"QARF21$Formfindingdesign"	0.666094221065649	0.6328123692709	1.05259355444189	0.292527312542156
"Other"	"(Intercept)"	-4.73215168691711	2.171330117043	-2.17937919700646	0.0293035102332593
"Other"	"QARF21$Formfindingdesign"	0.259218510421602	0.964010216435889	0.268896019982005	0.788009699807754

Table D.18. *Multinomial logistic regression to identify the impact of Machine based learning design on the facade geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Square"	"(Intercept)"	-2.59378373262634	0.934718479494392	-2.7749357582289	0.00552126128537776
"Square"	"QARF21$Machinebasedlearningdesign"	0.210337561352838	0.596389429843868	0.352684925029444	0.724324662136871
"Triangular"	"(Intercept)"	2.3444578666078	41.7796835093901	0.0561147828245487	0.955250367503643
"Triangular"	"QARF21$Machinebasedlearningdesign"	-6.26783286318488	41.7431159351797	-0.150152491560951	0.880644307098069
"Curved"	"(Intercept)"	-5.98580168827931	2.39426786372732	-2.50005514377193	0.0124173976315894
"Curved"	"QARF21$Machinebasedlearningdesign"	1.06946182546065	1.09968882521788	0.972513133657386	0.330795334259429
"Rectilinear"	"(Intercept)"	-2.01687128437448	0.740817653699743	-2.72249355060851	0.00647912980755828
"Rectilinear"	"QARF21$Machinebasedlearningdesign"	0.183658637332642	0.478323116253282	0.383963540736323	0.701005470359635
"Free form"	"(Intercept)"	-4.88860587317972	1.41781325909812	-3.44798995340853	0.000564775044471755
"Free form"	"QARF21$Machinebasedlearningdesign"	1.07033483251567	0.666702110583449	1.60541689537925	0.108402088668731
"Irregular"	"(Intercept)"	-2.00132732982141	1.28043060531843	-1.56301116320451	0.118049969146188
"Irregular"	"QARF21$Machinebasedlearningdesign"	-0.504304516644756	0.98967812085699	-0.509564176490094	0.610356826592867
"Polygonal"	"(Intercept)"	-5.29393825325951	1.71474875533176	-3.08729674641769	0.00201985849735949
"Polygonal"	"QARF21$Machinebasedlearningdesign"	1.070343875629	0.797128159345647	1.34275004976318	0.179352922400717
"Other"	"(Intercept)"	-5.98582578969491	2.39415428302791	-2.50018381527384	0.0124128881932695
"Other"	"QARF21$Machinebasedlearningdesign"	1.06953665703772	1.09960749942167	0.972653112679057	0.330725735812855

Table D.19. *Multinomial logistic regression to identify the impact of 2D design software tool on the roof geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Flat Square"	"(Intercept)"	-2.21801261242073	1.85812978029361	-1.19368013792355	0.232603112855626
"Flat Square"	"QARF21$`@2Ddesignsoftwaretool`"	-0.0501432559652524	0.445253835949591	-0.11261723519644	0.910334020268246
"Flat Triangular"	"(Intercept)"	-3.6051817128916	3.59170222338628	-1.00375295296407	0.315497706433719
"Flat Triangular"	"QARF21$`@2Ddesignsoftwaretool`"	-0.0500175619936686	0.861347629100004	-0.0580689611300497	0.95369369808819
"Flat Curved"	"(Intercept)"	-53.8799993893926	0.0392416791734986	-1373.02991421885	0
"Flat Curved"	**"QARF21$`@2Ddesignsoftwaretool`"**	**10.155841964412**	**0.196207416003792**	**51.7607446816163**	**0**
"Flat Rectilinear"	"(Intercept)"	-3.64916383276477	2.03115779845926	-1.79659297546101	0.0724002604010161
"Flat Rectilinear"	"QARF21$`@2Ddesignsoftwaretool`"	0.446274492650516	0.446935385156568	0.998521279522718	0.318026651089854
"Flat Organic"	"(Intercept)"	-53.8902162844506	0.0392424717135644	-1373.26253753336	0
"Flat Organic"	**"QARF21$`@2Ddesignsoftwaretool`"**	**10.1578769343704**	**0.196211380711301**	**51.7700701026939**	**0**
"Flat Free form"	"(Intercept)"	-62.8667029241285	0.0282975328226987	-2221.63194643246	0
"Flat Free form"	**"QARF21$`@2Ddesignsoftwaretool`"**	**12.0916885091876**	**0.141487439097299**	**85.4612154006993**	**0**
"Flat Irregular"	"(Intercept)"	-62.8456408623165	0.0282930064457643	-2221.24294152999	0
"Flat Irregular"	**"QARF21$`@2Ddesignsoftwaretool`"**	**12.0875453327731**	**0.141464806203463**	**85.4456006208928**	**0**
"Flat Polygonal"	"(Intercept)"	-2.21783747818556	1.85808706472905	-1.19361332430833	0.232629259458387
"Flat Polygonal"	"QARF21$`@2Ddesignsoftwaretool`"	-0.0501981958708375	0.445249620007329	-0.112741692783503	0.910235345891272
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"(Intercept)"	-0.739603759736872	0.913969722787438	-0.809221291796426	0.418387869910568
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"QARF21$`@2Ddesignsoftwaretool`"	0.0811149239617144	0.21384698390541	0.379312920296288	0.704455506293491
"Pyramidal"	"(Intercept)"	-3.60879616952239	3.59481182328948	-1.00389014694519	0.315431566305892
"Pyramidal"	"QARF21$`@2Ddesignsoftwaretool`"	-0.0492043702033468	0.861908914762738	-0.0570876682681622	0.954475359699865
"Others"	"(Intercept)"	-3.72378177946289	2.71000742003025	-1.37408545524253	0.169415154317472
"Others"	"QARF21$`@2Ddesignsoftwaretool`"	0.241296487033512	0.611573765831717	0.394550094386992	0.693174950332777

Table D.20. *Multinomial logistic regression to identify the impact of 3dmodeling software tool on the roof geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Flat Square"	"(Intercept)"	2.48994369352457	2.06317465320428	1.20685066078021	0.227489661781914
"Flat Square"	**"QARF21$`@3dmodelingsoftwaretool`"**	**-1.20490156016047**	**0.536644462676724**	**-2.24525108141535**	**0.0247520185141367**
"Flat Triangular"	"(Intercept)"	-0.641008335762794	4.35503856238224	-0.147187751975302	0.882983827813188
"Flat Triangular"	"QARF21$`@3dmodelingsoftwaretool`"	-0.739124807120793	1.05538859856948	-0.70033427319817	0.483718572629799
"Flat Curved"	"(Intercept)"	-41.6501216569516	326.879280199092	-0.12741744178947	0.898610012202427
"Flat Curved"	"QARF21$`@3dmodelingsoftwaretool`"	7.66673951241008	65.3786836140794	0.117266654643365	0.9066487484186
"Flat Rectilinear"	"(Intercept)"	0.815326723346739	1.92115532349845	0.424393964076793	0.671278521946576
"Flat Rectilinear"	"QARF21$`@3dmodelingsoftwaretool`"	-0.586399439214495	0.445869690196093	-1.31518121125613	0.188449008119238
"Flat Organic"	"(Intercept)"	-41.6662055771007	327.268696580679	-0.127314973941692	0.898691109256888
"Flat Organic"	"QARF21$`@3dmodelingsoftwaretool`"	7.67016537628085	65.456560655047	0.117179474441107	0.906717831875253
"Flat Free form"	"(Intercept)"	-54.4403478273862	0.0281368472919181	-1934.84178460262	0
"Flat Free form"	**"QARF21$`@3dmodelingsoftwaretool`"**	**10.3633970342914**	**0.140582089788259**	**73.7177619844777**	**0**
"Flat Irregular"	"(Intercept)"	-54.4215478825505	0.0281323838040744	-1934.48049982414	0
"Flat Irregular"	**"QARF21$`@3dmodelingsoftwaretool`"**	**10.3597077861134**	**0.140558823468543**	**73.703717279847**	**0**
"Flat Polygonal"	"(Intercept)"	-67.9274455771461	0.0205088160523232	-3312.10955346452	0
"Flat Polygonal"	**"QARF21$`@3dmodelingsoftwaretool`"**	**13.1994745841735**	**0.102541814032841**	**128.722850367618**	**0**
"Pitched : Hip Gable	"(Intercept)"	2.26110896094315	1.31647973187788	1.71754179437143	0.0858802248711644

Mansard Gambrel butterfly etc"					
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"QARF21$`@3dmodelingsoftwaretool`"	-0.616516510508328	0.299364663031533	-2.05941644636724	0.0394543615916449
"Pyramidal"	"(Intercept)"	2.5751922186756	3.3678518849579	0.76463939230148	0.444486305396814
"Pyramidal"	"QARF21$`@3dmodelingsoftwaretool`"	-1.65834808901383	1.0317614206493	-1.60729802047668	0.107989008341096
"Others"	"(Intercept)"	1.65852298055275	2.3775252489761	0.697583750694972	0.485437546508648
"Others"	"QARF21$`@3dmodelingsoftwaretool`"	-1.05325134771107	0.605034911000333	-1.7408108665493	0.081716736576133

Table D.21. *Multinomial logistic regression to identify the impact of BIM on the roof geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Flat Square"	"(Intercept)"	-1.01761498468254	1.14485166880451	-0.888861860807841	0.374077324873075
"Flat Square"	"QARF21$BIM"	-0.77018922934978	0.662309351194405	-1.16288442547402	0.244876397228312
"Flat Triangular"	"(Intercept)"	-3.40032098124335	2.12882893332838	-1.59727300207585	0.110204866123872
"Flat Triangular"	"QARF21$BIM"	-0.191722112737736	0.934321162928639	-0.205199368637634	0.837416362703339
"Flat Curved"	"(Intercept)"	-3.40033578375264	2.12885057051177	-1.59726372102069	0.110206934059403
"Flat Curved"	"QARF21$BIM"	-0.191725369558705	0.934332375501395	-0.205200391836812	0.837415563316807
"Flat Rectilinear"	"(Intercept)"	-1.1012051902866	0.809345513947585	-1.36061196523531	0.17363634832912
"Flat Rectilinear"	"QARF21$BIM"	-0.305205362191774	0.370481133447396	-0.823808109610821	0.410048598967971
"Flat Organic"	"(Intercept)"	-3.40033740152556	2.12877548989966	-1.59732081549183	0.110194213180689
"Flat Organic"	"QARF21$BIM"	-0.191685352632263	0.934278704691386	-0.205169347936257	0.837439816808189
"Flat Free form"	"(Intercept)"	14.0261505962493	0.372755163098863	37.6283201006373	0
"Flat Free form"	**"QARF21$BIM"**	**-16.0618075425598**	**0.372755231409938**	**-43.0894221975273**	**0**
"Flat Irregular"	"(Intercept)"	-3.52845408250128	1.62634223706386	-2.16956431560889	0.0300398671375151
"Flat Irregular"	"QARF21$BIM"	0.175058021079731	0.58556570335852	0.298955386348079	0.764974086180741
"Flat Polygonal"	"(Intercept)"	-3.69019298014613	1.32197846411956	-2.79141686517852	0.00524778366954308
"Flat Polygonal"	"QARF21$BIM"	0.486280094775	0.41446978768605	1.17325824275362	0.240692262098905
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"(Intercept)"	-0.223007080402003	0.505054373374217	-0.441550637235582	0.658814411145575
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"QARF21$BIM"	-0.0833709048913875	0.205208334749958	-0.406274457579771	0.684540950794192
"Pyramidal"	"(Intercept)"	10.5659371252974	0.513737458947613	20.5668030260858	5.44384421565788e-94
"Pyramidal"	"QARF21$BIM"	-13.2946762668396	0.513738680390107	-25.8782855453755	1.16940375551873e-147
"Others"	"(Intercept)"	-1.68205842633979	1.26419229376692	-1.33054000932703	0.183340413221126
"Others"	"QARF21$BIM"	-0.531668727904663	0.658186023151916	-0.807778818150244	0.41921792093702

Table D.22. *Multinomial logistic regression to identify the impact of parametric design on the roof geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Flat Square"	"(Intercept)"	-1.9801832783043	1.27484657290536	-1.55327183708977	0.120358205502935
"Flat Square"	"QARF21$Parametricdesign"	-0.210769626232236	0.577597972458038	-0.364907143519359	0.715180721720281
"Flat Triangular"	"(Intercept)"	-3.36937569661293	2.46412164482966	-1.36737392964455	0.171508129610938
"Flat Triangular"	"QARF21$Parametricdesign"	-0.209631246827623	1.12110939828738	-0.186985540526071	0.851671969986325
"Flat Curved"	"(Intercept)"	-3.36935431854843	2.4640339634156	-1.36741391091781	0.171495604484313
"Flat Curved"	"QARF21$Parametricdesign"	-0.209600676853699	1.12105681289426	-0.186967042564567	0.851686473473533

"Flat Rectilinear"	"(Intercept)"	-0.979129165684877	0.926652489344288	-1.05663037324566	0.290680312944494
"Flat Rectilinear"	"QARF21$Parametricdesign"	-0.369936273100962	0.43959709994007	-0.84153483531032	0.400048378205851
"Flat Organic"	"(Intercept)"	-6.24852787255455	3.5829583208018	-1.74395773355138	0.0811664602312818
"Flat Organic"	"QARF21$Parametricdesign"	0.94032894468485	1.15255689220119	0.815863365225275	0.414578287105772
"Flat Free form"	"(Intercept)"	-1.35488509533749	1.72738575295872	-0.784355835410125	0.432831345261496
"Flat Free form"	"QARF21$Parametricdesign"	-0.973315232807176	1.02960708202272	-0.945326862840764	0.344492028174535
"Flat Irregular"	"(Intercept)"	-5.55417989587986	2.55619329672094	-2.1728325095777	0.029792925546492
"Flat Irregular"	"QARF21$Parametricdesign"	0.939943651433816	0.826761747800384	1.13689784745672	0.255580992090364
"Flat Polygonal"	"(Intercept)"	-3.99083303989661	1.61303694380254	-2.47411136814306	0.013356805271167
"Flat Polygonal"	"QARF21$Parametricdesign"	0.637413293092153	0.564565877220936	1.12903262278232	0.258884072098026
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"(Intercept)"	0.447256288651836	0.581106926977975	0.769662635029626	0.441500040038082
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"QARF21$Parametricdesign"	-0.426272093398089	0.270405121718679	-1.57642019015294	0.114928998383253
"Pyramidal"	"(Intercept)"	8.89822243560274	266.500044351626	0.0333891968282836	0.973364224542872
"Pyramidal"	"QARF21$Parametricdesign"	-11.420966435258	266.494083803001	-0.0428563601573261	0.965816036314883
"Others"	"(Intercept)"	-3.10140233366534	1.5769924771689	-1.9666563909253	0.0492228376173863
"Others"	"QARF21$Parametricdesign"	0.174469261397472	0.628364541494183	0.277656121369616	0.781276346635702

