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DI PAVIA

UNIVERSITY OF PAVIA
FACULTY OF ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING AND ARCHITECTURE
MASTER DEGREE IN BUILDING ENGINEERING AND ARCHITECTURE

MASTER THESIS

Title in English: Vertical Oasis Tower – Sustainable design strategies for Arabic high-rise buildings

Titolo in italiano: Vertical Oasis Tower – Strategie di progettazione sostenibile per grattacieli nel contesto arabo

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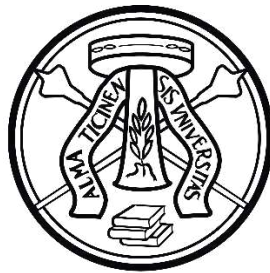
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A.Y. 2025 / 2026



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Department Of Civil Engineering And Architecture

Vertical Oasis Tower

Sustainable design strategies for Arabic high-rise buildings

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July, 2025

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ABSTRACT (English)

By examining the skyscraper not just as a representation of economic might and advancement but also as a possible model for sustainability and urban renewal, this thesis delves into the architectural, cultural, and technological significance of vertical construction. The study starts with a historical overview that covers the development of the skyscraper's design language and its effects on cities and societies, starting with ancient vertical structures like Mesopotamian ziggurats, Egyptian pyramids and Islamic minarets and ending with today's technologically sophisticated towers. Three main issues form the framework of the study has been analysed: the sociocultural and symbolic aspects of tall structures, the structural and functional approaches that support their growth, and the sustainable measures meant to lessen their environmental impact.

The role of dynamic and kinetic façades as creative solutions for energy efficiency and climate adaptation is highlighted in particular, showing how these systems—which are frequently influenced by biomimicry and traditional Islamic architecture, like the mashrabiya—allow buildings to react sensibly to environmental changes outside. By examining important case studies, such as the Shanghai Tower in China and the Al Bahar Towers in Abu Dhabi, the thesis shows how combining cutting-edge technologies, bioclimatic techniques and traditional design elements can create architecture that is not only recognizable but also effective and durable.

The practical outcome of this research is an architectural design proposal for a multifunctional eco-tower located in Casablanca Finance City. This project synthesizes the theoretical findings, combining environmental sustainability, flexible programming and references to Arab-Islamic architectural heritage to propose a new model for vertical living and working.

Ultimately, the thesis aims to redefine verticality in architecture not simply as a response to urban density or a quest for symbolic height, but as an opportunity to promote energy efficiency, user well-being, and social inclusiveness. In doing so, it positions the skyscraper as a key architectural typology for addressing the environmental and societal challenges of the 21st century.

ABSTRACT (Chinese)

摩天大楼不仅视为经济实力和技术进步的象征，而且作为可持续发展和城市更新的潜在模型，论文深入探讨了垂直建筑在建筑、文化与技术层面上的重要意义。研究从历史回顾开始，涵盖了摩天大楼设计语言的演变及其对城市和社会的影响，从古代的垂直结构，如美索不达米亚的金字塔式塔庙、埃及金字塔和伊斯兰宣礼塔，一直延伸到当今高度技术化的塔楼。

本研究围绕三大核心议题展开：高层建筑的社会文化与象征意义、支持其发展的结构和功能策略，以及旨在减轻其环境影响的可持续措施。

论文特别强调动态与可变立面在提高能效和应对气候变化方面的创新作用，展示了这些系统——通常受仿生学与传统伊斯兰建筑（如穆沙拉比耶）的启发——如何使建筑能够智能地响应外部环境的变化。

通过对典型案例的分析，例如中国的上海中心大厦和阿布扎比的阿尔巴哈尔塔楼，论文认为：前沿科技、生物气候设计手法与传统建筑元素的融合，能够催生出既具标志性，又高效且具有韧性的建筑形式。

研究的实践成果是一项关于位于卡萨布兰卡金融城的多功能生态塔楼的建筑设计方案。该项目整合了理论研究成果，结合环境可持续性、功能灵活性以及对阿拉伯-伊斯兰建筑传统的借鉴，提出了一种具有新意的垂直居住与工作模式。

最终，论文希望重新定义建筑中的垂直性，使其不仅能回应城市的高密度和对高度的追求，更能提升能效、改善用户福祉和促进社会包容性。因此，摩天大楼可以成为应对21世纪环境与社会挑战的关键建筑类型之一。

ABSTRACT (Italiano)

Attraverso l'analisi del grattacielo non soltanto come rappresentazione del potere economico e del progresso tecnologico, ma anche come possibile modello di sostenibilità e rigenerazione urbana, la tesi approfondisce il significato architettonico, culturale e tecnologico della costruzione in verticale. Lo studio prende avvio da un inquadramento storico che ripercorre l'evoluzione del linguaggio progettuale del grattacielo e i suoi effetti sulla città e sulla società, muovendo dalle antiche strutture verticali, come le ziggurat mesopotamiche, le piramidi egizie e i minareti islamici, fino alle torri tecnologicamente avanzate della contemporaneità.

L'indagine si articola intorno a tre principali questioni: gli aspetti socioculturali e simbolici degli edifici alti, gli approcci strutturali e funzionali che ne hanno sostenuto lo sviluppo, e le strategie di sostenibilità finalizzate a ridurre l'impatto ambientale.

Particolare attenzione è dedicata al ruolo delle facciate dinamiche e cinetiche, considerate soluzioni innovative per l'efficienza energetica e l'adattamento climatico. Tali sistemi, spesso ispirati alla biomimesi e all'architettura islamica tradizionale, come nel caso della mashrabiya, consentono agli edifici di rispondere in modo intelligente alle variazioni delle condizioni ambientali esterne.

Attraverso l'analisi di casi studio significativi, tra cui la Shanghai Tower in Cina e le Al Bahar Towers ad Abu Dhabi, la tesi evidenzia come l'integrazione tra tecnologie avanzate, strategie bioclimatiche ed elementi derivati dalla tradizione progettuale possa generare un'architettura non solo iconica, ma anche efficiente, resiliente e durevole.

L'esito applicativo della ricerca consiste in una proposta progettuale per una eco-torre multifunzionale localizzata nella Casablanca Finance City. Il progetto sintetizza gli esiti teorici dell'indagine, combinando sostenibilità ambientale, flessibilità funzionale e riferimenti al patrimonio architettonico arabo-islamico, con l'obiettivo di proporre un nuovo modello per l'abitare e il lavorare in verticale.

In conclusione, la tesi mira a ridefinire la verticalità in architettura non semplicemente come risposta alla densità urbana o come ricerca di altezza simbolica, ma come opportunità per promuovere efficienza energetica, benessere degli utenti e

inclusione sociale. In questa prospettiva, il grattacielo viene interpretato come una tipologia architettonica strategica per affrontare le sfide ambientali e sociali del XXI secolo.

Key Words: Vertical Architecture, Sustainable Design, Kinetic Façades, Bioclimatic Architecture, Arab-Islamic technologies, Energy Efficiency, Cultural Identity in Architecture, Mixed-Use Tower.

DEFINITIONS

Skyscraper

A skyscraper is a very tall, continuously habitable building, typically exceeding 150 meters in height, designed for mixed-use or commercial purposes. It is characterized by its vertical form, structural complexity, and integration into dense urban contexts, often symbolizing economic power and technological advancement.

Vertical Architecture

Vertical architecture refers to the design and organization of built forms that emphasize height and vertical development, rather than horizontal sprawl. This architectural approach addresses issues such as urban density, land scarcity, and environmental sustainability, and includes typologies like skyscrapers, towers, and multi-story buildings.

High-rise Buildings

High-rise buildings are structures that typically have more than 12 to 15 stories, requiring vertical transportation systems such as elevators. They are commonly found in urban areas and serve residential, commercial, or institutional functions. Their height necessitates specific considerations in terms of structural engineering, fire safety, and environmental control.

Towers

Towers are tall, slender structures that can be freestanding or integrated into larger buildings. Traditionally used for defense, communication, or observation, in contemporary architecture towers are often designed for residential, commercial, or symbolic purposes. They are distinguished by their verticality and prominence in the urban skyline.

High-rise Architecture

High-rise architecture is the field of architectural design and theory focused on buildings of significant height. It encompasses the aesthetic, structural, technological, and social challenges involved in designing and integrating tall buildings into the urban fabric. It often involves a multidisciplinary approach combining sustainability, engineering innovation, and spatial efficiency.

0. Introduction

0.1 Thesis' motivation

The architecture of towers has long embodied the synthesis of human ambition, technological advancement, and symbolic expression. From ancient civilizations to contemporary metropolises, vertical structures have signaled far more than spatial efficiency—they have reflected aspirations toward divinity, dominance, and permanence. Yet, despite their monumental presence throughout history, towers have not always evolved in step with the challenges of the societies that produce them. What began as cultural and spiritual expressions—seen in the Mesopotamian ziggurats, Egyptian pyramids, and Islamic minarets—has today become a contested architectural typology, often disconnected from its context and ecological impact.

In the modern age, particularly since the Industrial Revolution, towers shifted from symbolic ideals to material realities. Engineering breakthroughs, the development of steel and reinforced concrete, and the invention of the elevator catalyzed a rapid transformation of skylines around the world. Towers became instruments of capital and progress, as seen in early examples like the Woolworth Building (1913) and the Empire State Building (1931). However, this transformation prioritized vertical growth and monumental presence over environmental integration and human-scale experience. As cities expanded upward to accommodate swelling populations and economies, they simultaneously inherited problems related to energy consumption, spatial alienation, and the environmental costs of high-density urbanism.

What remains problematic is how the typology of the skyscraper has struggled to adapt meaningfully to these new challenges. Most towers, even those built in the 21st century, remain locked in a modernist paradigm: technologically impressive, yet insufficiently integrated with climate, culture, or social function. In this context, the notion of the high-rise as a neutral or universally valid form must be critically re-examined. Verticality alone is no longer enough. Instead, questions of sustainability, cultural specificity and urban livability must take precedence.

In response to these inadequacies, the field of architecture has increasingly turned to sustainability as a guiding principle. However, this shift is often implemented

in superficial ways—through green certifications or token gestures—rather than embedded in the design logic of towers. The real challenge is not merely to reduce carbon emissions or integrate photovoltaic panels but to fundamentally rethink the relationship between vertical form and environmental responsibility. This includes reconsidering material choices, passive strategies, spatial programming and the building's interaction with its micro and macro contexts.

Within this evolving discourse, kinetic and dynamic façades have emerged as promising solutions. Inspired by principles of biomimicry and real-time responsiveness, these systems offer the potential to mediate between interior comfort and external climatic variability. The Al Bahar Towers in Abu Dhabi, for example, employ a responsive skin that regulates solar exposure based on time and temperature, drawing directly from traditional Islamic *mashrabiya* screens. Such precedents reveal a significant opportunity: to reframe high-rise architecture not only as a space for technological display but as a medium for environmental intelligence and cultural continuity.

However, these innovations remain not largely used, often limited to isolated projects rather than constituting a paradigm shift in the way towers are conceived. What is missing is a cohesive design methodology that brings together kinetic adaptability, sustainable performance, and culturally grounded aesthetics—particularly in regions where climate extremes demand architectural specificity. The potential for synergy between advanced technologies and traditional passive systems is especially pertinent in hot-arid regions, where energy-intensive glass towers continue to dominate, despite their unsuitability for the climate.

Simultaneously, the socio-spatial implications of high-rise buildings must be analysed. The vertical expansion of cities has led to spatial fragmentation, social stratification and the erosion of communal urban life. In many global metropolises, towers function as exclusive enclaves—isolated from street life, separated by function, and disconnected from local identity. This alienation is compounded by the standardization of global architectural language, which tends to privilege efficiency over place-making and results in a homogeneous built environment.

Recent models suggest that towers can be reimagined as complex vertical ecosystems. Projects like Bosco Verticale in Milan demonstrate how green integration

and multifunctional programming can enhance both environmental and social sustainability. Similarly, sky gardens, public atria, and shared terraces are being explored as mechanisms to reintroduce human-scale interaction into vertical environments. Yet these strategies are still emerging, often deployed experimentally rather than systematically embedded in design approaches.

This thesis argues that for vertical architecture to remain relevant in the 21st century, it must evolve beyond mere height, iconography, or technological advancements. Instead, it should be reframed as a critical tool for addressing climate change, promoting well-being, and preserving cultural identity. In this light, Arab-Islamic architecture provides a rich series of formal, climatic, and symbolic solutions that remain highly underutilized in contemporary high-rise discourse. Elements such as *mashrabiya*, wind towers and internal courtyards are not merely historical curiosities—they represent tested environmental systems developed in response to harsh climates, and they offer strategies that are still highly relevant today.

Integrating such elements into modern vertical design could significantly enhance environmental performance while anchoring buildings in their local cultural context. The challenge lies in translating these vernacular principles into scalable, technologically sophisticated systems that meet contemporary needs. This process of reinterpretation—rather than replication—can help bridge the gap between tradition and innovation, allowing for architecture that is both regionally grounded and globally forward-looking.

Furthermore, the reception of towers varies significantly across cultures. In Western contexts, skyscrapers are often symbols of economic liberalism and technological prowess. In contrast, in Eastern and Arab cultures, verticality may be reframed through spiritual or environmental logics. Understanding these differing cultural interpretations is essential to designing towers that resonate with local communities and do not impose imported typologies insensitive to place.

This research recognizes that the adoption of verticality is not merely an architectural or urbanistic decision—it is a socio-cultural act. Skyscrapers alter city skylines, redefine public space, and shape how people live, work and interact. As such, their design must be approached with a holistic mindset that integrates ecological, functional, and symbolic dimensions. This is particularly urgent in rapidly developing

regions where new high-rise districts are being planned and built without critical reflection on their long-term impact.

Ultimately, this thesis seeks to contribute to a redefinition of the high-rise not just as a spatial solution to urban density, but as a vehicle for integrated sustainability and inclusive urbanism. It posits that the skyscraper can—and must—be transformed from a symbol of excess into a catalyst for innovation rooted in climate sensitivity, cultural continuity, and human-centered design. In doing so, it reframes the tower as not merely a vertical object, but a vertical opportunity.

0.2 Research goal

This research addresses a growing disconnect in contemporary high-rise architecture: while towers have evolved significantly in form and technology, many remain disengaged from their climatic, social and cultural contexts. To challenge this condition, the study undertakes a critical exploration of the historical, aesthetic, functional and theoretical evolution of towers, tracing their transformation from early utopian concepts to today's sustainable yet often superficial technological solutions. The aim is to interrogate how verticality can transcend its conventional role as a response to density and instead become a vehicle for integrated environmental and cultural design.

This thesis responds to the need for application by developing an architectural proposal that embodies the integration of sustainability, innovation, and regional specificity. The project envisions a multifunctional tower that challenges prevailing paradigms of isolated, monocultural skyscrapers, instead proposing a hybrid structure that merges environmental performance with aesthetic expression and spatial flexibility. This design acts as a testbed for the thesis's core hypotheses, translating conceptual findings into a tangible architectural vision.

The site selection process will prioritize a location with critical environmental and urban conditions, in order to rigorously evaluate the proposal's resilience and adaptability. Physical models, axonometric analyses, and simulation-based testing—including energy and climatic performance—will form an essential part of the design development. These tools are not merely illustrative but are used to

0. Introduction

validate whether the proposed strategies can truly outperform standard typologies in real-world scenarios.

Ultimately, the research seeks to redefine the skyscraper as a symbol—not of technological spectacle or economic power—but of ecological intelligence and cultural synthesis. In doing so, it aspires to contribute to a broader discourse on how architecture can respond more meaningfully to the intertwined challenges of sustainability, identity, and urban livability in the 21st century.

It can be said that this research is driven by the following questions:
How can kinetic and adaptive façade systems be strategically integrated into high-rise buildings to enhance climatic responsiveness and energy performance?

In what ways can Arab-Islamic architectural principles—such as mashrabiya, wind towers, and courtyards—be reinterpreted to inform sustainable vertical design?

Can the synthesis of traditional passive strategies and contemporary technological innovation lead to a new typology of context-sensitive, multifunctional towers?

How can high-rise buildings respond not only to environmental imperatives but also to socio-cultural expectations in dense urban contexts?

0.3 Methodology

The methodology adopted in this thesis is intentionally multidisciplinary, designed to address the complex and often fragmented understanding of vertical architecture in contemporary discourse. Rather than relying solely on theoretical or technical exploration, this study combines critical literature review, comparative analysis, empirical investigation, and design experimentation to bridge the gap between abstract concepts and their architectural application. This approach stems from the recognition that high-rise buildings, especially those incorporating kinetic façades and Arab-Islamic influences, must be examined not only as technological constructs but also as cultural artifacts shaped by environmental, historical, and socio-political forces.

At the core of the methodology lies an analytical framework that interrogates the tower typology from multiple angles: historically, as an evolving symbol of power and ideology; theoretically, as a subject of utopian speculation and functional redefinition; and practically, as a site of experimentation in sustainable and

bioclimatic strategies. The goal is to develop a design proposal not as a stylistic exercise, but as a direct response to the structural, climatic, and cultural issues identified through research. In doing so, the methodology seeks to ground architectural innovation in contextual relevance and technical credibility.

The first phase involves a critical review of literature across academic, technical, and professional sources. Historical and symbolic interpretations of towers are studied to uncover the ideological shifts that have accompanied their formal evolution—from religious and civic landmarks to speculative instruments of urban development.

Parallel to the historical review, the research engages with contemporary architectural theory and engineering innovation. Here, the focus shifts to examining how technological advances—particularly in materials, energy systems, and kinetic envelopes—have attempted to address the environmental inefficiencies of traditional high-rise models. However, instead of celebrating technology uncritically, the study interrogates the extent to which these solutions are integrated meaningfully into building design, or whether they remain superficial adaptations to green mandates. This section also examines bioclimatic design principles and their quantifiable impact on internal comfort, energy reduction, and environmental resilience, while considering the limitations and contradictions within international sustainability standards and certifications.

The third part involves the socio-cultural critique of vertical architecture. Through a review of urban theory, sociological studies, and architectural anthropology, the research examines how tall buildings influence human behavior, spatial perception, and social interaction. The analysis considers cross-cultural perspectives to highlight how the acceptance and interpretation of towers vary depending on local identity, climate, and economic context. Particular attention is given to the Arab-Islamic architectural tradition—not merely as a historical reference, but as a repository of passive systems and formal logics that can be reinterpreted to resolve specific climatic and cultural challenges in modern vertical design.

These theoretical investigations are reinforced by case study analysis, selected based on their relevance in integrating sustainability and innovation within high-rise architecture. Notably, Al Bahar Towers in Abu Dhabi and Shanghai Tower in

0. Introduction

China are examined as emblematic examples that synthesize advanced environmental strategies with cultural or contextual responsiveness. These case studies are not approached descriptively, but analytically—scrutinized for their structural systems, energy performance, and spatial organization through technical documentation, environmental data, and critical commentary. The aim is to extract actionable principles, rather than aesthetic inspiration, to inform the subsequent design phase.

The final and culminating stage of the methodology is the development of a design proposal—a speculative architectural response that materializes the findings of the research. Rather than presenting a singular, idealized solution, the proposal is conceived as a **testable hypothesis**, incorporating multiple strategies identified in previous phases. The architectural proposal is therefore both an outcome and a proof-of-concept, offering a tangible demonstration of how kinetic innovation and Arab-Islamic principles can be merged into a coherent and context-sensitive high-rise solution.

0.4 Thesis structure

This thesis research is structured into six main chapters, each dedicated to a key aspect of the topic to ensure an in-depth and systematic analysis.

The first chapter introduces the historical evolution of vertical architecture, exploring the earliest manifestations of towers over the centuries and their symbolic significance in different cultures. Special attention is given to the emergence of the modern "skyscraper" concept, the initial utopian and social visions related to this theme and the new theories that have been created around this theme.

The second chapter examines the social and cultural aspects of vertical architecture, with a particular focus on public perception of towers and their impact on urban quality of life. It will also address cultural differences in the acceptance of tall buildings, comparing major global cities. Additionally, this section will analyze and critique how society perceives, inhabits, utilizes, and manages these new building systems in terms of visual and functional impact.

The third chapter delves into the principles of environmental sustainability in architecture, particularly focusing on the concepts of "green architecture" and various

technological, material, and functional solutions applied in this field. A deeper analysis will explore the best renewable energy sources for vertical architecture, evaluating different case studies and solutions that exemplify this theme.

The fourth chapter is entirely dedicated to the study of kinetic and dynamic façades, their evolution, and their applications in buildings. It will analyze and explain the systems that enable their functionality and how they respond to internal and external stimuli. Selected case studies, such as Al Bahar Towers and the Fosun Foundation, will be examined for their relevance in applying dynamic strategies and innovative technologies.

The fifth chapter focuses on Arab-Islamic architecture, synthesizing the theoretical and practical elements analyzed in previous chapters. It will illustrate design strategies and solutions adopted to balance aesthetics, functionality, and sustainability. Key questions will be posed and answered regarding how this architectural style continues to achieve optimal results in sustainability, functionality, and innovation. Case studies such as the Qatar National Library and Masdar City will be explored to provide a comprehensive study of the contemporary application of traditional Arab-Islamic architectural solutions.

The sixth chapter centers on the design proposal, which represents the synthesis of the theoretical and technological aspects analyzed in previous chapters. The project will be developed with a focus on integrating sustainability, technological innovation, and architectural references to the Arab tradition, with particular attention to bioclimatic strategies and the use of adaptive façades.^[Fig.1]

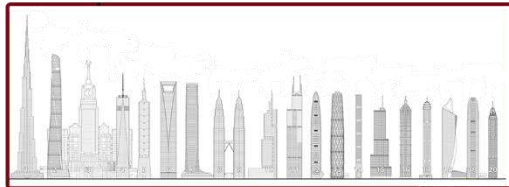
Ending with the last chapter that will present the research conclusions, summarizing the key findings and proposing future perspectives for vertical architecture. Additionally, it will discuss the study's limitations and potential project developments within the context of contemporary urban and energy challenges.



STEP 1

Identify the **topic** and the problems, getting the **motivations** and the questions.

How can tall high-rise buildings be sustainable, social-friendly and have cultural identity?



STEP 2

Studying, researching and analysing the **history of the evolution** of High-rise Tall Buildings

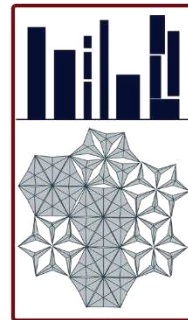
STEP 3

Evaluating and analysing the **social and cultural interactions** between the urban environment, population and high-rise buildings



STEP 4

Analysis of one of the most important aspects for these kind of buildings: **Structure, Core and Facade**.
Is it possible to create a new suitable, functional and structural identity?
How can the architectural composition influence the final design of the new proposal?



STEP 5



STEP 6



STEP 7

Sustainable strategies using **arab-islamic architectural technologies**, cultural elements and **innovative technological - technical elements**. Studying of numerous case studies for a better understanding in order to develop the proposal urban space and building idea.

Definition of the thesis design project and the urban space around it, a mixed-use high-rise tower

1. The Rise of Towers

1.1 Introduction

Vertical architecture has always fascinated humanity, representing a symbol of power, progress, and innovation. From the earliest monumental structures of antiquity to modern skyscrapers, the construction of height has undergone a technological and functional evolution that has transformed its use and perception over the centuries, bringing with it new innovations and relevant socio-cultural aspects. This chapter will explore the history of towers, the evolution of construction techniques, and the advantages and disadvantages that characterize vertical architecture, as well as notable case studies related to this topic.

1.2 The main new trends of high-rise building design

“And finally, in the last episode, the tower of Babel suddenly appersand some strongmen actually finish it under the song of new hope, and as they complete the top, the Ruler (of the Olympus, probably) runs off making a fool of himself while Mankind, suddenly understanding everything, finally takes its rightful place and right away begins its new life with new insights into everything...”¹

“Our role is not to retreat back to the catacombs, but to become more human in skyscrapers...”²

Starting with these important quotes, we can start to understand how the concept of the tower and skyscraper, as well as vertical architecture, has been deeply rooted in human history as a symbol of growth and power since ancient times. Today, the tower typology is embraced as the most important solution to represent what is sustainable growth in today’s urban areas.

¹ Rem Koolhaas - *Delirious New York: A Retroactive Manifesto for Manhattan*, 1978, p.p. 81 (citation from *Fyodor Dostoyevski, The Demon*)

² Rem Koolhaas - *Delirious New York: A Retroactive Manifesto for Manhattan*, 1978, p.p. 110 (citation from the *Regional Plan Association of New York, The Building of the City*)

1. The Rise of Towers

Mapping the annual completion of skyscrapers measuring 200 meters or more since 1960 reveals a gradual increase throughout the 1990s, followed by a sharp acceleration from the mid-2000s onward. [Fig.2]

While the global economic crisis of 2008–2009 led to a significant decline in skyscraper construction across most Western countries, this downturn has largely been counterbalanced over time by a surge in development across Asia, particularly in China.³

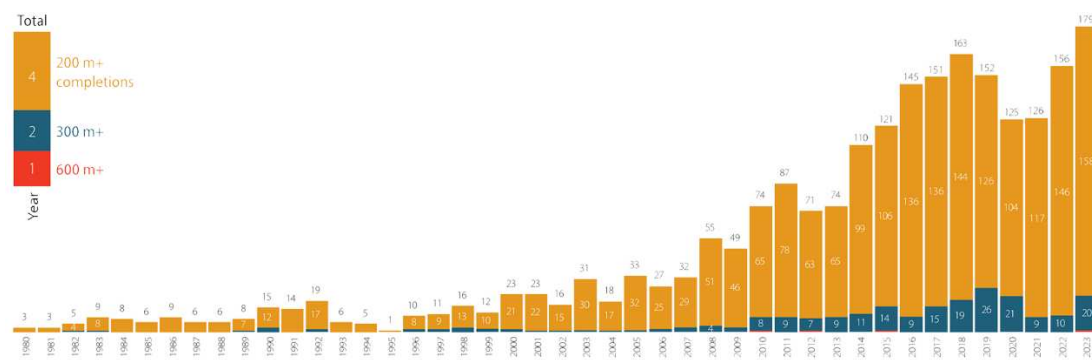


Figure 1 – Tall buildings completed each year over 200 meters, 300 meters, and 600 meters since 1980.

1.2.1 Trends and Drivers

Before delving into the history and evolution of the tower concept over the past centuries, it is essential to consider several trends that characterize these projects. Among them, the height of towers and skyscrapers stands out, as construction continues to reach ever greater heights, pushing closer to the sky both in terms of absolute and global height. The graph clearly illustrates that, over the years—especially from the 21st century onward—the maximum height achieved has increased dramatically, sparking a worldwide competition to reach new milestones and drive further innovation.

Another crucial aspect is **location**, as the geographical distribution of the tallest buildings has shifted significantly. Around the 1990s, 80 of the world's 100 tallest

³ Work, S. I. (ed.) (2024). *CTBUH (Council of Tall Buildings and Urban Habitants) Data Handbook: Edition 2024*.

skyscrapers were in North America. Today, however, the ranking has changed into a global mix, predominantly dominated by Asia and the Middle East [Fig.3].

Functionality is also a key factor to consider. Skyscrapers have evolved from being primarily office spaces to adopting a mixed-use and residential approach. More frequently, this shift is driven by urban growth and the increasing demand for residential areas and public spaces, often integrated within the same building: it is easier to plan and build a residential tower rather than an office one, because the residential floors tends to be smaller and requires less floor area.

It is also important to acknowledge that as time progresses, so does technological, material, and engineering advancement. These innovations enable transformations in design, material selection, and, of course, the overall cost of construction, shaping the future of vertical architecture.

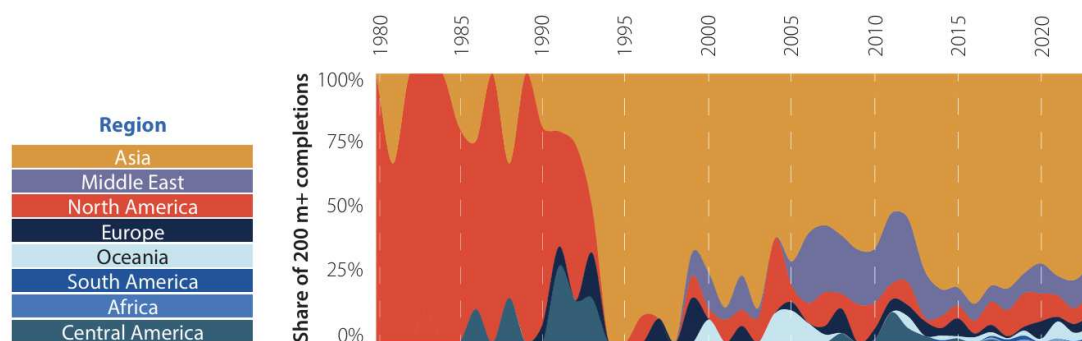


Figure 2 – Tallest Buildings geographical distribution since 1980.

Obviously, all these trends are driven by specific stimuli, or drivers, which encompass various themes. Historically speaking, the higher **cost of land** typical of city centers has always influenced the construction and design of tall buildings. This economic factor has shaped a mindset in which developers aim to maximize the number of floors areas available for sale or rent to ensure a high return on investment.

An important aspect lies in the **symbolism and representation** of the building itself. Historically, we have witnessed a shift from buildings representing a corporation or company to structures that symbolize an entire city or even a nation. By doing so, the project becomes a powerful icon of power and prestige, as many cities

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today believe that having a significant skyscraper is essential to being considered successful and thriving.

Last but not least, the number of tall buildings is increasing drastically, as they are seen as an optimal solution to address the challenges of rapid **urbanization**. With a continued migration from rural areas to urban centers, cities are becoming increasingly crowded, especially in countries with large populations. This trend is also linked to the growing need to respond to **climate change** and the demand for a sustainable approach to modern lifestyles.

1.2.2 Symbolism of the Tower

Louis Sullivan introduced the principle *"form ever follows function."*⁴ While this dictum was originally intended to strip architecture of unnecessary ornamentation, shaping much of modernist design philosophy for nearly a century, Sullivan could hardly have anticipated the radical transformations in form-finding that now define contemporary super-tower design.

Today, skyscrapers incorporate twists, curves, tapers, folds, and cantilevers, facilitated by advanced parametric design tools and structural analysis software. These innovations challenge the once rigid adherence to structural simplicity, allowing for an unprecedented exploration of complex geometries. As architecture reaches a critical juncture where almost any conceivable form is technically possible to make, the emphasis shifts toward defining what is contextually and functionally appropriate.

This paradigm shift is particularly pronounced in the realm of supertall and high-rise towers, where immense financial investments necessitate not only engineering excellence but also a distinct architectural identity. The skyscraper has historically been a symbol of technological advancement, economic power and cultural prestige, and today, the search of uniqueness, particular designs continues to reinforce its status as a landmark typology. The current trajectory of skyscraper evolution is thus

⁴ Citation from his 1896 essay titled *"The Tall Office Building Artistically Considered."* This influential article was published in Lippincott's Monthly Magazine and articulated Sullivan's belief that a building's design should be derived from its intended function rather than being dictated by historical styles or excessive ornamentation.

a natural extension of its historical legacy—one that remains intrinsically tied to emerging construction technologies and the expression of power and innovation.

The symbolism of towers has long been associated with wealth and power, yet this significance is inherently relative, shaped by comparisons to neighboring structures, the broader cityscape or global architectural benchmarks. This relativity fuels an ongoing competition in terms of height and distinct identity, as prominence in the realm of high-rise and supertall buildings is not only dictated by the number of floors but by the overall visual impact and architectural statement.

This pursuit of iconic status raises fundamental debates about how skyscraper architecture should be evaluated: while aesthetics and beauty remain central to architectural discourse, additional criteria—such as innovation, uniqueness, status, symbolism and contextual integration—are equally significant. However, as buildings grow exponentially taller, traditional principles of scale and proportion become increasingly challenging to apply, shifting the focus toward form, structure, and materiality as key determinants of architectural success.

In recent decades, advancements in design technology and construction techniques have expanded the formal possibilities of skyscrapers, leading to greater experimentation and innovation. The conventional extruded vertical form, whether rectilinear or curved, is increasingly being replaced by complex geometries that create distinctive silhouettes within the skyline. Structural engineering breakthroughs have enabled folded crystalline configurations and fluid, organic shapes, while advancements in curtain wall systems provide both aesthetic flexibility and enhanced energy efficiency.

As a result, height is no longer a purely technical limitation, but rather a function of economic ambition and aspirational intent. In this context, skyscrapers are not merely expressions of engineering prowess but serve as symbols of status, cultural identity, and urban ambition, reinforcing their role as defining landmarks in the contemporary cityscape.

1.3 *From ground to sky: The development of High-rise buildings*

The **skyscraper**, as an architectural typology, emerged as a response to the profound transformations in urbanization, technology, and economic ambition that characterized the late 19th and early 20th centuries.

The cities of **Chicago** and **New York** served as the primary laboratories for this new building form, where structural innovations and economic imperatives intersected to redefine the urban skyline.

Chicago was founded in 1803 and established as a frontier city, whose dominance originated from its strategic position along the major waterways of the American mid-continent. In the following years, there had been several changes regarding the city plan, the relationship with the nearby cities and the city's own development and urbanization. One of the biggest events of modern history is certainly the 1871 Chicago's Great Fire, a disaster of huge dimensions that destroyed most of the buildings in the city's downtown; in 1880s, despite everything, the city had begun to *"rise phoenix-like from the ashes to become the metropolis of the Midwest"*⁵.

Defined by the natural and infrastructural boundaries of the Chicago River, cable car networks, and later the elevated railway system of the 1890s, Chicago's downtown experienced spatial limitations that restricted horizontal growth. As a result, by the early 1880s, economic pressures catalyzed a shift toward vertical expansion, fundamentally altering the city's architectural trajectory. This era witnessed the establishment of a new height threshold for office buildings, facilitated by technological advances in vertical transportation. . The most revolutionary among these was the **elevator**, which provided access to upper floors, thereby eliminating the constraints imposed by stair-accessible buildings. The advent of these so-called "elevator buildings" not only transformed the real estate market by increasing the profitability of vertical space but also laid the groundwork for the modern skyscraper as a dominant typology in urban architecture.

The 1890s marked a significant moment in architectural history, as the concept of the skyscraper gained larger recognition, fundamentally reshaping the urban

⁵ Gail Fenske, *A Brief history of the twentieth-century Skyscraper*, p.p. 14_ describing the city as the mythological animal that rises from its own ashes stronger than ever.

landscapes of Chicago and, later on, New York. The rapid proliferation of fireproofed, steel-framed structures in Chicago during the building boom of 1889–1893 positioned the city at the forefront of architectural innovation, gaining both national and international attention.

Among the most emblematic structures of this period was Burnham and Root's Masonic Temple (1891–92), positioned on Randolph Street, asserting itself as the city's tallest building [Fig.3].



Figure 3 – Views of the Masonic Temple, Burnham and Root, 1891 - 1892

Its sheer verticality intensified the perception of Chicago as a city overwhelmed by incredible expansion. In response to concerns over congestion, *John Wellborn Root* incorporated an innovative internal light court, a striking vertical void that not only maximized natural illumination but also functioned as a unifying spatial element within the mixed-use complex, which included offices, retail spaces, a hotel and a rooftop observatory. This approach redefined the skyscraper beyond a mere speculative investment, demonstrating its potential to function as a self-contained urban microcosm.

Chicago's economic prosperity in the late 1880s and early 1890s spurred the construction of additional landmark structures, including Burnham and Root's Monadnock Building (1889–90) and D.H. Burnham and Company's Reliance Building (1894–95). However, this period of architectural innovation was paralleled by a

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growing cultural and civic discourse surrounding urban identity, culminating in the World's Columbian Exposition of 1893⁶. The exposition's intention was to impose an idealized vision of urban grandeur, contrasting sharply with the organic and often chaotic evolution of Chicago's commercial architecture. Amidst these debates, Holabird & Roche's Marquette Building (1893–94) emerged as an exemplar of the rationalized skyscraper, embodying the principles of simplicity, efficiency, and standardization. Its restrained aesthetic aligned with a broader movement advocating for civic decorum and the dignified representation of white-collar work environments. [Fig.4]



Figure 4 – Marquette Building, George A. Fuller Company and designed by architects Holabird & Roche, 1893 – 1894.

⁶ The World's Columbian Exposition, also known as the Chicago World's Fair, was a world's fair held in Chicago from May 5 to October 31, 1893, to celebrate the 400th anniversary of Christopher Columbus's arrival in the New World in 1492. It was the prototype of what Burnham and his colleagues thought a city should be. (https://en.wikipedia.org/wiki/World%27s_Columbian_Exposition)

Amidst these shifts, *Louis Sullivan*⁷, of Adler & Sullivan, emerged as one of the most influential voices in redefining the skyscraper's architectural language. Already renowned for projects such as the Chicago Auditorium (1886–87), Sullivan envisioned a new formal expression for tall buildings, one that would imbue the skyscraper with poetic and spiritual qualities. His Wainwright Building (1890–91) in St. Louis, while structurally influenced by Holabird & Roche's Tacoma Building, diverged conceptually by emphasizing verticality as an aesthetic principle. Sullivan's approach, articulated in his seminal essay *The Tall Office Building Artistically Considered* (1896)⁸, proposed that the skyscraper should derive its beauty from an organic integration of form and function, rejecting purely utilitarian design paradigms.

Deeply inspired by the transcendentalist philosophy of *Ralph Waldo Emerson* and the vision of *Walt Whitman*, Sullivan thought to counterbalance the industrial harshness of the modern metropolis with a naturalized ornamental vocabulary. His intricate foliate motifs, inspired by botanical forms, have the purpose to infuse the skyscraper with vitality, aligning it with the rhythms of the natural world. This approach culminated in some of the most elaborate organic ornamentation in architectural history, positioning Sullivan as a pivotal figure in the development of American architectural identity.

Chicago's early skyscraper boom thus encapsulated a complex interplay of economic ambition, engineering ingenuity, artistic vision, and regulatory intervention. The tension between the expansion and the imposition of civic order would continue to shape the evolution of the American skyscraper, influencing subsequent zoning laws, urban planning strategies and architectural discourse well into the 20th century. This transformative era not only redefined the physical character of the modern city but also laid the ideological foundations for skyscraper design as an art form, merging structural innovation with a deeper cultural and aesthetic significance.

⁷ Known as Chicago's "Father of Skyscrapers," *Louis Sullivan* foreshadowed modernism with his famous phrase "form follows function." (<https://www.archdaily.com/544355/spotlight-louis-sullivan>).

⁸ A famous essay by the architect *Louis Sullivan*, often regarded as one of the most influential documents in American architecture. In this work, Sullivan explores the relationship between form and function in tall buildings, particularly office buildings. He argues that the design of skyscrapers should reflect their purpose—offices—rather than mimicking traditional architectural forms like classical columns or facades.

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On the other hand, **New York** was founded as a Dutch colony in 1623, which led it to rise as the nation's banking and finance center in 1820. A few years later, it became the most popular American-European import-export hub, as well as the key port for European luxury commodities.

At the turn of the 20th century, the development of skyscrapers in this city followed a trajectory distinct from that of Chicago, shaped by both economic strong reasons and the absence of effective height regulations. Furthermore, the speculative nature of the real estate market in New York—especially following a brief economic downturn in 1893—intensified the competition for ever-greater heights, leading to a surge in construction.

One of the most notable buildings of this period was Bruce Price's American Surety Building (1894–96) ^[Fig. 5], designed as a campanile, which marked the widespread acceptance of steel skeleton construction in New York. By the late 1890s, pioneering structures such as George Post's St. Paul Building (1895) and R.H. Robertson's Park Row Building (1899) reached respectively 315 feet (96 meters) and 391 feet (119 meters), setting new global height records. The Park Row Building, in particular, exemplified the era's drive for structural experimentation, with Robertson implementing advanced wind-bracing systems and novel steel column placement to ensure long-term stability.

The early 20th century saw New York emerge as a global leader in skyscraper innovation, surpassing Chicago both in height and symbolic ambition. This transition was epitomized by George Post's World Building (1899–1900) ^[Fig. 6], now demolished, a cage-framed structure that not only showcased technical advancements but also foreshadowed a new era of publicity-driven high-rise architecture. Unlike Chicago's pragmatic approach to tall buildings, New York's skyscrapers increasingly functioned as marketing tools, integrating ornate facades, dramatic crowns and attention-capturing verticality to serve as urban billboards.

This architectural competitiveness reached new heights with the construction of Ernest Flagg's Singer Tower (1906–08), a 612-foot (186.5-meter) landmark, nearly doubling the height of its predecessor, the Park Row Building. The Singer Company, which had expanded its global operations, saw its headquarters as a



Figure 5 – Bruce Price, American Surety Building, 1894 - 1896

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Figure 6 - George Post, World Building, 1899 - 1900

skyscrapers of this era, the Metropolitan Life Tower (1908–09) by Pierre Le Brun and the Woolworth Building (1910–13) by Cass Gilbert, further established New York's dominance in vertical urbanism. The Woolworth Building, at 792 feet (241.5 meters), became the tallest building in the world and was engineered by Gunvald Aus, who employed the most extensive wind-bracing system ever designed. Beyond its structural achievements, the Woolworth Building redefined the skyscraper's role within the city, incorporating a grand public lobby, a shopping arcade, fitness facilities and a

symbol of corporate dominance, further emphasizing the connection between commerce and architecture. Flagg proposed a radical urban vision, advocating for height regulation through even cornice lines and proportional setbacks—a precursor to New York's 1916 Zoning Resolution.

A notable example of this imagery is Richard Rummell's 1911 view of Lower Broadway for *King's Views of New York*. [Fig.7]

Two of the most emblematic



Figure 7- The image shows a dense, chaotic metropolis, with buildings elevating to exaggerated heights, encapsulating both the ambition and potential perils of New York's architectural expansion in the early 20th century.

luxury observatory, making it not only a corporate headquarters but also an urban destination.

Years later, during the 1920s, a transformative era in New York's architectural history begun, as the city saw the emergence of setback skyscrapers, reaching unprecedented heights and fundamentally redefining the urban fabric. This new generation of high-rises, shaped by **Zoning Resolution of 1916**, introduced a distinctive tiered silhouette that became more and more associated with modernity.

A perfect example of this concept is Hugh Ferriss's *Metropolis of Tomorrow* (1922–29) [Fig.8]: through drawings of remarkable visual impact, Ferriss illustrated the artistic potential of a carefully planned metropolis of the future. His designs featured clusters of tiered skyscrapers, resembling massive mountain formations, spanning multiple city blocks. These structures, arranged in a meticulously ordered composition, rose above the transportation infrastructure that interconnected them below. Additionally, their setbacks functioned as terraces for gardens, open to sunlight and fresh air, introducing new forms of elevated public spaces—both as prestigious social settings and as breathtaking vantage points overlooking the city.

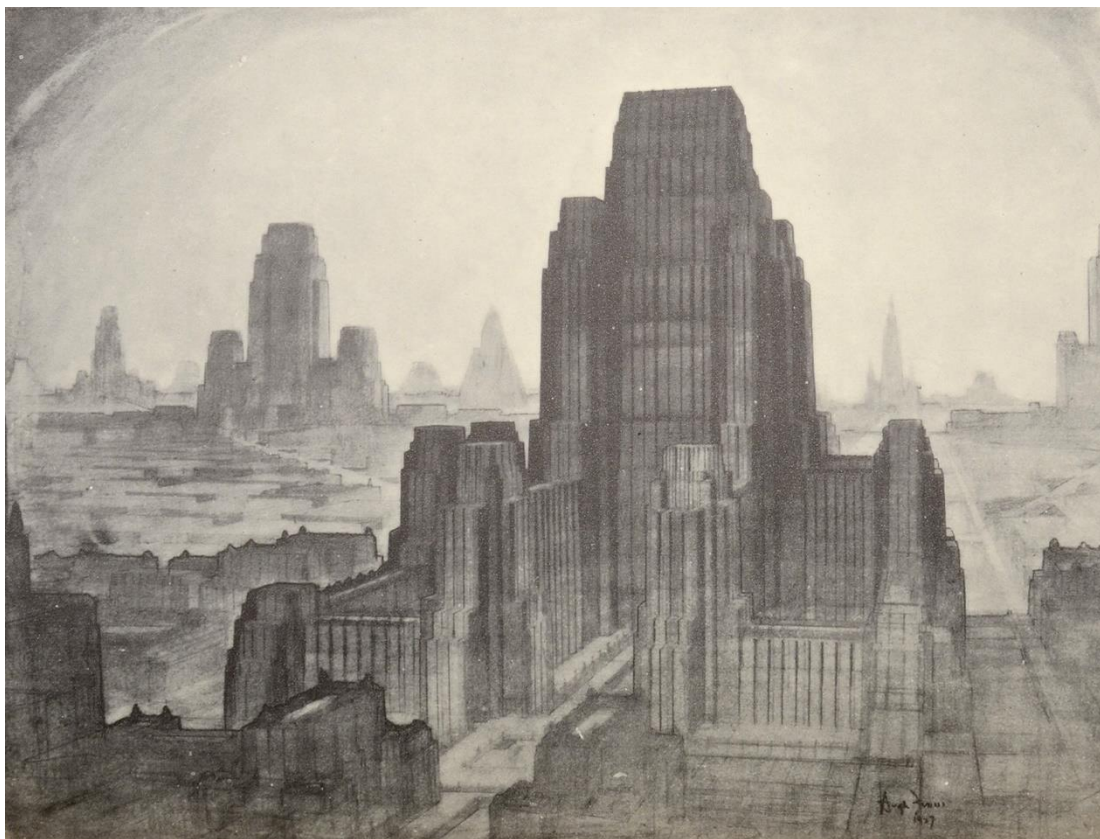


Figure 8 - "The Business Center," from Hugh Ferriss's *Metropolis of Tomorrow*, 1929

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He envisioned a future metropolis in stark contrast to what he referred to as "crowding towers"—the very embodiment of an overbuilt city, devoid of human scale and overwhelmed by noise, darkness, and chaos to the point of being scarcely habitable.⁹

One of the earliest and most influential applications of the setback principle was Ralph Walker's Barclay-Vesey Building (1923–26), which blended vertical piers and nature-inspired ornamentation reminiscent of Louis Sullivan's organic designs. However, the Chicago Tribune Tower competition of 1922, particularly the entry by Finnish architect Eliel Saarinen, also had a profound impact on the future of New York's skyline. Although not the official winner, Saarinen's design was widely regarded as the "unofficial victor" and served as inspiration for Raymond Hood's American Radiator Building (1923–24), which set a precedent for the gothic-inspired skyscraper aesthetic that dominated the decade.

This architectural shift was not merely theoretical—New York's competitive race for height intensified throughout the decade. The Chanin Building (1926–29), briefly holding the record as Midtown's tallest structure, exemplified early Art Deco ornamentation and the challenges posed by the zoning-defined height districts. Yet, even before its completion, the ambition to build ever taller was reignited by the commission of the Chrysler Building (1928–30). Originally conceived by William Reynolds, the design was ultimately acquired and modified by Walter Chrysler, with architect William Van Alen reconfiguring its crown as a tiered, spoked dome, symbolizing both the Chrysler Corporation and the automobile industry [Fig.9].

The rivalry between Van Alen and H. Craig Severance, his former business partner, culminated in a dramatic competition for the world's tallest building. Severance's Bank of Manhattan Company Building (1930), at 927 feet (282.5 meters), momentarily claimed the title, only for Van Alen to secretly install a hidden 185-foot (56.5-meter) spire within the Chrysler Building's crown, ultimately bringing its total height to 1,048 feet (319.5 meters) and securing its place as the tallest structure of its

⁹ In the *Metropolis of Tomorrow*, Hugh Ferriss presented his visionary ideas for the future urban landscape, featuring highly detailed illustrations of skyscrapers and cityscapes that reflect the possibilities of a modern, well-regulated metropolis.

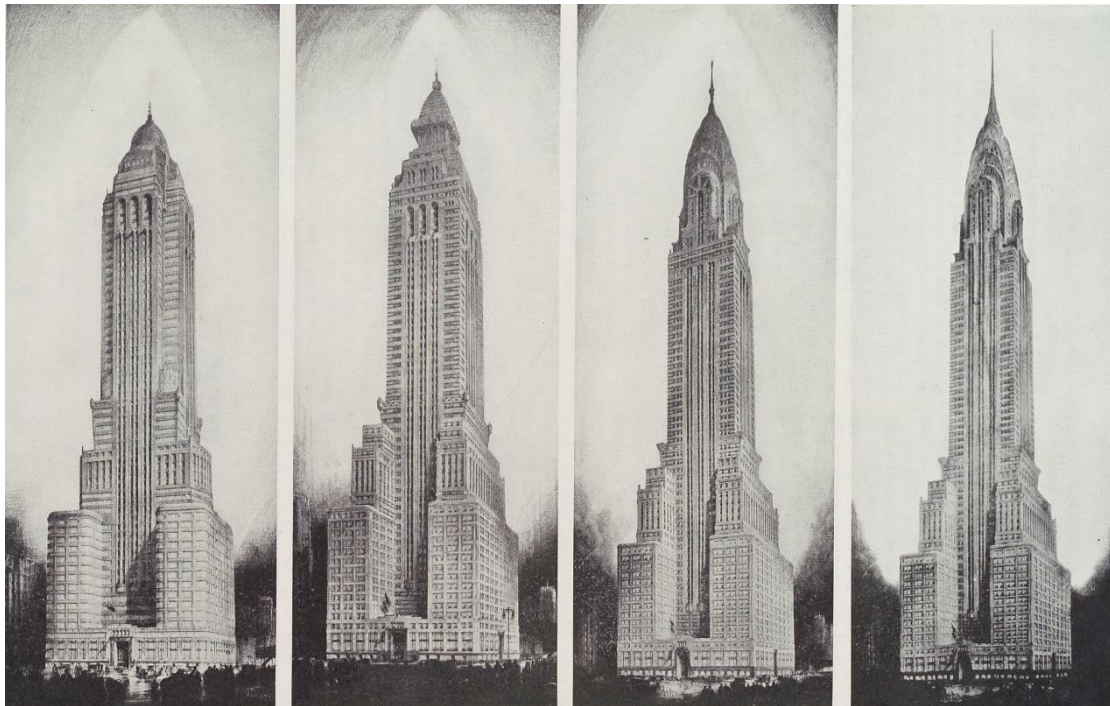


Figure 9 - Design History of the Chrysler Building, William Van Alen, 1928 -1930 (From left to right)

time. This spectacle underscored the increasingly theatrical and publicity-driven nature of skyscraper construction, reflecting the commercial and cultural ambitions embedded within New York's evolving skyline.

At the same time, Chicago also went through a vertical transformation, although under a different regulatory framework. Unlike New York's zoning laws, **Chicago's 1923 zoning regulation**¹⁰ imposed stricter limitations on building height and massing, capping towers at 25% of the lot size and limiting total cubic volume. This led to the emergence of a distinct "*city of towers*", characterized by mid-rise setbacks and a more controlled vertical expansion.

By the early 1930s, the Empire State Building (1931), standing at 1,250 feet (381 meters), became the ultimate embodiment of New York's relentless pursuit of height. Isolated from Midtown's densest skyscraper cluster, its commanding presence further solidified the notion that an iconic landmark could define an entire city's

¹⁰ The Chicago's 1923 zoning regulation was designed to separate different types of activities, such as residential, commercial, and industrial, to reduce conflicts between them and improve the quality of life in the city. It introduced regulations that established specific districts or zones for each use, thus guiding the city's development.

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identity. However, just as the skyscraper race peaked, Wall Street's economic collapse of 1929 halted new developments, reshaping priorities in urban architecture.

One of the most notable exceptions to this construction slowdown was Rockefeller Center, conceived as one of the most ambitious urban projects of its time. Initiated in 1926 as the most ambitious urban development of its time, Rockefeller Center spanned multiple blocks along Fifth Avenue. From the outset, its planners adopted a progressive approach to urban design, envisioning a cohesive arrangement of skyscrapers that prioritized public spaces and enhanced the city's vitality. Originally conceived as the future home of the Metropolitan Opera¹¹, the project ultimately evolved into a complex of office buildings featuring a carefully orchestrated sequence of public areas at street level, as well as elevated promenades connected by bridges spanning city streets.

By 1928, John D. Rockefeller had joined the initiative, establishing the *Metropolitan Square Corporation* and appointing the engineering firm Todd, Robertson, Todd to conduct financial assessments.

The final design, based on "Scheme G3," positioned the RCA Building as the central vertical landmark, replacing the originally intended Metropolitan Opera House.. At the base of the RCA Building, the central plaza—with its iconic *Prometheus* sculpture—became a focal point of urban life, hosting a café in summer and transforming into an ice-skating rink in winter. The design integrated sidewalk-level plazas with lower-level shopping arcades, widely spaced towers and elevated terraces, introducing a new form of spatial luxury that epitomized modern urbanity .

This innovative approach to urban design countered the somber atmosphere of the Great Depression, symbolically represented by the grandeur of Radio City Music Hall, the complex's most celebrated interior space. For modernist critics such as Sigfried Giedion, Rockefeller Center embodied a new paradigm in urban planning. A widely acknowledged architectural and civic achievement, it remains a testament to the idea that cities can be transformed not solely for private interests but for the collective benefit of the community.

¹¹ The **Metropolitan Opera** (often called the **Met Opera**) is one of the world's leading opera companies, based in **New York City**. Founded in **1883**, it is renowned for its grand productions, world-class singers, and innovative stagings.

In contrast to the developers of the 1920s, who embraced speculative enthusiasm and competition for height, the urban planners of the 1950s exemplified what historian Winston Weisman termed a "*return to earth*" (Weisman 1950: 197)¹². The corporate work environment of this era prioritized functionality, accommodating typewriters, emerging electronic calculators, and a rationalized paper flow. As a result, large, unobstructed interior spaces became essential, facilitated by modern construction techniques that eliminated the need for interior columns. Additionally, advancements such as air conditioning and fluorescent lighting ensured a higher standard of comfort, further reinforcing the shift away from the pursuit of excessive height.

Corporations such as the Seagram Company and the Lever Company sought to project an image of corporate responsibility and refinement. The Seagram Company, for instance, commissioned Ludwig Mies van der Rohe¹³ to design its headquarters, while the Lever Company entrusted Skidmore, Owings & Merrill (SOM), who followed Miesian principles. Instead of striving for the tallest or most ostentatious skyscraper, these companies adopted a restrained yet sophisticated modernist aesthetic, embodying a dignified and commanding urban presence. This approach aligned with the principles of modern architecture as defined in the Museum of Modern Art's 1932 **International Style** exhibition, tracing its lineage to the experimental designs of the European avant-garde, such as Walter Gropius's proposal for the Chicago Tribune Tower competition and Le Corbusier's visionary steel-and-glass skyscrapers for the **Ville Contemporaine** (both 1922). The influence of European modernism in American corporate architecture was further reinforced by the **PSFS Building** (1929–32) in Philadelphia, designed by Howe & Lescaze. With its asymmetrical composition, exposed structural elements, and emphasis on efficiency, this building marked the acceptance of avant-garde design principles within the American business sector.

¹² The phrase "**return to earth**" (Weisman 1950: 197) is taken from Winston Weisman's article "*The Cities of the 1950s*", published in **The Architectural Forum** in 1950. In this article, Weisman discusses the transition in urban architecture from the towering, speculative skyscrapers of the 1920s to the more restrained, horizontally oriented corporate buildings of the 1950s, emphasizing functionality, comfort, and open space.

¹³ Ludwig Mies van der Rohe was a pioneering modernist architect known for his minimalist approach, emphasizing clean lines, open spaces, and the use of steel and glass, as exemplified in iconic works like the Seagram Building and the Barcelona Pavilion.

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Figure 10 - Seagram Building, Mies Van der Rohe, 1953 - 1954

Mies van der Rohe's **Seagram Building** (1953–54)^[Fig.10] epitomized this modernist ethos with its refined elegance, restraint, and monumental presence. The design resonated with Seagram's president, *Samuel Bronfman*, who sought to enhance the company's public image following its controversial past, including its involvement in bootlegging during Prohibition. Having previously developed the **860–880**

Lakeshore Drive Apartments, where he perfected his signature *glass-and-metal*¹⁴ construction system, Mies further refined this architectural vocabulary in the Seagram Building. He used bronze-clad I-beams as striking vertical elements, reinforcing the structure's modernist aesthetic. Notably, the building was set back **90 feet (27.5 meters)** from the lot line, creating an expansive open plaza. This deliberate sacrifice of buildable space for the benefit of the public realm aligned with Bronfman's vision of corporate social responsibility.

The impact of the Seagram Building extended beyond its architectural significance. Recognizing its contribution to urban space, New York City planners incorporated its principles into the 1961 revision of the Zoning Resolution of 1916, leading to the adoption of a floor area ratio (FAR)-based zoning code. Both Mies's design and this new regulatory framework underscored the importance of integrating public space inside the city's evolving architectural landscape.

Similarly, **SOM's Lever House** (1951–52)^[Fig.11] introduced a groundbreaking approach to urban development along Park Avenue. Unlike the Seagram Building, Lever House derived its visual impact from the interplay between two distinct geometric forms—a horizontal podium and a vertical slab—both characterized by minimal detailing. The building featured an innovative **heat-absorbing blue-green glass curtain wall**, marking the first complete application of such a system.

As with Seagram, Lever House's developers prioritized urban aesthetics over maximizing buildable space. By **forgoing the option to construct a taller structure**, they contributed to a more open and inviting streetscape, reinforcing an image of corporate responsibility and civic engagement. This approach not only

¹⁴ Mies Van der Rohe pioneered the use of steel frameworks that allowed for open floor plans and expansive glass curtain walls, creating a sense of transparency and lightness while expressing the building's structural logic.



Figure 11 - Lever House, Skidmore, Owings & Merrill (SOM), 1951–52

enhanced the visual and functional quality of the city but also set a precedent for corporate modernism as a vehicle for urban transformation.

The resurgence of ambition in skyscraper construction during the 1960s marked a significant departure from the more restrained architectural principles of the 1950s, which had been characterized by a figurative and literal “return to earth.” Within a decade, the structural engineer Fazlur Khan, in collaboration with architect Bruce Graham of Skidmore, Owings & Merrill (SOM), introduced a revolutionary structural paradigm that facilitated unprecedented vertical expansion, as exemplified by the John Hancock Center (1965–70) and the Sears Tower (1968–74) in Chicago.

Khan’s innovation lay in reconceptualizing the skyscraper’s structural framework, replacing the conventional framed system with a “tube” like structure. That SOM—an architectural firm deeply influenced by the formal language of Mies van der Rohe—became the platform for such groundbreaking engineering advancements might seem counterintuitive. However, since its inception, the firm had cultivated a reputation for fostering collaboration between architects and engineers. This character was shaped by figures such as *John Merrill*, an engineer who joined the firm in 1930, and *Myron*

Goldsmith, an architect-engineer affiliated with the Illinois Institute of Technology, both of whom played pivotal roles in SOM's trajectory toward structural innovation.

SOM's Inland Steel Building in Chicago (1956–58) [Fig.12] demonstrated an evolution of the curtain-wall system in a relatively modest nineteen-story structure.



Figure 12 - Inland Steel Building, SOM, 1956 - 1958

Designed by architects Bruce Graham and Walter Netsch, the building's design placed its fourteen structural columns on the exterior, making their load-bearing function visibly apparent while simultaneously permitting uninterrupted, column-free office interiors.

Inland Steel's gleaming stainless steel cladding, paired with green-tinted dual glazing, served as an emblematic advertisement for the company's material products, reflecting the prosperity of the postwar

American consumer economy. The Inland Steel Building renovation aims to make the tower a modern embodiment of progress shaped around the needs of the dynamic global marketplace. The updated building will define a new paradigm for the contemporary workplace while satisfying Chicago Landmark requirements.

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The firm further advanced its structural experimentation with the Chase Manhattan Bank in New York (1957–61), designed in collaboration with engineers Weiskopf & Pickworth. This project refined the architectural principles first explored in Inland Steel by employing a curtain-wall system that integrated exposed exterior columns, thereby reinforcing the evolving skyscraper paradigm. Although reminiscent of the Seagram Building in its formal relationship to an open plaza, Chase Manhattan Bank expanded upon this precedent by becoming the first skyscraper to incorporate a plaza within its official address [Fig.13]. The project's genesis was driven by David Rockefeller, chairman of the building's development committee, who sought to counteract the prevailing 1950s perception of Lower Manhattan as an economic "backwater."¹⁵ His ambitious urban intervention consolidated two city blocks, closed the intervening street, and repurposed one block as public space while erecting the skyscraper on the other. Despite its imposing height of 800 feet (244 meters) and 60 stories, Chase Manhattan's



Figure 13 - View on the incorporated plaza of the Chase Manhattan Bank

¹⁵ David Rockefeller described **Lower Manhattan** as a "**declining economic center**" or an "**economic backwater**" to emphasize its stagnation and loss of business activity. His words reflected concerns about the area's outdated infrastructure and diminishing economic influence before major revitalization efforts took place.

structural system—an orthogonally framed scheme with extensive wind bracing—represented only incremental progress over the engineering principles established nearly three decades earlier in the Empire State Building.

This structural statement prompted Myron Goldsmith¹⁶ to pose a critical question: *How might engineers reduce the structural weight of high-rise buildings while simultaneously increasing their height?* His research at the Illinois Institute of Technology explored the implications of extreme verticality on what he termed the “super-frame”, particularly in relation to stiffness and deformation. His protégé, Fazlur Khan, employed emergent computational methods to conduct three-dimensional analyses of wind-induced stresses on such frameworks.