Table D.23. *Multinomial logistic regression to identify the impact of algorithm design on the roof geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Flat Square"	"(Intercept)"	-3.64796222747266	1.33313897841628	-2.73637054090662	0.00621210324862248
"Flat Square"	"QARF21$Algorithmdesign"	0.619646046592651	0.557890311025931	1.11069512114873	0.2666996029899
"Flat Triangular"	"(Intercept)"	-4.43793637991761	2.41069839959642	-1.84093388897615	0.0656312474445344
"Flat Triangular"	"QARF21$Algorithmdesign"	0.338605755162638	1.09762579631364	0.30848924679052	0.757710081356289
"Flat Curved"	"(Intercept)"	-7.35743141326834	3.7361455793525	-1.96925715473416	0.0489235685736403
"Flat Curved"	"QARF21$Algorithmdesign"	1.49959469870112	1.21558478498123	1.23364056315025	0.217336870895537
"Flat Rectilinear"	"(Intercept)"	12.6584318373242	435.841197163412	0.0290436790273824	0.976829754447563
"Flat Rectilinear"	"QARF21$Algorithmdesign"	-13.6934251196527	435.84063652137	-0.0314184221759261	0.974935849631404
"Flat Organic"	"(Intercept)"	-7.35704817358357	3.73579001274051	-1.96934199954846	0.0489138312907993
"Flat Organic"	"QARF21$Algorithmdesign"	1.49950143701898	1.21549292421619	1.23365706796354	0.217330718041776
"Flat Free form"	"(Intercept)"	11.369369506842	0.368202842556882	30.8780057967249	2.3579246875515e-209
"Flat Free form"	"QARF21$Algorithmdesign"	-13.7908866639397	0.368203326869656	-37.4545411666572	5.06657810437317e-307
"Flat Irregular"	"(Intercept)"	-3.74407250041201	1.7218842551512	-2.17440428368586	0.0296747866726738
"Flat Irregular"	"QARF21$Algorithmdesign"	0.338453095064223	0.786447158935559	0.430357070044366	0.666935918673014
"Flat Polygonal"	"(Intercept)"	13.4443173266267	0.270275601761499	49.7429928524973	0
"Flat Polygonal"	**"QARF21$Algorithmdesign"**	**-15.1724770987221**	**0.270275745138065**	**-56.1370280968852**	**0**
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"(Intercept)"	0.499739838263346	0.554637498357985	0.901020648158186	0.367577341339261
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"QARF21$Algorithmdesign"	-0.582984730958825	0.333539113693509	-1.74787515773797	0.0804856473751095
"Pyramidal"	"(Intercept)"	9.34876013091717	666.810434933414	0.0140201167245541	0.988813931788467
"Pyramidal"	"QARF21$Algorithmdesign"	-12.463817653757	666.808098850801	-0.0186917610557484	0.9850870008332
"Others"	"(Intercept)"	-5.07233927676026	1.82004305685867	-2.78693367041269	0.00532093689178586
"Others"	"QARF21$Algorithmdesign"	1.08165693604585	0.664055450264089	1.62886538408153	0.103341519502516

Table D.24. *Multinomial logistic regression to identify the impact of generative design on the roof geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Flat Square"	"(Intercept)"	-3.20533661426186	1.14664274651394	-2.79541001240956	0.00518339299445153
"Flat Square"	"QARF21$GenerativeDesign"	0.38982221286682	0.463190683332474	0.841602015960692	0.400010760486266
"Flat Triangular"	"(Intercept)"	-4.16241451669473	2.13704123884006	-1.94774646415059	0.051445307455717
"Flat Triangular"	"QARF21$GenerativeDesign"	0.187643596618771	0.943935197952516	0.198788642510404	0.842428080653712
"Flat Curved"	"(Intercept)"	-5.98576914130721	2.75649428389276	-2.17151516557982	0.0298922520254436
"Flat Curved"	"QARF21$GenerativeDesign"	0.921628534315984	0.866406876936711	1.06373640243313	0.287448128829439
"Flat Rectilinear"	"(Intercept)"	0.32851381880019	1.16335519239029	0.282384796104453	0.777648471769957
"Flat Rectilinear"	"QARF21$GenerativeDesign"	-1.51149461778278	0.953182677575298	-1.58573445924103	0.112799558775062
"Flat Organic"	"(Intercept)"	-5.98563347082573	2.75631985439958	-2.17160336499829	0.029885592992989
"Flat Organic"	"QARF21$GenerativeDesign"	0.921625501987504	0.866354493346743	1.06379722049718	0.287420570754783
"Flat Free form"	"(Intercept)"	-4.33096157002392	1.68158340171138	-2.57552587972516	0.0100087782908732
"Flat Free form"	"QARF21$GenerativeDesign"	0.572058955823603	0.617387231735002	0.926580477241138	0.354144395087884
"Flat Irregular"	"(Intercept)"	-3.47054043349338	1.52750615238268	-2.27203041249939	0.0230846735107618
"Flat Irregular"	"QARF21$GenerativeDesign"	0.188142262270086	0.676081880658355	0.278283248897126	0.780794933903915
"Flat Polygonal"	"(Intercept)"	-2.32658689321879	1.08493681262575	-2.14444460372583	0.031997279600672
"Flat Polygonal"	"QARF21$GenerativeDesign"	-0.0528334828297945	0.542357113366588	-0.0974145660261368	0.922397177727835
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"(Intercept)"	-0.0119903932376808	0.494229642124282	-0.0242607731623382	0.980644602395738
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"QARF21$GenerativeDesign"	-0.232009235877696	0.25995296254752	-0.892504680862347	0.372122484947578
"Pyramidal"	"(Intercept)"	9.38817524919828	0.509869573335799	18.4128956505025	1.03535889320884e-75
"Pyramidal"	"QARF21$GenerativeDesign"	-12.5352642257984	0.509870999708931	-24.5851680777184	1.82027995583154e-133
"Others"	"(Intercept)"	-4.22715053590256	1.45364224276797	-2.90797172201971	0.00363781230984239
"Others"	"QARF21$GenerativeDesign"	0.688814051064633	0.511633577052889	1.34630345223302	0.17820467294877

Table D.25. *Multinomial logistic regression to identify the impact of Performative design on the roof geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Flat Square"	"(Intercept)"	-3.64320196193028	1.20723370326972	-3.0178100164557	0.00254608468009929
"Flat Square"	"QARF21$Performativedesign"	0.57517389419301	0.450024032062961	1.27809595313465	0.201215595684598
"Flat Triangular"	"(Intercept)"	-4.17023860462042	2.14960051018031	-1.94000633367482	0.0523789201519931
"Flat Triangular"	"QARF21$Performativedesign"	0.19166723720101	0.9506454132549	0.201618010804642	0.840215363790601
"Flat Curved"	"(Intercept)"	-4.17017209665444	2.14961499465742	-1.939962322099	0.0523842690562998
"Flat Curved"	"QARF21$Performativedesign"	0.191621449867976	0.950674368927153	0.201563706912834	0.840257820506468
"Flat Rectilinear"	"(Intercept)"	0.314956516738976	1.14554845395748	0.274939497889337	0.783362721124201
"Flat Rectilinear"	"QARF21$Performativedesign"	-1.49774037424124	0.935984173562209	-1.60017702921308	0.109559316504538
"Flat Organic"	"(Intercept)"	-5.93330578200321	2.64725294975297	-2.24130670344777	0.0250062150450007
"Flat Organic"	"QARF21$Performativedesign"	0.904360458345755	0.829092098897718	1.09078407519274	0.275367905323547
"Flat Free form"	"(Intercept)"	-5.24321651854686	1.90171221861966	-2.75710302916	0.00583159738002552
"Flat Free form"	"QARF21$Performativedesign"	0.905207307091083	0.604688105485638	1.49698216134761	0.134397899775794
"Flat Irregular"	"(Intercept)"	-4.33370515738207	1.66855133648138	-2.59728607842593	0.00939636290918026
"Flat Irregular"	"QARF21$Performativedesign"	0.574328875067536	0.612501187230396	0.937677978494268	0.348409924141467

"Flat Polygonal"	"(Intercept)"	-2.78327315018336	1.10899000219782	-2.50973691797709	0.0120821137320742
"Flat Polygonal"	"QARF21$Performativedesign"	0.19128638235852	0.493837108086616	0.38734712160385	0.698499244948498
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"(Intercept)"	0.0675974737108087	0.499257731591425	0.135395947690857	0.892298827905803
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"QARF21$Performativedesign"	-0.281987503554469	0.267101176807429	-1.05573291336628	0.291090255579844
"Pyramidal"	"(Intercept)"	7.62799173750996	330.619720179399	0.0230717990244832	0.981593000814783
"Pyramidal"	"QARF21$Performativedesign"	-10.7781035978029	330.615029933597	-0.032600162188536	0.973993440492702
"Others"	"(Intercept)"	-3.64450778455469	1.33229728564481	-2.73550642474724	0.00622843704504951
"Others"	"QARF21$Performativedesign"	0.456664738572097	0.520574827186886	0.877231696046176	0.380360803402595

Table D.26. *Multinomial logistic regression to identify the impact of Form finding design on the roof geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Flat Square"	"(Intercept)"	-3.07837547686707	1.20883756802401	-2.54655841139934	0.010879100284069
"Flat Square"	"QARF21$Formfindingdesign"	0.316926128990665	0.491365315532857	0.644990842804965	0.518933119949841
"Flat Triangular"	"(Intercept)"	-3.98018619685893	2.23301721502488	-1.78242521825546	0.0746799161086125
"Flat Triangular"	"QARF21$Formfindingdesign"	0.0887567925705608	0.996464905120455	0.0890716693728733	0.929024952445616
"Flat Curved"	"(Intercept)"	-3.98019647116144	2.23307327610649	-1.78238507161806	0.0746864582417702
"Flat Curved"	"QARF21$Formfindingdesign"	0.0887320809433535	0.99650122042383	0.0890436249597508	0.929047240089779
"Flat Rectilinear"	"(Intercept)"	-0.505157354087791	0.870198283939257	-0.580508331734487	0.561571869809626
"Flat Rectilinear"	"QARF21$Formfindingdesign"	-0.759059261934371	0.547380336310399	-1.38671269605844	0.165529387634096
"Flat Organic"	"(Intercept)"	-6.10113379925157	2.97699393570769	-2.04942768813576	0.0404203120852294
"Flat Organic"	"QARF21$Formfindingdesign"	0.940718606889518	0.943923519130648	0.996604690765538	0.318956428197119
"Flat Free form"	"(Intercept)"	-3.28661713234661	1.59554457257621	-2.05987171329218	0.0394108065395768
"Flat Free form"	"QARF21$Formfindingdesign"	0.0886041706533817	0.712687521862	0.124324010082133	0.901058737480989
"Flat Irregular"	"(Intercept)"	-5.4073401487073	2.13344700240064	-2.53455564756132	0.0112590042883925
"Flat Irregular"	"QARF21$Formfindingdesign"	0.940528197988763	0.683835752328666	1.37537149057501	0.169016302923749
"Flat Polygonal"	"(Intercept)"	-2.59356710646279	1.15147833685936	-2.25238028666411	0.0242982504070035
"Flat Polygonal"	"QARF21$Formfindingdesign"	0.0886477933898353	0.515191315886778	0.172067716702968	0.863384292528079
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"(Intercept)"	0.3958431307141	0.516956469361319	0.76571849696194	0.443843818657864
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"QARF21$Formfindingdesign"	-0.46884719335502	0.277350622788131	-1.69044939810059	0.0909420113213519
"Pyramidal"	"(Intercept)"	-6.10112456530093	2.9769090967609	-2.04948299292693	0.0404149091919866
"Pyramidal"	"QARF21$Formfindingdesign"	0.940742741737777	0.943890201412222	0.996665438766357	0.318926930797984
"Others"	"(Intercept)"	-5.00290792912227	1.76534559561608	-2.83395383971619	0.00459759725879003
"Others"	"QARF21$Formfindingdesign"	0.940870034991623	0.571485470837065	1.64635862677928	0.0996899458037118

Table D.27. *Multinomial logistic regression to identify the impact of Machine based learning design on the roof geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Flat Square"	"(Intercept)"	-2.66253914204417	1.22023337279207	-2.18199174142557	0.029110142243499
"Flat Square"	"QARF21$Machinebasedlearningdesign"	0.165855691810036	0.738895115482872	0.224464458262995	0.82239591952729
"Flat Triangular"	"(Intercept)"	-5.31590530697071	2.42455436176045	-2.19252881717647	0.0283413446485641
"Flat Triangular"	"QARF21$Machinebasedlearningdesign"	0.898927221540147	1.11551182553023	0.805842843586949	0.420333470967787
"Flat Curved"	"(Intercept)"	10.7890561980064	0.508018456689956	21.2375279990879	4.29927071687642e-100
"Flat Curved"	"QARF21$Machinebasedlearningdesign"	-14.1869093456389	0.508018674975346	-27.9259602933443	1.29148854779833e-171
"Flat Rectilinear"	"(Intercept)"	29.9045013684624	0.198360154545922	150.758610956513	0
"Flat Rectilinear"	**"QARF21$Machinebasedlearningdesign"**	**-31.2229656185076**	**0.198360154545934**	**-157.405430994849**	**0**
"Flat Organic"	"(Intercept)"	10.789056217424	0.508018447134941	21.2375284367542	4.29923066734235e-100
"Flat Organic"	"QARF21$Machinebasedlearningdesign"	-14.1869093262214	0.508018665420333	-27.9259607803647	1.29147096054733e-171
"Flat Free form"	"(Intercept)"	-3.3556650240729	1.68848604680776	-1.98738096202637	0.0468801957848502
"Flat Free form"	"QARF21$Machinebasedlearningdesign"	0.165867380840792	1.01989431138361	0.162631930573055	0.870808244719444
"Flat Irregular"	"(Intercept)"	20.8670253525632	0.36481780547748	57.1984838438794	0
"Flat Irregular"	**"QARF21$Machinebasedlearningdesign"**	**-23.5717481539482**	**0.3648178054926**	**-64.6123840422759**	**0**
"Flat Polygonal"	"(Intercept)"	-3.92935507938036	1.26637753667465	-3.1028306848354	0.00191679269031523
"Flat Polygonal"	"QARF21$Machinebasedlearningdesign"	0.898809964057474	0.602694925605872	1.49131828703208	0.135877949988365
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"(Intercept)"	-0.214683617664446	0.569106157917933	-0.377229475867672	0.706003077041452
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"QARF21$Machinebasedlearningdesign"	-0.136881681612579	0.373359137590875	-0.366622021080874	0.713900979890956
"Pyramidal"	"(Intercept)"	10.7890568206511	0.508018150298586	21.2375420333109	4.29798667253593e-100
"Pyramidal"	"QARF21$Machinebasedlearningdesign"	-14.1869087229941	0.50801836858401	-27.9259759101566	1.29092471351128e-171
"Others"	"(Intercept)"	-3.40826322904661	1.37921049106924	-2.4711697388586	0.0134671880047601
"Others"	"QARF21$Machinebasedlearningdesign"	0.455780284223563	0.755839919165862	0.603011659832095	0.546500932562449

Appendix E - Statistical models on Geometry and Digital fabrication

Table E.1. *Multinomial logistic regression to identify the impact of Additive Digital Fabrication on the floor geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Square"	"(Intercept)"	-1.53193115637122	2.17984614105527	-0.702770313701871	0.482198900377057
"Square"	"QARF21$AdditiveDigitalFabrication"	-0.771467517846145	1.20385541338826	-0.640830708793211	0.521632678823678
"Curved"	"(Intercept)"	-18.5494213146066	185.488153907376	-0.100003266644561	0.920341732040605
"Curved"	"QARF21$AdditiveDigitalFabrication"	7.18719564519527	92.748185433538	0.0774914960502975	0.938232556101452
"Rectilinear"	"(Intercept)"	-31.8894744903398	0.0628366275859677	-507.498185619706	0
"Rectilinear"	**"QARF21$AdditiveDigitalFabrication"**	**15.1000941891657**	**0.125673140297442**	**120.153711074832**	**0**
"Organic"	"(Intercept)"	-18.5494209550548	185.488991794904	-0.100002812973209	0.920342092212494
"Organic"	"QARF21$AdditiveDigitalFabrication"	7.187186251464	92.7486044333074	0.0774910446941774	0.938232915151882
"Free form"	"(Intercept)"	-18.5494863662303	185.505064919261	-0.0999945008202538	0.920348691273961
"Free form"	"QARF21$AdditiveDigitalFabrication"	7.18707836575959	92.7566417773092	0.0774831670061361	0.938239181796022
"Irregular"	"(Intercept)"	-22.8115732246769	452.266676163051	-0.0504383241723803	0.959773096964254
"Irregular"	"QARF21$AdditiveDigitalFabrication"	9.66674890747938	226.134190208265	0.0427478432101598	0.965902541036082
"Polygonal"	"(Intercept)"	-26.1638128987657	880.018159486554	-0.029730992044563	0.97628159476421
"Polygonal"	"QARF21$AdditiveDigitalFabrication"	11.6876438790381	440.009306031679	0.0265622652039923	0.978808870637191
"Other"	"(Intercept)"	-0.430665693658315	2.32649098313724	-0.185113846036733	0.853139741725169
"Other"	"QARF21$AdditiveDigitalFabrication"	-1.87140898401897	1.45398472066763	-1.28708985549702	0.198062970887628