Khan’s paradigm underwent a dramatic validation with the John Hancock Center (1965),^[Fig.14] where he and Graham tested the “tube system” at a monumental scale. Utilizing advanced computer simulations, Khan meticulously calculated the structural response of a rigid tube supported by closely spaced exterior columns and reinforced with large-scale cross-bracing. The resultant tower—distinguished by its industrial, oil-derrick aesthetic—manifested its structural logic in an overt visual language. Rigid diaphragms, distributed throughout the structure to efficiently channel lateral loads, ensured an optimized use of structural steel. Notably, the Hancock Center was not

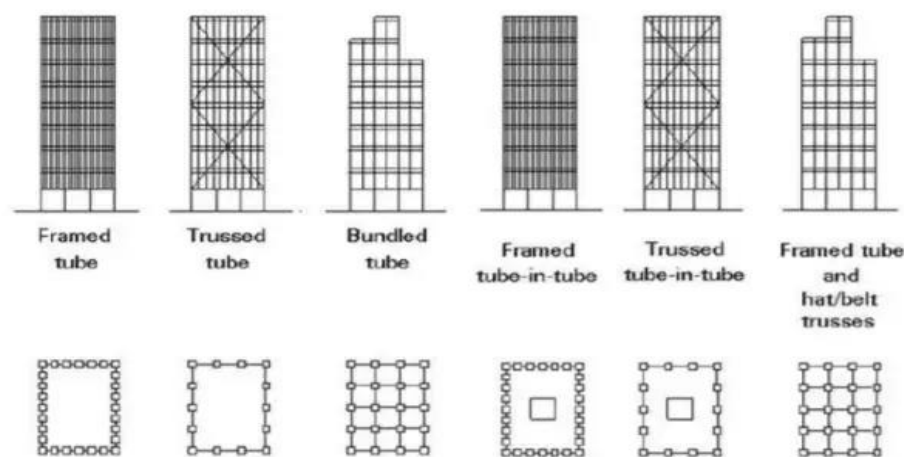


Figure 14 - Various types of "Tube Systems"

¹⁶ **Myron Goldsmith** (1918–1996) was an American architect and structural engineer known for his work in **modernist architecture** and **high-rise structural design**. He was a student of **Ludwig Mies van der Rohe** and later became a key figure at **Skidmore, Owings & Merrill (SOM)**, one of the most influential architecture firms in the world.

1. The Rise of Towers

merely an engineering feat but also the world's first “supertall” skyscraper and an early example of a true “mixed-use” high-rise, accommodating residential, commercial, and public functions within a single vertical complex.

In designing the Sears Tower (now the Willis Tower) between 1968 and 1974, Khan and Graham not only surpassed existing height records—achieving 110 stories and 1,451 feet (442.5 meters)—but also refined the relationship between skyscraper form and structure [Fig.15]. The Sears Tower employed a “bundled tube” configuration, wherein nine interconnected vertical tubes functioned as an integrated structural system, stabilized by belt trusses. This modular arrangement facilitated greater flexibility in office layout while maintaining structural efficiency. Graham, recognizing the significance of the Chicago skyline as an architectural tableau, described the design as “one more mountain [...] for this city on the plains”¹⁷, underscoring the dual imperatives of engineering logic and urban iconography.

While the towers were initially celebrated as engineering marvels, critical opinion shifted by the decade’s end. Architectural critic Wolf von Eckardt decried them as “a fearful instrument of urbicide,” while Ada Louise Huxtable dismissed them as “graceless.” Detractors also highlighted their wind-swept plaza, which exemplified an urbanism antithetical to Jacobs’s vision of vibrant public space.

¹⁷ a reference to the city's tradition of constructing towering skyscrapers that stand as "man-made mountains" on the otherwise flat Midwestern landscape.



Figure 15 - Sears Tower, Skidmore, Owings & Merrill (SOM), 1973

1. The Rise of Towers

Nonetheless, the structural innovations pioneered by Khan and his contemporaries profoundly influenced subsequent high-rise architecture. The "tube concept" inspired an array of permutations, including the Bank of China Tower in Hong Kong (1984–90) [Fig.21] by I.M. Pei and Leslie Robertson. Pei's design reinterpreted the "bundled tube" as a sequence of triangular shafts that progressively terminated at different heights, yielding a crystalline silhouette evocative of natural mineral formations. Despite engineering challenges—compounded by the client's aversion to "X"-shaped bracing due to Feng Shui beliefs—the Bank of China Tower exemplified an architectural-structural synthesis reminiscent of the Hancock Center and Sears Tower, yet with an enhanced sensitivity to public space and human scale.

Thus, while early implementations of the "tube concept" prioritized structural efficiency, later iterations integrated greater architectural refinement, demonstrating an evolving dialogue between engineering innovation and urban experience.



Figure 16 - IBM Tower, T.R. Hamzah & Yeang, 1989 - 1992

During the 1990s, architects and designers began exploring innovative approaches to skyscraper design. Between 1989 and 1992, Ken Yeang¹⁸ introduced a radical reimagining of skyscraper typology with his IBM Tower, or *Mesiniaga*, in Malaysia [Fig.16]. Termed a "bioclimatic skyscraper," Yeang's design integrated exterior plantings, "skycourts," strategically placed east- and west-facing windows to minimize solar

¹⁸ **Ken Yeang** is a Malaysian architect, ecologist, and author, internationally recognized for his pioneering work in **bioclimatic architecture** and **ecological design**.

gain, and a rooftop sun terrace shaded by fins and louvers. These elements collectively contributed to an environmentally responsive architectural approach.

Yeang's skycourts ascended from a three-story-high planted mound, spiraling along the building's facade and intersecting with expansive atria filled with greenery. These features were intended to enhance occupants' connection to nature, facilitate air circulation, provide shade and foster an oxygen-rich environment. His bioclimatic skyscraper was grounded in extensive research and development, including "sunpath projects," "windrose projects," "cladding and skin projects," and studies of "lifestyle patterns based on ecological principles." Central to Yeang's methodology was a commitment to "energy reduction" and the conceptualization of buildings as "open systems." **Charles Jenks** hailed the tower as "*a striking alternative to the reigning mode of corporate towers and a new synthesis for contemporary architecture that is responsive to the climate of a particular place and finds inspiration for a new architectural language from forces that are ultimately cosmic.*"¹⁹

Similar to Yeang, **Foster + Partners** wanted to redefine the skyscraper. The firm's Commerzbank Tower in Frankfurt (1993–1997) faced opposition as Europe's tallest skyscraper and the world's first ecological office, standing at 53 stories and 850 feet (259 meters)^[Fig.17]. To mitigate resistance, Norman Foster incorporated supplementary facilities and energy-efficient features into the design. Collaborating with *Arup*²⁰, he restructured the conventional skyscraper interior by turning it "inside out," thereby exposing it to the external environment. His approach involved a triangular floor plan with structural service cores at each corner, framing a central atrium that functioned as a vertical ventilation shaft. The design also included nine thematically curated sky gardens, each spanning four stories and occupying the full space between the structural cores. This configuration maximized natural light penetration into office spaces while providing occupants with semi-public gathering areas beyond their immediate workspaces. "*The sun streams in, a cool fragrant breeze*

¹⁹ Citation from: <https://www.archdaily.com/774098/ad-classics-menara-mesiniaga-t-r-hamzah-and-yeang-sdn-bhd>

²⁰ **Arup** is a globally renowned engineering, design, and consulting firm specializing in the built environment. Founded in 1946 by **Ove Arup**, the company has played a key role in some of the world's most iconic architectural and infrastructure projects.

1. The Rise of Towers

*wafts from one garden to another. It's an extraordinary reversal of a Modernist aesthetic: the garden in the machine rather than the machine in the garden"*²¹.



Figure 17 - Exploded axonometric view of the Commerzbank, Foster + Partners, 1993 - 1997

²¹ This citation is from **Charles Jencks**, a renowned architectural historian and theorist. The phrase **"the garden in the machine rather than the machine in the garden"** is a play on Leo Marx's famous concept from his book *The Machine in the Garden: Technology and the Pastoral Ideal in America* (1964). Marx explored the tension between industrialization and nature, where machines intruded into pastoral landscapes.

Commerzbank Tower quickly gained recognition as a "green skyscraper" and remains an iconic example of sustainable high-rise architecture.

Parallel to the emergence of the "green skyscraper" was the rise of the supertall, long and slender skyscraper. Pelli later expanded on this concept with the **Petronas Towers** in Kuala Lumpur, Malaysia, which, upon completion in 1998, became the world's tallest buildings at 1,483 feet (452 meters).^[Fig.18] Working alongside Charles Thornton of Thornton Tomasetti Engineers, Pelli developed a structural system comprising core walls and high-strength concrete perimeter columns. His design sought to permeate the skyscraper with cultural significance, drawing inspiration from Malaysian mosque towers and city gates to symbolically represent Kuala Lumpur's ascendance in the global economy.



Figure 18 - Petronas Twin Towers, Pelli Clarke Pelli Architects with Adamson Associates, 1998

1. The Rise of Towers



Figure 19 - 30 St Mary Axe, Foster + Partners, 1997 - 2004

By the late twentieth century, some architects began to challenge the notion of height as an end in itself. Foster + Partners, in collaboration with Arup, designed 30 St Mary Axe (1997–2004) amid ongoing debates about high-rise development in London^[Fig.19].

Rising to 590 feet (180 meters) across 40 stories, the tower features a circular steel core and a "diagrid" structural framework composed of interlocking steel members

that spiral upwards to the tower's apex. Notably, six triangular light wells punctuate each circular floor plate, rotating slightly as they ascend to enhance vertical airflow and reduce energy consumption; equally important, they serve as communal spaces that encourage social interaction. The tower's double-layered glass facade dissipates heat gain. The aerodynamic form of 30 St Mary Axe minimizes wind turbulence and has become a distinguished landmark, often juxtaposed with St. Paul's Cathedral and affectionately known as "the Gherkin."

In the twenty-first century, the pursuit of extreme height persists, as demonstrated by the Burj Khalifa in Dubai, which stands at 2,717 feet (828 meters), as well as numerous proposed skyscrapers in China, South Korea, and the Middle East. However, contemporary skyscraper design increasingly prioritizes ecological responsibility, urban community-building, and the preservation of public spaces. This shift is evident in projects such as Renzo Piano's London Bridge Tower (2012), which

incorporates a spacious winter garden and upper-level atria, reflecting the evolving criteria that now define high-rise architecture.

1.4 Conclusions

The evolution of towers and skyscrapers represents a dynamic intersection of technological advancement, economic ambition, and cultural symbolism. From the earliest high-rise structures in Chicago and New York, which defined the modern skyscraper, to the supertall and sustainable towers of today, the drive for vertical expansion has continuously reshaped urban landscapes.

Throughout the 19th and 20th centuries, innovations such as steel-frame construction, elevators, and tube structures enabled the rapid ascent of skyscrapers, transforming them from purely functional spaces into iconic urban landmarks. The postmodern era saw a growing emphasis on contextual and environmental considerations, with architects like Ken Yeang, Norman Foster, and César Pelli redefining the skyscraper as an ecologically responsive and culturally significant structure.

By the 21st century, the competition for height persists, as seen in the Burj Khalifa and other megastructures. However, the primary focus has shifted towards sustainability, community integration, and adaptive design strategies, ensuring that towers contribute positively to both their urban environment and the well-being of their inhabitants. This evolution underscores that the future of skyscrapers lies not only in height but in their ability to harmonize technology, culture, and sustainability, paving the way for a new era of responsible vertical urbanism.

2. Socio – cultural aspects related to the vertical architecture

2.1 Introduction

Many cities deliberately limit or exclude high-rise developments, often limiting them to designated peripheral zones in an effort to preserve the historical character and identity of their urban cores. Even in cities where skyscrapers have been enthusiastically embraced, specific high-rise proposals frequently encounter strong local opposition, reflecting broader tensions between urban transformation and heritage conservation. While some of these objections are rooted in legitimate concerns, others are often influenced by *NIMBY (Not In My Backyard)* sentiment²².

Much of the opposition to high-rise construction stems from two primary concerns: their perceived negative impact on the urban fabric (both visually and physically) and the deficiencies of their internal environments. To create truly livable high-rise structures, the social, cultural, and functional elements of the urban environment—such as parks, public squares, retail spaces, restaurants, schools, and medical facilities—must be reinterpreted within the vertical dimension, fostering a sense of community that would typically emerge at ground level. Beyond their social and spatial contributions, such spaces also play a vital role in sustainability. **Atria and sky gardens**, for instance, can facilitate natural ventilation and daylight penetration, significantly reducing energy consumption and reliance on mechanical systems. However, perhaps the most profound benefits of such interventions extend beyond energy savings. Research indicates that enhanced workplace environments—which prioritize air quality, natural light, and social well-being—can lead to higher employee satisfaction, reduced absenteeism, and substantial productivity gains. This underscores the imperative to rethink high-rise design, ensuring that skyscrapers serve not only as symbols of progress and innovation but also as sustainable, socially integrated and human-centric environments.

²² **NIMBY ("Not In My Backyard") sentiment** refers to **public opposition to developments** that, while often necessary or beneficial at a broader scale, are perceived as undesirable when located **near one's own community or neighborhood**. This reaction is common in urban planning, infrastructure projects, and environmental policies.

2.2 Cultural background and high-rise buildings

Throughout history, humanity has sought to extend its influence and assert control over nature, a pursuit evident since the Neolithic era, when the first stone monuments were erected, like the Stonehenge monument. From funerary markers and solar calendars, which regulated agricultural cycles, to the construction of supertall skyscrapers, these vertical structures have consistently served social, cultural and symbolic purposes, having a constant evolution through time.

Building against the force of gravity has long been a testament to human ingenuity, symbolizing our intellectual capacity and ability to shape the natural world. This symbolism has evolved across historical epochs: during the Gothic period, towering structures embodied spiritual reverence; in the twentieth century, they became expressions of individual and corporate power; and in the contemporary era, they stand as technological triumphs, signifying the economic and geopolitical aspirations of emerging nations.

Today, skyscrapers evoke both admiration and controversy: in some contexts, they are celebrated as monuments of progress and national pride, captivating even those who never step inside them; however, in other regions, they are perceived as symbols of architectural excess and flawed urban planning. Incredibly, opposition to high-rise developments is found in progressive urban centers such as Los Angeles, while enthusiastic adoption often occurs in socially conservative regions, such as parts of the Middle East.



Figure 20 - Burj Khalifa, Skidmore, Owings & Merrill (SOM), 2009 - 2010

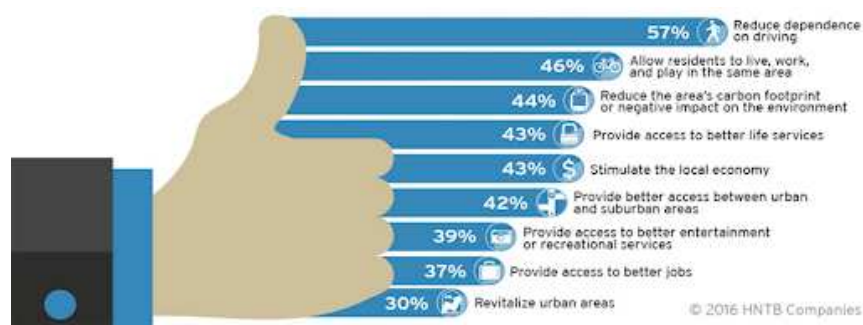
The Burj Khalifa, designed by Skidmore, Owings & Merrill (SOM), exemplifies this dramatic architectural ambition. ^[Fig.20] As the tallest structure ever built, it represents an unparalleled feat of engineering and a striking manifestation of human achievement. Its tapered setbacks, which diminish in scale as they ascend, create an imposing yet elegant form, despite their impact on interior functionality. Moreover, while its curtain wall bears strong similarities to other recent SOM

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projects, its sheer height remains unparalleled. Rising from the vast, unbroken desert, the Burj Khalifa accentuates humanity's defiance of gravity in a way that a similar structure in a dense urban setting could not.

It is intriguing to consider how such an engineering marvel, designed by Bill Baker and Adrian Smith, would be perceived by Nat Owings, a founding partner of SOM. Towards the end of his life, Owings voiced skepticism regarding the role of skyscrapers, arguing that they conflicted with fundamental human needs and urban experiences. His perspective raises a critical question: *Do supertall structures enhance or modify the human experience? How does the social experience change in relationship to the vertical architecture?* This debate continues to shape contemporary discourse on vertical urbanism and the evolving role of high-rise architecture in modern society.

We are at a critical situation where it is mandatory to develop collective strategies to address the increasingly complex challenges facing urban environments. Among these challenges, traffic congestion remains the most frequently cited concern, influencing both public perception and political decision-making regarding high-rise developments. Issues related to the scale, massing and shadow impact of tall buildings, even if significant, tend to be secondary concerns. However, the promotion of **transit-oriented development (TOD)**²³ offers a promising solution, mitigating traffic concerns by integrating high-rise structures directly with public transportation networks. A convincing argument can be made that office towers, if fully integrated with transit systems, could function as vertical extensions of transportation hubs, effectively eliminating traffic-related objections



²³ **Transit Oriented Development** is the exciting fast growing trend in creating vibrant, livable, sustainable communities. Also known as TOD, it's the creation of compact, walkable, pedestrian-oriented, mixed-use communities centered around high quality train systems. This makes it possible to live a lower-stress life without complete dependence on a car for mobility and survival.

(<http://www.tod.org/>)

In the context of sustainable urbanism, the densification of functions along transit corridors makes skyscrapers more relevant than ever. As mobility decreases and congestion intensifies, particularly in rapidly growing cities, the viability of their economic and environmental sustainability will depend on **effective spatial planning**. The most impactful approach to energy conservation remains limiting urban sprawl, as compact, high-density cities inherently support more sustainable lifestyles. The form and scale of future urban developments will be shaped by existing population needs, feeling the needs of the vertical expansion of urban environments and the adoption of new architectural typologies that embrace the third dimension of the built environment.

During the 2010 *Council on Tall Buildings and Urban Habitat*²⁴ conference in Mumbai, architect Charles Correa argued that allocating excessive land area to high-rise residential developments can create a risk of reducing the availability of essential urban elements, such as open spaces, schools and public services, making large-scale housing towers less viable than office towers. However, residential skyscrapers could become more functional and socially inclusive if integrated with elevated public spaces, such as **skybridges** transformed into gardens and communal areas. While elevated outdoor spaces remain visually striking, their usability is often limited because of the strong winds and maintenance challenges. Future design strategies must address these limitations, ensuring that sky-level public spaces are not only visually compelling but also functional and accessible. Currently, many of these spaces remain exclusive and private, but with higher urban densities and mixed-use developments, they could evolve into meaningful social and environmental assets.

Mixed-use developments present a compelling opportunity for the future of vertical architecture and urbanism. Despite the intrinsic link between skyscrapers and transit systems, certain functions—such as healthcare, higher education and cultural institutions—remain underrepresented in high-rise structures. Many tall buildings are positioned at key transportation hubs, yet their ground-level integration with the public realm is often poorly executed, resulting in windswept plazas and

²⁴ The **Council on Tall Buildings and Urban Habitat** (CTBUH) is the world's leading non-profit organization for all those interested in the future of cities. It explores how increased urban density and vertical growth can support more sustainable and healthy cities, especially in the face of mass urbanization and the increasing effects of climate change worldwide. The relationship between policy, buildings, people, urban density, urban space, interior space, and infrastructure is key. (<https://www.ctbuh.org/about>)

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unwelcoming urban spaces. Ideally, transit stations should be designed to seamlessly connect with vibrant, crowded public areas, creating well-integrated and socially engaging environments. Furthermore, towers linked by landscaped skybridges not only enhance lateral structural stability but also introduce new communal and functional spaces, shifting the focus from isolated vertical structures to interconnected urban networks. The philosophy of Nat Owings, who titled his autobiography *The Spaces in Between* ²⁵, underscores the importance of viewing skyscrapers not as solitary objects but as components of a larger urban fabric.

Fundamentally, the construction of a tall building is a demonstration of power, the ability to mobilize financial, material and human resources to realize such an ambitious undertaking. This dynamic inherently establishes a divide between those with access to such resources and those without, raising concerns in democratic societies when an individual structure disrupts the established urban landscape or visually dominates its surroundings. Many contemporary skyscrapers, particularly in China, South Korea, Saudi Arabia and India, continue to follow traditional high-rise development models, prioritizing engineering feats and aesthetic distinctiveness over urban integration. While these structures are often remarkable achievements, they frequently function as standalone icons, detached from the broader urban context—leaning more to sculptural objects rather than integral elements of the city.

To redefine the role of skyscrapers, architects and urban planners must envision high-rise developments as interconnected systems with the surrounding environment, rather than isolated statements of power and prestige. While skyscrapers will undoubtedly continue to symbolize human ingenuity and technological progress, they must also evolve into multi-functional urban nodes, incorporating renewable energy generation, water management and waste collection systems alongside traditional residential, commercial and cultural functions. By embracing a holistic approach that integrates public accessibility, sustainable technologies and social

²⁵ *The spaces in between* was published in 1973, offering Owings' reflections on his career, architectural philosophy, and the evolution of urban spaces. One of the key arguments of this book speaks about how he believed that tall buildings should be carefully planned within the larger urban context, rather than serving as isolated monuments of power and prestige.

engagement, high-rise buildings can become meaningful contributors to urban life rather than exclusive enclaves.

As we transition toward a post-automobile society, urban planning and architectural strategies must adapt to new mobility patterns and environmental imperatives. The tall building, once a monument to economic power, must be redefined as an inclusive and sustainable component of the modern city, fostering a sense of belonging while addressing the pressing challenges of climate change, resource efficiency, and urban livability.

For centuries, urban development followed the Hellenic model²⁶, where a grid of streets facilitated movement, while blocks of buildings provided spaces for living and working. However, in the second half of the twentieth century, influenced by a reaction to industrial-era cities, Modernist architects and engineers reconceptualized urban paradigms. They envisioned cities where green spaces became primary environments for living and working, while roads were concealed, leading to a historic separation between spaces for movement and spaces for habitation. This shift, enabled by economic prosperity and technological advancements, fueled the rise of suburbanization—a pattern that persisted for nearly seventy years amid unprecedented urbanization and population growth.

Despite its well-intended principles, the sprawling city model introduced by Modernist urbanism has led to significant unintended consequences. These include widespread depletion of virgin land resources, environmental degradation, declining air and water quality, social fragmentation, increased energy consumption and the devaluation of existing urban infrastructure. Addressing these pressing challenges necessitates a fundamental rethinking of the relationship between mobility and urban form. As cities continue to attract new residents, investment, cultural and technological innovation, the role of high-density development becomes increasingly relevant. When tall buildings are developed in tandem with infrastructure and public space enhancements, they can serve as catalysts for social, economic and environmental sustainability. In addition, dense urban environments offer proximity to workplaces,

²⁶ The Hellenic model refers to the urban planning principles of ancient Greek cities: this model was influential in shaping classical and later urban developments, particularly through the work of **Hippodamus of Miletus**, who is often regarded as the "*father of urban planning*."

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open spaces, commercial areas, and cultural amenities, reinforcing their appeal to professionals in technology and creative industries. Given these advantages, high-density development appears not only inevitable but also essential, raising the question of how best to implement it in an intelligent and integrated manner.

Tall buildings can play a pivotal role in restoring environmental and social balance in contemporary urban centers, particularly as new models of integrated urban planning and public-private collaborations emerge. The growing verticality of cities has sparked widespread debate—both due to its impact on urban morphology and as a response to the need for higher-density solutions to accommodate rising global urban populations. Urban planners today must navigate two contrasting challenges: on one hand, disconnected high-rise developments that require retrofitting infrastructure to support them; on the other, newly planned developments where holistic planning strategies and public-private partnerships can create fully integrated urban environments.

While each urban context is unique, shaped by historical planning frameworks, governance structures and socio-economic conditions, analyzing both successful and flawed examples offers valuable insights for future urban planning decisions. By considering the continuum between uncoordinated, infrastructure-deficient high-rise clusters and fully integrated, transit-oriented developments, planners and architects can formulate more sustainable and socially responsive strategies for the cities of tomorrow.

2.3 The future of tall buildings in the urban environment

The role of tall buildings in shaping the cities of the future is a subject of multifaceted discourse, involving a complex interplay of urban planning, environmental sustainability, technological advancement and socio-economic considerations. While projections and conjectures abound, one fact remains indisputable: high-rise structures will continue to apply a profound influence on the evolution of urban landscapes, particularly in response to increasing environmental challenges and population growth.

A critical precedent in sustainable high-rise development is the Commerzbank Tower in Frankfurt, which established key environmental benchmarks

for future skyscrapers. The project redefined the office environment by incorporating ecological principles and innovative spatial configurations, most notably through its



Figure 21 - View on the Sky Garden of the Commerzbank, Frankfurt

spiraling sky gardens ^[Fig.21], which provide natural daylight, improved ventilation, and communal spaces within the building's core. This model highlights the potential of tall buildings as solutions to urban densification while simultaneously addressing human-centric and ecological concerns.

However, high-rise solutions are not universally applicable. In some contexts, mid-rise developments with integrated public squares and active streetscapes may offer more sustainable and socially engaging alternatives. The contrast is evident in cities such as Hong Kong, where densely packed residential towers can create claustrophobic environments, limiting access to natural light and ventilation at lower levels^[Fig.22]. To mitigate such drastic situation, contemporary high-rise design increasingly focuses on integrating mixed-use functions and transport connectivity: by positioning skyscrapers over major transit nodes, cities can minimize reliance on private vehicles, actively enhancing urban sustainability and sustainable transportations.

One of the most effective strategies for optimizing high-rise efficiency is through functional diversity: projects such as **The Shard in London**, designed by

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Figure 22 - Density of Hong Kong's tower blocks

Renzo Piano, exemplify this principle by incorporating residential, commercial and hospitality functions within a single structure. Despite regulatory and financial constraints in some regions—such as lease-length discrepancies in the UK—integrating mixed uses within a single high-rise structure enhances energy efficiency. For example, waste heat generated by office spaces can be repurposed for residential heating, creating sustainable energy-sharing ecosystems.

Beyond functionality and mixed-use situations, the cultural and contextual integration of tall buildings remains a fundamental challenge. In an era of increasing global homogenization, where urban landscapes are dominated by corporate architectural identities, high-rise structures must reflect the cultural and environmental specificity of their location. The construction of towers as mere status symbols—intended solely to mark financial power—has led to questionable urban interventions in various global contexts. Cities such as Dublin, for example, do not necessarily require iconic skyscrapers to reinforce their urban identity. The prevailing trend of *"mine's bigger than yours"* ²⁷ is increasingly giving way to contextually responsive, function-driven architectural approaches.

²⁷ The **"Mine's Bigger Than Yours"** trend in skyscrapers refers to the competitive race among cities, developers, and countries to build the **tallest, most iconic, or most technologically advanced** buildings. This trend has been driven by a mix of **national pride, economic ambition and architectural one-upmanship**.

One of the most pivotal transformations in high-rise architecture occurred with the shift from solid masonry structures from Chicago to lightweight glass curtain walls: a change that was largely driven by the rise of air-conditioning systems. Today, a new paradigm shift is underway, dictated by sustainability imperatives such as zero-carbon targets and the LEED certification agenda²⁸. Architectural innovation in high-rise design is no longer solely about height and form but also about minimizing ecological impact. Corporations now recognize the economic and branding advantages of sustainable buildings, as environmentally responsible workspaces attract a new generation of professionals who prioritize green values and workplace well-being. Consequently, office design is evolving beyond the bunker-like structures of the past, embracing biophilic design, energy efficiency and adaptability as core principles.

The future of tall buildings will not be characterized by superficial "*greenwashing*"—such as merely placing wind turbines atop towers or using solar panels on the roof—but by comprehensive lifecycle sustainability assessments. The focus will shift toward material efficiency, embodied carbon reduction and adaptive reuse. Instead of demolishing aging high-rises, refurbishment and re-skinning strategies will be prioritized to enhance building performance without excessive resource consumption. Upgrading façade systems, HVAC technologies²⁹ and energy management solutions will become central to the next phase of high-rise evolution.

Simultaneously, the pressure on land availability—pressed by climate change, rising sea levels and extreme weather events—will necessitate further vertical expansion. If urban populations continue to grow exponentially, the logical trajectory will be upward development, maximizing land efficiency while preserving agricultural and ecological zones. Although speculative, the notion of "vertical cities" may evolve beyond architectural theory into a pragmatic urban solution in the centuries ahead.

²⁸ **LEED-certified buildings** focus on occupant well-being, offering a healthier and more satisfying indoor space while addressing community and public health. The rating system focuses on strategies like banning smoking and reducing toxic exposure from materials to improve air quality.

²⁹ **HVAC** is an acronym that stands for Heating, Ventilation, and Air Conditioning. A residential HVAC system is a complete home comfort system that can heat and cool your home, as well as provide improved indoor air quality and humidity control.

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In the end, tall buildings will continue to evoke divided opinions: while some perceive them as oppressive, monolithic presences, others admire their symbolic, aesthetic, and technological significance. The challenge for architects, engineers and urban planners lies in ensuring that skyscrapers transcend mere visual spectacle, contributing instead to the social, environmental and economic well-being of urban populations. Future high-rise developments must embrace multifunctionality, sustainability and contextual sensitivity, integrating seamlessly into the urban fabric while redefining the parameters of vertical living.

As the discipline of architecture progresses, the aspiration remains clear: the next generation of skyscrapers must not only reach new heights in engineering and design but also serve as catalysts for resilient, inclusive and intelligent urban environments.

2.4 The public realm's influence on tall buildings

Given that high-rise buildings frequently generate substantial financial returns, whereas landscapes rarely do, the prosperity of a city's public spaces is often intrinsically tied to the success of its skyscrapers. However, from the standpoint of urban quality of life, tall buildings are only as valuable as the public spaces they facilitate. Whether these take the form of traditional plazas, green park spaces or innovative areas that foster human interaction—such as the "sky lobbies" characteristic of Asia's supertall structures or the redevelopment of the **World Trade Center** site—their relationship with the built environment across all scales remains fundamental. While architects may emphasize the iconic or aesthetic significance of a high-rise as an autonomous entity, urban designers and landscape architects perceive such structures as both generators of social interaction (*urban fabric*) and sources of economic viability (*financial sustainability*) for the broader cityscape.

The dynamic interplay between open space and urban density continues to evolve, with historical precedent deeply embedded in this discourse. Many of the earliest monumental structures were constructed with sacred intent, establishing vertical connections between human civilization and perceived supernatural realms,

both celestial and subterranean (La Boda, Ring, & Salkin, 1996)³⁰. These edifices were frequently sited in locations of geographic, natural or cultural significance, reinforcing notions of transcendence. Civilizations that fostered agricultural stability and hierarchical social structures were also those that advanced the engineering capabilities necessary for durable tall construction. Consequently, the impetus for building vertically has long been intertwined with considerations of microclimate, geology, geomorphology, sociology, commerce and cultural identity—elements that collectively contribute to a city's sense of place.