Table E.2. *Multinomial logistic regression to identify the impact of Subtractive Digital Fabrication on the floor geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Square"	"(Intercept)"	-1.92506584856532	2.16385857169581	-0.88964494895646	0.373656562558551
"Square"	"QARF21$SubtractiveDigitalFabrication"	-0.559731799977052	1.19686146132718	-0.467666324017465	0.64002322707697
"Curved"	"(Intercept)"	-19.0462159755477	190.202887535524	-0.100136313503603	0.920236106198845
"Curved"	"QARF21$SubtractiveDigitalFabrication"	7.4514994160618	95.1054497539055	0.0783498678082409	0.937549750571058
"Rectilinear"	"(Intercept)"	-3.2251604964776	2.10746520743481	-1.53035052967885	0.125929987130349
"Rectilinear"	"QARF21$SubtractiveDigitalFabrication"	0.739974239712416	1.09107152277692	0.678208737250411	0.497639353507721
"Organic"	"(Intercept)"	-19.0462195686588	190.20223156481	-0.100136677745387	0.920235817029386
"Organic"	"QARF21$SubtractiveDigitalFabrication"	7.45150990658184	95.1051217137982	0.078350248359976	0.937549447865246
"Free form"	"(Intercept)"	-19.0462026848635	190.198496202322	-0.100138555588806	0.920234326220459
"Free form"	"QARF21$SubtractiveDigitalFabrication"	7.4515323006986	95.1032538680384	0.0783520226451775	0.937548036529159
"Irregular"	"(Intercept)"	-22.5445870741602	383.508070702597	-0.0587851698475547	0.953123220779297
"Irregular"	"QARF21$SubtractiveDigitalFabrication"	9.54730032317026	191.755044203922	0.0497890439482635	0.96029049751851
"Polygonal"	"(Intercept)"	-25.1738179101119	622.273908136555	-0.0404545612164533	0.967730732258758
"Polygonal"	"QARF21$SubtractiveDigitalFabrication"	11.2084875381147	311.137274514009	0.0360242518535335	0.971263021319295
"Other"	"(Intercept)"	-0.825675567245553	2.31254866744531	-0.357041379871882	0.721060827918899

"Other"	"QARF21$SubtractiveDigitalFabrication"	-1.65881343915867	1.44879277306528	-1.14496253018231	0.252224679297748

Table E.3. *Multinomial logistic regression to identify the impact of Forming Digital Fabrication on the floor geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Square"	"(Intercept)"	-1.73454298818516	2.17059098904236	-0.799110931972687	0.424226091324507
"Square"	"QARF21$FormingDigitalFabrication"	-0.662920313273827	1.19983649650716	-0.55250887533731	0.58059975532895
"Curved"	"(Intercept)"	-18.1760415725812	160.463948135977	-0.11327180830163	0.909815067085425
"Curved"	"QARF21$FormingDigitalFabrication"	7.00848585172682	80.2367216756605	0.0873476097398034	0.930395211504178
"Rectilinear"	"(Intercept)"	-3.03552060347853	2.11475843155795	-1.43539827442241	0.151173637451173
"Rectilinear"	"QARF21$FormingDigitalFabrication"	0.637259062878807	1.09450931921728	0.582232651371603	0.560409982933995
"Organic"	"(Intercept)"	-18.1760507244511	160.466518338201	-0.113270051052912	0.909816460201269
"Organic"	"QARF21$FormingDigitalFabrication"	7.00846296963554	80.2380069574389	0.0873459253960916	0.930396550299128
"Free form"	"(Intercept)"	-18.1760369234245	160.465094892511	-0.113270969836773	0.909815731805567
"Free form"	"QARF21$FormingDigitalFabrication"	7.00846691010864	80.2372951753529	0.0873467493488176	0.930395895383043
"Irregular"	"(Intercept)"	-21.5514218561974	313.74408461909	-0.0686910858649733	0.945235513893922
"Irregular"	"QARF21$FormingDigitalFabrication"	9.04280480993705	156.873274962301	0.057644011142817	0.954032192112333
"Polygonal"	"(Intercept)"	-24.0520150100637	492.957776487905	-0.0487912274787977	0.961085673307391
"Polygonal"	"QARF21$FormingDigitalFabrication"	10.6396998442805	246.479292374456	0.0431667088207817	0.965568642852683
"Other"	"(Intercept)"	-0.633949233762291	2.31848432168484	-0.273432616228175	0.784520683575757
"Other"	"QARF21$FormingDigitalFabrication"	-1.76271289944721	1.45117667561194	-1.21467835658529	0.22448879048706

Table E.4. *Multinomial logistic regression to identify the impact of Robotic Assembly construction on the floor geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Square"	"(Intercept)"	4.99678707200031	2.55216762340971	1.95786006615215	0.0502464348832388
"Square"	**"QARF21$RoboticAssemblyconstruction"**	**-4.30377232406451**	**1.41896359785662**	**-3.0330392763884**	**0.00242104087182661**
"Curved"	"(Intercept)"	-15.0818993843207	254.62380670287	-0.0592320866599891	0.952767253040526
"Curved"	"QARF21$RoboticAssemblyconstruction"	5.38867565562139	127.314890009678	0.0423255728784886	0.966239159340125
"Rectilinear"	"(Intercept)"	-34.6267750887046	0.0622426984849412	-556.31866759572	0
"Rectilinear"	**"QARF21$RoboticAssemblyconstruction"**	**16.4037555962959**	**0.124485384568495**	**131.772542239849**	**0**
"Organic"	"(Intercept)"	-15.0817305444621	254.562218307205	-0.059245753925123	0.952756367257919
"Organic"	"QARF21$RoboticAssemblyconstruction"	5.38899065923758	127.284094180728	0.0423382881728008	0.966229023089219
"Free form"	"(Intercept)"	-15.0817905824493	254.589176263872	-0.0592397163295646	0.952761176115962
"Free form"	"QARF21$RoboticAssemblyconstruction"	5.38883889913399	127.297573913816	0.0423326127392058	0.966233547373828

"Irregular"	"(Intercept)"	-19.8783243910252	710.185453104449	-0.0279903288699179	0.97766986457007
"Irregular"	"QARF21$RoboticAssembly construction"	8.13355437396243	355.09326900108	0.0229054028448444	0.981725730680446
"Polygonal"	"(Intercept)"	-25.5322100053405	0.102667992325545	-248.687146081339	0
"Polygonal"	**"QARF21$RoboticAssemblyconstruction"**	**11.3072334820907**	**0.205329954976019**	**55.0686015755043**	**0**
"Other"	"(Intercept)"	-19.8765070879377	709.828664510259	-0.0280018377415787	0.977660685416986
"Other"	"QARF21$RoboticAssembly construction"	8.13274210775667	354.914874874783	0.0229146273754403	0.981718372501196

Table E.5. *Multinomial logistic regression to identify the impact of 3D printing technology on the floor geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Square"	"(Intercept)"	-38.6367418416617	0.103226702740616	-374.29018670437	0
"Square"	**"QARF21$`@3Dprintingtechnology`"**	**17.9560824064692**	**0.206453405233797**	**86.9740190825865**	**0**
"Curved"	"(Intercept)"	-27.8471002065036	0.201627753951478	-138.111443790646	0
"Curved"	"QARF21$`@3Dprintingtechnology`"	11.8681399739026	0.403255309711236	29.4308337375673	2.21487283627461e-190
"Rectilinear"	"(Intercept)"	-47.4275029697014	0.0631588446359134	-750.92416973589	0
"Rectilinear"	**"QARF21$`@3Dprintingtechnology`"**	**22.9007747839832**	**0.126317689270424**	**181.295073684864**	**0**
"Organic"	"(Intercept)"	-27.8470992697543	0.201628787341759	-138.110731294305	0
"Organic"	"QARF21$`@3Dprintingtechnology`"	11.8681342962792	0.403257376489699	29.4306688189804	2.22566169018396e-190
"Free form"	"(Intercept)"	-27.8471011676025	0.201630734615705	-138.109406885201	0
"Free form"	"QARF21$`@3Dprintingtechnology`"	11.8681254292051	0.403261271033997	29.4303626003416	2.24583370627191e-190
"Irregular"	"(Intercept)"	-34.1225654862986	0.143718580091503	-237.426263636709	0
"Irregular"	**"QARF21$`@3Dprintingtechnology`"**	**15.3524389906897**	**0.287437155756624**	**53.4114629344885**	**0**
"Polygonal"	"(Intercept)"	-38.6364030375062	0.103226563240794	-374.287410376921	0
"Polygonal"	**"QARF21$`@3Dprintingtechnology`"**	**17.9559144444015**	**0.206453126234111**	**86.9733230585239**	**0**
"Other"	"(Intercept)"	-34.1224896952849	0.143723809384276	-237.417097706137	0
"Other"	**"QARF21$`@3Dprintingtechnology`"**	**15.3523635172512**	**0.287447614341691**	**53.4092570307498**	**0**

Table E.6. *Multinomial logistic regression to identify the impact of Additive Digital Fabrication on the façade geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Square"	"(Intercept)"	0.0283766905219304	1.66961102638212	0.0169959889300802	0.986439815680955
"Square"	"QARF21$AdditiveDigital Fabrication"	-1.28103166644055	0.926713814080908	-1.38233794184998	0.166867961189972
"Triangular"	"(Intercept)"	-18.0021587665612	191.840798690379	-0.0938390524302168	0.925237009187568

"Triangular"	"QARF21$AdditiveDigital Fabrication"	6.92945821261246	95.9243711084178	0.0722387661502674	0.942411894819754
"Curved"	"(Intercept)"	-18.0021561420104	191.847471350546	-0.0938357749272422	0.925239612768455
"Curved"	"QARF21$AdditiveDigital Fabrication"	6.92938602561914	95.9277078545726	0.0722355008849389	0.942414493335901
"Rectilinear"	"(Intercept)"	-31.6617276377867	0.062995439142425	-502.603491122642	0
"Rectilinear"	**"QARF21$AdditiveDigitalFabrication"**	**15.0017064222252**	**0.125990792990986**	**119.069862694637**	**0**
"Free form"	"(Intercept)"	-0.438902736414938	2.25455359140826	-0.194673898233125	0.845648247136612
"Free form"	"QARF21$AdditiveDigital Fabrication"	-1.50567280388968	1.28753393215145	-1.16942378471822	0.242232931648267
"Irregular"	"(Intercept)"	0.539717293114768	1.70899231141954	0.315810252338972	0.752146535843359
"Irregular"	"QARF21$AdditiveDigital Fabrication"	-1.79220509875447	0.996043670110932	-1.79932381735318	0.0719674726741776
"Polygonal"	"(Intercept)"	-22.3478178691568	478.07453572604	-0.0467454679116462	0.962716091778914
"Polygonal"	"QARF21$AdditiveDigital Fabrication"	9.44887734038667	239.038077194045	0.0395287539596309	0.968468829081677
"Other"	"(Intercept)"	-18.00218297461	191.848384299561	-0.093835468254455	0.925239856383044
"Other"	"QARF21$AdditiveDigital Fabrication"	6.92940334014132	95.9281642796944	0.0722353376839101	0.942414623212195

Table E.7. *Multinomial logistic regression to identify the impact of Subtractive Digital Fabrication on the façade geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Square"	"(Intercept)"	-2.50995848293871	2.13244038034178	-1.17703571273417	0.239181252354215
"Square"	"QARF21$SubtractiveDigitalFabrication"	0.112092623698638	1.12895338295661	0.099288974541251	0.920908832201417
"Triangular"	"(Intercept)"	-18.3482303387777	164.142109533475	-0.111782591261481	0.910995791164014
"Triangular"	"QARF21$SubtractiveDigitalFabrication"	7.13525439624643	82.0757020975176	0.0869350394075061	0.930723147524339
"Curved"	"(Intercept)"	-18.348242231235	164.143985781548	-0.11178138598178	0.910996746848647
"Curved"	"QARF21$SubtractiveDigitalFabrication"	7.13524342764639	82.0766403230298	0.0869339120066824	0.930724043667298
"Rectilinear"	"(Intercept)"	-27.6769562722272	908.33716232885	-0.0304699151593306	0.975692286460851
"Rectilinear"	"QARF21$SubtractiveDigitalFabrication"	13.0421635230382	454.168663965397	0.0287165640384909	0.977090645623323
"Free form"	"(Intercept)"	-1.41100441277074	2.20911210311636	-0.638720149502717	0.523005002225033
"Free form"	"QARF21$SubtractiveDigitalFabrication"	-0.986736269883148	1.26798484183283	-0.778192480958094	0.436455548829505
"Irregular"	"(Intercept)"	-2.10421971278443	2.15177356887783	-0.977900157906392	0.32812370704006
"Irregular"	"QARF21$SubtractiveDigitalFabrication"	-0.293518758623799	1.16522332609077	-0.25189914418254	0.801119021105999
"Polygonal"	"(Intercept)"	-21.3972439074775	295.787330530232	-0.0723399608398391	0.942331363831968
"Polygonal"	"QARF21$SubtractiveDigitalFabrication"	9.00641049230413	147.894976070102	0.0608973389876008	0.95144096869487
"Other"	"(Intercept)"	12.2069318671728	640.788488027193	0.0190498613743117	0.9848013289888

"Other"	"QARF21$SubtractiveDigitalFabrication"	-14.6049324732701	640.785934004227	-0.0227922176474831	0.981816015831308

Table E.8. *Multinomial logistic regression to identify the impact of Forming Digital Fabrication on the façade geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Square"	"(Intercept)"	-0.942086298983419	1.60672011809712	-0.586341260293148	0.557646209119062
"Square"	"QARF21$FormingDigitalFabrication"	-0.762975087742299	0.898939115045883	-0.848750571615026	0.396020099470865
"Triangular"	"(Intercept)"	-19.0910680948549	197.563717521923	-0.0966324603237763	0.92301827750558
"Triangular"	"QARF21$FormingDigitalFabrication"	7.50752725437309	98.7857135332361	0.0759981072753724	0.939420604020257
"Curved"	"(Intercept)"	-19.0913804014758	197.638066892402	-0.0965976883991155	0.923045892301401
"Curved"	"QARF21$FormingDigitalFabrication"	7.50708704429494	98.8228912902615	0.0759650618017764	0.939446894493709
"Rectilinear"	"(Intercept)"	-30.199544583333	0.0633348635655479	-476.823393676031	0
"Rectilinear"	**"QARF21$FormingDigitalFabrication"**	**14.3034674601789**	**0.126669195129464**	**112.919857472528**	**0**
"Free form"	"(Intercept)"	-1.40632074790427	2.20727189240274	-0.63713072809232	0.524039694650792
"Free form"	"QARF21$FormingDigitalFabrication"	-0.98922794185191	1.26723053807814	-0.780621924841045	0.435024892753787
"Irregular"	"(Intercept)"	-26.3179533711713	804.953396322454	-0.0326950025820236	0.973917809124168
"Irregular"	"QARF21$FormingDigitalFabrication"	11.9249316321647	402.476900299825	0.0296288597514073	0.976363048659854
"Polygonal"	"(Intercept)"	-22.9458861527251	435.636622248569	-0.0526720780137543	0.957993186649948
"Polygonal"	"QARF21$FormingDigitalFabrication"	9.78082000171672	217.819200997096	0.0449033875661271	0.964184316682729
"Other"	"(Intercept)"	-19.0915870596671	197.716313377198	-0.0965605049657418	0.923075422346088
"Other"	"QARF21$FormingDigitalFabrication"	7.50650205050266	98.8620182297396	0.0759290795890768	0.939475521466936

Table E.9. *Multinomial logistic regression to identify the impact of Robotic Assembly construction on the façade geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Square"	"(Intercept)"	1.04205762026042	2.48636802590177	0.419108357815407	0.675136942805289
"Square"	"QARF21$RoboticAssemblyconstruction"	-1.73490671084593	1.29674057483046	-1.3378980688352	0.180929666772366
"Triangular"	"(Intercept)"	-14.2423236922253	142.921878463584	-0.0996511090207522	0.920621316598288
"Triangular"	"QARF21$RoboticAssemblyconstruction"	5.01132995873322	71.4662646170371	0.0701216159202835	0.944096862031979
"Curved"	"(Intercept)"	-14.2420666279039	142.912707746225	-0.0996557048880081	0.920617667789615
"Curved"	"QARF21$RoboticAssemblyconstruction"	5.01120124940309	71.4616796019228	0.070124313860491	0.944094714673166
"Rectilinear"	"(Intercept)"	-34.1040598898081	0.0626220737403015	-544.601254044065	0
"Rectilinear"	**"QARF21$RoboticAssemblyconstruction"**	**16.1847331029957**	**0.125244130310724**	**129.225481967436**	**0**