The Egyptian pyramids stand as the most prominent early examples of tall structures erected for purposes of religious and political assertion. Similarly, the **Potala Palace** in Lhasa, Tibet [Fig.23]—a thirteen-story monastery dating to the seventeenth century—remained one of the tallest inhabited buildings globally well into the nineteenth century. However, it was in the West that the proliferation of high-rise structures took root. Church steeples and cathedral spires served both as navigational landmarks and symbols of communal pride; meanwhile, the merchant houses of seventeenth-century Amsterdam, typically four to five stories in height, illustrate the early economic motivations behind high-density development, as land surrounding such urban centers became increasingly valuable. These compact structures efficiently integrated residential, commercial and storage functions within a limited footprint,

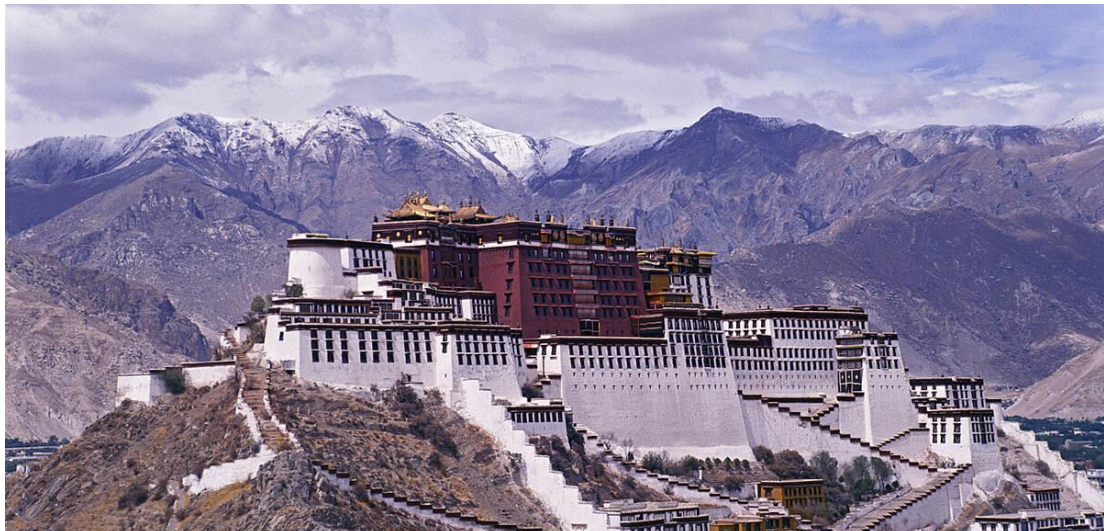


Figure 23 - Potala Palace, 1694.

³⁰ The reference "(La Boda, Ring, & Salkin, 1996)" corresponds to the multi-volume work titled "International Dictionary of Historic Places," edited by Trudy Ring, with Robert M. Salkin as associate editor and Sharon La Boda as photo editor. This comprehensive set, published between 1994 and 1996, provides detailed histories of approximately 1,000 historic sites worldwide.

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benefiting from close proximity to waterways and trade hubs. Many of the prerequisites for the eventual rise of modern skyscrapers—economic activity, transport infrastructure, and public gathering spaces—were already in place, reinforcing the significance of both vertical development and the necessity for urban squares and agoras to counterbalance the density.

The integration of landscape with high-rise development continued into the modern era, particularly in financial and commercial centers. By the early twentieth century, projects such as the **Flatiron Building** (1902) in Manhattan - distinguished not only by its triangular form but also by its considerable height relative to its surroundings (Alexiou, 2010)³¹ - necessitated a reconsideration of the spatial relationship between tall buildings and their immediate urban context. The Rockefeller Center developed in the 1930s, represents a particularly effective synthesis of high-rise construction and pedestrian - scale urbanism. Spanning six blocks, the complex comprises multiple towers with strategic setbacks and articulated facades that create diverse and engaging public spaces. Thoughtful pedestrian corridors, interspersed with vegetation and sculptural elements, provide an experience that harmonizes architectural form with



Figure 24 - Crowded view on The Rockefeller Plaza

³¹ *The Flatiron: The New York landmark and the incomparable city that arose with it* by Thomas Dunne Books.

This book provides a historical account of the Flatiron Building, its construction and its significance in the development of New York City.

human-scale interaction. The Rockefeller Center's holistic design approach extends beyond its built structures to include programmed public spaces, extensive art installations and common areas such as theaters, gardens and recreational facilities. Its success underscores the critical role of spatial programming in fostering socially vibrant and economically resilient urban environments. [Fig.24]

Conversely, the redevelopment of the World Trade Center site following the 2001 attacks demonstrates the complexity of integrating monumental architecture within a highly scrutinized urban fabric. Spearheaded by the *Port Authority of New York & New Jersey* alongside private developers, the project comprises seven new towers within a 16-acre precinct, emphasizing connectivity between the built environment and the public realm. The 9/11 Memorial Park serves as the focal point, surrounded by pedestrian-friendly streetscapes, transit hubs and civic spaces that reestablish the site's engagement with the broader city. The integration of at-grade, below-grade, and vertical circulation networks ensures that these structures do not merely stand as isolated monuments but instead actively contribute to the city's socio-spatial dynamics. By unifying infrastructure, open space and high-rise development within a coherent urban vision, the World Trade Center exemplifies a model in which tall buildings are seamlessly interwoven with public life.

Nevertheless, in certain contemporary urban contexts, the lessons of history appear to be ignored until just a few years ago, as developers pursue ever-taller structures with minimal consideration for their surrounding environment. An example of this situation is in Pudong, (Shanghai), where an expanse of supertall buildings dominates the skyline yet remains largely detached from the pedestrian realm. In contrast to the Bund—Shanghai's historic waterfront district, characterized by human-scale streetscapes and active public spaces—Pudong's urban fabric is fragmented by multi-lane roadways, effectively severing pedestrian connectivity. High-quality public space in this district exists predominantly within the upper levels of skyscrapers, accessible only to an exclusive subset of the population. Nowadays, more sky bridges, underground passages and pedestrian walkways have been developed to connect key buildings in Pudong and some efforts have been made to create greener and more pedestrian-friendly streets, but challenges remain due to the dominance of wide roads and car-oriented planning; the public spaces are expanding: new parks, riverfront promenades and commercial spaces aim to **soften the urban sterility** of Pudong,

2. Socio – cultural aspects related to the vertical architecture

having The Lujiazui Central Green Space as an example of an effort to introduce a **more livable, walkable** area amidst the skyscrapers.

Efforts to address these deficiencies have included proposals for an "elevated landscape"—a pedestrian network situated two stories above the street, designed to interconnect major towers. While reminiscent of projects such as **Manhattan's High Line**, this intervention primarily serves as a compensatory measure rather than an inherently integrated urban strategy. The phenomenon of vertical



Figure 25 - View on the elevated pedestrian walkway in Lujiazui, Shanghai

urbanism, whereby entire districts are linked via subterranean and elevated corridors, is not unique to Shanghai ^[Fig.25]; similar patterns can be observed in Hong Kong and Tokyo, where superblocks function as insular entities detached from street-level life. This mode of development raises critical questions about the role of the public realm in contemporary cities and the extent to which high-rise environments can remain socially and culturally inclusive.

Without meaningful social and cultural contributions, tall buildings risk becoming mere speculative real estate assets, sustained by artificial market forces rather than genuine urban vitality. The ongoing debate underscores the need for a balanced approach, one that acknowledges the economic imperatives driving high-rise

development while ensuring that the urban environment remains accessible, dynamic and deeply connected to the lived experience of its inhabitants.

2.5 Conclusions

The socio-cultural implications of vertical architecture extend far beyond the urban aesthetics, influencing community dynamics, accessibility, and the mere urban experience. While skyscrapers have historically symbolized economic power and technological progress, their impact on social cohesion and urban life remains a subject of critical debate.

Throughout this chapter, I have explored how high-rise developments can either enhance or hinder social interaction, depending on their integration with public spaces and transit networks. Well-designed vertical environments that incorporate public realms, sky gardens and mixed-use programs have the potential to foster vibrant communities, whereas isolated, car-centric skyscraper clusters risk social fragmentation and economic exclusivity.

Additionally, the evolution of urban planning paradigms has highlighted the shifting perception of tall buildings, from mere icons of corporate dominance to integral components of sustainable and livable cities. The case studies analyzed demonstrate that successful vertical architecture requires a balance between density, accessibility and environmental responsibility. As cities face incredible challenges related to population growth and resource constraints, the role of skyscrapers must be reassessed to prioritize inclusivity and long-term sustainability.

Moving forward, the future of vertical urbanism will depend on its ability to harmonize human-scale design with technological advancements. Rather than simply reaching for greater heights, the next generation of skyscrapers must prioritize social equity, environmental performance and integration within the urban fabric to ensure a sustainable and inclusive cityscape.

3. General design strategies for high-rise buildings

3.1 Introduction

The evolution of high-rise architecture, more importantly tall buildings, has been driven by the need to balance structural efficiency, sustainability and functional adaptability. As cities continue to expand vertically to suit growing populations and optimize land use, the role of structural systems in shaping efficient and environmentally responsible skyscrapers becomes increasingly crucial. Sustainable high-rise design is not just about reaching greater heights but also about integrating innovative construction techniques, material efficiency and smart-energy structural solutions that contribute to the longevity and environmental performance of buildings.

Structural systems in high-rise architecture serve as the backbone of the design, determining stability, safety and spatial organization. The selection of an appropriate structural framework influences the building's ability to resist to lateral forces such as wind and seismic loads, nothing less than protecting the users inside from disasters such as fires, while also optimizing interior flexibility and usable space. Core systems, braced frames, tubular structures and hybrid models represent key advancements in high-rise construction, allowing architects to push the limits of design while maintaining safety and efficiency.

In parallel, efficient construction techniques play an extremely important role in reducing the environmental footprint of skyscrapers. Prefabrication, modular construction and the use of high-performance materials such as engineered timber and advanced concrete composites have redefined the possibilities of sustainable vertical development. These methods not only minimize construction waste but also enhance energy efficiency and resource conservation, aligning with global sustainability goals.

This chapter explores the relationship between structural innovation and sustainability in high-rise design. It examines how architectural strategies contribute to creating resilient, adaptable and environmentally conscious towers. Through the analysis of key structural typologies, material advancements and real-world case studies, this section aims to provide a comprehensive understanding of the principles guiding the future of sustainable high-rise architecture.

3.2 Core Systems and structural frameworks

A well-conceived core is fundamental to the functionality and stability of a high-rise building. In multi-story structures, various essential services and circulation systems must traverse the building vertically, and these are primarily concentrated within the core. Structurally, the core acts as a stabilizing element, often incorporating columns and shear walls to enhance rigidity and resist lateral forces.

Beyond its structural role, the core serves as the central hub for mechanical, electrical and plumbing systems, housing power distribution, data cabling, ventilation and water supply networks. Additionally, it accommodates vertical circulation, providing access through stairwells and elevators, ensuring both efficiency and safety in movement throughout the building. Given its strategic positioning, the core is also the most practical location for essential facilities such as restrooms, which benefit from proximity to vertical risers for plumbing and air circulation systems.

By integrating multiple functions within a single, centralized zone, the core optimizes spatial efficiency enhances structural integrity, and contributes to the overall performance of the building.

3.2.1 Central Core System

The core is typically positioned at the center of the building, ensuring an equal distribution of space between the core and the external façade on all sides. This **central core** serves as a structurally efficient solution, similar to a tree trunk that anchors into the ground while supporting branches—represented by the floors and service systems—extending at each level.

From a safety perspective, any multi-story building must incorporate at least two emergency staircases, strategically spaced apart to facilitate evacuation during a fire or other emergencies. A centrally located core can efficiently house these anti-fire stairs on opposite sides, enhancing safety and compliance with fire regulations.

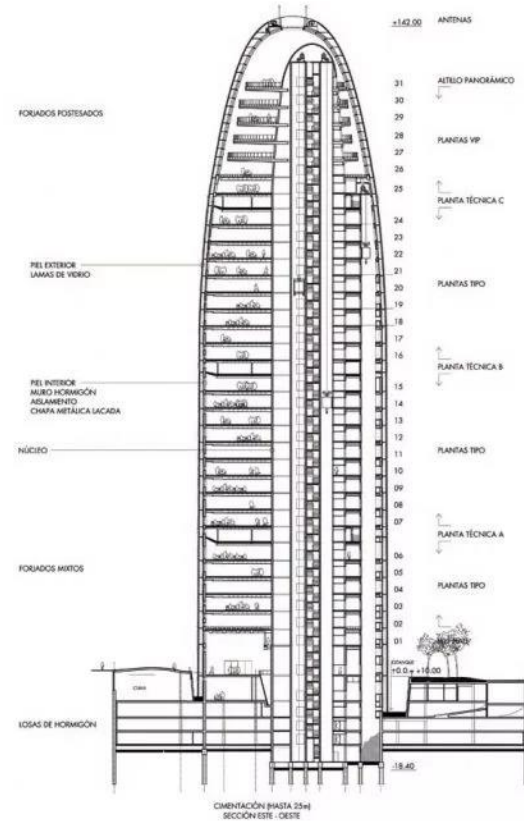
However, this configuration is not without its drawbacks: a core positioned in the middle of the structure can disrupt the openness of interior spaces, dividing the office floor into separate zones and creating a **doughnut-shaped layout**. This design can pose

3. General design strategies for high-rise buildings

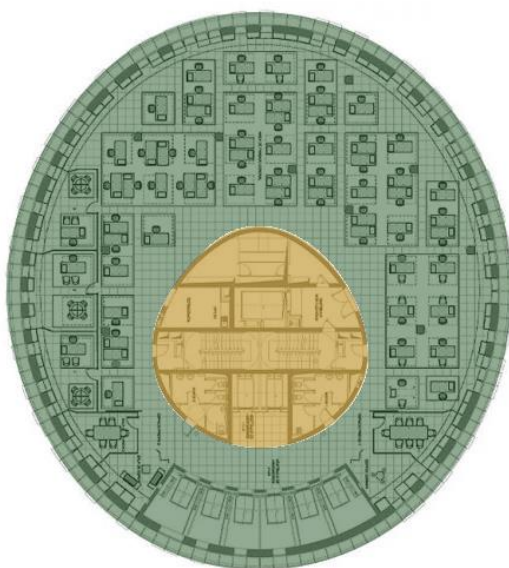
challenges in space planning and workplace flexibility, especially in office buildings, where everything should be clear and well connected. Nevertheless, one advantage is that it brings all occupants closer to windows, improving **natural light and ventilation**.



View on Torre Agbar, Jean Nouvel & B720 Fermin Vazquez Arquitectos, 1999 - 2005



Section Torre Agbar



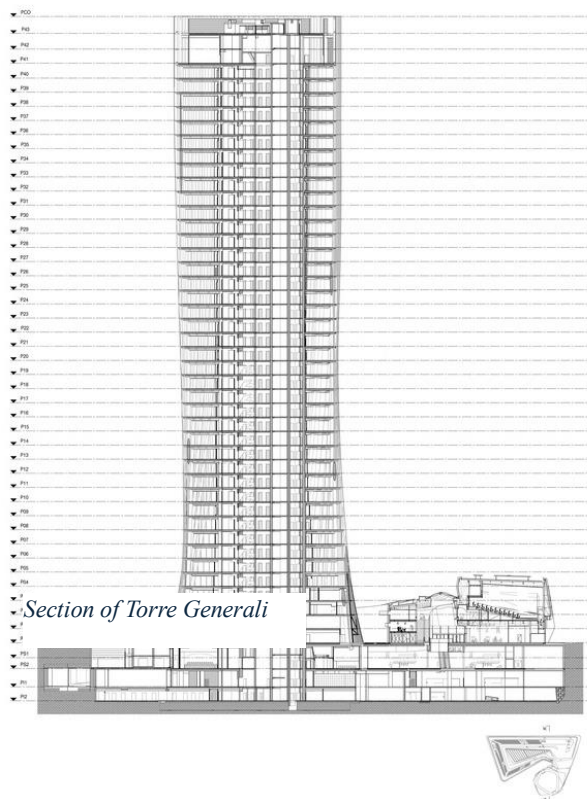
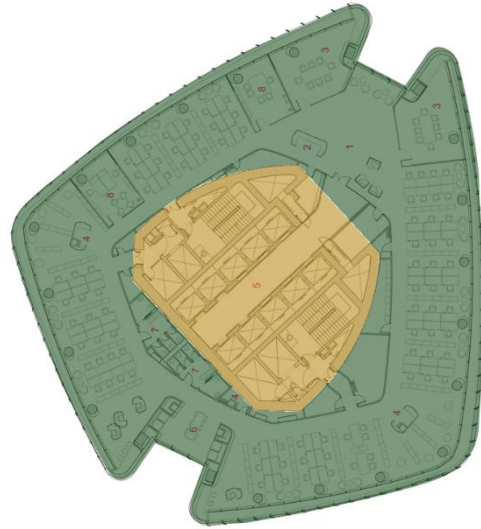
General design floor plan (Yellow: CORE - Green: Floor Area)

The eccentric shape of the interior core dictates the standard floor plan – office spaces set into the exterior wall, wrapping around the interior lift shafts.

3. General design strategies for high-rise buildings



View on Torre Generali, Zaha Hadid Architects, 2017



Section of Torre Generali

The internal structure of Generali Tower consists of reinforced concrete with a central vertical core and a series of perimeter columns, each of which has a different angle of inclination, depending on the location and height within the building, to accommodate the twisting form of the structure. The otherwise column-free floor plates are then enclosed with a double-façade system, complimented by sun-deflecting louvers that reduce solar heat gain and ventilation registers that introduce natural airflow.

3.2.2 Eccentric Core System

As an alternative to central cores, many contemporary towers choose an **eccentric core**, positioned asymmetrically to one side of the building. This configuration maximizes open floor space by providing a large, unobstructed floor area in front of the core. While this design is advantageous for developers and tenants seeking expansive, flexible workspaces, it poses significant structural challenges in seismically active regions.

In the event of an earthquake, the asymmetrical rigidity of an eccentric core can subject the building to extreme physical stress: the side containing the core remains comparatively rigid, while the opposite side experiences greater lateral displacement, inducing torsional movement. This twisting motion places considerable strain on the building's columns, potentially leading to structural failure. If the columns fracture, the integrity of the building is compromised, increasing the risk of progressive collapse.

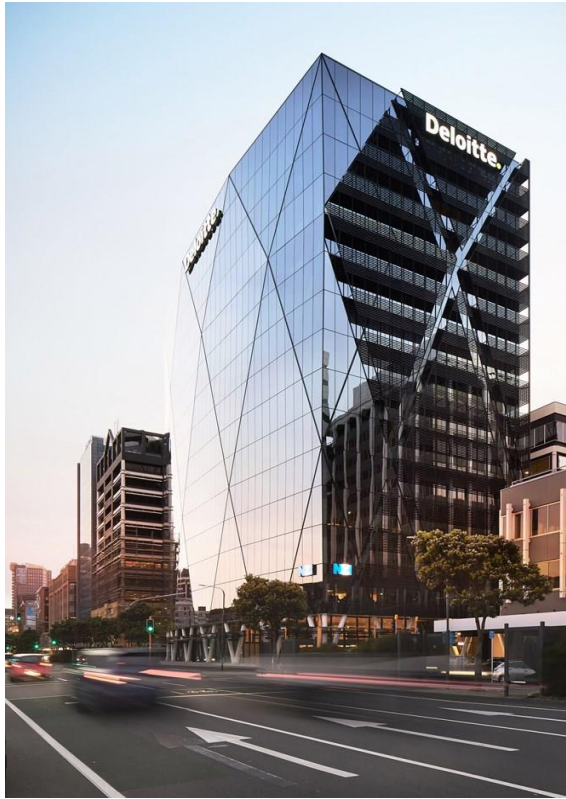
Historical evidence underscores these risks. The **CTV** and **PGG** buildings in Christchurch, both of which collapsed during the 2011 Canterbury earthquake, exemplify the vulnerabilities associated with eccentric core structures. The CTV building, in particular, suffered catastrophic failure due to a combination of factors, including an **eccentric core, inadequate column strength, poor connections between the bracing wall and floor slabs, and the impact of a severe seismic event**. The collapse resulted in 115 fatalities, the majority of whom were on a single floor.

Given these risks, structural engineers and architects exercise extreme caution when implementing eccentric cores in high-seismic regions such as California, Japan or New Zealand. One critical safety concern is that this layout often concentrates all emergency egress routes (fire stairs) on one side of the building, which may impede evacuation during an emergency. Therefore, when designing buildings with eccentric cores, additional **seismic reinforcement** is necessary on the side opposite the core. This typically involves the integration of **bracing systems** within one or more bays of the structural grid.

Despite these challenges, well-engineered eccentric core buildings can achieve exceptional spatial efficiency and architectural quality. A notable example is

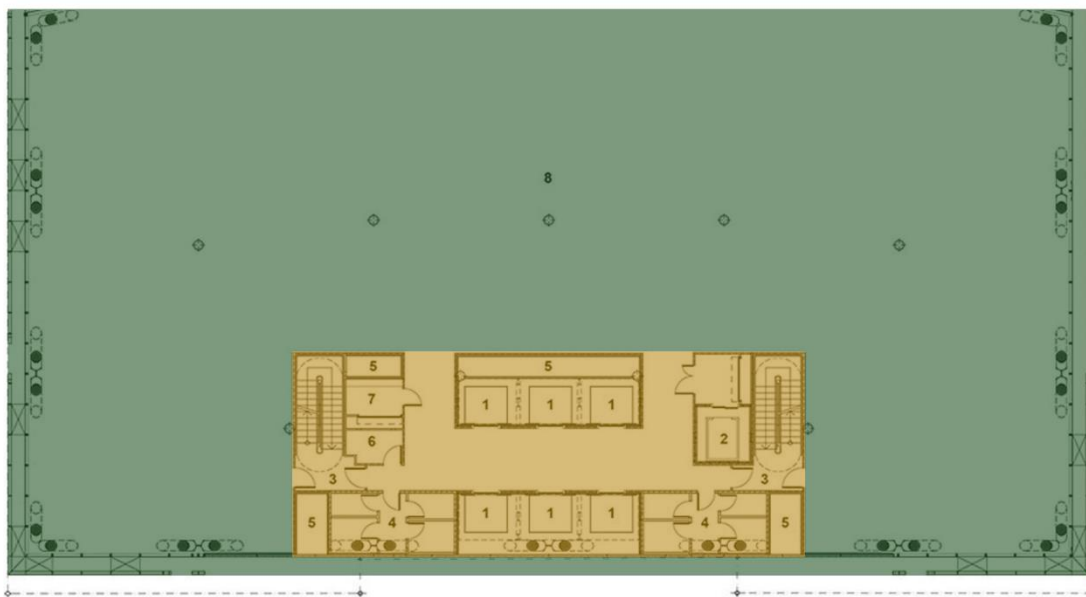
3. General design strategies for high-rise buildings

the **XXCQ office building** in Wellington, completed in 2019, which demonstrates a robust and efficient structural system with an eccentric core. Designed by Studio Pacific Architecture in collaboration with Dunning Thornton Consultants, this building successfully mitigates seismic risks while maintaining expansive open-plan workspaces. Similarly, the **122 Leadenhall Building** in London—commonly known



as *The Cheesegrater*—features a fully offset core, allowing for highly flexible, column-free floor plates. However, this design strategy may also result in unequal access to natural light, as occupants situated near the core may be located significantly farther from perimeter windows.

XXCQ is also a very efficient and sustainable building. The architects carefully planned the building's core to make sure it works as hard as it can, to free up extra floor plate. It has also received a 5 Green Star 'excellence' rating from the New Zealand Green Building Council, which



General design floor plan of the XXCQ Office Building (Yellow: CORE - Green: Floor Area)

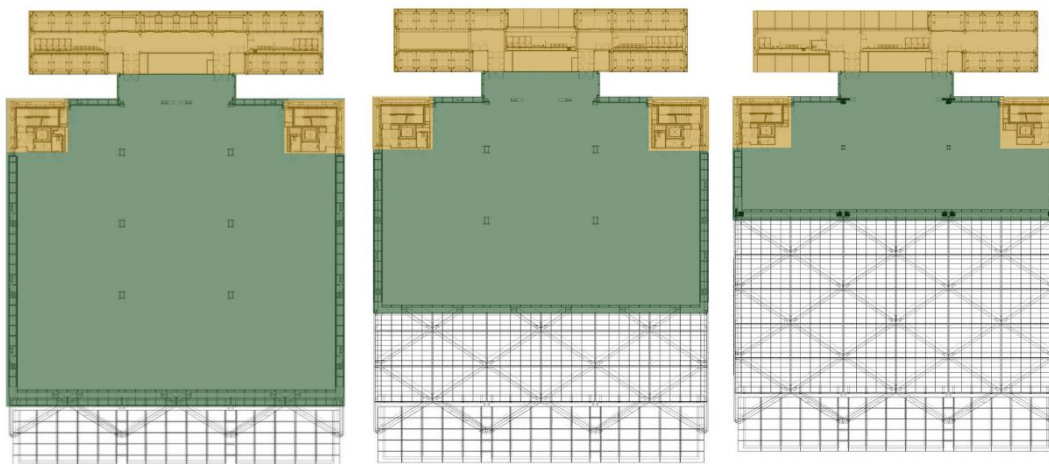
3. General design strategies for high-rise buildings



View on the Leadenhall Building, Rogers Strick Harbour + Partners, London, 2014

looked at both the life cycle of the building and the sustainability of the materials used. The main particularity is that in XXCQ's basement, the base isolators hold the weight of the building and allow the foundations to move sideways.

Instead of using a central core, the Leadenhall Building's stability structure is integrated into an external mega-frame. This in itself is not unique, but the positioning of the main service core outside of the structural frame is very much a departure from the standard arrangement.



Design of the 6th, 22nd and 40th floor plan of the Leadenhall Building (Yellow: CORE - Green: Floor Area)

3.2.3 Split Core System

In contemporary high-rise architecture, an alternative to the centralized core or eccentric core approach is the **split core configuration**, where a building incorporates two or more distinct cores. This design strategy typically features a primary core, housing key vertical circulation elements such as elevators and at least one egress staircase, while a secondary, smaller core is positioned elsewhere in the building, often containing an additional staircase and other service functions. This spatial distribution of services and circulation routes can enhance both functionality and flexibility in large-scale developments.

A significant advantage of the split core configuration lies in its ability to optimize floor usability and tenant adaptability. By distributing mechanical, electrical and plumbing (MEP) systems between multiple cores, architects can create more efficient layouts while improving spatial efficiency. While certain elements—such as elevators—are best centralized for ease of access, other building services, including electrical wiring and air-handling systems, may be strategically divided between multiple cores to enhance redundancy and operational efficiency.

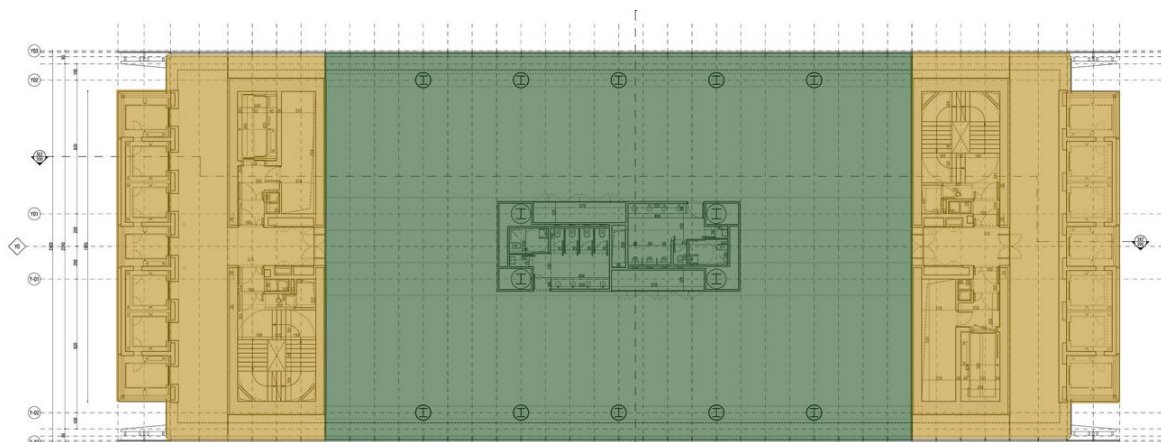
An example of this strategy can be observed in the **SOHO Tower** and the **Allianz Tower**, both of which employ a split core configuration to maximize spatial efficiency and structural performance. The **SOHO Tower**, designed with a distributed core system, integrates multiple vertical circulation elements to create open and adaptable floor plates, allowing for flexible tenant layouts and improved access to natural light. Similarly, the **Allianz Tower** in Milan utilizes two longitudinally positioned cores, which enhance structural stability while preserving expansive, uninterrupted office spaces. This arrangement not only optimizes interior functionality but also improves safety by providing multiple, well-distributed egress routes, ensuring efficient evacuation in case of emergencies. In conclusion, the split core strategy offers a versatile design solution, particularly for large-scale office and mixed-use buildings. While it presents organizational and engineering challenges, when effectively implemented, it can enhance spatial efficiency, improve tenant flexibility and facilitate the distribution of essential building services.

3. General design strategies for high-rise buildings



View on the Allianz Tower, Arata Isozaki, 2015

The Allianz Tower features a **split core structure**, with **two separate cores** positioned along the building's longitudinal sides. This design maximizes **interior space flexibility**, allowing for large open floor plates free from central structural obstructions. Additionally, the distributed cores enhance the **building's stability**, improving resistance to vertical and lateral loads. The dual-core configuration also optimizes **safety**, providing multiple evacuation routes on different sides, thus increasing the efficiency of emergency egress systems.



General design floor plan of the The Allianz Tower (Yellow: CORE - Green: Floor Area)

3. General design strategies for high-rise buildings



View on the SOHO Tower, Zaha Hadid Architects, 2015 - 2019

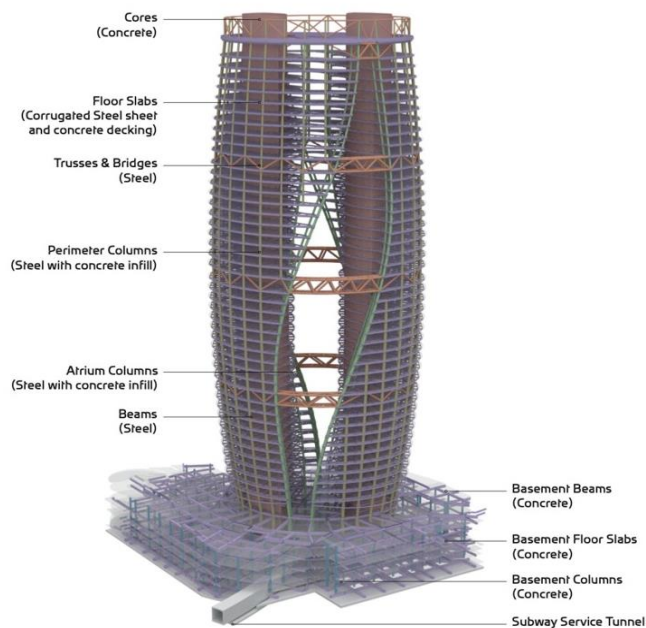


OPEN PLAN



MULTIPLE-UNIT PLAN

General design floor plan of the The Allianz Tower (Yellow: CORE - Green: Floor Area)



Axonometric Structural view of the SOHO Tower

*This configuration enhances **floor plate flexibility**, allowing for open and adaptable interior layouts while optimizing natural light distribution. By separating the primary and secondary cores, the design improves **structural stability and emergency egress efficiency**, ensuring safe and efficient evacuation routes.*

3.3 Architectural Composition of Towers

The architectural composition of tall buildings has undergone significant evolution, driven by advancements in engineering, material applications and environmental considerations. The form and spatial organization of a high-rise are not solely dictated by aesthetic preferences but are instead a complex synthesis of structural efficiency, functionality and contextual responsiveness. With the rapid urbanization of global cities, architects and engineers are continually refining design methodologies to balance innovative architectural expression with the demands of **structural stability, sustainability and occupant comfort**.

A crucial aspect of high-rise composition is its **formal articulation**, which is intrinsically linked to structural integrity and environmental performance. Historically, early skyscrapers adopted a rigid, rectilinear form due to limitations in construction techniques and material capabilities. However, contemporary towers incorporate **aerodynamic modifications, parametric design principles and adaptive structural strategies** to optimize their interaction with natural forces, particularly wind and seismic loads. The architectural composition of towers, therefore, is not only a visual statement but a response to **engineering imperatives and environmental forces**.