"Free form"	"(Intercept)"	-21.6948746116122	699.715464348411	-0.0310052810277888	0.975265328047912
"Free form"	"QARF21$RoboticAssemblyconstruction"	9.28698684762669	349.858105224776	0.0265450098452343	0.978822633568588
"Irregular"	"(Intercept)"	-25.7548183264961	0.092675432366437	-277.903406208692	0
"Irregular"	**"QARF21$RoboticAssemblyconstruction"**	**11.5723705806894**	**0.185345818771291**	**62.4366422582705**	**0**
"Polygonal"	"(Intercept)"	-18.8213465459502	377.536749876301	-0.0498530184203708	0.960239516585
"Polygonal"	"QARF21$RoboticAssemblyconstruction"	7.64748334848013	188.769397444053	0.0405123047063105	0.967684697358672
"Other"	"(Intercept)"	-14.242362923349	142.923585090221	-0.0996501935937197	0.920622043385819
"Other"	"QARF21$RoboticAssemblyconstruction"	5.0113453049475	71.4671179115822	0.0701209934217222	0.944097357494378

Table E.10. *Multinomial logistic regression to identify the impact of 3D printing technology on the façade geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Square"	"(Intercept)"	-0.939374979631816	1.60606828192009	-0.584891059867498	0.558620970298428
"Square"	"QARF21$`@3Dprintingtechnology`"	-0.764452237440926	0.898666158740812	-0.850652080314292	0.394962649780035
"Triangular"	"(Intercept)"	-19.2884829114804	207.650461080506	-0.0928891889337165	0.925991594593308
"Triangular"	"QARF21$`@3Dprintingtechnology`"	7.60548832705669	103.828903377995	0.0732502037449869	0.941607016843338
"Curved"	"(Intercept)"	-19.288541456947	207.651323098465	-0.0928890852662698	0.925991676951884
"Curved"	"QARF21$`@3Dprintingtechnology`"	7.605538568743	103.829334220271	0.0732503836787403	0.941606873661619
"Rectilinear"	"(Intercept)"	-30.5033535069536	0.0633319560445775	-481.642371593311	0
"Rectilinear"	**"QARF21$`@3Dprintingtechnology`"**	**14.4554131978609**	**0.126663464409622**	**114.124568321556**	**0**
"Free form"	"(Intercept)"	-1.40719904620972	2.20785087774287	-0.637361454251988	0.523889429875443
"Free form"	"QARF21$`@3Dprintingtechnology`"	-0.988830053429828	1.26749152771841	-0.780147268684155	0.435304196321302
"Irregular"	"(Intercept)"	-26.5847338363925	860.545901251098	-0.0308928713712337	0.97535497503306
"Irregular"	"QARF21$`@3Dprintingtechnology`"	12.0582864848093	430.273139713902	0.0280247251613874	0.977642431061987
"Polygonal"	"(Intercept)"	-23.1829644377671	462.302037835249	-0.0501467926603189	0.960005411468684
"Polygonal"	"QARF21$`@3Dprintingtechnology`"	9.89921745708652	231.151857674574	0.042825601994612	0.965840555267278
"Other"	"(Intercept)"	-19.2884863431334	207.647632547966	-0.0928904707771123	0.925990576233214
"Other"	"QARF21$`@3Dprintingtechnology`"	7.60551900167056	103.827488952585	0.0732514970591633	0.941605987692682

Table E.11. *Multinomial logistic regression to identify the impact of Additive Digital Fabrication method on the roof geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Flat Square"	"(Intercept)"	-0.630837109169616	2.27216524379332	-0.277636985643021	0.781291037442837
"Flat Square"	"QARF21$AdditiveDigitalFabrication"	-0.97956206178958	1.24874553107068	-0.784436890796881	0.4327837990302
"Flat Triangular"	"(Intercept)"	-25.3074750338611	0.202486983860583	-124.98321892772	0
"Flat Triangular"	"QARF21$AdditiveDigitalFabrication"	10.8093016274175	0.40497349497241	26.6913804523279	5.92649859748668e-157
"Flat Curved"	"(Intercept)"	-25.3072320477933	0.202486988609915	-124.982015987935	0
"Flat Curved"	"QARF21$AdditiveDigitalFabrication"	10.8091801104005	0.404973504413625	26.6910797684197	5.97432093393975e-157

"Flat Rectilinear"	**"(Intercept)"**	**-40.5043387217678**	**0.0774566835529668**	**-522.928905083703**	**0**
"Flat Rectilinear"	**"QARF21$AdditiveDigitalFabrication"**	**19.4475148743938**	**0.154913366494826**	**125.538004333817**	**0**
"Flat Organic"	**"(Intercept)"**	**-25.3073323192343**	**0.20248698965556**	**-124.982510541953**	**0**
"Flat Organic"	**"QARF21$AdditiveDigitalFabrication"**	**10.8092302408038**	**0.404973506528618**	**26.6912034158955**	**5.95460892077031e-157**
"Flat Free form"	**"(Intercept)"**	**0.47491467820949**	**2.41226876821668**	**0.196874695086559**	**0.843925596510069**
"Flat Free form"	**"QARF21$AdditiveDigitalFabrication"**	**-2.08242695474542**	**1.49141838315857**	**-1.39627282207371**	**0.162632354743783**
"Flat Irregular"	**"(Intercept)"**	**-31.2288130860122**	**0.144947801781855**	**-215.448683609644**	**0**
"Flat Irregular"	**"QARF21$AdditiveDigitalFabrication"**	**14.1163098585484**	**0.289895578939871**	**48.6944640900381**	**0**
"Flat Polygonal"	**"(Intercept)"**	**-36.2815199137488**	**0.1048807340101**	**-345.931216597462**	**0**
"Flat Polygonal"	**"QARF21$AdditiveDigitalFabrication"**	**16.9894857317606**	**0.209761465130053**	**80.9943128554477**	**0**
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	**"(Intercept)"**	**-1.47607053661665**	**1.6914941780641**	**-0.872642989706292**	**0.382857700764368**
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	**"QARF21$AdditiveDigitalFabrication"**	**0.55974772654993**	**0.872251419457041**	**0.641727504322505**	**0.521050127629871**
"Pyramidal"	**"(Intercept)"**	**29.7479998742747**	**0.547694753081039**	**54.3149257993221**	**0**
"Pyramidal"	**"QARF21$AdditiveDigitalFabrication"**	**-31.35715462504**	**0.547694753081468**	**-57.2529761306216**	**0**
"Others"	**"(Intercept)"**	**1.85691686547823**	**1.95580679302379**	**0.949437782965941**	**0.342398001563666**
"Others"	**"QARF21$AdditiveDigitalFabrication"**	**-2.77299617697231**	**1.31347457541561**	**-2.11119136135153**	**0.0347558670559615**

Table E.12. *Multinomial logistic regression to identify the impact of Subtractive Digital Fabrication method on the roof geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Flat Square"	"(Intercept)"	-1.35139977940434	2.22007580095008	-0.608717854960632	0.542711470072422
"Flat Square"	"QARF21$SubtractiveDigitalFabrication"	-0.593843834225958	1.22554013462326	-0.484556823109273	0.627990747563276
"Flat Triangular"	"(Intercept)"	-28.7764784393127	0.202606277774871	-142.031524172652	0
"Flat Triangular"	"QARF21$SubtractiveDigitalFabrication"	12.56948641417	0.405212444717237	31.0194974957918	2.94290820148448e-211
"Flat Curved"	"(Intercept)"	-28.776295942093	0.202601650244778	-142.033867479985	0
"Flat Curved"	"QARF21$SubtractiveDigitalFabrication"	12.5694186069695	0.405203189649106	31.0200386572827	2.89386842680324e-211
"Flat Rectilinear"	"(Intercept)"	-44.9842715732245	0.0777980972537456	-578.218146216407	0
"Flat Rectilinear"	**"QARF21$SubtractiveDigitalFabrication"**	**21.7130705559502**	**0.155596194434719**	**139.547568209067**	**0**
"Flat Organic"	"(Intercept)"	-28.7762862915875	0.202602197349225	-142.033436300722	0
"Flat Organic"	"QARF21$SubtractiveDigitalFabrication"	12.5694110102539	0.405204283857209	31.0199361433289	2.90309509656883e-211
"Flat Free form"	"(Intercept)"	-0.254192177969795	2.365932750672	-0.107438462863154	0.914441142131019
"Flat Free form"	"QARF21$SubtractiveDigitalFabrication"	-1.69164578582075	1.47277538549161	-1.14861084893545	0.250716481521501
"Flat Irregular"	"(Intercept)"	-35.0315947315677	0.145093174466707	-241.442058596672	0
"Flat Irregular"	**"QARF21$SubtractiveDigitalFabrication"**	**16.0435914782425**	**0.290186344437471**	**55.2872035014024**	**0**
"Flat Polygonal"	"(Intercept)"	-40.9961404783689	0.105131233028497	-389.952056086476	0
"Flat Polygonal"	**"QARF21$SubtractiveDigitalFabrication"**	**19.3724255734048**	**0.210262465742592**	**92.1344925019616**	**0**
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"(Intercept)"	-0.739596670077683	1.27915849254101	-0.57819001663234	0.563135838211513
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"QARF21$SubtractiveDigitalFabrication"	0.180039850224826	0.676494830419275	0.266136328215903	0.790134217685506
"Pyramidal"	"(Intercept)"	-28.7766224403771	0.202613927971857	-142.026872132769	0
"Pyramidal"	"QARF21$SubtractiveDigitalFabrication"	12.5695196627894	0.405227745115603	31.018408325431	3.04413942202293e-211
"Others"	"(Intercept)"	1.13182987532652	1.89677089098328	0.596714068476549	0.550698298191727
"Others"	"QARF21$SubtractiveDigitalFabrication"	-2.3846096081722	1.29190636212514	-1.84580684644171	0.0649202561555874

Table E.13. *Multinomial logistic regression to identify the impact of Forming Digital Fabrication method on the roof geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Flat Square"	"(Intercept)"	-0.15752064952008	2.31462402983365	-0.0680545295865612	0.945742226526261
"Flat Square"	"QARF21$FormingDigitalFabrication"	-1.22872236419531	1.26793769165469	-0.969071565805248	0.33250948345959
"Flat Triangular"	"(Intercept)"	-26.5343505097975	0.20242312303961	-131.083594163327	0
"Flat Triangular"	"QARF21$FormingDigitalFabrication"	11.4103970915452	0.404846050304878	28.1845335602319	9.04855991982855e-175
"Flat Curved"	"(Intercept)"	-26.534236768018	0.202422508564331	-131.083430178839	0
"Flat Curved"	"QARF21$FormingDigitalFabrication"	11.4103433303107	0.404844821343615	28.184486323529	9.06062982982234e-175
"Flat Rectilinear"	"(Intercept)"	-40.6627100870516	0.0773020288562084	-526.02384036633	0
"Flat Rectilinear"	**"QARF21$FormingDigitalFabrication"**	**19.514292215943**	**0.154604057306157**	**126.221087311438**	**0**
"Flat Organic"	"(Intercept)"	-26.5342766280083	0.202426339192125	-131.081146524239	0
"Flat Organic"	"QARF21$FormingDigitalFabrication"	11.4103438749971	0.404852482600425	28.183954317649	9.19768328048447e-175
"Flat Free form"	"(Intercept)"	41.6744550282604	0.433008846877309	96.243888153326	0
"Flat Free form"	**"QARF21$FormingDigitalFabrication"**	**-42.367586679771**	**0.43300884687731**	**-97.8446213866285**	**0**
"Flat Irregular"	"(Intercept)"	-31.959148192788	0.144828091042414	-220.669539747151	0
"Flat Irregular"	**"QARF21$FormingDigitalFabrication"**	**14.4693741270747**	**0.289656169420856**	**49.95361968642**	**0**
"Flat Polygonal"	"(Intercept)"	-37.07614437675	0.104764915734992	-353.898479435004	0
"Flat Polygonal"	**"QARF21$FormingDigitalFabrication"**	**17.3744311260287**	**0.209529830061431**	**82.9210385983457**	**0**
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"(Intercept)"	0.455477507717708	1.43625739622975	0.317128050245979	0.751146441527278
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"QARF21$FormingDigitalFabrication"	-0.45547610855166	0.750231811800973	-0.607113829868484	0.543775372727182
"Pyramidal"	"(Intercept)"	32.7128418945431	0.559012038402529	58.5190293719354	0
"Pyramidal"	**"QARF21$FormingDigitalFabrication"**	**-34.0991232680374**	**0.559012038402567**	**-60.9989068669774**	**0**
"Others"	"(Intercept)"	2.32690055603291	2.00609157475634	1.1599174161905	0.246082431114715
"Others"	**"QARF21$FormingDigitalFabrication"**	**-3.02015012820961**	**1.33201599306478**	**-2.26735275247008**	**0.0233686853039339**

Table E.14. *Multinomial logistic regression to identify the impact of Robotic Assembly construction on the roof geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Flat Square"	"(Intercept)"	2.68530313272523	2.89079546676914	0.928914952162432	0.352933163482801
"Flat Square"	"QARF21$RoboticAssemblyconstruction"	-2.68542669570971	1.53499583795565	-1.74946838897377	0.080210088354549
"Flat Triangular"	"(Intercept)"	-25.4710433783772	0.202260734824551	-125.931725702825	0
"Flat Triangular"	"QARF21$RoboticAssemblyconstruction"	10.8434211005582	0.404521353911314	26.8055592015433	2.78334956583602e-158
"Flat Curved"	"(Intercept)"	-25.4710186648907	0.202263334161674	-125.929985137747	0
"Flat Curved"	"QARF21$RoboticAssemblyconstruction"	10.843395600409	0.404526552584308	26.8051516795035	2.81396358041483e-158
"Flat Rectilinear"	"(Intercept)"	-48.8059708160632	0.0768704468511645	-634.912021658475	0
"Flat Rectilinear"	**"QARF21$RoboticAssemblyconstruction"**	**23.5506115830236**	**0.153740893698389**	**153.183782248759**	**0**
"Flat Organic"	"(Intercept)"	-25.4710084341815	0.202259881771044	-125.932084065066	0
"Flat Organic"	"QARF21$RoboticAssemblyconstruction"	10.8434079419205	0.404519647802222	26.8056397280907	2.77733969154573e-158
"Flat Free form"	"(Intercept)"	-33.0367858198212	0.144599317063783	-228.471243783597	0
"Flat Free form"	**"QARF21$RoboticAssemblyconstruction"**	**14.9728728594124**	**0.289198630750671**	**51.7736644207042**	**0**
"Flat Irregular"	"(Intercept)"	-33.0370856822572	0.144599483052838	-228.473055261098	0
"Flat Irregular"	**"QARF21$RoboticAssemblyconstruction"**	**14.9730215905272**	**0.289198962729293**	**51.7741192749119**	**0**

"Flat Polygonal"	"(Intercept)"	-41.1452160558445	0.104446487172803	-393.935853369307	0
"Flat Polygonal"	**"QARF21$RoboticAssemblyconstruction"**	**19.3736593715719**	**0.208892974246919**	**92.7444278172397**	**0**
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"(Intercept)"	-59.4205699875792	0.0473542872680876	-1254.8086649722	0
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	**"QARF21$RoboticAssemblyconstruction"**	**29.5187839722685**	**0.0947085745361109**	**311.680163246607**	**0**
"Pyramidal"	"(Intercept)"	-25.4710139910371	0.202260108818783	-125.931970173407	0
"Pyramidal"	"QARF21$RoboticAssemblyconstruction"	10.8434095722811	0.404520101898036	26.8056136676598	2.77928321949733e-158
"Others"	"(Intercept)"	3.09146527462327	2.91927723843639	1.05898310510553	0.289607474087373
"Others"	"QARF21$RoboticAssemblyconstruction"	-3.09128306448249	1.58827286625223	-1.94631736785684	0.0516166285953766

Table E.15. *Multinomial logistic regression to identify the impact of 3D printing technology on the roof geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Flat Square"	"(Intercept)"	-1.90744347320674	2.1914164756796	-0.870415776451259	0.384073228104523
"Flat Square"	"QARF21$`@3Dprintingtechnology`"	-0.288818958480241	1.21303251493353	-0.238096633787321	0.811806145523959
"Flat Triangular"	"(Intercept)"	20.226376273247	0.527013172244525	38.3792613514834	0
"Flat Triangular"	**"QARF21$`@3Dprintingtechnology`"**	**-22.4233244836883**	**0.52701317316902**	**-42.5479392646924**	**0**
"Flat Curved"	"(Intercept)"	-28.2435327013402	0.20275061180962	-139.301837115345	0
"Flat Curved"	"QARF21$`@3Dprintingtechnology`"	12.3300375336335	0.405501040687813	30.4069195795878	4.44977931513752e-203
"Flat Rectilinear"	"(Intercept)"	-2.75815631187012	2.14898648361194	-1.28346843170196	0.199328012513143
"Flat Rectilinear"	"QARF21$`@3Dprintingtechnology`"	0.560300132789022	1.13247674496623	0.494756413568324	0.620772074725916
"Flat Organic"	"(Intercept)"	-28.2435585588394	0.202767857340979	-139.290116930833	0
"Flat Organic"	"QARF21$`@3Dprintingtechnology`"	12.3299630455735	0.405535531737478	30.404149773873	4.84120097842542e-203
"Flat Free form"	"(Intercept)"	-0.810289900629294	2.33919357687952	-0.346397112508413	0.7290442948365
"Flat Free form"	"QARF21$`@3Dprintingtechnology`"	-1.38667441648436	1.46248544390468	-0.948162884125592	0.343046538992221
"Flat Irregular"	"(Intercept)"	-33.0779545847105	0.145294454981149	-227.661507034127	0
"Flat Irregular"	**"QARF21$`@3Dprintingtechnology`"**	**15.0937961942213**	**0.290588895657851**	**51.9420955850744**	**0**
"Flat Polygonal"	"(Intercept)"	-37.6915869101667	0.105408750455525	-357.57550248231	0
"Flat Polygonal"	**"QARF21$`@3Dprintingtechnology`"**	**17.7471748536098**	**0.210817499033478**	**84.1826458191288**	**0**
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"(Intercept)"	-4.17647086747376	2.12222625944161	-1.96796682205443	0.0490718552824986
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"QARF21$`@3Dprintingtechnology`"	1.98009861272096	1.08289279141774	1.82852691274137	0.0674705103858293
"Pyramidal"	"(Intercept)"	-28.2435850150819	0.202757971830911	-139.297038533388	0
"Pyramidal"	"QARF21$`@3Dprintingtechnology`"	12.3300263819298	0.405515760728601	30.4057883219536	4.60567411896807e-203
"Others"	"(Intercept)"	-35.7911744049355	0.120183906787856	-297.803386173097	0
"Others"	**"QARF21$`@3Dprintingtechnology`"**	**16.6531327767211**	**0.240367809420486**	**69.2818760418496**	**0**

Appendix F – Statistical models on Presence of specialized professionals and geometry of buildings

Table F.1. *Multinomial logistic regression to identify the impact of artist on the floor geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Square"	"(Intercept)"	-25.1631424650718	427.340354995983	-0.0588831412032415	0.953045186121006
"Square"	"QARF21$PresenceofArtist"	11.2988485830106	213.670650259978	0.0528797407096531	0.957827726379825
"Curved"	"(Intercept)"	-20.8987654049549	208.086779913828	-0.100432931941228	0.920000626022746
"Curved"	"QARF21$PresenceofArtist"	8.47374780815865	104.047063826349	0.0814414890390471	0.935090855193933
"Rectilinear"	"(Intercept)"	-27.455384060326	575.750391745249	-0.0476862620572459	0.961966282937491
"Rectilinear"	"QARF21$PresenceofArtist"	12.9949017071968	287.875329404942	0.0451407271823471	0.963995138895245
"Organic"	"(Intercept)"	-20.8987612628847	208.086554678643	-0.100433020745428	0.920000555523699
"Organic"	"QARF21$PresenceofArtist"	8.47374583102117	104.046951212056	0.0814415581841603	0.935090800206775
"Free form"	"(Intercept)"	7.95846284404838	170.791578087753	0.0465975133736356	0.962834013919766
"Free form"	"QARF21$PresenceofArtist"	-11.0951896194485	170.782401923914	-0.0649668203190605	0.948200417973533
"Irregular"	"(Intercept)"	-2.33434080406579	2.28325974599985	-1.02237198731131	0.306604873603779
"Irregular"	"QARF21$PresenceofArtist"	-0.806871928571475	1.43716061988949	-0.56143476060005	0.574501192958856
"Polygonal"	"(Intercept)"	-1.61720753605809	1.63871464259623	-0.98687562435882	0.323703615301198
"Polygonal"	"QARF21$PresenceofArtist"	-0.820923106148847	1.03012447114955	-0.796916420432915	0.425499573666239
"Other"	"(Intercept)"	-24.4045142560125	420.50657023222	-0.0580359879811994	0.953719962560454
"Other"	"QARF21$PresenceofArtist"	10.5724632245132	210.254212591933	0.0502841921414079	0.95989592067696

Table F.2. *Multinomial logistic regression to identify the impact of Special modeling group on the floor geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Square"	"(Intercept)"	-28.3861617293189	826.026322923729	-0.0343647180986264	0.972586317723154
"Square"	"QARF21$PresenceofSpecialmodeliggroup"	12.9718977003458	413.013408194124	0.0314079335996976	0.974944214176408
"Curved"	"(Intercept)"	-36.6308267696779	0.202159154246929	-181.197962101359	0

"Curved"	**"QARF21$PresenceofSpecialmodeliggroup"**	**16.4011067988883**	**0.404318301921075**	**40.5648389423881**	**0**
"Rectilinear"	"(Intercept)"	-2.21251907892028	1.1333744220916	-1.95215194184209	0.0509201679555587
"Rectilinear"	"QARF21$PresenceofSpecialmodeliggroup"	0.23164276674117	0.656651808289245	0.352763464315529	0.724265776310216
"Organic"	"(Intercept)"	35.9998251930319	0.508540310608863	70.7905045913276	0
"Organic"	**"QARF21$PresenceofSpecialmodeliggroup"**	**-39.3671014742754**	**0.508540310614411**	**-77.4119586050369**	**0**
"Free form"	"(Intercept)"	35.9996087334777	0.508646731576864	70.7752679779828	0
"Free form"	**"QARF21$PresenceofSpecialmodeliggroup"**	**-39.3673179338377**	**0.508646731571719**	**-77.3961877474228**	**0**
"Irregular"	"(Intercept)"	10.7634127963132	464.801998036374	0.0231569847844562	0.981525050566608
"Irregular"	"QARF21$PresenceofSpecialmodeliggroup"	-13.4376349824055	464.800273059146	-0.0289105574184883	0.976935925540052
"Polygonal"	"(Intercept)"	-0.708877007000978	1.57889434769365	-0.448970514104671	0.653452927262307
"Polygonal"	"QARF21$PresenceofSpecialmodeliggroup"	-1.55982829547644	1.1787485846559	-1.32329176533585	0.185738369101568
"Other"	"(Intercept)"	-2.90659887500973	2.27174196158461	-1.27945819734839	0.200735751196505
"Other"	"QARF21$PresenceofSpecialmodeliggroup"	-0.46100254096297	1.4340422015402	-0.321470693448102	0.747853717833479

Table F.3. *Multinomial logistic regression to identify the impact of specialized Architect in geometry on the floor geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Square"	"(Intercept)"	-33.0512598950328	0.103031574249475	-320.787682181817	0
"Square"	**"QARF21$PresenceofGeometryArchitect"**	**15.1315788447116**	**0.206063136737875**	**73.4317602083282**	**0**
"Curved"	"(Intercept)"	-22.9831866342171	561.875702050565	-0.0409043967381753	0.967372112292636
"Curved"	"QARF21$PresenceofGeometryArchitect"	9.40439818797054	280.939206379831	0.0334748514070184	0.973295920259483

"Rectilinear"	"(Intercept)"	-42.1883956406315	0.0628371324780152	-671.392757385801	0
"Rectilinear"	**"QARF21$PresenceofGeometryArchitect"**	**20.2494909186849**	**0.125674264758218**	**161.126790418409**	**0**
"Organic"	"(Intercept)"	-22.9831870397408	561.875769704072	-0.0409043925347512	0.967372115643678
"Organic"	"QARF21$PresenceofGeometryArchitect"	9.40439835245621	280.939240206524	0.0334748479619396	0.973295923006719
"Free form"	"(Intercept)"	-22.9831864137739	561.875671227145	-0.0409043985897775	0.967372110816506
"Free form"	"QARF21$PresenceofGeometryArchitect"	9.40439807712931	280.939190968197	0.0334748528488285	0.973295919109729
"Irregular"	"(Intercept)"	-28.551745602236	0.143586872129835	-198.846490481517	0
"Irregular"	**"QARF21$PresenceofGeometryArchitect"**	**12.5352094475305**	**0.287173561192009**	**43.6502907701496**	**0**
"Polygonal"	"(Intercept)"	-1.52809572107228	2.17866185224001	-0.70139187478826	0.48305849128839
"Polygonal"	"QARF21$PresenceofGeometryArchitect"	-0.773879703164317	1.20341224210718	-0.643071157236404	0.520177928818839
"Other"	"(Intercept)"	-28.5517464330836	0.143584734790512	-198.849456209536	0
"Other"	**"QARF21$PresenceofGeometryArchitect"**	**12.5352252061781**	**0.287169286572258**	**43.650995396487**	**0**

Table F.4. *Multinomial logistic regression to identify the impact of Presence of geometry and mathematical consultant on the floor geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Square"	"(Intercept)"	1.8040943281972	2.51957573097971	0.71603099919354	0.473972207950367
"Square"	"QARF21$PresenceofGeo.andMat.consultant"	-2.49784531615926	1.35914384976652	-1.83780790869808	0.0660907158440355
"Curved"	"(Intercept)"	-18.9304118625997	469.614003329564	-0.040310577896704	0.967845520692602

"Curved"	"QARF21$PresenceofGeo.andMat.consultant"	7.31956836389305	234.808621866803	0.0311724855148	0.975131982625377
"Rectilinear"	"(Intercept)"	-42.8704158181523	0.0623015646040893	-688.1113835677	0
"Rectilinear"	**"QARF21$PresenceofGeo.andMat.consultant"**	**20.5323899947557**	**0.124603129094568**	**164.782298357633**	**0**
"Organic"	"(Intercept)"	-18.9302919896043	469.533985858332	-0.0403171922794869	0.967840247465491
"Organic"	"QARF21$PresenceofGeo.andMat.consultant"	7.319789302063	234.768612509543	0.0311787390308211	0.97512699546564
"Free form"	"(Intercept)"	-18.9304169644214	469.578733947839	-0.0403136164307735	0.967843098262284
"Free form"	"QARF21$PresenceofGeo.andMat.consultant"	7.31972367797922	234.79098680934	0.03117548836712	0.975129587859793
"Irregular"	"(Intercept)"	-24.8296001542286	0.143349415469474	-173.210334153864	0
"Irregular"	"QARF21$PresenceofGeo.andMat.consultant"	10.6161162804345	0.286696284593813	37.0291379795007	3.89141829470994e-300
"Polygonal"	"(Intercept)"	-31.6206659896643	0.102697461428158	-307.90114526623	0
"Polygonal"	**"QARF21$PresenceofGeo.andMat.consultant"**	**14.3582998028813**	**0.205394905244971**	**69.9058225702161**	**0**
"Other"	"(Intercept)"	-24.8314075664632	0.143354493775801	-173.216806201403	0

"Other"	"QARF21$PresenceofGeo.andMat.consultant"	10.6169835713818	0.286706446240458	37.0308505811462	3.65212752154931e-300

__Table F.5.__ Multinomial logistic regression to identify the impact of geometry consulting body on the floor geometry of buildings.

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Square"	"(Intercept)"	-1.30305146527925	2.18917680731333	-0.595224406236253	0.551693478177152
"Square"	"QARF21$PresenceofGeometryconsultingbody"	-0.894008740149809	1.20809449728394	-0.740015571761758	0.459290545772727
"Curved"	"(Intercept)"	-17.5495573581687	152.847278668155	-0.114817597742583	0.908589700323329
"Curved"	"QARF21$PresenceofGeometryconsultingbody"	6.67985990290541	76.4286212410954	0.087399979149613	0.930353585952745
"Rectilinear"	"(Intercept)"	-2.60364982157559	2.1336912968052	-1.2202561005306	0.222367805855056
"Rectilinear"	"QARF21$PresenceofGeometryconsultingbody"	0.405945978519817	1.10349647014603	0.36787247580964	0.712968324415434
"Organic"	"(Intercept)"	-17.5495242371832	152.839706411902	-0.114823069535919	0.908585363148371
"Organic"	"QARF21$PresenceofGeometryconsultingbody"	6.67992586609475	76.4248345498478	0.0874051727483662	0.930349457858327
"Free form"	"(Intercept)"	-17.5495662453835	152.849837933137	-0.114815733419753	0.908591178065123
"Free form"	"QARF21$PresenceofGeometryconsultingbody"	6.6798353028489	76.4299010752378	0.0873981937549971	0.930355005061179
"Irregular"	"(Intercept)"	-19.3087479273659	199.513681914488	-0.0967790666889783	0.922901848248701
"Irregular"	"QARF21$PresenceofGeometryconsultingbody"	7.90612495110895	99.7587774348141	0.0792524242418177	0.936831847169449
"Polygonal"	"(Intercept)"	-19.3900018951587	171.21416500905	-0.113249986612579	0.909832366955956
"Polygonal"	"QARF21$PresenceofGeometryconsultingbody"	8.29331424982344	85.6082439938216	0.0968751823763839	0.922825517683992
"Other"	"(Intercept)"	-19.3088062361755	199.518614869993	-0.096776966143019	0.922903516411577

"Other"	"QARF21$PresenceofGeometryconsultingbody"	7.90613381020616	99.7612439409793	0.0792505536005904	0.936833335045335

Table F.6. *Multinomial logistic regression to identify the impact of artist on the façade geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Square"	"(Intercept)"	-3.62001891118646	2.09904323629089	-1.72460426188419	0.0845988148668553
"Square"	"QARF21$PresenceofArtist"	0.73023796269704	1.11396818143664	0.655528564339498	0.512127501712456
"Triangular"	"(Intercept)"	-43.8545865496436	0.201912808028268	-217.195664692573	0
"Triangular"	**"QARF21$PresenceofArtist"**	**19.9516736003603**	**0.403825615947771**	**49.4066567657779**	**0**
"Curved"	"(Intercept)"	7.09224769416894	86.5859533403245	0.0819099105635875	0.934718353434059
"Curved"	"QARF21$PresenceofArtist"	-9.98260370473462	86.567664481045	-0.115315617726067	0.908194959787106
"Rectilinear"	"(Intercept)"	-1.13607138952656	1.16892599803251	-0.971893337507039	0.331103614646057
"Rectilinear"	"QARF21$PresenceofArtist"	-0.367876410715689	0.670649992902067	-0.548537112665576	0.583323153423072
"Free form"	"(Intercept)"	-2.52201897440514	2.17732557729163	-1.15831045237721	0.246737367412294
"Free form"	"QARF21$PresenceofArtist"	-0.368106007476794	1.25485359700281	-0.293345780221699	0.769257864371631
"Irregular"	"(Intercept)"	-3.2158102930356	2.11935490621228	-1.51735336238842	0.129177492130977
"Irregular"	"QARF21$PresenceofArtist"	0.325438290823174	1.15101480926196	0.28274031594072	0.777375909012717
"Polygonal"	"(Intercept)"	-40.094194147299	0.144116251322083	-278.207306806039	0
"Polygonal"	**"QARF21$PresenceofArtist"**	**18.4180387384382**	**0.288232502120941**	**63.8999370400984**	**0**
"Other"	"(Intercept)"	7.09224769413862	86.5859533486087	0.0819099105554005	0.934718353440569
"Other"	"QARF21$PresenceofArtist"	-9.9826037047649	86.567664489328	-0.115315617715383	0.908194959795574