In the structural design and analysis of tall buildings, regarding the significance of wind and seismic, Alaghmandan and Elnimeiri (2013) indicate that: *“the larger base shear, resulting from wind forces has to be considered rather than seismic forces. Hence, the main lateral force resisting system is sized for wind; although ductile detailing is used to account for seismic demands.”*³²

The primary design challenges of tall buildings arise from two key factors: the **complexity of wind forces** and the **inherent slenderness of the structure**. To address these issues, three primary architectural and structural strategies are employed to minimize the impact of wind and mitigate the dynamic and aerodynamic response of these buildings:

- The use of aerodynamic forms and modifications;

³² **Alaghmandan** and **Elnimeiri** are structural engineers or researchers in the field of **structural design**, particularly in relation to **lateral force-resisting systems**, which are critical for ensuring a building can withstand both wind and seismic forces.

- The enhancement of structural stiffness through the implementation of lateral-load-resisting systems;
- The incorporation of damping mechanisms.

High-rise buildings have consistently depended on technological advancements in engineering and scientific research. Breakthroughs in structural systems, design methodologies, construction techniques, vertical transportation, natural lighting, ventilation, and the development of novel materials—combined with the latest digital innovations—have progressively transformed the architectural situation of tall buildings worldwide. In response to significant demographic shifts and urbanization, vertical cities dominated by skyscrapers are increasingly regarded as a pragmatic solution for contemporary urban centers. The majority of high-rise structures are conceived and constructed utilizing cutting-edge technologies, including advanced lateral load-bearing systems, vertical mobility solutions, energy dissipation mechanisms, and state-of-the-art materials. Furthermore, these buildings incorporate sustainability-oriented innovations, such as renewable energy systems, high-performance façades and nanotechnology-enhanced smart materials.

Historically, high-rise buildings were predominantly conceived in rigid, box-like configurations, dictated by repetitive floor layouts and stringent structural frameworks, such as rigid frames and core-interaction systems. However, contemporary skyscraper design has moved away from monolithic vertical extrusions dictated solely by efficiency-driven floor plans. Enabled by advancements in structural engineering and digital fabrication, complex geometries—including twisting, tilting, leaning, bundling, and regionally inspired cultural forms—are now feasible. Iconic structures such as the Petronas Twin Towers, Jin Mao Tower, Taipei 101, Bahrain World Trade Center and Shanghai World Financial Center exemplify this architectural evolution. A key design consideration in these unconventional forms is the mitigation of wind-induced forces at high altitudes, ensuring both structural efficiency and occupant comfort by minimizing wind-induced oscillations.

The integration of aerodynamic design principles—further explored in subsequent sections—plays a crucial role in reducing material consumption and enhancing sustainability. This approach has been effectively demonstrated in buildings such as the Swiss Re Tower in London, Shanghai Tower and Burj Khalifa in Dubai.

3. General design strategies for high-rise buildings

Aerodynamic geometries respond dynamically to wind loads, mitigating their impact and optimizing structural behavior. Additionally, these forms disrupt vortex shedding patterns, altering airflow around the building and diminishing harmonic wind effects. By strategically dispersing wind forces, irregular aerodynamic forms prevent the concentration of wind pressures, thus improving stability and reducing oscillatory movement. As a result, aerodynamic designs have become instrumental in both structural performance and aesthetic articulation. For instance, the **Pearl River Tower** in Guangzhou employs a funnel-shaped façade that not only mitigates wind loads but also harnesses wind energy through integrated turbines. [Fig. 26]

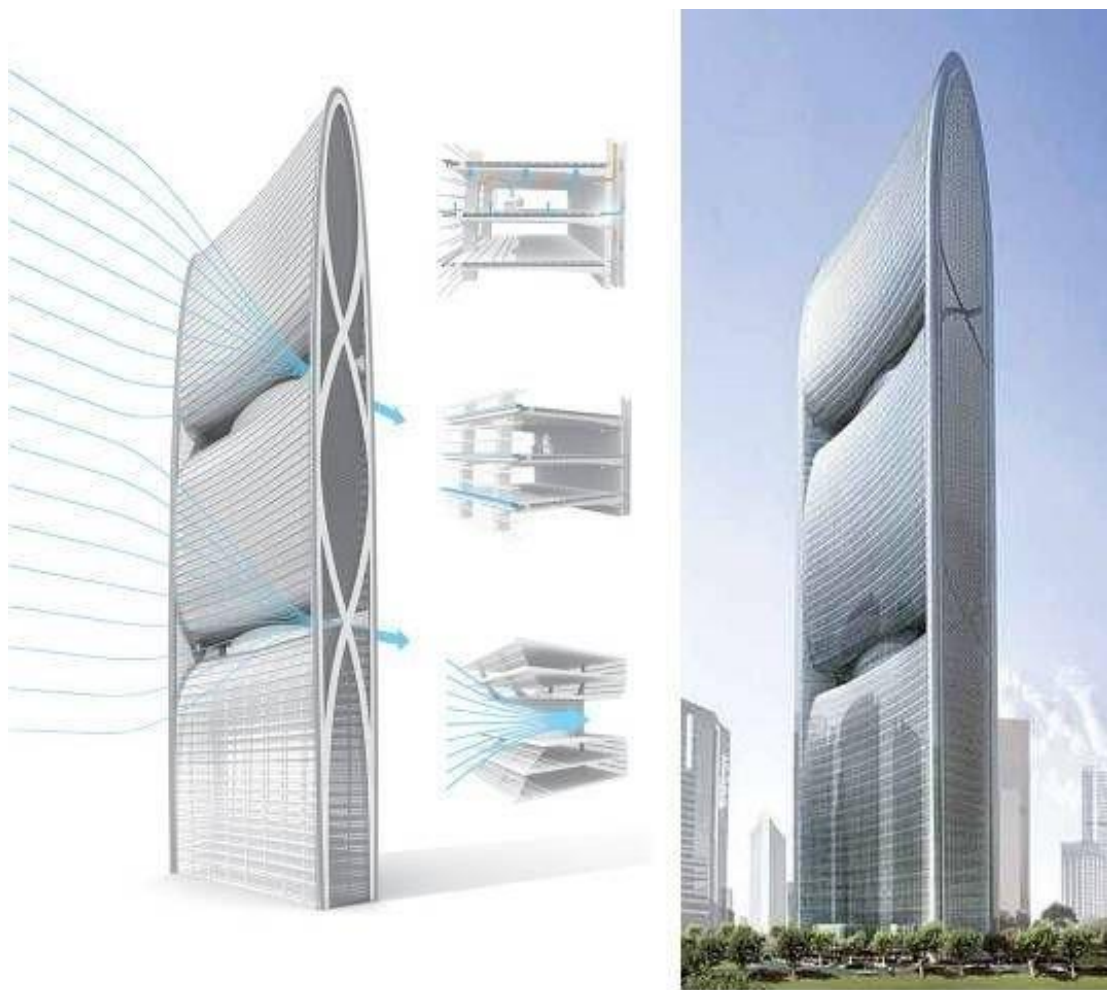


Figure 26 - View on Pearl River Tower's wind turbine system

Such strategies seamlessly integrate functionality with architectural expression. Another method for optimizing wind performance involves introducing porosity within the building envelope, as exemplified by **Aspire Tower** in Doha and the **O-14 Building** in Dubai.

Among the most effective passive architectural strategies for mitigating the dynamic response of skyscrapers is the implementation of aerodynamic (geometric) modifications, such as tapering, setbacks, and strategically placed openings along the building's height. However, recent studies in wind and structural engineering suggest that while these modifications often enhance performance, their effectiveness varies depending on specific conditions. Consequently, there is no universal consensus regarding their benefits across all scenarios. Aerodynamic modifications can be categorized into two primary scales based on their influence on a building's form and geometry: [Fig.33]

- **Macro Modifications:** These alterations significantly impact the overall architectural concept, influencing the primary shape and configuration of tall buildings. Examples include tapering, twisting, and setbacks, which are designed to optimize aerodynamic performance.
- **Micro Modifications:** This category encompasses localized changes, such as rounded or recessed corners, that do not alter the fundamental architectural concept but nonetheless contribute meaningfully to reducing wind effects.

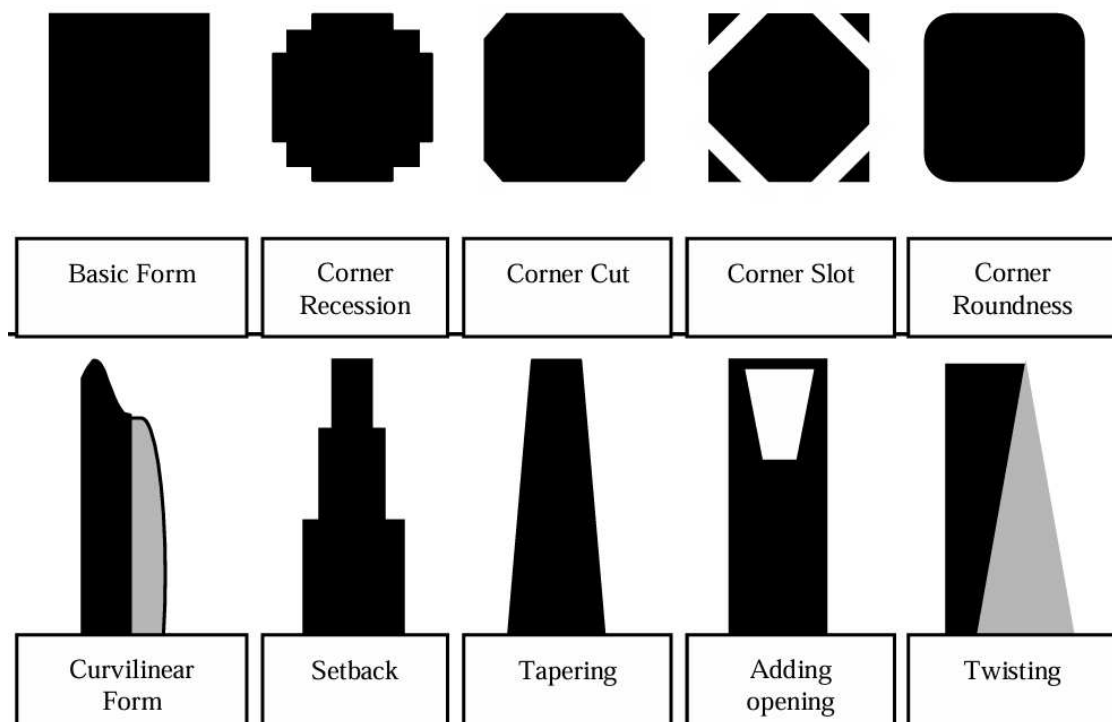


Figure 27 - Design modifications (Source: INNOVATIVE DESIGN METHOD OF TALL BUILDINGS A computational-based approach in optimizing the wind effects on tall buildings, *Matin Alghmandan, Jamshid Mohammadi, Farid Abdolhossein Pour* - 2013)

3. General design strategies for high-rise buildings

Despite their localized nature, micro modifications play a crucial role in optimizing aerodynamic performance and structural resilience.

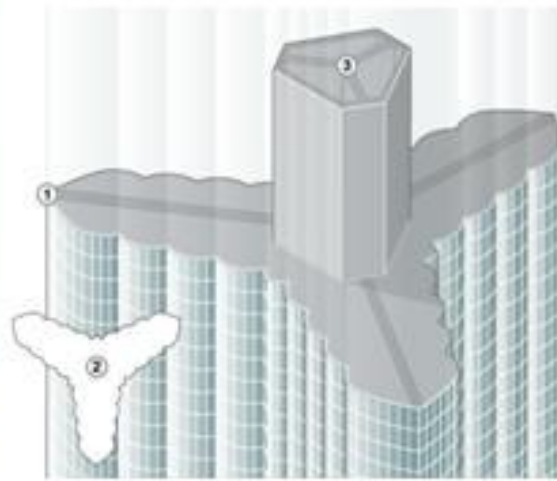
The structural system plays a crucial role in defining the overall form and efficiency of a tall building. As previously mentioned, over the past two decades, the typology of tall buildings has shifted from North America to Asia, where the most significant trend involves designing iconic and innovative forms. These new configurations are made possible by technological advancements and innovative structural systems, including mega frames, diagrid systems, core and outrigger structures, and the buttressed core. As buildings increase in height, the risk of collapse due to wind, seismic, and gravitational loads also rises. A fundamental parameter for evaluating the structural efficiency of a skyscraper is its **slenderness ratio**: while the dynamic influence of wind becomes relevant for slenderness ratios above 4, it becomes particularly critical at higher values.

Aerodynamic modifications, in conjunction with structural optimization, are effective design strategies for reducing wind-induced vibrations in slender buildings. The principle underlying these strategies is to "confuse" the wind by disrupting its boundary layer flow and preventing its reorganization through the creation of moderate turbulence around the structure. These modifications include adopting specific cross-sectional shapes, varying the cross-section along the building's height, incorporating chamfered or slotted corners, fins, setbacks, openings, and sculpted tops. Additionally, the implementation of advanced damping systems can significantly enhance structural efficiency.

A recent innovation in the structural systems of ultra-tall buildings is the "*buttressed core system*," introduced by Bill Baker and implemented in the Burj Khalifa [Fig.28], currently the tallest building in the world. As a residential tower, the structure required floor plates with shallow lease spans to maximize exterior window areas, while its considerable height necessitated a wide base to ensure stability and resistance to high wind loads. The Y-shaped floor configuration, with reinforced concrete walls surrounding a central hexagonal reinforced concrete core, meets both requirements, making the buttressed core an extremely efficient solution for super-tall residential towers. The structural concrete core, functioning as a solid tube, is gaining increasing significance in the design of ultra-tall buildings for resisting lateral loads. This solution



Burj Khalifa



“Buttressed Core”
Structural System

Figure 28 - Buttressed core system, Burj Khalifa

was also adopted in the unbuilt 610-meter-tall Chicago Spire Tower project, designed by Santiago Calatrava and engineered by SOM. Moreover, the central concrete core serves as a reliable evacuation route during emergencies, such as fires or terrorist attacks.

Today, a wide variety of lateral load-resisting systems are being employed, given the importance of limiting excessive displacement caused by earthquakes or wind loads in skyscraper design. Another innovative approach to increasing the structural efficiency of ultra-tall buildings is the use of *twin-tower* or *bundled-type* structures connected by skybridges, which help control the displacement of each individual unit. Notable examples of this strategy include the **Petronas Twin Towers** in Kuala Lumpur (88 stories, 452 m), the proposed **Incheon Tower** in South Korea (102 stories, 487 m), and the **East Pacific Center** in Shenzhen (70 stories, 300 m). In this context, the outrigger system is effective in controlling lateral displacement on central floors, while the skybridge provides stability on upper floors.

3. General design strategies for high-rise buildings

What are the steps to design a tall building?

The proposed design methodology for tall buildings begins with considering the aerodynamic modifications in shaping the form of skyscrapers to mitigate wind effects as an architectural strategy. The second step involves optimizing structural systems to reduce wind-induced responses through static, dynamic and aerodynamic strategies. However, both architectural and structural approaches are interdependent in reducing wind effects and controlling building responses. A fundamental and unique aspect of this design approach is the simultaneous and integral consideration of these two critical factors rather than treating them separately.

The primary objective of this design methodology is to analyze the relationship between the geometry and form of tall buildings and their structural systems to mitigate wind effects and control building responses. A crucial aspect is determining which structural systems are most compatible with specific aerodynamic modifications and forms. If all levels of this design methodology are considered from the initial stages of the design process, gaps can be effectively closed and pertinent design issues adequately addressed.

As urban populations continue to grow, cities worldwide are expanding at an unprecedented rate. In this context, vertical expansion becomes a necessity, as horizontal urban sprawl poses significant risks and is unsustainable for green spaces. Furthermore, horizontal expansion is constrained by infrastructure limitations and municipal services. In the future, agriculture and green spaces may also shift toward vertical configurations. Consequently, future cities will no longer be flat but will evolve into three-dimensional urban landscapes characterized by both horizontal and vertical architectural elements, necessitating the construction of massive skyscrapers—essentially, vertical cities that were once conceptualized as visionary projects.

Many of these visionary tall building projects were proposed in the late twentieth century, particularly for East Asian cities such as Tokyo, Shanghai and Hong Kong, where limited land availability and high population densities pose significant urban challenges. For instance, Tokyo, with a population of approximately 35 million, faces severe land scarcity. In this scenario, vertical cities emerge as the only viable solution to manage rapid population growth and urbanization challenges. Japanese architects, at the peak of their creative efforts, have conceptualized numerous visionary projects for

the city. Similar visionary skyscraper projects have also been proposed for East Asian and North American cities.

Notable examples of these visionary projects include the **Holonic Tower**, **Sky City 1000**, **Bionic Tower**, **Millennium Tower**, **Sky Mile Tower** ^[Fig.29], **Ultima Tower**, and **X-Seed 4000**—all envisioned for Tokyo—as well as **NOAH** for New Orleans and **BoA** for Boston. A common characteristic among these projects is their conceptualization as vertical cities housed within a single skyscraper, accommodating thousands of residents and providing a comprehensive urban environment within a single structure. The realization of such projects is heavily dependent on future advancements in structural systems, materials, construction techniques and the integration of sustainable solutions, including renewable energy systems.



Figure 29 - Sky Mile Tower, a project envisioned for Tokyo City

3.4 Elevated Realms: Skygardens, Skycourts and Atriums

Skycourts can be spatially conceptualized as interstitial environments that mediate the relationship between the figurative void, known as the semi-public space, and the solid mass of the private high-rise structure. Analogous to the allocation of open space within horizontal mixed-use developments, skycourts establish a vertical equilibrium between built-up areas and open space within tall buildings. By doing so, they not only facilitate social interaction through communal spaces but also enhance

3. General design strategies for high-rise buildings

environmental performance by enabling deeper penetration of natural daylight and ventilation, improving interior habitability.

A notable example of this integration is the **Newton Suites** in Singapore (2007), where a series of sky terraces are strategically positioned at five-floor intervals across its thirty-six stories. These terraces provide residents with shared spaces, fostering the emergence of sub-communities within a vertical neighborhood. Moreover, the inclusion of designated green spaces and vertical vegetation serves as an environmental buffer, mitigating solar heat gain from the low-angled east and west facing sun. This spatial typology reflects a vertical reinterpretation of the tropical verandah, reinforcing skycourts as critical components within the urban framework that support social interaction and climate responsiveness. [Fig.30]

Beyond external spaces, socio-environmental considerations extend into the interior domain, as exemplified by Norman Foster's **Commerzbank Tower** in Frankfurt (1997). Recognized as Europe's first ecological high-rise, the tower's design features three triangular office wings arranged around a full-height central atrium. Within this configuration, enclosed skycourts are stacked in a rotational sequence every four floors, creating dynamic internal green spaces that offer occupants visual connectivity to both the urban landscape below and the sky above. These skycourts function as social hubs within the workplace, accommodating informal meetings, events and recreational activities, while also fostering a more engaging and biophilic office environment. [Fig.31]

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Furthermore, skycourts contribute to the convenience and functionality of tall buildings by providing spaces for leisure, commerce and wellness, thereby reducing the necessity for occupants to descend to ground level for everyday activities. As mixed-use high-rises become increasingly prevalent, skycourts act as critical nodes for social interaction, facilitating new relationships between different building users. Just as open spaces within horizontally planned developments serve as communal and recreational zones, skycourts perform a similar role in the vertical space, effectively binding functions and social groups to establish cohesive vertical communities.

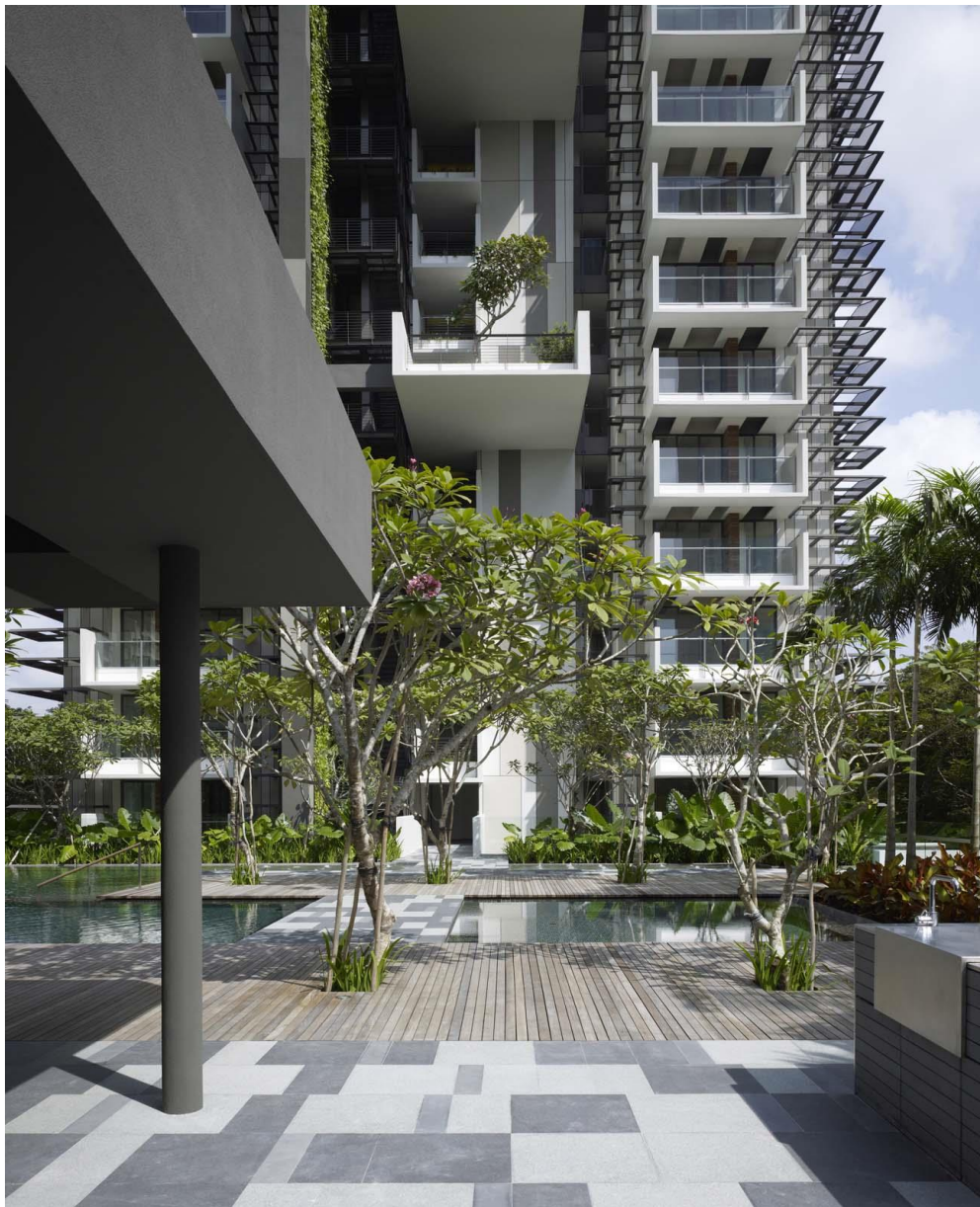


Figure 30 – The Newton Suits' Sky Terraces, WOHA, 2007

3. General design strategies for high-rise buildings

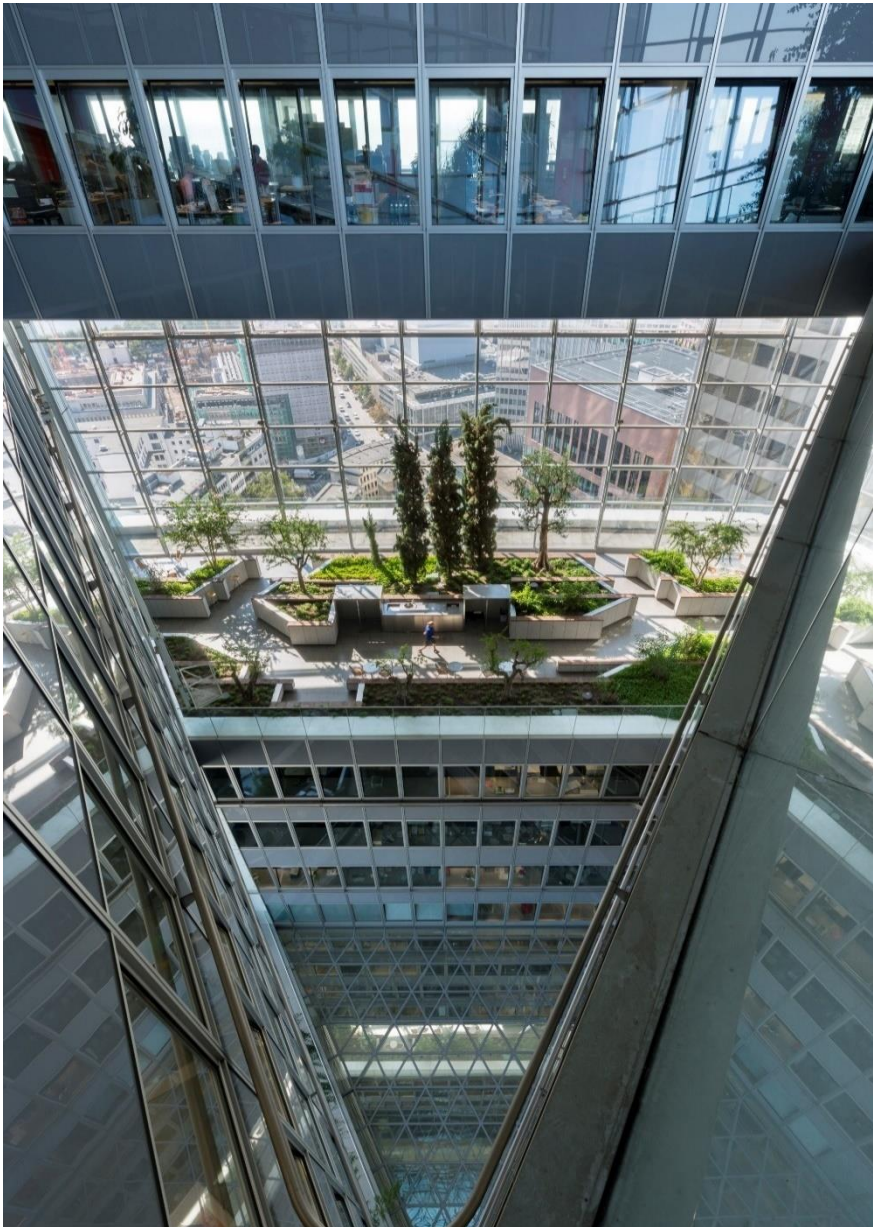


Figure 31 - Skygardens view of the Commerzbank, Norman Foster + Partners

A compelling example is **The Shard** in London, where a three-story skycourt at mid-level serves as a communal hub, effectively bridging the transition between work and living spaces. Beyond offering panoramic views of the city, this space accommodates retail, dining, leisure, cultural and social functions, reinforcing architect Renzo Piano's vision of the tower as a "*small vertical town*" designed for both its occupants and the broader public.

In addition to their social and recreational roles, skycourts serve as critical transitional nodes within high-rise circulation networks: by linking various vertical

circulation systems—including ramps, staircases, escalators and lifts—these spaces facilitate seamless movement throughout the building. Transfer lobbies, often integrated within skycourts, further enhance accessibility and pedestrian flow, fostering social interaction through increased foot traffic and chance encounters. When strategically connected to broader movement frameworks—such as skybridges, podium decks, and skyways—skycourts contribute to urban permeability, mitigating the isolation often associated with vertical developments. This integration not only strengthens the relationship between high-rises and the urban fabric but also enhances security by maintaining visual connectivity, creating "*new eyes on the street in the sky*" that aid in surveillance and wayfinding. Moreover, the incorporation of skybridges between towers provides an alternative means of exits, reducing reliance on traditional phased evacuation strategies, which can be logistically and economically challenging.

A particularly innovative application of this concept is evident in **The Pinnacle**, Singapore (2009), where twelve sky gardens interconnect seven fifty-story high-density residential blocks housing 1,848 family units. These elevated gardens reinterpret the traditional void decks of earlier social housing projects, offering residents shared green spaces that foster social interaction. While intermediate gardens at the 26th floor serve as private communal spaces for residents, the rooftop garden at the 50th floor is accessible to both residents and the public, reinforcing the notion of skycourts as permeable social infrastructures. This spatial configuration echoes the function of traditional arcades, positioning skycourts not only as destinations for

3. General design strategies for high-rise buildings

planned gatherings and recreation but also as transitional spaces that encourage movement and serendipitous encounters within the vertical cityscape.^[Fig. 32]

The integration of sky gardens at the summits of tall buildings presents both social and economic opportunities, offering panoramic cityscape views while generating revenue. A notable example is **Marina Bay Sands** in Singapore, an



Figure 32 - The Pinnacle with its sky gardens

integrated resort catering to meetings, incentive travel, conventions, and exhibitions, accommodating up to 52,000 attendees. Its renowned sky park has become an income-generating asset, charging an entrance fee for access to its observation deck, where visitors can experience great views of Singapore's skyline. Additionally, its rooftop bars, restaurants, and gardens provide an alternative social setting for both residents and tourists, while exclusive amenities such as the rooftop pool and performance areas further enhance its role as a recreational and cultural hub.

Sky courts and sky gardens function as dynamic social spaces that attract diverse user groups, serving both as spectators of the evolving city skyline and as active participants in localized social interactions. These spaces are inherently adaptable, their functions shifting in response to temporal and societal needs. A sky garden may serve as a calm setting for sunrise observation in the early hours, only to transform into a

vibrant recreational or meeting space later in the day. Similarly, sky courts may act as informal study areas for students, networking hubs for office workers during lunch breaks, communal gathering spots for residents in the evenings, or vantage points for tourists admiring the city at sunset.

The utilization and social dynamics of these elevated spaces are inherently linked to the primary function of the tall buildings in which they are situated. Whether integrated within a library, office, residential complex or hotel, sky courts and sky gardens adapt to the behavioral patterns of their occupants. Their evolving use underscores their significance not only as architectural elements that enhance the urban experience but also as critical socio-spatial infrastructures that foster vertical communities within the high-rise environment.