Table F.7. *Multinomial logistic regression to identify the impact of Special modeling group on the façade geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Square"	"(Intercept)"	-4.60855723940301	2.07574092894587	-2.22019866503446	0.02640528490222
"Square"	"QARF21$Presenceof Specialmodeliggroup"	1.32058964592775	1.1042322300281	1.19593470468992	0.23172204075418
"Triangular "	"(Intercept)"	-19.8407675685768	140.633694300225	-0.141081180205795	0.88780581095786
"Triangular "	"QARF21$Presenceof Specialmodeliggroup"	8.03954204233873	70.322305369745	0.114324210505727	0.90898079111129
"Curved"	"(Intercept)"	-19.8423371739599	140.962152088416	-0.140763580010569	0.88805671546791
"Curved"	"QARF21$Presenceof Specialmodeliggroup"	8.03644609969903	70.4865630107465	0.114013873799944	0.90922679546015
"Rectilinear "	"(Intercept)"	-0.0575514494560213	0.960060650366601	-0.0599456393031473	0.95219893032091
"Rectilinear "	"QARF21$Presenceof Specialmodeliggroup"	-1.15875904268762	0.659816347402107	-1.75618419769379	0.07905696203545
"Free form"	"(Intercept)"	-3.54225327294932	2.17037677494611	-1.63209140175086	0.10266023280838
"Free form"	"QARF21$Presenceof Specialmodeliggroup"	0.237219687715094	1.25295718442533	0.189327848280702	0.84983587023901
"Irregular"	"(Intercept)"	-1.3105761077691	1.41538284232134	-0.925951670870649	0.35447109681243
"Irregular"	"QARF21$Presenceof Specialmodeliggroup"	-0.882320118956563	0.946509360843083	-0.932183193804502	0.35124185933705
"Polygonal"	"(Intercept)"	-2.80794189478688	2.26570476013026	-1.23932382726929	0.21522559810028
"Polygonal"	"QARF21$Presenceof Specialmodeliggroup"	-0.477415142461931	1.43241442468255	-0.333294006423969	0.73891236319005
"Other"	"(Intercept)"	-19.840823824416	140.646372978414	-0.141068862312298	0.88781554189813
"Other"	"QARF21$Presenceof Specialmodeliggroup"	8.03941800321865	70.3286458402673	0.114312139913486	0.90899035932398

Table F.8. *Multinomial logistic regression to identify the impact of Geometry Architect on the façade geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Square"	"(Intercept)"	-19.4415725988722	157.534955105151	-0.123411166657555	0.901781514955336

"Square"	"QARF21$PresenceofGeometryArchitect"	8.62974715402199	78.7682351751281	0.109558721670419	0.912759348855346
"Triangular"	"(Intercept)"	-17.5670181091723	160.422320261565	-0.109504825017676	0.912802094974758
"Triangular"	"QARF21$PresenceofGeometryArchitect"	6.71890016888058	80.2159211604919	0.0837601821643081	0.933247106754435
"Curved"	"(Intercept)"	-17.5669980140142	160.414485767282	-0.109510047861258	0.912797952660177
"Curved"	"QARF21$PresenceofGeometryArchitect"	6.71897774843476	80.2120033247436	0.0837652404869198	0.933243084930639
"Rectilinear"	"(Intercept)"	-0.9418639974534	1.61585537429446	-0.582888798364552	0.559968161866746
"Rectilinear"	"QARF21$PresenceofGeometryArchitect"	-0.441129893188716	0.860132346110497	-0.512862811384198	0.608047288814174
"Free form"	"(Intercept)"	-0.72993157966208	2.24083535480561	-0.325740835040243	0.744620445895912
"Free form"	"QARF21$PresenceofGeometryArchitect"	-1.35050545647391	1.28115644451338	-1.05413001063025	0.29182339796965
"Irregular"	"(Intercept)"	-19.3435658390185	167.116199026057	-0.115749196976425	0.90785131471222
"Irregular"	"QARF21$PresenceofGeometryArchitect"	8.41365546213037	83.559068352873	0.100691111425503	0.919795667567136
"Polygonal"	"(Intercept)"	-19.108125742039	198.173163611251	-0.0964213589460717	0.923185929170622
"Polygonal"	"QARF21$PresenceofGeometryArchitect"	7.8373119204367	99.0885345448422	0.0790940340013803	0.936957828825606
"Other"	"(Intercept)"	-17.5650684268027	159.950890304762	-0.109815383917746	0.912555790234262
"Other"	"QARF21$PresenceofGeometryArchitect"	6.72283646591293	79.9801742819261	0.0840562867769613	0.933011679689881

Table F.9. *Multinomial logistic regression to identify the impact of Geometry and mathematical consultant on the façade geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Square"	"(Intercept)"	2.44171387670712	2.86063010768501	0.853558057068447	0.393349906559446
"Square"	"QARF21$PresenceofGeo.andMat.consultant"	-2.44202405975183	1.47704773368064	-1.6533142457533	0.0982669251919102

"Triangular"	"(Intercept)"	-27.1118627126271	0.201344989302341	-134.653774134482	0
"Triangular"	"QARF21$PresenceofGeo.andMat.consultant"	11.4393808121404	0.402689839142745	28.4074235309557	1.63726702081728e-177
"Curved"	"(Intercept)"	-27.1125676707302	0.201495623020443	-134.556608547171	0
"Curved"	"QARF21$PresenceofGeo.andMat.consultant"	11.4389745908474	0.402991107037872	28.3851787076096	3.08169737988544e-177
"Rectilinear"	"(Intercept)"	1.83724868127549	2.84675903567042	0.645382576556155	0.518679291637876
"Rectilinear"	"QARF21$PresenceofGeo.andMat.consultant"	-1.83670697987359	1.45088180673201	-1.26592460623007	0.205540075941048
"Free form"	"(Intercept)"	-18.4532433986038	441.61220410219	-0.0417860811526252	0.966669230953202
"Free form"	"QARF21$PresenceofGeo.andMat.consultant"	7.65879666160982	220.80669286333	0.0346855276997889	0.97233050120658
"Irregular"	"(Intercept)"	-17.5893069575629	313.161519613475	-0.0561668846775069	0.955208861700005
"Irregular"	"QARF21$PresenceofGeo.andMat.consultant"	7.48230697557479	156.581273516136	0.0477854522929508	0.961887230699846
"Polygonal"	"(Intercept)"	-19.667286753293	662.013858383404	-0.0297082704602578	0.976299715960924
"Polygonal"	"QARF21$PresenceofGeo.andMat.consultant"	8.06311930354093	331.007512117664	0.0243593242097621	0.980565993268163
"Other"	"(Intercept)"	-27.1119857529871	0.201410930757266	-134.610299704447	0
"Other"	"QARF21$PresenceofGeo.andMat.consultant"	11.439110131519	0.402821722286321	28.3974510276987	2.17411578992749e-177

Table F.10. *Multinomial logistic regression to identify the impact of Geometry consulting body on the façade geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Square"	"(Intercept)"	-2.06928035674777	2.14856008835028	-0.963100993994831	0.335496843003819
"Square"	"QARF21$PresenceofGeometryconsultingbody"	-0.124919474439031	1.13638859446167	-0.109926723171846	0.912467488945209

"Triangular"	"(Intercept)"	-19.3984886527597	237.872964571223	-0.0815497830437618	0.935004735538467
"Triangular"	"QARF21$PresenceofGeometryconsultingbody"	7.64430883222526	118.939683846751	0.0642704653736482	0.948754870036487
"Curved"	"(Intercept)"	-19.3984254614453	237.848922983556	-0.0815577603552422	0.93499839169642
"Curved"	"QARF21$PresenceofGeometryconsultingbody"	7.64444778839854	118.927662302176	0.0642781304233091	0.94874876683147
"Rectilinear"	"(Intercept)"	-2.6840729148139	2.13469679768418	-1.25735557280346	0.20862490899532
"Rectilinear"	"QARF21$PresenceofGeometryconsultingbody"	0.485764649925015	1.1043926878648	0.439847760006613	0.660047373838062
"Free form"	"(Intercept)"	-25.4361066632239	818.064731876581	-0.0310930243929173	0.975195352709575
"Free form"	"QARF21$PresenceofGeometryconsultingbody"	11.2114928309045	409.032686843069	0.0274097723520222	0.978132903968392
"Irregular"	"(Intercept)"	-27.7238977273887	0.0930682484180034	-297.887821020017	0
"Irregular"	**"QARF21$PresenceofGeometryconsultingbody"**	**12.6108956051513**	**0.186134061313994**	**67.751681321119**	**0**
"Polygonal"	"(Intercept)"	-23.5017595509	557.985995645969	-0.0421189057329162	0.966403908948038
"Polygonal"	"QARF21$PresenceofGeometryconsultingbody"	10.0423628227769	278.993691480273	0.035994945869545	0.97128638895624
"Other"	"(Intercept)"	-19.3984478764075	237.85666105472	-0.0815552013148994	0.935000426735941
"Other"	"QARF21$PresenceofGeometryconsultingbody"	7.64440513764726	118.931531572845	0.0642756806084269	0.94875071746723

Table F.11. *Multinomial logistic regression to identify the impact of Artist on the roof geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Flat Square"	"(Intercept)"	-41.5128500418646	0.106458101788201	-389.94542777453	0
"Flat Square"	**"QARF21$PresenceofArtist"**	**19.7489729183446**	**0.212916203155336**	**92.754673555476**	**0**
"Flat Triangular"	"(Intercept)"	-32.0056262524504	0.203306117040506	-157.425790814123	0
"Flat Triangular"	"QARF21$PresenceofArtist"	14.3022131169737	0.406612185467013	35.1740887955607	4.97980738595198e-271
"Flat Curved"	"(Intercept)"	-32.0056101515115	0.203302259942664	-157.428698335857	0

"Flat Curved"	"QARF21$PresenceofArtist"	14.3022246709709	0.406604471272001	35.1747845424045	4.859322191521e-271
"Flat Rectilinear"	"(Intercept)"	-43.1074658497912	0.0795822259373407	-541.672029678235	0
"Flat Rectilinear"	**"QARF21$PresenceofArtist"**	**20.8928542774552**	**0.159164451572001**	**131.265832735294**	**0**
"Flat Organic"	"(Intercept)"	-32.0056243935704	0.203309332198289	-157.423292120969	0
"Flat Organic"	"QARF21$PresenceofArtist"	14.3021958461586	0.406618615781645	35.1734900741458	5.08587712956819e-271
"Flat Free form"	"(Intercept)"	-2.01455418463295	2.30208167788635	-0.875101089585411	0.381518904283692
"Flat Free form"	"QARF21$PresenceofArtist"	-0.693364665905898	1.44912332140747	-0.478471815105746	0.632314430126117
"Flat Irregular"	"(Intercept)"	21.78156298644	0.376386251511955	57.8702407405766	0
"Flat Irregular"	**"QARF21$PresenceofArtist"**	**-23.7964600079357**	**0.376386251610511**	**-63.2235101736939**	**0**
"Flat Polygonal"	"(Intercept)"	-3.11309195276054	2.15234455486688	-1.44637248981406	0.148072753640164
"Flat Polygonal"	"QARF21$PresenceofArtist"	0.405236273642745	1.19714448424933	0.338502393799901	0.734984623463483
"Pitched: Hip Gable Mansard Gambrel butterfly etc."	"(Intercept)"	-1.25856709543465	0.956508558838544	-1.31579282151211	0.188243589312134
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"QARF21$PresenceofArtist"	0.49643099123678	0.535103562561999	0.927728809839986	0.353548260161323
"Pyramidal"	"(Intercept)"	-32.0056288098678	0.203305547247836	-157.426244601442	0
"Pyramidal"	"QARF21$PresenceofArtist"	14.3022172917419	0.40661104588189	35.1741976431607	4.96076271523755e-271

"Others"	"(Intercept)"	-2.70858436940171	2.19110127744645	-1.23617488487722	0.216393564107824
"Others"	"QARF21$PresenceofArtist"	0.000299826349380458	1.26499249704864	0.00023701828278032	0.999810886773312

Table F.12. *Multinomial logistic regression to identify the impact of special modeling group on the roof geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Flat Square"	"(Intercept)"	-44.5862188869772	0.106904124761101	-417.067339418513	0
"Flat Square"	**"QARF21$PresenceofSpecialmodeliggroup"**	**21.3201586698149**	**0.213808249398972**	**99.7162585155026**	**0**
"Flat Triangular"	"(Intercept)"	11.4136192146409	0.514459020639661	22.1856722435338	4.72321252836333e-109
"Flat Triangular"	"QARF21$PresenceofSpecialmodeliggroup"	-14.2465812776165	0.514460068469755	-27.6922975188191	8.64485487700535e-169
"Flat Curved"	"(Intercept)"	-36.4655169756319	0.203519924967477	-179.174186416682	0
"Flat Curved"	**"QARF21$PresenceofSpecialmodeliggroup"**	**16.5667591902755**	**0.407039843528747**	**40.7005836250658**	**0**
"Flat Rectilinear"	"(Intercept)"	-0.947494360710093	1.23327287021273	-0.76827633494172	0.44232303102586
"Flat Rectilinear"	"QARF21$PresenceofSpecialmodeliggroup"	-0.499239757728266	0.771063078519097	-0.647469411565012	0.517328185217834
"Flat Organic"	"(Intercept)"	11.4136195065189	0.51445887882404	22.1856789265809	4.72251086254878e-109
"Flat Organic"	"QARF21$PresenceofSpecialmodeliggroup"	-14.2465809857383	0.514459926654377	-27.6923045850944	8.64316120523556e-169

"Flat Free form"	"(Intercept)"	-2.33291539610248	2.29557916298885	-1.0162644066977	0.30950349324472
"Flat Free form"	"QARF21$PresenceofSpecialmodeliggroup"	-0.499789259808847	1.44721254891305	-0.345346134667102	0.729834167150111
"Flat Irregular"	"(Intercept)"	17.9390961177194	0.37378374069609	47.9932489420535	0
"Flat Irregular"	**"QARF21$PresenceofSpecialmodeliggroup"**	**-20.0791187814071**	**0.373783744058959**	**-53.7185447482701**	**0**
"Flat Polygonal"	"(Intercept)"	-0.13684868433282	1.61379555341526	-0.0847992696740354	0.932420974166192
"Flat Polygonal"	"QARF21$PresenceofSpecialmodeliggroup"	-1.59765921157778	1.19492348005979	-1.33703893030693	0.181209929605835
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"(Intercept)"	-0.482577513377411	0.829022855463512	-0.582103991701892	0.560496636603897
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"QARF21$PresenceofSpecialmodeliggroup"	0.0474134019545166	0.487932952737034	0.0971719612060504	0.922589834364558
"Pyramidal"	"(Intercept)"	-36.4655125872326	0.203537255786668	-179.158908506917	0
"Pyramidal"	**"QARF21$PresenceofSpecialmodeliggroup"**	**16.5666688028155**	**0.407074505166557**	**40.6968960044233**	**0**
"Others"	"(Intercept)"	-3.02685979741242	2.18412999937093	-1.38584232544958	0.165795055024985
"Others"	"QARF21$PresenceofSpecialmodeliggroup"	0.193898322999409	1.26269318657601	0.153559332592262	0.877957204413993

Table F.13. *Multinomial logistic regression to identify the impact of Geometry Architect on the roof geometry of buildings.*

"y.level"	"term"	"estimate"	"std.error"	"statistic"	"p.value"
"Flat Square"	"(Intercept)"	-45.6891048394293	0.105267298966413	-434.029421178625	0
"Flat Square"	**"QARF21$PresenceofGeometryArchitect"**	**21.7322399378932**	**0.210534597913696**	**103.224078860435**	**0**
"Flat Triangular"	"(Intercept)"	-29.9773764621723	0.202691606470656	-147.896486609139	0
"Flat Triangular"	"QARF21$PresenceofGeometryArchitect"	13.1831992952112	0.405383152991868	32.5203432799676	5.50016186237764e-232
"Flat Curved"	"(Intercept)"	-29.977379372289	0.202689774471809	-147.897837719773	0
"Flat Curved"	"QARF21$PresenceofGeometryArchitect"	13.1832100329349	0.405379488995	32.5206637011117	5.44309280716156e-232
"Flat Rectilinear"	"(Intercept)"	-52.5670594054175	0.0779813753543216	-674.097618393753	0
"Flat Rectilinear"	**"QARF21$PresenceofGeometryArchitect"**	**25.5177961175558**	**0.155962750707708**	**163.614683645707**	**0**
"Flat Organic"	"(Intercept)"	-29.977381221294	0.202690921560244	-147.897009844045	0
"Flat Organic"	"QARF21$PresenceofGeometryArchitect"	13.1832051451755	0.405381783171462	32.520467599797	5.47794907457295e-232
"Flat Free form"	"(Intercept)"	-37.051526289413	0.145191585479223	-255.190589503653	0
"Flat Free form"	**"QARF21$PresenceofGeometryArchitect"**	**17.0668950814285**	**0.2903831696655**	**58.7737061383011**	**0**
"Flat Irregular"	"(Intercept)"	-37.0502358494487	0.145199453577031	-255.167873822561	0
"Flat Irregular"	**"QARF21$PresenceofGeometryArchitect"**	**17.0661927426684**	**0.29039890586026**	**58.7681027657888**	**0**

"Flat Polygonal"	"(Intercept)"	-1.64697194601372	2.20473178828088	-0.747016918233821	0.455053348566374
"Flat Polygonal"	"QARF21$PresenceofGeometryArchitect"	-0.432630105553243	1.21879658867377	-0.354964979040519	0.722615827667478
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"(Intercept)"	-2.49407830207386	1.60088880981421	-1.5579334971823	0.119249013603406
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"QARF21$PresenceofGeometryArchitect"	1.10769332666217	0.829317253275626	1.33566897624162	0.181657493923441
"Pyramidal"	"(Intercept)"	-29.9773788240659	0.202689850617904	-147.897779453087	0
"Pyramidal"	"QARF21$PresenceofGeometryArchitect"	13.1832093729924	0.405379641287142	32.5206498558578	5.44554646226759e-232
"Others"	"(Intercept)"	-43.1644176649955	0.120055368278202	-359.5375890645	0
"Others"	**"QARF21$PresenceofGeometryArchitect"**	**20.3261034521586**	**0.240110736494822**	**84.6530386307689**	**0**

Table F.14. *Multinomial logistic regression to identify the impact of Geometry and mathematical consultant on the roof geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Flat Square"	"(Intercept)"	1.27628547097522	2.52122899173726	0.506215609592763	0.612705298093811
"Flat Square"	"QARF21$PresenceofGeo.andMat.consultant"	-1.96943547785546	1.3625675313793	-1.44538559190665	0.148349608165245
"Flat Triangular"	"(Intercept)"	-27.2199771779937	0.202312146455147	-134.544453484054	0

"Flat Triangular"	"QARF21$PresenceofGeo.andMat.consultant"	11.7293891343102	0.404624233007477	28.9883506163938	9.22700562838951e-185
"Flat Curved"	"(Intercept)"	-27.2200248917868	0.202312083222136	-134.544731378697	0
"Flat Curved"	"QARF21$PresenceofGeo.andMat.consultant"	11.729413311026	0.404624106542905	28.9884194277046	9.2085967921888e-185
"Flat Rectilinear"	"(Intercept)"	-58.8104106571092	0.0770080013159991	-763.692209278139	0
"Flat Rectilinear"	**"QARF21$PresenceofGeo.andMat.consultant"**	**28.5643263050926**	**0.154016002631981**	**185.463366253873**	**0**
"Flat Organic"	"(Intercept)"	-27.2199954958596	0.20231215966557	-134.544535241259	0
"Flat Organic"	"QARF21$PresenceofGeo.andMat.consultant"	11.7293982264269	0.404624259428868	28.9883711940135	9.22149672453332e-185
"Flat Free form"	"(Intercept)"	-36.2381033068639	0.144672942090008	-250.482936085716	0
"Flat Free form"	**"QARF21$PresenceofGeo.andMat.consultant"**	**16.5850247040966**	**0.289345883623951**	**57.3190276508351**	**0**
"Flat Irregular"	"(Intercept)"	-36.2360282233596	0.144673143236633	-250.468244573152	0
"Flat Irregular"	**"QARF21$PresenceofGeo.andMat.consultant"**	**16.5839857073249**	**0.289346285916623**	**57.3153571153964**	**0**
"Flat Polygonal"	"(Intercept)"	-46.8562666173639	0.104547703687653	-448.180734388504	0
"Flat Polygonal"	**"QARF21$PresenceofGeo.andMat.consultant"**	**22.2406811585077**	**0.209095407371788**	**106.366186795113**	**0**
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"(Intercept)"	-81.8472743462447	0.0475769461700118	-1720.31374300005	0
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	**"QARF21$PresenceofGeo.andMat.consultant"**	**40.7436361706203**	**0.0951538923400237**	**428.186752729217**	**0**
"Pyramidal"	"(Intercept)"	-27.2199373788483	0.20231222627539	-134.544203679496	0
"Pyramidal"	"QARF21$PresenceofGeo.andMat.consultant"	11.7293688310231	0.404624392646747	28.9882890013093	9.24352047472121e-185

"Others"	"(Intercept)"	-42.3978497421377	0.119430092094912	-355.001398713182	0
"Others"	**"QARF21$PresenceofGeo.andMat.consultant"**	**19.867631881937**	**0.238860184161577**	**83.1768256047959**	**0**

Table F.15. *Multinomial logistic regression to identify the impact of Geometry consulting body on the roof geometry of buildings.*

"y.level"	**"term"**	**"estimate"**	**"std.error"**	**"statistic"**	**"p.value"**
"Flat Square"	"(Intercept)"	4.57082474532595	2.08703592499997	2.19010352939948	0.0285167293334438
"Flat Square"	"QARF21$PresenceofGeometryconsultingbody"	-4.16575614180102	1.36237749475403	-3.05771062560976	0.00223034839086864
"Flat Triangular"	"(Intercept)"	-21.9252327223442	0.20227501159301	-108.393184851024	0
"Flat Triangular"	"QARF21$PresenceofGeometryconsultingbody"	9.08226322709409	0.404548619819256	22.4503626564141	1.26931983315778e-111
"Flat Curved"	"(Intercept)"	-21.9253408577615	0.202277829743504	-108.3922092973	0
"Flat Curved"	"QARF21$PresenceofGeometryconsultingbody"	9.0823030383091	0.404554256199174	22.4501482783501	1.27545572531925e-111
"Flat Rectilinear"	"(Intercept)"	1.96912343661556	2.04671970538473	0.962087496121222	0.336005654533206
"Flat Rectilinear"	"QARF21$PresenceofGeometryconsultingbody"	-1.96928088717242	1.09074409204678	-1.80544721858365	0.0710047278847981
"Flat Organic"	"(Intercept)"	-21.9253791814519	0.202300297037174	-108.380360793157	0
"Flat Organic"	"QARF21$PresenceofGeometryconsultingbody"	9.08220855053388	0.404599190837136	22.4474214388377	1.35613504047565e-111

"Flat Free form"	"(Intercept)"	-26.3308307745752	0.144679435776752	-181.994287116277	0
"Flat Free form"	**"QARF21$PresenceofGeometryconsultingbody"**	**11.6313999373643**	**0.289358671214024**	**40.1971708280384**	**0**
"Flat Irregular"	"(Intercept)"	-26.3356536120477	0.144665555253189	-182.045087138786	0
"Flat Irregular"	**"QARF21$PresenceofGeometryconsultingbody"**	**11.6339117625671**	**0.289330910624667**	**40.209709143933**	**0**
"Flat Polygonal"	"(Intercept)"	-30.6790790694997	0.104551692060759	-293.434553423305	0
"Flat Polygonal"	**"QARF21$PresenceofGeometryconsultingbody"**	**14.1521063893121**	**0.209103345626852**	**67.6799615371375**	**0**
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"(Intercept)"	0.427994183549731	2.01458050085811	0.212448290533651	0.831757315093236
"Pitched : Hip Gable Mansard Gambrel butterfly etc"	"QARF21$PresenceofGeometryconsultingbody"	-0.428375697055446	1.02900905262671	-0.416299250197994	0.677191041172706
"Pyramidal"	"(Intercept)"	41.6617393743411	0.612169531094711	68.0558852706041	0
"Pyramidal"	**"QARF21$PresenceofGeometryconsultingbody"**	**-42.3543386772565**	**0.612169531094711**	**-69.1872700712766**	**0**
"Others"	"(Intercept)"	1.67814210122537	2.55488250032915	0.656837291346732	0.511285543164261
"Others"	"QARF21$PresenceofGeometryconsultingbody"	-2.37282958701105	1.42272295498028	-1.66780860511521	0.0953537271196298

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Annex I – Manuscript

The impact of geometry on the construction of buildings and its interplay with computational design and Digital fabrication

By Eyob Alene

Msc. Architectural engineering,

Ethiopian institute of Architecture building construction and city development, Addis Ababa University.

Abstract

In this thesis the Author looked at the Impact of geometry on the construction of buildings and its interplay with computational design, digital fabrication and presence of specialized professionals in the AEC industry of Addis Ababa. It mainly focused on high-rise and all buildings of the city. For the two focus areas two different research methods were applied to answer the research question of the study accordingly. The first research method was an intensive building analysis based on around 24 building parameters to identify the impact of geometry on the construction method and material of buildings, 40 high-rise buildings was deeply studied based on the parameters. The second research method was mainly based on a systematic questionier survey to identify the impact of geometry on the construction method and material of the entire buildings of the city. Besides the second method was used for realization of the level of the AEC industry in using advanced design and construction approaches and tools in deciding the architectural geometry and construction of all buildings of the city. The questionier survey was applied on 102 design and engineering firms. The main parts of buildings in which the research was focused on are the three major parts of a building, when combined they make a perfect geometrical solid, as a geometric solid is a combination of three surfaces to make a 3D volumetric object these are the base, vertical and overhead surfaces. Here in this thesis the base surface is the floor or slab of a building, the vertical surface is the façade of a building and the overhead top surface is the roof of a building. SPSS, STATA and advanced programing tools such as R-studio was used as a tool to make statistical analysis of data in a scientific manner. The former tools were used for descriptive statistics, correlations and multinomial regression model tests and the later tool was used to run complex multinomial logistic regression tests for datas which needs high performance statistical tools. Overall this thesis results a deeper understanding of the substantial role that geometry plays in determining construction practices and materials in the AEC industry. Through a comprehensive building analysis method, the research identified how geometric design choices influence the construction of high-rise buildings under method type one approach of the research. The findings provide a valuable knowledge in understanding the relation between building design and construction. Besides, on method type two study approach, the thesis deeply explored the interplay of geometry with construction and identified the impact of computational design, digital fabrication and presence of specialized professionals on the geometry of our buildings to know how much our firm are applying such advanced design and construction approaches in the AEC industry or to know how much the geometry of the buildings is driven by advanced design and construction tools, approaches and professionals.

Key words – Geometry, Construction, Computational design, digital fabrication, specialized professionals.

1. Introduction

The AEC industry in Ethiopia faces significant challenges, primarily related to a lack of collaboration and professionalism, as well as a weak capacity among contractors and consultants Mahesh (2020). Conversely, in other countries' AEC industries, advanced geometries in architecture are breaking down the traditional barriers between professionals from diverse fields such as architecture, engineering, construction, science, and technology (Helmut Pottmann, 2008). This indicates that our AEC industry is currently lagging behind in terms of the utilization and development of advanced geometries within the field.

Excluding vernaculars and historical architectural and construction achievements of the past, currently the Ethiopian AEC industry is not contributing a new, modern and outshining construction method and material for self and the world (Abebe, 2020). But in accordance with Helmut (2008) challenges and problems related to construction, engineering and design can be solved easily with a concrete realization of geometry. Moreover, although geometrical complexity remains the precondition for efficient structures in architecture and this simple paradigm can be observed in nature (Placeholder3), the AEC industry is not producing geometrically intricate buildings in the skyline of Addis Ababa.

Architecture and geometry have been interwoven for thousands of years, such that geometry and architecture were inextricably fused into a single body of knowledge (Wallner et al., 2010).

According to (Helmut Pottmann, 2008) "Geometry lies at the core of the architectural design process. It is omnipresent, from initial form-finding stages to actual construction. It also underlies the main communication medium; namely, graphical representations obtained by precise geometric rules. Whereas the variety of shapes that could be treated by traditional geometric methods has been rather limited, modern computing technologies have led to a real[8] geometry revolution**.** Scale and construction technologies pose new challenges to engineering and design. We are convinced that such challenges can be met more effectively with a solid understanding of geometry."

[8] Real – Actual happening

Moreover, According to Sigrid (2016) "Architecture and geometry have always been intrinsically linked. However, their operational relationship has been dramatically strengthened by the recent advent of computational design and digital fabrication techniques. These distinct developments are reciprocally dependent, as the digital fabrication of complex architectural components induces the need for advanced geometric strategies, and in return the potentials of geometrical computing instils a need for efficiency in the production of complex forms. The conjecture of speculation that the decline of complex form in architecture may be amplified by the current accumulation of global political, social, and environmental emergencies demanding fast and pragmatic architectural solutions rather than extravagant shapes; however, this critical assumption proves to be short-sighted and simplistic. As a matter of fact, geometrical complexity remains the precondition for efficient structures in architecture, and this simple paradigm can be observed in nature, beyond time-dependent stylistic and formal discourse."

2. Methodology

2.1 Location of the study area

The study focuses in the architecture, engineering and construction industry of our country specifically in Addis Ababa the capital city of Ethiopia, as a typical example of other Ethiopian urban areas. The reason for the selection is that the city is a major center for the construction industry that many big and mass buildings are constructed and a home of many buildings compared to other cities of Ethiopia.

2.2 Data type and sources

2.2.1 Method one

The primary data sources for this research consist of an onsite building survey including identification of the geometrical shape and form of the buildings and measurements of various building components, such as floor size, exterior wall dimensions, and roof slab measurements etc. Are taken along with interviews with site engineers, resident engineers, architects, and construction managers structured as a reinforcing element to fill the data required based on 24 buildings analysis parameters and capturing of required building photographs. Overall, the primary data source for this building analysis method involves sourcing data related to the 24 measuring parameters of the research variables through on-site investigations conducted on buildings. The secondary data source for this research method consists of architectural and structural drawing reviews along with other related documents of the buildings.

2.2.2 Method two

The primary data source for this research method type is questionnaire survey. Through this survey, valuable information is collected to address the research objectives through a structured questionier. Participants in the survey include consulting architects and engineering companies. No secondary data is used in this research method. Overall, the combination of the questionnaire survey and the building analysis method ensures a robust and multi-faceted approach to data collection, enabling the research to address its objectives effectively.

2.3 Data collection and analysis

This research utilizes two interlinked and unique methods: questionnaire survey and building analysis. In both methods, the predominant approach to data collection is through the gathering of primary data.

2.3.1 Data collection

2.3.1.1 Method one

On the building analysis method, primary data sources play a crucial role. The researcher have direct access to all selected buildings to get primary data and had a possibility to review secondary data of the buildings from respective bodies such as architectural and structural drawings and other documents which are fundamental in understanding the geometry and construction aspects of the buildings. These drawings serve as a main sources of information that are directly accessed and used for analysis and interpretation.

Besides, in this study, an essential primary data collection method involves conducting onsite observations of buildings, based on the 24 building analysis parameters. These observations aim to identify and explore the relationship between the independent variable (geometry) and the dependent variables (construction method and material) in the context of building design. Through this primary data collection method, valuable insights and information are obtained to accomplish the research objectives and contribute to a comprehensive understanding of the interplay of the variables.

Furthermore, to acquire further primary data, interviews are carried out with site engineers and architects. These interviews provide an opportunity for direct communication with industry professionals who possess firsthand knowledge and experience regarding the construction of buildings. The insights and information gathered from these interviews directly contribute to the primary data collected for the research. It is important to note that these interviews are not conducted in isolation from the building analysis parameters; instead, they are a means to reinforce and answer required datas in the 24 building analysis parameters. These parameters serve as the foundation for the interview process, allowing for in-depth discussions and clarifications regarding the collected data. By aligning the interviews with these parameters, the research ensures that relevant and comprehensive information is obtained to address the research objectives effectively.

2.3.1.1 Method two

Similarly In the case of the questionnaire survey, primary data is collected directly from the participants. The researcher design and administer the survey to target individuals, such as consulting architects and engineering companies. Through this survey, firsthand information is obtained. The survey responses serve as primary data points that contribute to the research findings.

Overall, the data collection methods employed in this research primarily rely on the collection of primary data. The questionnaire survey gathers primary data from the participants, while the building analysis method involves an onsite accessing of existing buildings, as well as conducting interviews with relevant professionals. This focus on primary data ensures that the research findings are based on direct and firsthand information, enhancing the validity and reliability of the study.

2.3.2 Data analysis

This study utilized four distinct data analysis techniques to investigate the influence of a building's geometry on its construction methods and materials and to identify the interplay of geometry with advanced design and construction methods. The four data analysis methods employed in this research encompass descriptive statistics, inferential statistics, statistical modeling, and data visualization.

Descriptive statistics were utilized to provide a concise summary of the data gathered from both the building analysis and questionnaire survey methods in the research. This involved calculating various measures, such as the mean, median, mode, range, standard deviation, and frequency distribution of the independent, dependent and control variables along with their related statistical outputs.

Inferential statistics were applied in this study to examine the correlation and interplay between the independent, dependent and control variables. Techniques like hypothesis testing, Sampling, confidence Intervals, regression analysis, analysis of variance (ANOVA), Significance Level, P-Value and Chi-Square Tests were utilized to identify patterns and relationships between the variables of the study.

Statistical modeling in this study encompassed the use of statistical techniques to create mathematical models that portray the connections between the variables, such as starting from the variable identification, the research includes exploratory data Analysis based on descriptive analysis, data collection, selection of appropriate model to analyze the data, Parameter Estimation, Model Fitting, Model Evaluation, parameter Interpretation of the model, Predictions, Inferences and finally expression of findings based on appropriate method.