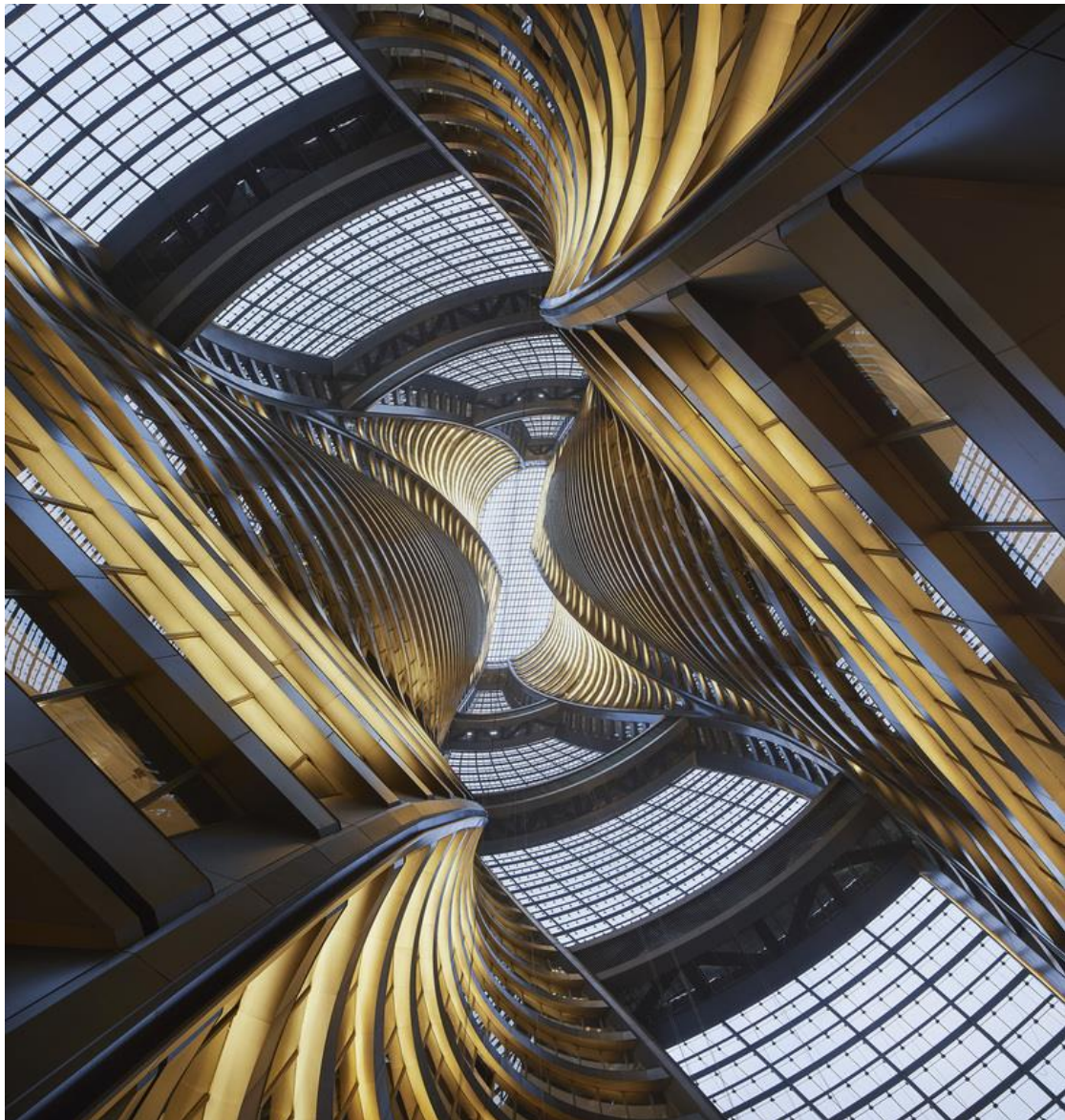
Another essential element for contemporary and sustainable tall buildings is the **atrium**: historically used as grand entrances, courtyards, and semi-public sheltered spaces, have been integral to architecture for nearly two millennia (Saxon, 1983)³³. The advancements in materials like iron and glass technology during the Industrial Revolution enabled the enclosure of large courtyards, significantly improving indoor climatic conditions. This innovation transformed the atrium into a social hub, leading to its widespread adoption in taller public buildings by the late nineteenth century.

In the early skyscrapers of New York and Chicago, atria played a crucial role in introducing natural light and ventilation while helping to dissipate fumes from oil- and gas-fired lamps. However, despite their functional benefits, their development slowed in the early twentieth century and nearly ceased with the onset of the First World War. As buildings grew taller with smaller footprints and increasingly expansive floor areas, the trend shifted towards fully glazed Modernist towers, which relied heavily on artificial lighting and mechanical climate control, rendering atria largely obsolete.

³³ **Richard Saxon**, an architect and author known for his work on architectural design, building technology, and sustainable development. He has written extensively on topics related to atria, office buildings, and urban architecture. His 1983 work may discuss the historical evolution of atria and their role in architecture over time.

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Although a few architects continued to experiment with atria, their widespread use was only revived in the early 1970s, when *John Portman* reintroduced them as striking design elements in his **Hyatt Regency Hotels** across the United States. Since the late twentieth century, atria have regained prominence, primarily for their role in improving energy efficiency and indoor climate regulation. Today, they are a fundamental feature in contemporary tall buildings, contributing not only to environmental sustainability but also to social, cultural, and economic considerations, reinforcing their significance in modern architectural design.



View inside the Atrium of the SOHO Tower; Zaha Hadid Architects, 2015 – 2019

But what's the true function of the Atrium?

Atria function as powerful architectural elements that enhance orientation and connectivity both within and between buildings. They serve as transitional spaces, linking high-rise structures to their immediate urban surroundings and integrating them into the broader cityscape. A notable example is **Jean-Paul Vigier's *Cœur Défense*** (2001) in Paris, Europe's largest office complex, which spans a hectare of floor space. Its soaring 44-story atrium unites two 180-meter twin towers with three eight-story buildings, creating both a physical and symbolic center. Situated atop a three-level podium, the atrium connects the *Charles de Gaulle Esplanade*³⁴ with office spaces, restaurants, a conference center, and various exits, demonstrating how atria can seamlessly blend public and private realms.

As vertical arcades, atria often incorporate shops, cafés, restaurants, exhibition areas and performance spaces, fostering social engagement, enhancing natural surveillance, and reinforcing commercial viability. From an ecological perspective, the ***EDITT Tower*** (*acronymus of Ecological Design In The Tropics Tower*), a conceptual project made by TR Hamzah & Yeang in Singapore, addresses the common disconnect between street-level activity and the enclosed, compartmentalized nature of traditional high-rises. The rapid increase in urban density and high-rise living throughout the 20th century led to a decline in the quality of public spaces.

In contemporary skyscrapers, atria of varied sizes, configurations and orientations—including vertically stacked arrangements—are strategically integrated alongside sky courts and sky gardens to expand public facility spaces at height. *Commerzbank* (1997) in Frankfurt, designed by Norman Foster, exemplifies this approach, incorporating a central atrium around which four-story sky gardens spiral, flanked by deep office spaces. Such atria play a crucial role in linking sky courts and upper-level spaces, facilitating movement, reinforcing spatial legibility, and weaving together a complex vertical urban fabric.

Beyond new construction, atria also serve as effective tools for adaptive reuse and the sensitive integration of historic structures. In Toronto, WZMH

³⁴ The **Charles de Gaulle Esplanade** is a large public space located in **La Défense**, the business district of Paris, France. It serves as a major pedestrian thoroughfare connecting various office towers, commercial buildings, and public transport hubs within the district.

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Partnership's *Bank of Nova Scotia Headquarters* (1988) features a 14-story glazed atrium that connects the 68-story office tower with the original limestone bank building. This architectural intervention not only forms a grand entrance but also extends below ground, linking the development to Toronto's 28-kilometer PATH³⁵ network

Functioning as both a literal and symbolic bridge between past and present, the atrium reinforces the connection between the building and its broader urban context. Given their substantial volumes and extensive interior surfaces, atria also offer opportunities for artistic display: in the *Bank of Nova Scotia* atrium, a decorative marble bas-relief adorns the north wall of the historic banking hall, while the south wall features Canada's largest commissioned abstract mural.

The versatility of atria extends across various building typologies, each benefiting from their integration in distinct ways. In deep-plan structures, atria introduce natural light and external views, enhancing psychological well-being, occupant satisfaction, and productivity in office environments. In educational settings, they contribute to improved student performance and behavior, while in healthcare facilities, they create uplifting environments that aid patient recovery and enhance the experience of staff and visitors.

From an economic point of view, atrium-based buildings are often competitive in the real estate market, attracting premium tenants and generating higher revenue (Bednar, 1986). The combination of shallow-plan perimeter spaces and centrally positioned atria facilitates natural ventilation and daylight penetration, reducing operational costs typically associated with deep-plan buildings. As the demand for high-quality, sustainable design grows, developers and regulatory bodies are increasingly embracing the idea that spatially efficient layouts can be balanced with energy-efficient, environmentally responsible solutions.

An example of this approach is The **Unipol Tower** in Milan,^[Fig.33] designed by *Mario Cucinella Architects*, integrates a central atrium as a fundamental architectural and environmental feature. The atrium, extending vertically through the structure, enhances natural ventilation and daylight penetration, reducing the building's

³⁵ The **PATH** is a mostly underground pedestrian walkway network in downtown Toronto that spans more than 30 kilometres of restaurants, shopping, services and entertainment.

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energy consumption while improving indoor environmental quality. Functionally, it acts as a social and connective hub, fostering interaction between different floors and spaces within the tower. This void also plays a symbolic role, emphasizing transparency and openness, key concepts in the tower's sustainable and biophilic design. By incorporating green elements and optimizing passive climate control strategies, the



Figure 33 - Unipol Tower, Mario Cuccinella Architects, 2017

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Figura 34 - View on the Atrium of the Unipol Tower

atrium contributes to the overall energy efficiency and ecological performance of the Unipol Tower, making it a benchmark in sustainable high-rise architecture.^[Fig.34]

It's important to mention that the atria works as good as a sheltered or buffer space, putted in between the interiori space and the exterior urban environment: this brings many advantages as bringing inside the building a great amount of daylight, protecting from the wind, rain and extreme temperatures. This essential element has been largely developed in coller climate areas at higher altitude, where there's no

“greenhouse effect” during summer times and it protects from the cold temperatures and the harsh weather during winter times, maintaining the relationship with the exterior.

3.4.1 Ventilation, fire control and daylighting

An atrium plays an important role in enhancing natural ventilation in tall buildings, primarily through cross-ventilation and the stack effect³⁶. Its effectiveness is further amplified when integrated with sky courts and sky gardens, as previously said, promoting passive cooling and airflow. However, the unregulated movement of air within the atrium can pose **fire safety** risks, particularly due to temperature stratification and the potential spread of smoke. To mitigate these risks, atria can be divided into **compartmentalized sections**, as seen in the Commerzbank Tower, where horizontal glazed screens at 12-story intervals control airflow and improve fire safety.

A prime example of an environmentally responsive atrium is the **Manitoba Hydro Place** [Fig.35] in Winnipeg, designed to achieve a 60% reduction in energy consumption despite the region’s extreme climatic conditions. The building’s atria optimize passive solar gain and prevailing winds, acting as thermal buffers that pre-condition incoming air through adjustable vents in the raised flooring. In winter, heat recovery from exhaust air and passive solar radiation helps warm the interior, while in summer, the building operates entirely on natural ventilation through manually and automatically controlled windows. A solar chimney on the north side enhances passive ventilation by leveraging the stack effect—glass louvers at the top extract warm air during hot months, while in winter, recovered heat is redirected to warm parking areas and preheat incoming air. This demonstrates how atria, beyond their social and spatial roles, can be integrated into a building’s broader environmental strategy, improving energy efficiency, air quality and user comfort.

From a fire safety perspective, atria require carefully designed smoke control measures to ensure safe evacuation and firefighter access. Factors such as building function, occupant profile, spatial configuration, and degree of openness influence the choice of fire mitigation strategies. The size and height of the atrium significantly affect both natural ventilation efficiency and smoke behavior, with elements such as air inlets,

³⁶ The **stack effect** or **chimney effect** is the movement of air into and out of buildings through unsealed openings, chimneys, flue-gas stacks, or other purposefully designed openings or containers, resulting from air buoyancy. (Source: https://en.wikipedia.org/wiki/Stack_effect)

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outlet sizing, and adjacent room pressure differentials playing key roles in smoke control. Additionally, the building's context and proximity to neighboring structures must be considered to prevent fire spread beyond the site. Effective fire protection strategies include dedicated evacuation routes, fire-resistant materials to limit flame propagation and automatic sprinkler systems to suppress fire and control temperature. In this way, an atrium must be properly designed, balancing aesthetic, environmental, and safety considerations to create a high-performing, resilient space within a tall building.



Figure 35 - View on Manitoba Hydro Place, KPMB Architects, 2009

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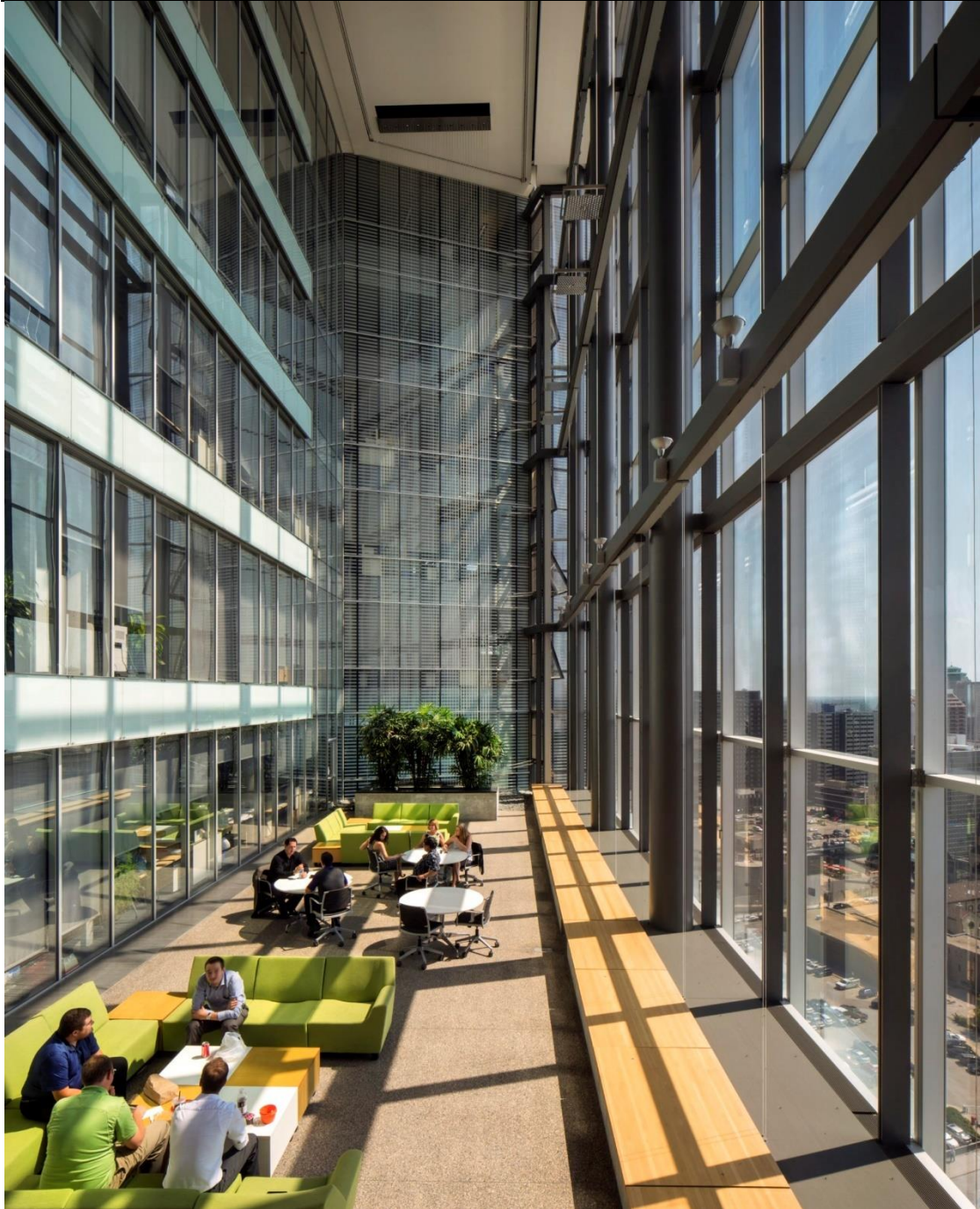


Figure 36 - The Manitoba Hydro Place's Atrium

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Manitoba Hydro Place Ventilation and Passive energy system, particularly cold and hot air flow

Daylighting is one of the primary advantages of atrium design, significantly enhancing a building's aesthetic appeal, occupant experience and environmental performance. Achieving optimal daylight distribution within an atrium building is complex, as it depends on various factors, including prevailing sky conditions, roof and fenestration systems, atrium orientation and geometry, surface reflectance and the characteristics of adjacent spaces.

According to *Goncalves (2007)*³⁷, improved daylighting in office buildings is among the most desirable features in contemporary sustainable skyscrapers. In Europe, the approach has been to design detailed facades that respond to local climate conditions and functional needs. Highly glazed facades, particularly double- and triple-skin systems with integrated sun-shading devices, balance daylight penetration with solar control, providing additional benefits such as thermal efficiency, sound insulation and improved air and water infiltration control.

Certain atrium geometries and roof designs can maximize daylight penetration into the lower levels of high-rise buildings. Strategies include two- and three-sided atria, sky courts, high-reflectance surfaces, and variable facade openings—smaller at the top and progressively larger toward the bottom. Additionally, higher floor-to-floor heights and shallower floor plates contribute to a brighter indoor environment. Transparent elements, such as glass balustrades and light-colored opaque walls, further enhance daylight distribution by maintaining visual openness and reflectivity within the central atrium.

An example of effective atrium integration is London's **Heron Tower** ^[Fig.37], where the 36-story structure is divided into three-story modules, each linked by a north-facing glazed atrium serving as a focal amenity space. The concrete core on the southern facade provides structural stability and solar protection, while the east and west facades incorporate triple glazing with anti-glare and heat-resistant blinds. Additionally, recessed upper floors in each module facilitate deeper daylight penetration into the office interiors, eliminating the need for external solar shading. Beyond daylighting, the design leverages the stack effect for natural ventilation while incorporating localized heating and mechanical ventilation with heat recovery systems. This approach minimizes temperature stratification, enhances daylight uniformity, reduces dependency on centralized mechanical systems, and optimizes environmental

³⁷ **Joana Carla Gonçaves**, who has written extensively on sustainable architectural design, including daylighting strategies, passive design techniques, and environmental performance in high-rise buildings.

"The Environmental Performance of Tall Buildings" (2007) – This book explores **sustainable design strategies**, including how daylighting can enhance indoor environmental quality in skyscrapers while reducing energy consumption.

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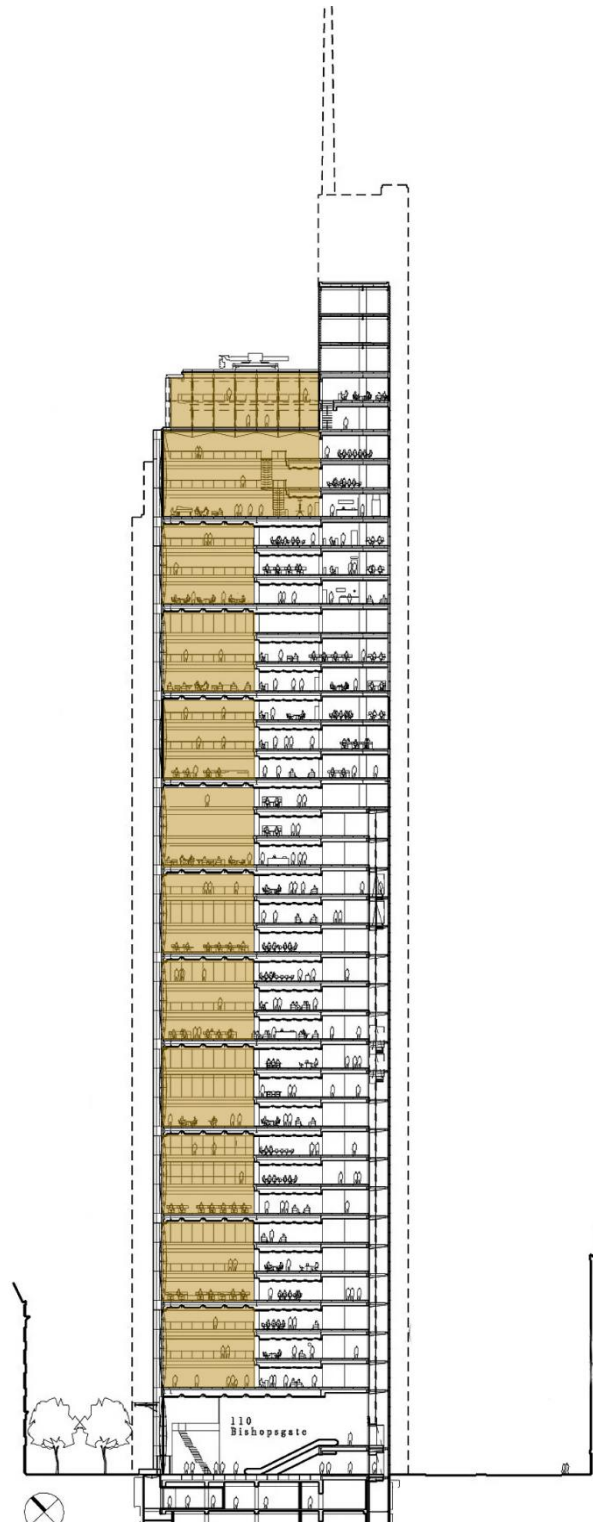


Figure 37 - Section of Heron Tower, KPF Architects with the 3-story atrias in yellow.

management, demonstrating how atria can serve as multifunctional elements in sustainable tall buildings.

3.5 Technical Strategy Framework

The previous sections of this chapter have explored the evolution of structural logic, spatial organization and functional typologies in high-rise architecture. These analyses have highlighted a fundamental connection between technological possibility and environmental responsibility—between the vertical drive for density and the horizontal needs of climate, identity, and human experience. In light of these findings, this section introduces a comprehensive framework of technical strategies aimed at reorienting the design of tall buildings toward more sustainable, adaptable and culturally friendly solutions.

This framework is not intended as a fixed set of prescriptive rules, but rather as a **systematic and adaptable design toolkit**. It integrates insights from traditional passive systems, advanced responsive technologies and contemporary design thinking, offering a roadmap for the multidimensional challenges posed by high-density urban development in climatically and socially sensitive contexts. Each strategy addresses a specific problem or limitation identified in the architectural discourse surrounding towers and proposes a targeted response, grounded in both conceptual and practical feasibility.

The following five strategies form the conceptual and technical backbone of the design proposal that will be developed in the subsequent chapters. Together, they articulate a vision of the skyscraper as a living, responsive and inclusive organism—rather than a static monument to efficiency or prestige or power representative.

Strategy 1 - Adaptive Kinetic Façade: Climate-responsive exterior systems

This strategy envisions the high-rise façade as a dynamic interface between interior and exterior, capable of adapting in real-time to environmental stimuli such as solar radiation, air temperature, humidity, and user needs. Drawing inspiration from the traditional *mashrabiya*—a vernacular Islamic architectural element known for its intelligent shading and ventilation properties—the adaptive façade employs operable panels and sensor-integrated mechanisms to optimize energy performance while enhancing indoor comfort. This solution not only contributes to reduced cooling loads and glare control, but also imbues the building's skin with a **cultural and poetic dimension**, linking high-tech innovation to ancestral wisdom.

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Strategy 2 – Passive Cooling and Ventilation through Vernacular Techniques

Contemporary vertical architecture often overlooks the potential of passive design systems in favor of technologically intensive solutions. This strategy proposes the reactivation of **traditional environmental devices**—such as wind towers, shaded loggias, and internal courtyards—within a vertical framework. These elements are reinterpreted through modern materials and engineering to facilitate **natural airflow, evaporative cooling and thermal buffering**, particularly in arid and semi-arid climates. The result is a significant reduction in mechanical energy demand, along with the reintroduction of spatial typologies that resonate with regional identity and environmental logic.

Strategy 3 – Integrated Green Terraces and Skycourts: Vertical bioclimatic ecology

This strategy promotes the insertion of **multi-level landscaped spaces**—skycourts, green terraces, and vertical gardens—throughout the height of the tower. These components are not merely ornamental: they serve as **climatic regulators**, absorbing solar heat, filtering pollutants, capturing rainwater, and improving humidity. Socially, they create public and semi-public platforms for interaction, contributing to the humanization of vertical living. Ecologically, they support urban biodiversity and reinforce the building's role as a mediator between nature and infrastructure. Strategically located at transitional programmatic nodes, these bioclimatic layers provide rest points, thermal buffers and community hubs within the tower's internal logic.

Strategy 4 – Modular and Multifunctional Spatial Layout

Acknowledging the fluid nature of urban life and economic cycles, especially in a finance city centre, this strategy introduces a **modular spatial organization** that enables long-term adaptability. A rational structural grid and open-plan floorplates allow for a wide range of functional uses—residential, office, cultural or public. Through flexible partitions, vertical zoning and modular service cores, the building is designed to **evolve over time**, accommodating changing needs without major structural intervention. This system fosters a sense of **programmatic hybridity**, breaks down social enclosure and encourages vertical communities to form around shared resources and experiences.

Strategy 5 – Smart Environmental Monitoring and Control: Digital performance intelligence

The final strategy incorporates **sensor-based management systems** and responsive building automation to fine-tune the tower's environmental performance. Real-time data collection informs dynamic adjustments to HVAC, lighting, shading and ventilation systems, ensuring efficient energy usage and optimal indoor environmental quality. This approach transforms the building from a passive consumer into an **active, intelligent agent**, capable of learning from its users and surroundings. By integrating IoT (Internet of Things) platforms and adaptive AI-based algorithms, this strategy aligns with the emerging paradigm of **data-driven architecture**, where performance and user comfort are continuously calibrated and refined.

Together, these five strategies do not function in isolation; they are conceived as **interdependent and cross-reinforcing components** of an integrated design system. The adaptive façade enhances the effectiveness of passive cooling; modular layouts accommodate the placement of skycourts; green skycourts improve thermal mass and reduce HVAC loads and smart systems enable feedback across all strategies. This framework will serve as the operational basis for the presented design proposal, where each strategy will be applied and validated in response to the real-world parameters of site, climate and user needs.

3.6 Conclusions

The evolution of structural and functional strategies in high-rise architecture has been driven by the need to balance innovation, efficiency and sustainability. As urbanization continues to accelerate, the role of skyscrapers as a viable response to spatial constraints and environmental challenges has become increasingly evident. This chapter has explored how advancements in structural systems, spatial strategies and architectural designs have allowed for the creation of resilient, adaptable and energy-efficient towers.

Structural frameworks, including core systems, diagrid structures, outrigger configurations and aerodynamic modifications, have enabled architects and engineers to push the boundaries of height while maintaining stability and efficiency. These innovations not only enhance the structural performance of tall buildings but also contribute to their aesthetic and functional integration within the urban fabric. Furthermore, the incorporation of advanced damping mechanisms and hybrid structural

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systems has been instrumental in mitigating the effects of wind loads, seismic forces, and gravitational actions, ensuring both safety and occupant comfort.

In parallel, the integration of functional spaces such as atria, sky gardens and sky courts has redefined the relationship between tall buildings and their surrounding environment. These elements facilitate natural ventilation, optimize daylighting and promote social interaction, thus transforming high-rise developments into dynamic and habitable vertical communities. Case studies examined throughout this part of the thesis have demonstrated that well-designed atria can enhance thermal efficiency and spatial fluidity, while sky courts and sky gardens contribute to fostering communal engagement and improving the well-being of occupants.

Ultimately, the success of future high-rise developments will depend on the ability to harmonize structural innovation with environmental responsibility. As sustainability continues to shape architectural discourse, skyscrapers must evolve beyond their role as mere landmarks and instead serve as integral components of resilient and inclusive urban ecosystems. Through the continued advancement of construction techniques, smart material applications, and bioclimatic strategies, high-rise architecture can play a pivotal role in addressing contemporary urban challenges while enhancing the quality of life for future generations.

4. Main sustainable design strategies for high-rise buildings

4.1 Introduction

“Right at the outset, we should be clear that the sky scraper is not an ecological building type. In fact, it is one of the most un-ecological building types. The tall building over and above all built typologies uses a third more (and in some instances much more) energy and material resources to build, operate and eventually, to demolish.”

Ken Yeang, from Richards, 2007, p. 20³⁸

The increasing demand for urban expansion has made high-rise buildings an essential component of modern cityscapes, offering a solution to land scarcity and housing shortages. However, their construction and operation have historically posed significant environmental challenges, including high energy consumption, substantial embodied carbon and complex microclimatic impacts. In response to these concerns, sustainable strategies have become a fundamental aspect of contemporary skyscraper design, driving the industry toward more energy-efficient, resilient and environmentally responsible solutions.

Sustainability in tall buildings encompasses multiple dimensions, including energy efficiency, material selection, bioclimatic design and social sustainability. The integration of passive design strategies, renewable energy sources, and high-performance façades has been pivotal in reducing skyscrapers’ environmental footprints. Studies indicate that high-rise buildings generally require more operational energy compared to low-rise structures, particularly in extreme climates, due to increased heating, cooling and ventilation demands. Nevertheless, when properly designed, tall buildings can achieve lower per-capita land use, improved access to daylight, and enhanced urban density, thereby offsetting some of their environmental drawbacks.

³⁸ **Ken Yeang** is widely perceived to be one of the earliest pioneers of sustainable tall building design through both his built work with T.R. Hamzah and his published theories on bioclimatic skyscrapers (Hamzah & Yeang, 2000). Despite this achievement, Yeang argues that the skyscraper is inherently un-ecological, but inevitable due to growing city populations.

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One of the most critical aspects of sustainable high-rise design is the optimization of energy performance through strategies such as natural ventilation, façade-integrated photovoltaics, and thermal mass utilization. For example, buildings like the Commerzbank Tower in Frankfurt and the Pearl River Tower in Guangzhou incorporate advanced ventilation systems, atria and on-site renewable energy generation, demonstrating how skyscrapers can transition from energy-intensive structures to energy-efficient urban ecosystems. Additionally, the reduction of embodied carbon—achieved through material innovations, structural optimization, and circular construction principles—plays a key role in minimizing the life-cycle impact of these buildings.

This chapter will explore the principles and design strategies shaping the future of sustainable high-rise architecture, analyzing case studies, technological advancements and policy frameworks that contribute to the realization of low-carbon, resource-efficient and socially inclusive skyscrapers. By critically examining the intersection between form, function, and environmental performance, this section aims to demonstrate how high-rise buildings can transition from symbols of excessive energy consumption to integral components of a sustainable urban future.

4.2 Height and sustainability

It is essential to establish a clear definition of **sustainability**: one of the most widely accepted definitions comes from the *Brundtland Report*, which describes **sustainable development** as “*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*”³⁹. Over time, this definition has expanded into three core dimensions—**environmental, social, and economic sustainability**.

These interconnected principles, often referred to as the “**triple bottom line**” or the “**three Ps**”—Planet, People, and Profit—are considered equally significant. However, within the context of high-rise architecture, the environmental impact of tall

³⁹ Definition from United Nations General Assembly, 1987, p. 16.

buildings is frequently analyzed, particularly in light of the urgent need to address anthropogenic climate change.

The rapid rise in CO₂ emissions and other **greenhouse gases** (GHGs) since the Industrial Revolution has been driven by the burning of fossil fuels, industrial activity and large-scale deforestation. Current atmospheric GHG concentrations are at their highest levels in 800,000 years, resulting in observable climate shifts. If decisive action is not taken to significantly curb emissions, global temperatures will continue to rise, leading to severe environmental consequences. These include widespread species extinctions, the degradation of ecosystems, rising sea levels, extreme flooding, food and water scarcity and increasingly frequent and severe weather events.