To establish these relationships, methods such as descriptive statistics, correlation and multinomial logistic regression were employed. These techniques allowed for a comprehensive understanding of how one variables behave on other variables of the study.

Finally, data visualization techniques were employed to visually represent the connections between the variables aiding in the illustration and comprehension of these relationships.

3. Results and discussions

3.1 Method one

3.1.1. Impact of Floor geometry on floor construction method

Based on method one building analysis approach the research proofs that the floor geometry of a high-rise buildings have an impact on the floor construction method of buildings. For instance, a building with a higher thickness of floor are a greater risk of to be constructed by a flat plate slab relative to solid slab than those buildings with less thickness of floor. Rectilinear shape is the dominant floor geometry and solid slab is the most used floor construction method of high-rise buildings in the city.

3.1.2 Floor geometry to floor construction material

Floor geometry doesn’t have an impact in deciding the floor construction material of high-rise buildings. Besides concrete and steel rebar which are the major constituents of reinforced concrete slab are the major construction materials used for floor construction of high-rise buildings in the city.

3.1.3 Façade geometry to Façade construction method

The facade geometry of a building have an impact on the facade construction method of buildings. For instance, The results indicates that in the construction method of facade, a building with an increased thickness of façade are a greater risk of to be constructed by a masonry wall relative to the combination of Curtain and Masonry wall than those buildings with thin thickness of façade. Rectangular shape is the most dominant façade geometry of high-rise buildings of the city and Masonry wall construction is the major construction method used on the façade construction of these buildings.

3.1.4 Façade geometry to Façade construction material

Besides, façade geometry also have an impact on the selection of façade construction material of buildings, for instance buildings which have a thick thickness of façade are a greater risk of to be constructed by HCB and mortar materials relative to a combination of glass, aluminum, mortar and, HCB materials than those buildings with a thin thickness of façade. Hollow concrete block (HCB) and mortar are the most commonly used material for the façade construction of high-rise buildings.

3.1.5 Roof geometry to roof construction method

Roof geometry have an impact in deciding the construction method of roofs. For instance in the research it is found that in the construction method of roof, a building with a thick slab in the case of flat roofs have a greater risk of to be constructed by a flat plate slab relative to a solid slab than those buildings with a thin thickness of roof. So if a thick flat slab roof is designed the architect or engineer can understand that the construction method of this flat roof will be flat plate slab by referring this thesis. So this research can be a guide for knowing which roof geometry goes with a certain roof construction method. Flat Rectilinear slab roof geometry is the most constructed roof geometry and solid slab is the major roof construction method in the construction of high-rise buildings.

3.1.6 Roof geometry to roof construction material

On the other hand roof geometry doesn’t have any impact in deciding the roof construction material of buildings. Concrete and Steel rebar are the most widely used roof construction materials.

3.1.7 Volumetric geometry on floor construction method

Volumetric geometry of buildings have an impact in deciding the floor construction method of buildings, that the research indicate that in the construction method of floor, a building with a wide building width are a greater risk of to be constructed by a flat plate slab relative to a solid slab than those buildings with a narrow building width. So width of buildings affects the floor construction method of buildings. Rectilinear prism is the most widely designed and constructed building geometry in high-rise buildings of the city.

3.1.8 Volumetric geometry on floor construction material

On the other hand, volumetric geometry of buildings doesn’t have any impact in deciding the floor construction material of buildings.

3.1.9 Volumetric geometry on façade construction method

Volumetric geometry of buildings have an impact in deciding the façade construction method of buildings, for instance the research proofs that in the construction method of facade, a building with a higher building height have a greater risk of their facade to be constructed by a curtain wall relative to masonry wall than those buildings with a shorter building height.

3.1.10. Volumetric geometry on façade construction material

Besides, volumetric geometry of a building also have an impact in deciding the construction material of a façade or exterior wall, for instance the result indicates that in the construction material of facade, a building with higher building height have a greater risk of their façade to be constructed by a combination of glass and aluminum material relative to HCB and mortar material than those buildings with a shorter building height. Which shows that taller buildings have a higher tendency of their façade material be a combination of glass and aluminum than HCB and mortar. Moreover a building with a wider building width are a greater risk of their faced to be constructed by HCB and mortar material relative to a combination of glass, aluminum, mortar and HCB material than those buildings with a narrower building width.

3.1.11. Volumetric geometry on roof construction method

Volumetric geometry of buildings have an impact in deciding the roof construction method of buildings. For instance, a building with a wider building width are a greater risk of their roof be constructed by a flat plate slab roof construction method relative to Solid slab roof construction method than those buildings with a narrower building width.

3.1.12. Volumetric geometry on roof construction material

On the other hand, volumetric geometry of buildings doesn't have any impact in deciding the roof construction material of high-rise buildings of the city.

3.2 Method two

3.2.1 Floor geometry on floor construction method

Considering all buildings in the city Floor geometry of buildings have an impact in deciding the floor construction method. For instance Organic, freeform and irregular shaped floors have an effect on deciding the floor construction method of buildings, these floor geometries have relatively higher possibility of to be constructed by one way concrete slab than one way concrete joist slab. Besides rectilinear shaped floor geometries have relatively a higher possibility of to be constructed by two way concrete slab than one way concrete slab construction method. Rectangular shaped floors are the most designed and constructed floor geometries of the city. Besides, two way concrete slab is the major commonly used floor construction methods in the city.

3.2.2 Floor geometry on floor construction material

Like the effect of floor geometry on floor construction method, floor geometry also have an impact on the floor construction material of buildings in the city, For instance, floor geometries which have a rectilinear shaped geometry have relatively higher possibility of to be constructed by concrete material than wooden material. Besides floor geometries which have square, curved, rectilinear, organic, freeform, irregular and polygonal shaped geometry also have relatively a higher possibility of to be constructed by concrete material than other types of materials which are not listed in this research. The research reveals that concrete is the most commonly used floor construction material in the city.

3.2.3 Façade geometry on Façade construction method

Façade construction method of buildings is also determined by the façade geometry of buildings, that certain façade geometries are constructed by a specific type of façade construction method, for instance facade geometries which have a triangular, curved, rectilinear, irregular and polygonal shape have relatively higher possibility to be constructed by concrete and masonry bearing walls construction method than metal and wood stud wall construction method. Besides, facade geometries which have a square and curved shape have relatively higher chance of to be constructed by concrete and masonry bearing walls than curtain wall construction method. Rectangular shaped façades are the most widely used façade geometry in the buildings of the city and concrete and bearing masonry walls are the major façade construction method.

3.2.4 Façade geometry on Façade construction material

The research revealed that most façade geometries have a substantial impact in deciding the facade construction material of buildings, in view of the fact that when their facade geometry varies, the possible facade construction material differs accordingly. For instance, facade geometries which have a triangular, curved, rectilinear, freeform, irregular, polygonal shape have relatively a higher possibility to be constructed by HCB (concrete) material than timber materials. On the other hand facade geometries which have a square, rectilinear, freeform and irregular shaped facades have a higher probability of to be constructed by HCB material than Glass material, but polygonal façade geometries have a greater possibility to be constructed by glass material than HCB (concrete) material. Concrete or HCB are the commonly used façade construction material in the city.

3.2.5 Roof geometry on roof construction method

The most designed and constructed roof geometry in the city is flat rectangular roof. Common pitched roof geometry and flat rectilinear roof follow as the second and the third most designed and constructed roof in the city respectively. Here roof geometry have a substantial impact on the type of roof construction method of buildings, for example from the multinomial logistic regression it is revealed that Flat-triangular, flat-rectilinear, flat-organic, flat-irregular, flat-polygonal and other roof geometry types not listed in this thesis have a greater possibility to be constructed by reinforced concrete roof slab construction method than precast concrete roof construction method. But roofs which have pyramidal shaped geometries have relatively a higher chance to be constructed by precast concrete roof systems than reinforced concrete roof slab construction method. Flat rectangular shaped roofs are the major roof geometry and reinforced concrete slabs are the dominant construction method of roofs in the city.

3.2.6 Roof geometry to roof construction material

The most widely used roof construction material in the city is metal, besides concrete and wooden materials follows it as second and third ranked material respectively used in the construction industry of the city. This shows that the usage of metal material as a reinforcing material for flat concrete roofs and using it as a metal member in a steel framed truss construction of roofs is a common practice. According to the interplay of geometry and construction material roof geometry have a substantial impact on the type of roof construction material of buildings. For instance roof geometries which have Flat Square, flat organic, pitched (including hip, gable, mansard, butterfly etc.) and pyramidal shaped roofs have relatively a higher chance of to be constructed by metal material than concrete material. On the other hand roof geometries which have flat rectilinear shaped floors have relatively higher probability to be constructed by concrete than metal material. Metal is the major material used for the construction of roofs in the city.

3.2.7 Computational design on floor geometry

Among the elements of computational design levels 2d design software tools, 3d modeling software tool, parametric design, algorithm based computational design, generative based computational design, Per-formative design based computational design, Form finding based computational design and machine based learning computational design doesn't have any impact on the floor geometry of buildings only BIM have a very little effect on the floor geometry of buildings. 2d design software tools and 3D modeling software tools are widely used in the firms. But using BIM, parametric design, algorithm based computational design, generative based computational design, Per-formative design based computational design, Form finding based computational design and machine based learning computational design in firms are uncommon.

3.2.8 Computational design on façade geometry

Among the elements or levels of computational design, 2D design software tool, 3d modeling software tool, BIM, parametric design, Performative design based computational design, Form finding based computational design and machine based learning computational design doesn't have an impact on the façade geometry of buildings, however algorithm based computational design and generative Design-based computational design are rarely affect the façade geometry of buildings. 2d design software tools and 3D modeling software tools are widely used in the firms. But using BIM, parametric design, algorithm based computational design, generative based computational design, Per-formative design based computational design, Form finding based computational design and machine based learning computational design in firms are uncommon.

3.2.9 Computational design on roof geometry

Among the elements or levels of computational design 2D design software tool, 3D modeling software tool, BIM, algorithm based computational design and machine based learning computational design have an effect on the roof geometry of buildings but parametric design, generative Design-based computational design, performative design based computational design and Form finding based computational design doesn't have an effect on the roof geometry of buildings. 2d design software tools and 3D modeling software tools are widely used in the firms. But using BIM, parametric design, algorithm based computational design, generative based computational design, Per-formative design based computational design, Form finding based computational design and machine based learning computational design in firms are uncommon.

3.2.10 Digital fabrication on floor geometry

Among the elements of digital fabrication methods, additive digital fabrication method have an impact on the floor geometry of buildings, for instance the research revealed that rectilinear shaped floor geometries have a higher chance of to be constructed by Additive Digital Fabrication method than rectangular shaped floor geometries and Robotic Assembly construction method also have an impact that rectangular shaped floor geometries have a higher risk of to be constructed by Robotic Assembly construction method than squared shaped floor geometries of buildings, on the other hand buildings which have rectilinear and polygonal shaped floors have a higher chance of to be constructed by robotic Assembly construction method than buildings which have rectangular shaped floor. But subtractive Digital Fabrication method, Forming Digital Fabrication method and 3D printing technology doesn't have any impact on the floor geometry of buildings. The research also indicates that Additive Digital Fabrication method, subtractive Digital Fabrication method, Forming Digital Fabrication method, Robotic Assembly construction method and 3D printing construction technologies are uncommon in the building construction practice of the city.

3.2.11 Digital fabrication on façade geometry

Among the elements of digital fabrication methods, additive Digital Fabrication method, forming Digital Fabrication method, Robotic Assembly construction method and 3D printing construction technology have an effect on the facade geometry of buildings but subtractive Digital Fabrication method doesn't have an impact on the façade geometry of buildings. The research also indicates that Additive Digital Fabrication method, subtractive Digital Fabrication method, Forming Digital Fabrication method, Robotic Assembly construction method and 3D printing construction technologies are uncommon in the building construction practice of the city.

3.2.11 Digital fabrication on roof geometry

Among the elements of digital fabrication methods, additive Digital Fabrication method, subtractive Digital Fabrication method, Forming Digital Fabrication method Robotic Assembly construction method and 3D printing construction technology have an effect on the roof geometry of buildings. for instance flat rectilinear, flat free form, flat irregular, flat polygonal and pitched (common hip, gable, mansard, gambrel, butterfly etc.) shaped roof geometries have a higher chance of to be constructed by Forming Digital Fabrication method than flat rectangular shaped roof geometries. The research also indicates that Additive Digital Fabrication method, subtractive Digital Fabrication method, Forming Digital Fabrication method, Robotic Assembly construction method and 3D printing construction technologies are uncommon in the building construction practice of the city.

3.2.12 Specialized professional on floor geometry

Among the elements of specialized professionals special modeling group have an impact on the floor geometry of buildings for instance floors which have a curved geometry have a higher possibility of to be designed and modeled by special modeling group than floors which have a rectangular floor geometry. Furthermore specialized architect in geometry and geometric and mathematical consultant also have an effect on the floor geometry of buildings. But Artists and geometry consultancy body in the city doesn't have an impact on the floor geometry of buildings. It is visible that the presence of artists, presence of specialized architect in geometry, presence of geometric and mathematical consultant in the firms and presence geometry consultancy body in the city is uncommon but presence of special modeling group are the most common specialized professionals in the firms of the city.

3.2.13 Specialized professional on façade geometry

Among the elements of specialized professionals, artists and geometry consultancy body in the city have an impact on the façade geometry of buildings. The research uncovers that building façades which have triangular and polygonal shaped geometry have higher risk of to be consulted by artists than floors which have a rectangular shaped geometry and building façades which have irregular shaped geometry have higher risk of to be consulted by geometry consultancy body than facades which have a rectangular shaped geometry. On the other hand special modeling group, specialized architect in geometry, geometric and mathematical consultant in a firm doesn't have an impact on the façade geometry of buildings. It is visible that the presence of artists, presence of specialized architect in geometry, presence of geometric and mathematical consultant in the firms and presence geometry consultancy body in the city is uncommon but presence of special modeling groups are the most common specialized professionals in the firms of the city.

3.2.14 Specialized professional on roof geometry

Among the elements of specialized professionals, artists, special modeling group, specialized architects in geometry, geometry and mathematical consultant and geometry consultancy body in the city have an impact on the roof geometry of buildings. The research indicates roofs which have flat square and flat rectilinear shaped geometry have higher risk of to be consulted by artists than façades which have a flat rectangular shaped geometry. Besides, roofs which have pyramidal, flat curved and flat square shaped geometry have higher risk of to be consulted by special modeling group than façades which have a flat rectangular shaped geometry. It is visible that the presence of artists, presence of specialized architect in geometry, presence of geometric and mathematical consultant in the firms and presence geometry consultancy body in the city is uncommon but presence of special modeling group are the most common specialized professionals in the firms of the city.

4. Conclusion and recommendation

4.1 Conclusion

Overall this thesis contributes to a deeper understanding of the significant role that geometry plays in determining construction method and materials of buildings in the construction industry of the city. Geometry have impact on the construction method and material on the elements or components of most high rise and all buildings of the city, on the other hand geometry of a building doesn't have an impact on the construction method and material of some building elements. In the wider context of the study geometry of buildings have a poor interaction with computational design, digital fabrication method and specialized professionals. And this results the domination of ordinary and conventional architectural geometry and construction practices in the city.

4.2 Recommendation

The research recommends designers and constructors to be informed about the relation between geometry and building construction to decide quickly on what factors should they have to focus.

The research also recommends a logical use of materials and construction methods especially in this research there are some elements of a building in which their material or construction technique is not driven by their geometry, so for such scenarios we recommend that the professionals to focus on other construction determining parameters which may affect the material and construction method of specific building components rather than focusing on the geometric aspect of the buildings that designers and constructors are not obliged to use a conventional and common construction technique and material in such cases.

Due to the poor level of using computational design, the unavailability of specialized professionals and uncommon culture of using digital fabrication method in the construction of buildings in the city the research recommends that to develop our geometry knowledge and application the research recommends the integration and adaptation of advanced design and construction approaches through education, training and systematical adoption of such design and construction approaches is crucial to develop the cities architectural geometry level.

Moreover, the research recommends architects and engineers to break the common conventional design and construction trends through new geometrical revolution or practice because geometry is one of the driving factor for the creation of new material and construction techniques. Finally since there are no sufficient researches on geometry related cases we recommend further researches in this area.

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