Recognizing the gravity of these challenges, the 2015 United Nations Conference on Climate Change (COP21) in Paris established a global framework for climate action, where 196 countries committed to policies aimed at limiting global temperature rise to below 2°C above pre-industrial levels, with an aspirational target of 1.5°C. However, existing policies remain insufficient to meet this objective. Research indicates that, even if all current nationally determined contributions (NDCs) to GHG reduction are implemented, global temperatures are still projected to increase by 2.6–3.1°C by 2100, a scenario that would result in irreversible and catastrophic consequences for the planet. Therefore, more ambitious, immediate and sustained efforts are required to transition toward a low-carbon future, particularly within the built environment, where high-rise buildings play a significant role in global energy consumption and emissions.

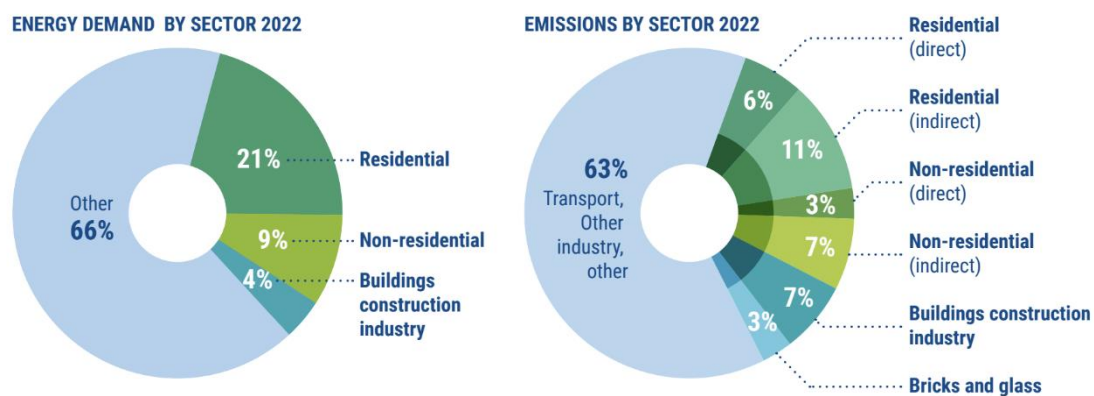
In recent years, the average energy consumption of buildings has continued to decline due to advancements in energy-efficient technologies. However, despite these improvements, the rapid expansion of the global building stock has led to an overall increase in CO₂ emissions within the construction sector. Projections indicate that, without significant interventions, building-related emissions could double by 2050, precisely when a substantial reduction is necessary.

Cities are experiencing exponential growth in the 21st century, with a significant increase in skyscraper construction to accommodate expanding urban populations. For instance, **Dubai** witnessed a 1288% increase in the number of skyscrapers between 2000 and 2020, rising from 25 to 347 such structures. Similarly,

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Shenzhen experienced an 865% increase, growing from 20 to 193 skyscrapers during the same period. Furthermore, between 2012 and 2021, the global average annual completion of buildings exceeding 200 meters was 106, compared to 12 per year in the decade from 1991 to 2000.

Given the magnitude of this expansion, it is imperative that the next generation of skyscrapers actively contributes to the reduction of greenhouse gas emissions. This necessitates that new buildings be highly energy and resource-efficient while simultaneously providing vibrant and comfortable environments for living, working, and socializing. While examples of sustainable design are more prevalent in low-rise buildings, many contemporary skyscrapers have yet to fully integrate



Global energy-related CO₂ demand and emission by sector, 2022

environmental considerations beyond merely complying with local energy performance regulations. However, assessing the sustainability of tall buildings is a complex and context-dependent issue, influenced by factors such as climate, function, and architectural design. Therefore, it is insufficient to generically assert that skyscrapers are more or less sustainable than low-rise typologies; rather, their environmental performance must be evaluated on a case-by-case basis, taking into account both innovative design and long-term impact.

One of the principal problems of high-rise buildings is their considerably higher energy consumption compared to low- and mid-rise structures, primarily due to factors influenced by their height. However, the environmental variations associated with increased elevation can introduce both energy advantages and challenges. The exposure to wind, solar radiation, and atmospheric conditions changes with altitude, significantly affecting the energy usage and overall efficiency of tall buildings.

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For instance, air temperature decreases linearly with height at an approximate rate of 1°C each 150 metres. In cooling-dominated buildings, such as office towers where the majority of the annual energy demand is for cooling rather than heating, this temperature gradient can be advantageous. A study on the **Freedom Tower** (the original design of One World Trade Center) in New York demonstrated that the outside air temperature drops by 1.85°C between the ground level and the highest occupied floor, located 284 metres above grade. This cooler air reduces conductive heat gain through the building envelope and lowers the temperature of the infiltrating and ventilating air, ultimately decreasing the uppermost floor's heating and cooling energy demand by approximately 2.4% compared to the ground floor.

Additionally, air pressure and density decline with, meaning less energy is required to cool the thinner, less dense outdoor air. Consequently, in cooling-dominated skyscrapers, drawing in ventilation air from the highest possible level is more energy-efficient. On the other hand, in residential towers located in colder climates, upper floors are likely to have higher energy demands due to the increased need for heating to contrast lower outdoor temperatures. Nevertheless, they may also benefit from greater passive solar gains, which can partially offset heating costs.

Wind speed, which intensifies with altitude, is perhaps the most significant environmental factor impacting tall buildings. While this can enhance natural ventilation potential, it also poses structural challenges. Stronger lateral wind forces necessitate more robust structural reinforcement, increasing the need for bracing and other resistance measures, which can further influence the building's overall energy performance.

From a sustainability perspective, tall buildings necessitate substantially larger quantities of structural steel and concrete compared to low-rise structures, resulting in significantly higher embodied energy and carbon footprints. A study conducted in Melbourne, Australia, which calculated the initial embodied energy of five office buildings of varying heights—3, 7, 15, 42, and 52 storeys—revealed a marked increase in embodied energy with height, primarily driven by the greater structural demands required to withstand wind loads and maintain stability.

Despite this, the elevated exposure of tall buildings can offer certain environmental advantages. Upper floors benefit from greater access to wind for natural

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ventilation, unlike low-rise buildings in dense urban areas, where surrounding structures often cover airflow. However, this benefit is often compromised when clusters of high-rises form "*urban walls*," blocking wind paths to neighboring buildings or public spaces, thereby limiting their access to natural ventilation.

Moreover, the high wind speeds at greater altitudes, while offering potential for enhanced ventilation, can also be excessive. When wind speeds exceed 8 m/s, natural ventilation through operable windows becomes impractical, as it may lead to discomfort or even safety hazards. On the 40th storey, for instance, opening a window may result in a forceful gust rather than a gentle breeze, making natural ventilation unfeasible.

As a consequence, despite the theoretical potential for increased wind exposure, many tall buildings fail to capitalize on this opportunity. Instead, they often rely on sealed façades and energy-intensive air conditioning systems, thereby negating the sustainability benefits that natural ventilation could provide and exacerbating their environmental impact.

The higher wind speeds at greater altitudes also create opportunities for renewable energy generation. Placing wind turbines on the rooftops of tall buildings can be particularly advantageous in dense urban areas, where wind speeds are stronger and airflow is less obstructed. However, in practice, integrating wind turbines into high-rise structures presents challenges, particularly due to turbulence, vibration and noise issues. As a result, the application of this technology in tall buildings is still in its early stages.

In heating-dominated buildings, such as residential towers in colder climates, increased solar exposure at higher elevations can be advantageous. It enhances passive solar heat gain, lowering the need for artificial heating. Conversely, in hot climates or cooling-dominated buildings, this same effect becomes a drawback, as the additional solar gain raises indoor temperatures and intensifies the cooling load.

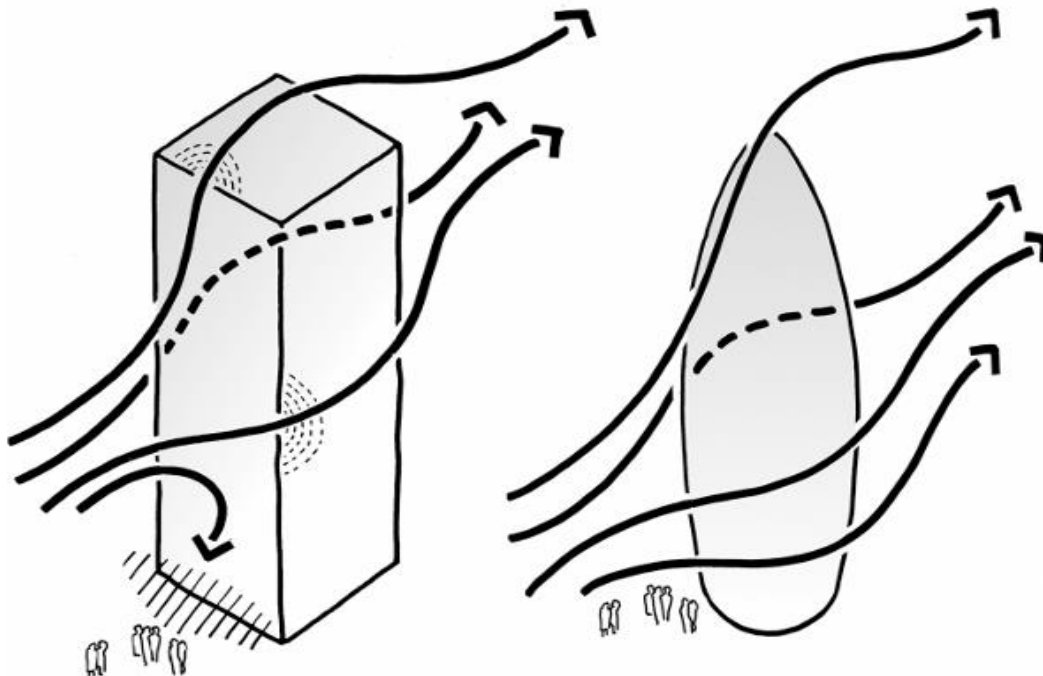
Tall buildings also offer greater potential for solar energy generation. Their elevated position and reduced shading from nearby structures make their rooftops and façades well-suited for photovoltaic panels or solar-thermal systems. Unlike low-

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rise rooftops, which are frequently shaded in dense urban areas, high-rise surfaces benefit from more consistent and unobstructed sun exposure.

However, this advantage can come at the expense of neighboring buildings. By towering over their surroundings, high-rises cast extensive shadows, reducing both solar gain and natural daylight for adjacent structures. This shading effect can increase the energy consumption of neighboring properties by raising their heating and lighting demands, thus undermining the broader environmental benefits. As a result, the energy savings achieved by the tall building through enhanced solar exposure may be partially offset by the additional energy usage of its overshadowed neighbors.

In hot and tropical climates, the shadows cast by tall buildings can offer notable benefits by shading streets and public spaces, thereby reducing direct solar exposure and enhancing outdoor comfort. In Singapore's tropical setting, for example, one of the key community spaces is the 'void deck'—an open area at the base of high-rise residential clusters. These spaces become popular gathering spots precisely because the surrounding towers provide ample shade, creating cooler and more pleasant environments for social interaction.



Wind shaping for London's 30 St Mary Axe showing the use of an aerodynamic form to reduce wind loads.

However, the arrangement of tall buildings can also have negative consequences. When towers are aligned in rows along narrow streets, they create 'urban

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canyons', which can trap heat and exacerbate the **Urban Heat Island (UHI)** effect. This phenomenon occurs when urban areas experience significantly higher temperatures compared to rural or suburban surroundings. The effect is driven by heat emissions from vehicles and air-conditioning systems, combined with the absorption and re-radiation of solar heat by large buildings, paved surfaces, and roads.

According to Santamouris et al. (2017), over 400 major cities worldwide are affected by increased urban temperatures, with urban areas registering temperature differentials of 4–5°C higher than their rural counterparts, and in some cases reaching differences of 7–8°C. Urban canyons are particularly susceptible to UHI effects due to their low sky view factor—the proportion of visible sky relative to the built environment. This limited sky exposure reduces the ability of urban areas to dissipate heat, which is especially problematic in warmer climates, where any additional heat retention further intensifies thermal discomfort.

The design and geometry of tall buildings significantly influence their energy consumption compared to other building typologies. High-rises typically exhibit a lower *surface-area-to-volume ratio* than low- and medium-rise structures. In Europe, where space heating accounts for the largest portion of building energy demand—representing 70% of the total energy consumption in residential buildings⁴⁰—this compactness can offer considerable environmental advantages. Urban energy modeling reveals that taller buildings in Europe, due to their compact form, generally have lower heating demands than their low-rise counterparts. This translates into reduced greenhouse gas emissions (GHGs) and lower energy expenses for residents, which becomes increasingly relevant as energy prices continue to rise.

However, one of the key challenges associated with tall buildings is the risk of overheating. Their inherently compact form reduces the building envelope, making it more difficult to ventilate spaces by opening windows, as there is less façade area available for natural airflow compared to low-rise buildings.

Another major drawback of tall buildings is the energy required for vertical transportation of people and resources (e.g., water, air, and equipment such as

⁴⁰ Source: **The World Business Council for Sustainable Development (WBCSD)** brings together transformational organizations to form a global community that shifts the systems they work within towards a better future.

elevators), which is notably higher than in low-rise structures. Elevators, in particular, are often cited as major contributors to skyscraper energy consumption and are frequently used to argue that tall buildings are more energy-intensive. However, advancements in elevator technology over recent decades have significantly improved their energy efficiency. Modern elevator motors now incorporate a process known as ‘*elevator regeneration*,’ whereby much of the energy expended to lift the cab is recovered when it descends, moving with gravity. As a result, contemporary elevators typically account for just 2% of a tall building's total energy consumption, a substantial reduction from the 8% they consumed approximately 30 years ago.

Moreover, empirical studies have challenged the assumption that elevator usage in taller buildings necessarily leads to higher energy consumption. For instance, Lam et al. (2004) conducted a comparative analysis of office buildings in Hong Kong and found no consistent correlation between building height and increased elevator energy demands.

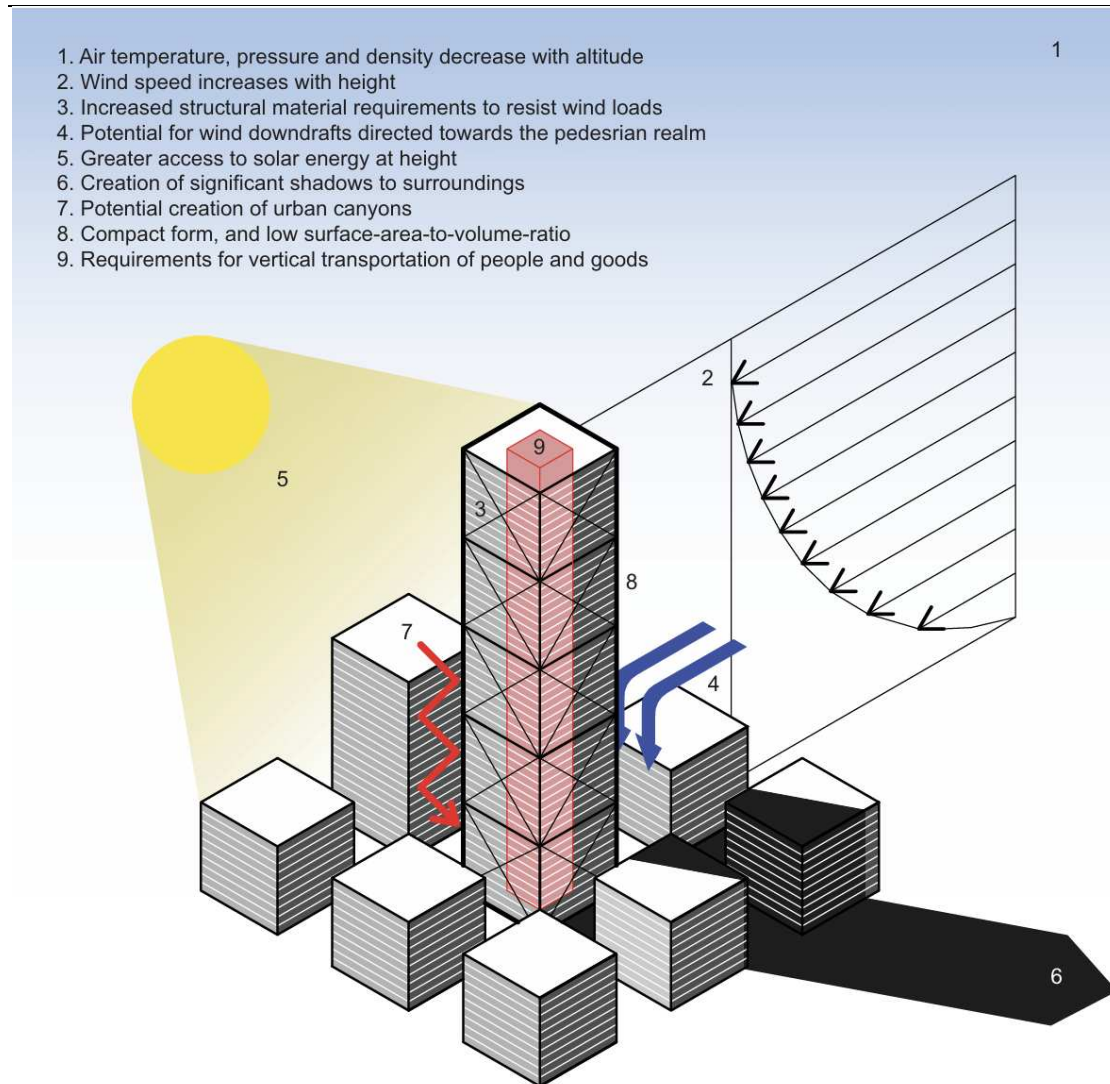
After carefully analyzing all this data and studies, there's one very remarkable question: *How we should build the tall buildings of the future?*

A key takeaway is the need for further research: only with accurate building performance data can we make informed strategic decisions to enhance the energy efficiency of the built environment. Another conclusion is the acknowledgment that, in general, tall buildings currently consume more energy than low-rise structures. However, it is important to recognize that a building's environmental impact extends beyond its direct energy consumption or the boundaries of its site. It also involves factors such as transportation-related greenhouse gas (GHG) emissions, the influence on the energy loads of neighboring buildings, and the resources required for infrastructure, such as roads and utilities.

One of the main environmental arguments in favor of tall buildings is their potential to increase urban density, promoting more compact cities and thereby reducing urban sprawl. This, in turn, can lower GHG emissions from transportation and infrastructure development.

Finally, building height presents both environmental opportunities and challenges in terms of air, sunlight, wind exposure, and overall form. However, these

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A summary of environmental and microclimate factors influenced by height (Source: The sustainable tall building: A design Primer – Oldfield Philipp)

opportunities are often underutilized, and the challenges insufficiently addressed. When tall building designs effectively respond to local climate conditions and leverage the potential benefits of height, studies show that their operational energy consumption can be significantly lower than the industry average.

4.3 Climate and solutions

“There is much more to our current place in architectural history than symbol and iconography. Rather than symbol, the specifics of each environmental condition, culture, lifestyle and the tools and methods we use to build should be the basis for a

new kind of high-rise building that would inherently “add value” but also transform cities.”

Jeanne Gang, 2008.

Climate has always been a fundamental element in the evolution of the building environment, influencing architectural design and construction techniques for thousands of years. Across various cultures and climatic conditions, designers have demonstrated ingenuity and innovation in utilizing natural forces—such as solar radiation, wind patterns and ambient temperature variations—to create buildings that offer both thermal comfort and visual harmony for occupants.

In cold climates, architectural strategies have historically prioritized passive solar heating, with windows and openings strategically oriented toward the sun to maximize solar gain, thereby providing natural heating without additional energy consumption. In tropical regions, traditional typologies like the Kampong House in Southeast Asia exemplify climate-responsive design, featuring elevated structures on stilts to enhance airflow and cooling, while extended eaves offer shade and protection from heavy rainfall. Similarly, in hot-arid climates, buildings have traditionally relied on thick adobe or ceramic walls, which function as thermal mass, moderating indoor temperatures by absorbing heat during the day and releasing it at night. Additionally, **windcatcher towers**, an architectural feature found in regions such as the Middle East and North Africa, capture high-altitude breezes to facilitate natural ventilation and cooling. The result of these climate-driven adaptations has been a diverse range of architectural styles, with each region developing unique forms tailored to its specific environmental challenges.

However, much of this regional architectural diversity began to diminish in the early twentieth century, coinciding with technological advancements in artificial climate control. The Industrial Revolution facilitated the development of mechanical heating, ventilation, and air conditioning systems, which became increasingly affordable and widespread. By 1904, the journal *Ice and Refrigeration* had already predicted the widespread adoption of mechanical air cooling, stating that “*the day is at hand, or soon will be, when the modern office building, factory, church, theatre and even residence will be incomplete without a mechanical air cooling plant.*” As a result, architectural design gradually shifted away from passive climate adaptation, leading to

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the globalization of building typologies that often disregarded local environmental conditions.

While mechanical conditioning systems have undoubtedly enhanced indoor comfort, particularly in extreme climates where passive strategies alone may be insufficient, their widespread use has also resulted in increased energy consumption and environmental impact. However, at the building scale, it is essential to re-emphasize climate-responsive design, ensuring that buildings are better adapted to local environmental conditions. This includes reducing heat loss in colder climates through improved insulation and airtight construction, while simultaneously mitigating unwanted heat gain in warmer regions through shading devices, natural ventilation strategies and high-performance materials. The integration of passive design principles with modern technological advancements represents a critical step toward achieving sustainable, energy-efficient architecture in the face of ongoing climate challenges.

After this introduction, *what can it be said about tall buildings?*

As Antony Wood⁴¹ stated, “*the rectilinear, air-conditioned, glass skinned box is still the main template for the majority of tall buildings developing around the world*”.

While the International Style of Modernism has largely fallen out of favor, the globalized approach to skyscraper design remains dominant. Regardless of geographical location or climatic conditions, contemporary high-rise buildings continue to follow a standardized architectural model, often prioritizing aesthetic uniformity and global recognition over climate adaptability and environmental efficiency.

The diversity of global climates is well documented by the **Köppen Climate Classification** ^[Fig.38], which categorizes climates into five primary groups: A - tropical, B - arid, C - temperate, D - cold, and E - polar. Except for polar regions, skyscrapers have become possible across all climate zones, often without significant adaptation to local environmental conditions. In the modern era, the skyscraper has evolved into a universal typology, frequently used by urban planners and policymakers as a tool for enhancing a city’s global image and competitive standing. However,

41 **Antony Wood** is the Executive Director of the Council of Tall Buildings and Urban Habitats (CTBUH).

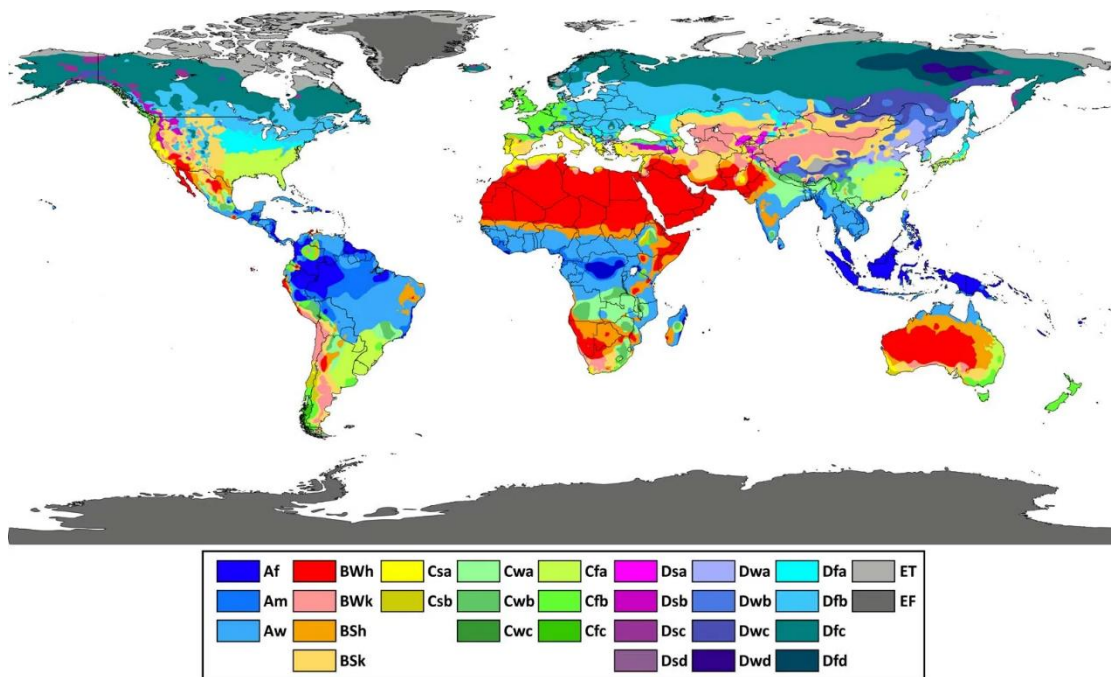


Figure 38 - World map of the Koppen-Geiger climate classification

beyond serving as symbols of economic power and architectural ambition, skyscrapers must also function as environmentally responsive structures that harmonize with their surroundings, climate and cultural context.

This does not imply that skyscrapers should simply blend into their environment, nor does it suggest rejecting global advancements in engineering, materials, or design technologies. High-rise buildings will inevitably remain regional and global landmarks, benefiting from international best practices in structural innovation, safety and building systems. However, they must also capitalize on the unique climatic challenges and opportunities of their specific locations to enhance thermal comfort and reduce energy consumption.

As Chris Abel (2006) argues, the design of tall buildings requires a careful balance between global architectural trends and local environmental considerations.⁴² Yet, from a sustainability perspective, this balance is often skewed toward air-conditioned, glass-clad global icons, rather than toward climate-adaptive skyscrapers that integrate passive strategies for energy efficiency. In many cases, standardized high-

⁴² **Chris Abel** is an award winning author and internationally known theorist and educator on interdisciplinary approaches to architecture and environmental issues. (Source: <https://www.ctbuh.org/people-profile/chris-abel>)

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rise designs fail to leverage local climate conditions, resulting in excessive reliance on mechanical cooling and artificial lighting. To address this imbalance, contemporary skyscrapers must move beyond generic, one-size-fits-all solutions, instead embracing region-specific, climate-responsive strategies that optimize energy efficiency while maintaining architectural identity.

Due to this thesis research and its topic, this part is going to be studied mainly on the **arid** and **temperate** climate zone, thanks to the chosen site project and the main focus of the study itself.

4.5.1 Temperate climate zone

Temperate climates are characterized by cold-to-cool winters, warm-to-hot summers, and mild transitional seasons, encompassing cities such as Sydney, New York, and Rome. Despite slight variations within these climates, they are often categorized together due to the similar passive design strategies required to balance heat loss during winter and heat gain in summer. High-rise buildings in these regions must incorporate adaptable design elements that respond to fluctuating external conditions throughout the year, ensuring indoor thermal comfort with minimal energy consumption. A fundamental aspect of this approach is a thorough understanding of the local sun path, as solar exposure significantly influences a building's thermal performance. One of the most effective strategies involves integrating solar shading on sun-facing façades to limit direct solar radiation in summer while permitting low-angle sunlight to enter interior spaces during winter for passive heating.

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An exemplary case of this approach is Studio Gang's **Solstice on the Park**^[Fig.39] in Chicago, a city with a highly variable climate characterized by harsh winters and warm, humid summers. Given that passive solar gain is advantageous for much of the year, except during peak summer months, the building incorporates a form-driven shading strategy. The structure features a rectilinear slab configuration oriented southward, maximizing views of the adjacent Jackson Park. Its distinctive façade is sculpted with a sawtooth design, incorporating inclined glazing set at a 72° angle,



Figure 39 - View on the Solstice in the Park, Studio Gang, 2018

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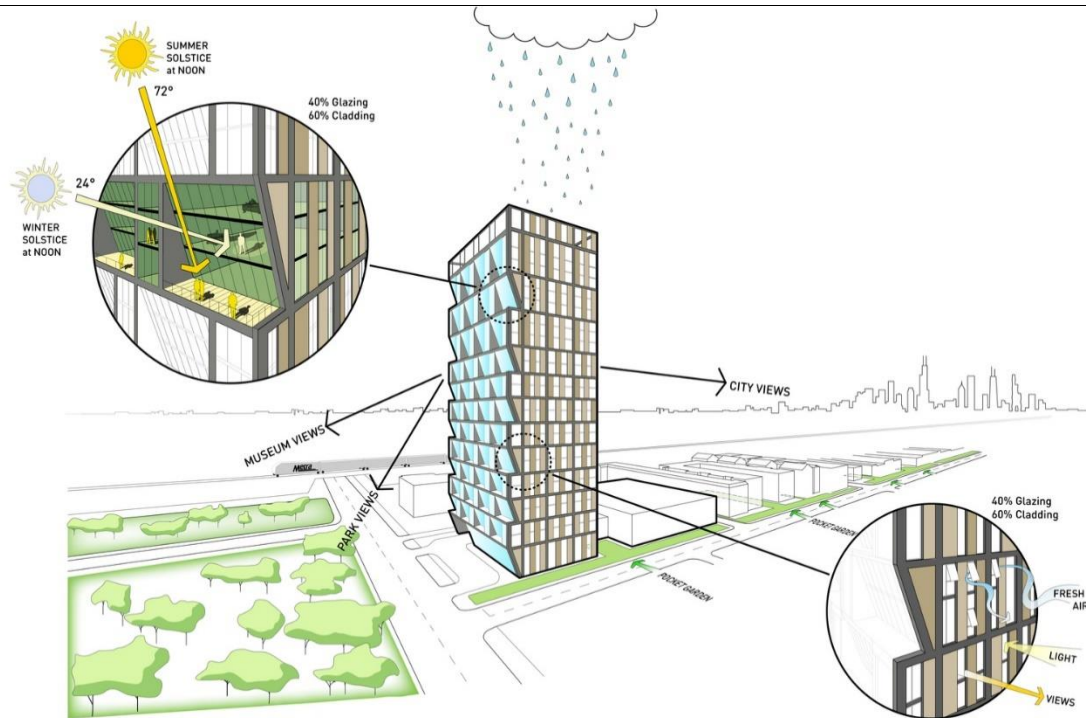


Figure 40 - Environmental Diagram of the Solstice in the Park (Source: <https://www.archdaily.com/930072/solstice-in-the-park-studio-gang>)

corresponding to the sun's altitude at midday in mid-summer. This self-shading geometry effectively blocks excessive solar radiation in summer while allowing sunlight to penetrate living spaces in colder months, thereby enhancing thermal performance through passive solar heating. [Fig.54]

While residential buildings in temperate climates benefit from solar heat gain, commercial structures, such as office towers, often require stricter solar control due to the significant internal heat loads generated by occupants, electronic equipment, and artificial lighting. The **Heron Tower** in London, designed by Kohn Pedersen Fox and completed in 2011, exemplifies an adaptive approach to solar management. The building is organized around a south-facing core, which acts as a solar buffer, shielding the north-facing office spaces from excessive heat gain—critical in a setting where cooling demands outweigh heating requirements. The façade composition is customized for each orientation: the south-facing core is clad with photovoltaic panels to harness solar energy, while the east and west façades incorporate a double-skin system with integrated blinds in the cavity to regulate solar exposure and mitigate glare from low sun angles.

One of the most effective approaches to achieving this balance is the **Passivhaus standard**, which emphasizes high-performance façade design to maximize energy efficiency. This strategy relies on super-insulation to minimize heat loss and strategically positioned windows to optimize passive solar heating. To attain Passivhaus certification, buildings must demonstrate annual heating and cooling energy consumption below 15 kWh/m², a threshold approximately 75% lower than that of conventional new constructions.

Passivhaus buildings are characterized by six key principles:

- The incorporation thick insulation and triple-glazed windows to create a highly efficient thermal envelope.
- Careful orientation of glazing ensures that solar heat is harnessed when beneficial while mitigating unwanted heat loss.
- Mechanical ventilation with heat recovery (MVHR) captures waste heat from indoor air to preheat fresh air, improving overall energy efficiency.
- Air infiltration is minimized through an airtight building fabric, typically achieving a leakage rate below 0.6 air changes per hour at 50 Pascals of pressure.
- The reduction of thermal bridges in the construction mitigates conductive heat losses.
- Passivhaus buildings often feature compact, high-density forms that reduce the quantity of exposed façade, thereby limiting heat dissipation.

When applied to high-rise buildings, the Passivhaus standard can lead to substantial energy savings. The inherent compactness of high-rise buildings further enhances their Passivhaus performance by reducing the surface-area-to-volume ratio, which minimizes heat loss. Consequently, high-rise structures can achieve Passivhaus standards with relatively less insulation and double glazing instead of triple glazing, yielding economic and constructability advantages while also reducing embodied carbon relative to low-rise Passivhaus projects.

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One of the most notable examples of a completed Passivhaus high-rise is **The House at Cornell Tech**^[Fig.41], a 26-story residential tower in New York designed by Handel Architects. Located in a temperate climate with cold winters and warm summers, the building prioritizes heating efficiency, as residential buildings typically require higher heating loads. The façade functions as a thermally insulated envelope, comprising super-insulated panels, triple-glazed windows and a window-to-wall ratio of approximately 30%—significantly lower than that of conventional residential towers in the city. To enhance construction efficiency and thermal performance, the façade was

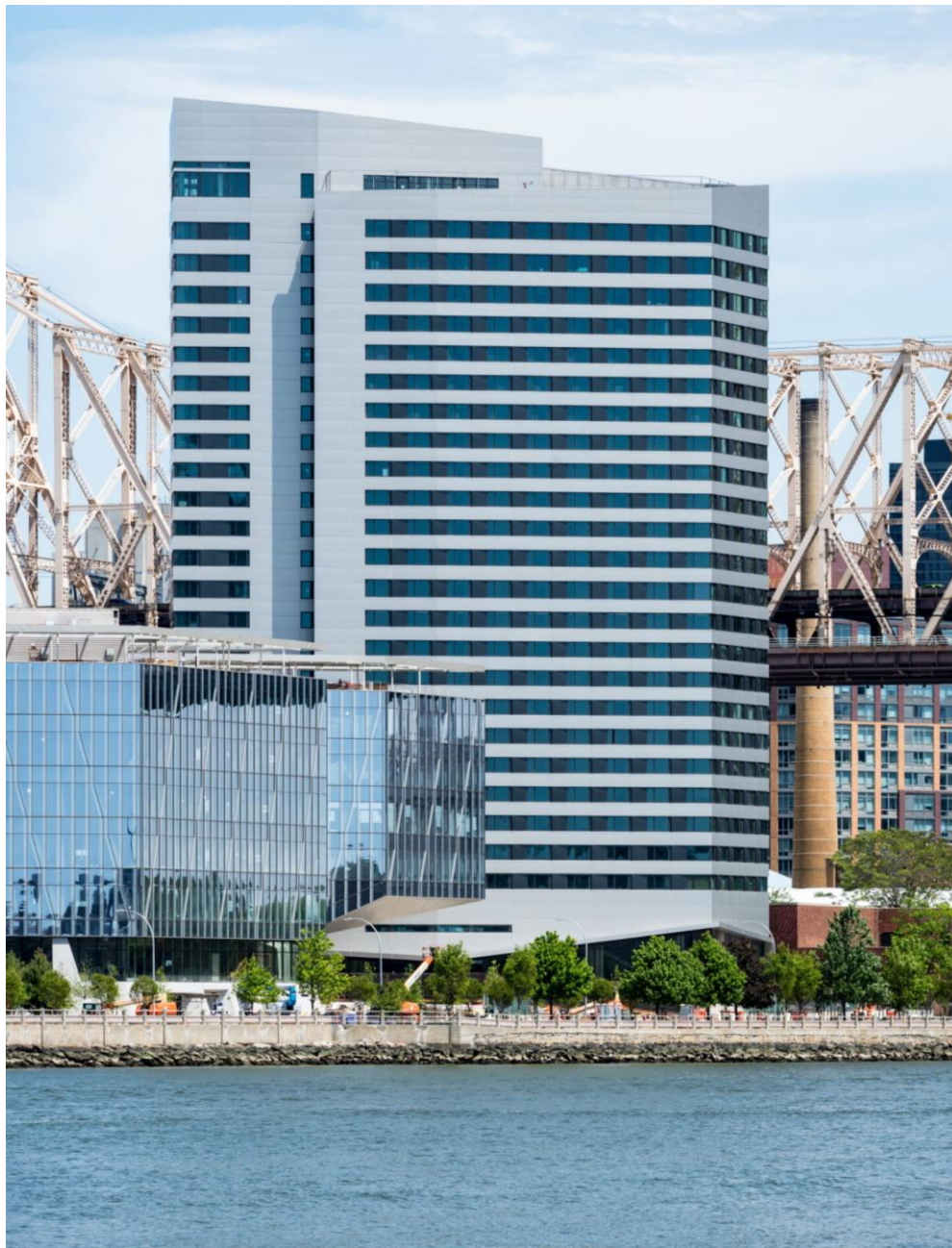


Figure 41 - View on The House at Cornell Tech, Handel Architects, 2017

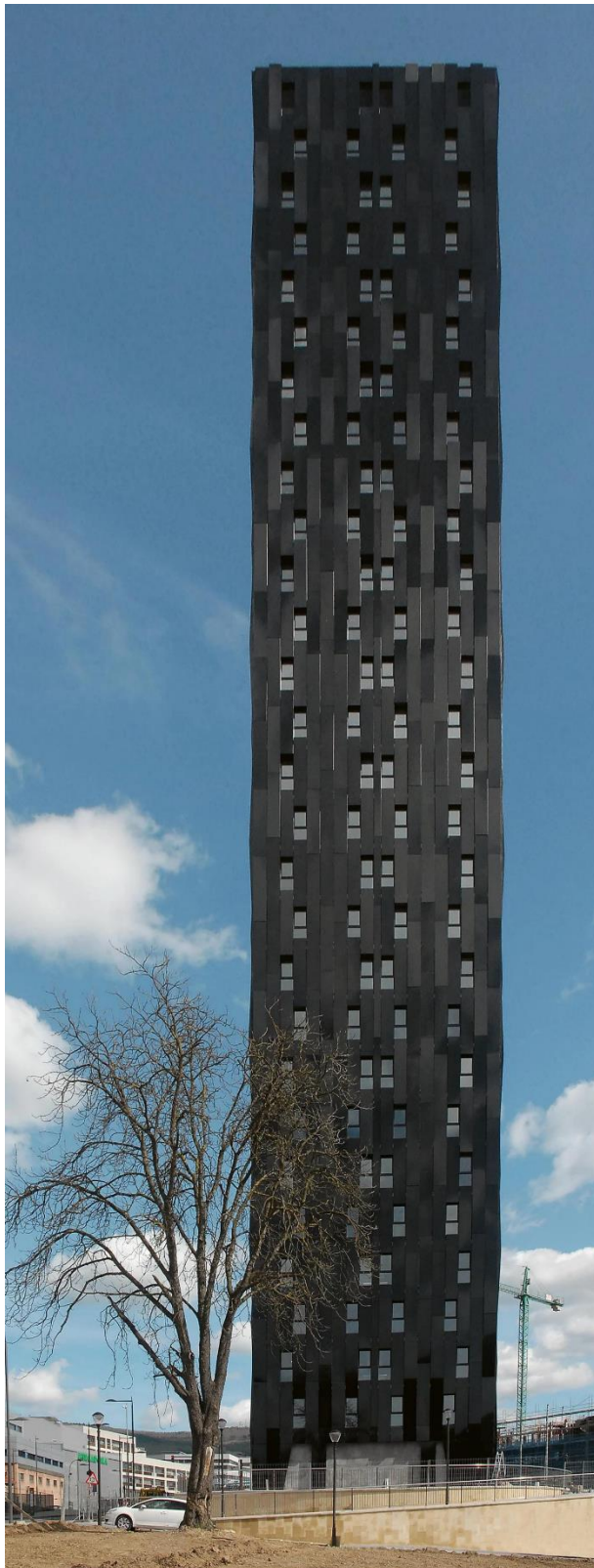


Figure 42 - Bouleta Passivhaus High-Rise Building, VArquitectos, 2018

prefabricated off-site and transported via barges along the Hudson River before being craned into place, reducing the number of on-site joints and improving airtightness. Compared to a conventional high-rise, the implementation of Passivhaus strategies in this project is projected to achieve an annual carbon reduction of approximately 882 tonnes of CO₂, underscoring the environmental benefits of high-performance building envelopes in sustainable skyscraper design.

Another great example of high-rise passivehaus is the **“Bouleta” High-Rise Building**, located in Bilbao, Portugal. To achieve Passivhaus certification, every design element was meticulously analyzed, with particular attention given to the building envelope. The façade, clad in aluminum composite panels, is composed of three distinct panel types: **flat** sections and **two variations with opposing inclinations**, one sloping upward and the other downward. This fragmented arrangement was intentionally designed to reduce the visual impact of the building’s substantial mass.

Despite its seemingly random composition, the façade follows a structured logic, where

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vertical bands organize the different panel types. The opaque sections adhere to a consistent sequence—flat, downward, upward—while the glazed sections present two distinct rhythmic patterns. The resulting façade integrates the repetitive window arrangement into a fragmented yet rhythmic composition, with a bright finish that evokes the industrial materials historically associated with Bilbao: **steel** and **coal**.

To attain net-zero energy consumption, several advanced strategies were implemented: increasing insulation thickness, employing construction techniques to eliminate or significantly reduce thermal bridges and integrating high-performance window frames and glazing. By minimizing air leakage, the building ensures controlled ventilation, maintaining high indoor air quality while enabling heat recovery systems to reclaim up to 90% of the thermal energy from outgoing stale air. Even if these modifications resulted in a 3% increase in construction costs, the building's initial energy efficiency was improved by an astonishing 80%. Importantly, the overall cost per square meter remained within the standard pricing range for subsidized housing in the Basque Country. The first of these towers, completed in 2018, reached a height of 88 meters, establishing itself as the tallest Passivhaus-certified building in the world at the time of its completion.

One of the challenges of achieving Passivhaus performance in any building type is minimising thermal bridges, which is a localised area of heat transfer due to an uninsulated part of the envelope assembly. This creates a pathway for conductive heat to escape through the building fabric, increasing heating loads and subsequent carbon emissions. In towers, this is especially prevalent in projecting concrete balconies, where the slab penetrates through the envelope insulation and creates a path for heat loss in winter months. Instead, an alternative is introducing a structural **thermal break** into the slab; this consists of an insulating material to limit the thermal bridge, with steel reinforcement bars to provide a structural connection between interior slab and exterior balcony.

4.5.2 Hot and Arid climate zone

Arid climates are characterized by consistently high temperatures, with an annual mean of 18°C or higher. This climate type is the most widespread in terms of land coverage, spreading for approximately 14.2% of the Earth's total landmass. These regions are predominantly hot, dry, and exposed to intense solar radiation, often

experiencing extreme summer temperatures that can reach 45°C – 50°C in some desert areas. Major cities with high-rise developments in such climates include Dubai, Jeddah and Las Vegas.

In recent decades, the Middle East has witnessed a surge in urban expansion, marked by large-scale construction projects and an increasing number of skyscrapers. Dubai, for instance, is synonymous with the Burj Khalifa, the world's tallest completed building at 828 meters. However, this record will soon be surpassed by the Jeddah Tower, which is set to exceed 1,000 meters in height. The rapid growth of high-rise architecture in these extreme climates has had profound energy implications. In the Gulf Cooperation Council (GCC)⁴³ region, air conditioning accounts for up to 70% of annual peak electricity demand, with cooling requirements projected to triple by 2030.

To enhance the energy efficiency of skyscrapers in arid environments, thoughtful design strategies must be implemented. Measures such as optimizing the window-to-wall ratio (WWR), incorporating thermal mass to mitigate heat transfer, and employing high-performance façade insulation can significantly reduce cooling loads. However, minimizing glazing is not the sole solution for improving building efficiency in desert climates. Architects must also strike a balance between reducing radiative and conductive heat gains while ensuring sufficient natural daylight and outward visibility. After all, a well-designed high-rise should not only be energy-efficient but also provide a comfortable and visually appealing indoor environment, rather than resembling an enclosed concrete structure devoid of natural light.

Design innovation and creative approaches to building layout, form, façade, and technological integration are fundamental to the development of climatically responsive towers, exemplified by the **National Commercial Bank in Jeddah** [Fig.43]. A key architectural strategy involved an inversion of the conventional glass skyscraper model, intended to counteract the region's extreme environmental conditions, including intense heat, dust and glare. Instead of exposing large glass surfaces to the exterior, the design places a glazed core at the center of the structure, encircled by an opaque stone-clad exterior.

⁴³ **The Gulf Cooperation Council (GCC)** is made up of Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates.

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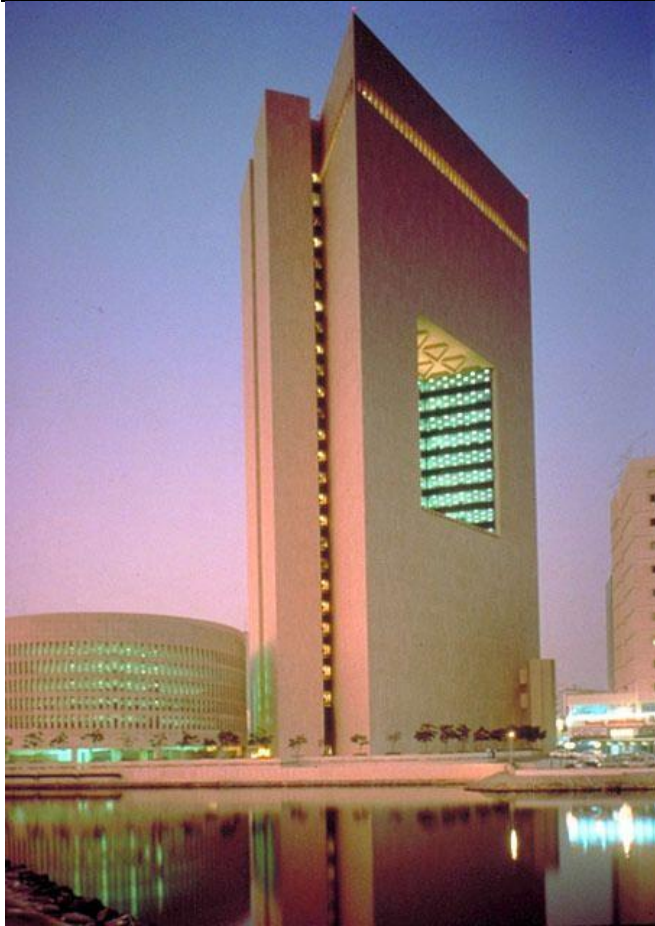
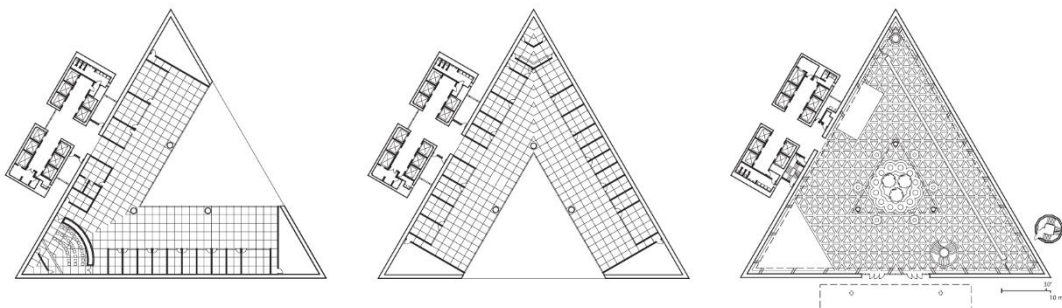


Figure 43 - National Commercial Bank of Jeddah, SOM, 1983

This configuration results in a series of V-shaped floor plans, where glazing is restricted to the internal façades, which are naturally shaded by the overhanging building mass. The design also incorporates sky gardens positioned alternately, with two facing southeast and one oriented north, benefiting from shade and reduced solar exposure. The building features no external windows, apart from those on the uppermost floor, and the core is pushed to the perimeter on the sun-exposed southwestern side, acting as a thermal buffer against solar radiation.

As a result, the tower achieves 15% lower air-conditioning loads compared to buildings of a similar era. The combination of self-shading geometry and the vertical air circulation driven by the stack effect within the atrium creates a microclimate around the glass surfaces, where temperatures can be up to 10°C cooler than the ambient external conditions, significantly reducing conductive heat transfer into the building.



National Commercial Bank of Jeddah, Typical office plan

Another great and certainly more recent example of desert climate responsive design is the **Wafra Wind Tower** in Sakmiya, near Kuwait City, by Agi Architects [Fig.44]. The

design of the tower draws inspiration from traditional Middle Eastern courtyard housing, reinterpreting the courtyard concept as a central atrium within the building. The service core is positioned on the southern side of the plan, where it is clad in light-colored granite to reflect solar radiation. The exterior incorporates a window-to-wall ratio of approximately 20%, minimizing heat gain. While the atrium remains shaded by the building's mass, it opens toward the north façade at ground level, allowing prevailing breezes to flow through. As these breezes pass over a swimming pool, the air is both humidified and cooled before being drawn upwards through the atrium. This effect fosters natural ventilation throughout the apartments, reducing the reliance on mechanical cooling systems. Inside the atrium, larger windows are strategically placed to maximize access to diffused daylight and promote cross-ventilation, enhancing indoor comfort. Additionally, the atrium serves as a dynamic social hub, encouraging interaction and communication among residents. Furthermore, the variation in microclimatic conditions with increasing height offers environmental advantages for tall buildings in hot desert climates, improving their overall energy performance.

When designing hot climate skyscrapers, it is essential to consider not only climate, energy efficiency and thermal comfort, but also the sustainability of water resources. The scarcity of rainfall, combined with high evaporation rates and a lack of natural potable water sources, makes water conservation a critical priority in many arid regions. In the Gulf Cooperation Council (GCC) countries, where natural freshwater supplies are minimal, desalination of seawater is commonly employed to meet potable water demands. However, this process carries a substantial environmental cost. For instance, *in the United Arab Emirates (UAE)*, producing one cubic meter of desalinated water generates approximately 1.3 to 3 kg of CO₂, depending on the specific technology of the desalination plant. Beyond its carbon footprint, desalination also has a detrimental impact on marine ecosystems. Over the past two decades, the practice has contributed to rising sea temperatures and increased salinity in the Gulf waters, harming marine biodiversity. Therefore, in hot climates with restricted access to potable water,

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all building design should actively incorporate strategies for water reuse, reduction and capture to promote sustainable water management.

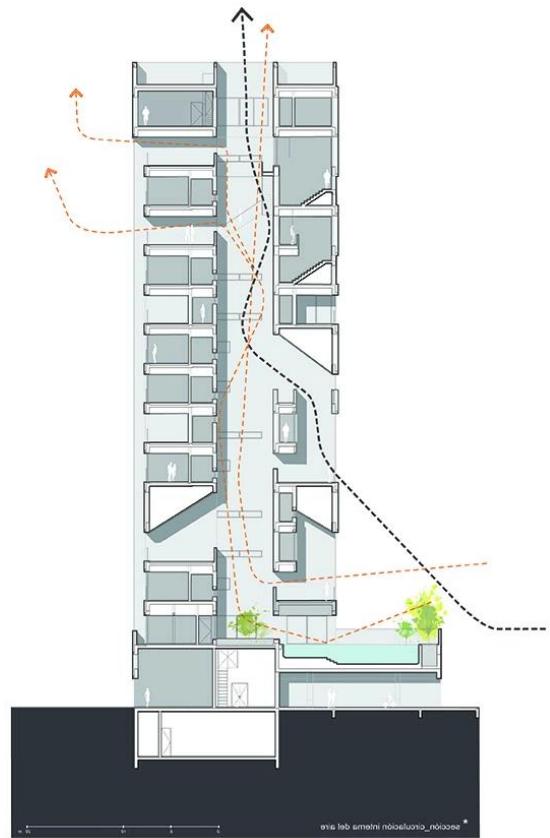


Figure 44 - View on the Wafra Wind tower (Top Left), a section showing the natural air circulation over the pool, cooling the atrium inside the tower (Top Right), a view on the internal atrium as social space (Bottom left).

In the Burj Khalifa, for example, the hot and humid exterior air causes a build-up of condensation in the building cooling system.

This is collected, saving 15 million litres of water per year, used to irrigate the exterior landscaping. A further opportunity is recycling **grey water**; this is waste water that comes from baths, showers, basins and washing machines, which can be captured, treated, cleaned and then re-used for toilet flushing or irrigation of landscaped areas. In tall buildings, grey water recycling can be efficient, given the proximity of units and the use of centralised systems.

4.4 The energy generations from a sustainable point of view

The evolution of energy-efficient tall buildings can be categorized into **five distinct generations**, each reflecting advancements in architectural design, materials, construction techniques and sustainability strategies. These generations illustrate how high-rise buildings have transitioned from passively ventilated masonry structures to high-performance, energy-efficient skyscrapers that integrate bioclimatic principles and renewable energy systems.

The **first generation** of tall buildings emerged in the late 19th century, primarily in North America, with the rise of steel-frame construction, elevators and early HVAC (Heating, Ventilation & Air Conditioning) systems. These buildings were characterized by thick masonry walls, which provided thermal mass and insulation, while narrow floor plates and high ceilings allowed for natural ventilation and daylighting. However, the limited window-to-wall ratio restricted interior illumination, leading to a compromise between energy efficiency and spatial functionality: it was a mere 20-40% ratio, compared to the 50-75% ratio of façade transparency of contemporary high-rise buildings. The lack of zoning regulations during this period resulted in densely packed urban centers, with buildings competing for light and air access. The necessity to regulate urban density led to New York City's 1916 Zoning Law, which marked the transition into the second generation.

The **second generation** of tall buildings was shaped by the introduction of zoning laws, which fundamentally altered the form, function and energy performance of high-rise structures: the 1916 Zoning Resolution in New York City, acted in response

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to concerns about overcrowding, lack of daylight, and poor ventilation in densely packed urban areas. This led to streets and lower floors being cast in perpetual shadow, with poor air circulation and limited natural light, creating unsanitary and uncomfortable environments for both building occupants and city dwellers.

To address these concerns, the 1916 Zoning Resolution introduced setback requirements, which mandated that as a building increased in height, it had to progressively recede from the street. This resulted in the emergence of the "**wedding cake**" skyscraper style, where buildings were designed with stepped-back profiles, ensuring that sunlight could penetrate to the street level.

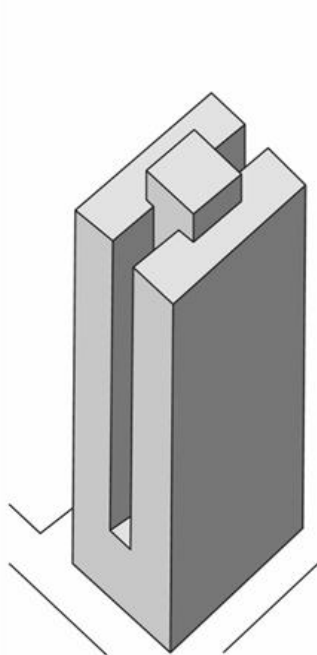
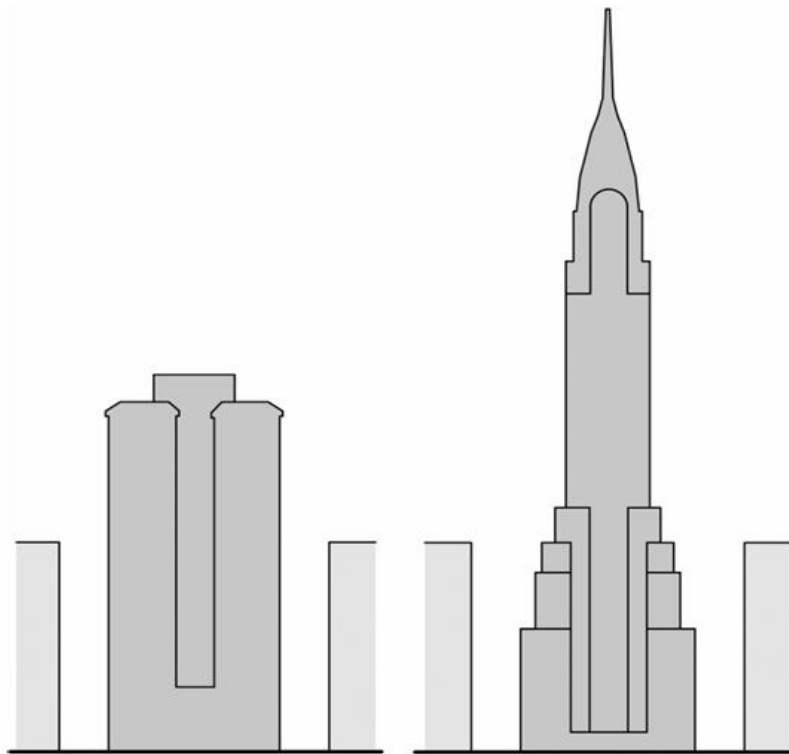
From an energy efficiency perspective, the increased surface-area-to-volume ratio of these stepped-back buildings had both advantages and disadvantages. On one hand, the greater exposure to daylight improved natural illumination, reducing reliance on artificial lighting and improving indoor environmental quality. On the other hand, the expanded façade area also led to greater heat loss in colder months and higher heat gain during the summer, particularly in buildings with large window openings. During this period, passive design strategies—such as thick masonry walls for insulation, operable windows for ventilation, and external shading devices—were still the primary means of temperature regulation, as mechanical heating and cooling systems remained relatively underdeveloped.

Despite these advancements, many second-generation skyscrapers continued to struggle with indoor air quality and temperature control, leading to the gradual adoption of early mechanical ventilation systems. By the 1930s and 1940s, centralized heating and cooling technologies began to emerge, allowing architects to experiment with deeper floor plates and more enclosed spaces. However, these systems were not yet widespread, and most high-rises still relied on a combination of natural ventilation and passive climate control techniques to maintain thermal comfort.

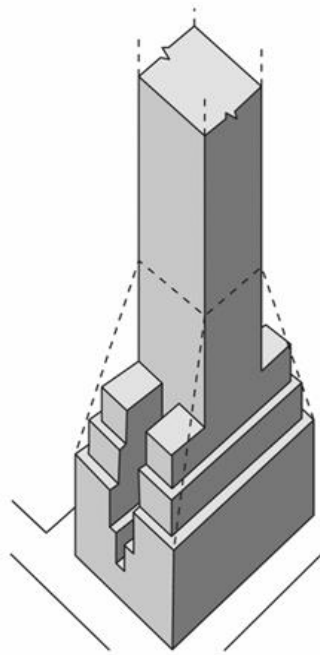
4. Main sustainable design strategies for high-rise buildings

By the early 1950s, the introduction of fluorescent lighting, air conditioning and glass curtain walls signaled the beginning of the third generation of high-rise buildings, where mechanized climate control began to replace passive ventilation as the dominant approach to indoor environmental management.

Nonetheless, the second generation laid the foundation for modern urban planning, zoning regulation, and the integration of daylighting strategies, shaping the way cities approached vertical growth and architectural sustainability.



Pre-Zoning Law
Building
New York City



Post-Zoning Law
Building
New York City

4. Main sustainable design strategies for high-rise buildings

“Towering, glazed office blocks became fashionable as company headquarters. . . . Glass curtain walls became the status symbol of confident companies and the silhouette of glass towers the sign of a prosperous city”.

Schittich et al., 2007, p. 30

The **third generation** of skyscrapers, lasting from the early 1950s to the 1973 energy crisis, was marked by unprecedented technological advancements in building systems, leading to radical changes in architectural design and energy consumption patterns. This era saw the widespread adoption of glass curtain walls, which fundamentally transformed façade transparency, daylighting and thermal performance. Unlike the massive masonry structures of previous generations, third-generation skyscrapers prioritized sleek, minimalist aesthetics, characterized by fully glazed exteriors, steel frames and deep-plan office layouts.

The shift toward fully glazed curtain walls was largely enabled by improvements in glass manufacturing, lightweight steel framing and HVAC (Heating, Ventilation, and Air Conditioning) systems. By the late 1950s and 1960s, high-rises became entirely dependent on mechanical climate control, moving away from the passive ventilation techniques of earlier generations. Air conditioning and fluorescent lighting became standard features, allowing for the creation of deep, open-plan office floors with high occupant densities.

However, the widespread use of glass curtain walls introduced significant energy inefficiencies. These façades, while visually striking, lacked proper thermal insulation, resulting in substantial heat gain during summer and heat loss in winter. Since these buildings were completely sealed, they relied entirely on mechanical ventilation systems, which drastically increased energy demand.

Additionally, skyscrapers featuring black or dark-colored cladding are particularly susceptible to high levels of solar absorption, leading to excessive heat gain during the summer months compared to buildings with brick or lighter-colored façades. As a result, these structures become heavily reliant on energy-intensive air-conditioning systems to maintain a comfortable indoor environment, significantly increasing cooling demand and operational energy consumption.

4. Main sustainable design strategies for high-rise buildings

Beyond the use of dark cladding materials, many of these buildings also incorporated bronze or dark-tinted glazing, which further compromised energy efficiency. Although these façades feature large glazed surfaces, the low light transmittance of dark-tinted glass restricts the amount of natural daylight reaching interior office spaces. This, in turn, leads to a greater dependence on artificial lighting, exacerbating primary energy consumption and reducing the overall sustainability of the building [Fig.48].

Material	Solar absorptance	Glazing colour (float glass, 6mm thick single glazing with no coatings)	Light transmission (%)
Flat black paint	0.95	Clear	88
Dark grey paint	0.91	Green	75
Red bricks	0.7	Bronze	50
Uncoloured concrete	0.65	Grey	44
Light buff bricks	0.6		
White semi-gloss paint	0.3		

Left: Solar absorption values for different coloured materials _ **Right:** Light transmission values for coloured and clear glazing (Source: *The sustainable tall building: A design Primer* – Oldfield Philipp)

Prominent examples of third-generation skyscrapers include the **Seagram Building** (1958) in New York [Fig.45], designed by Mies van der Rohe, which epitomized the International Style's focus on glass and steel minimalism. Similarly, the **John Hancock Center** (1969) in Chicago and the World Trade Center Twin Towers (1973) in New York demonstrated the era's emphasis on structural efficiency and architectural modernism. However, by the early 1970s, growing concerns over energy consumption and environmental sustainability began to challenge the viability of such energy-intensive designs, setting the stage for the fourth generation of high-rise buildings.

The 1973 oil crisis marked a pivotal turning point in skyscraper design, prompting a fundamental reassessment of energy consumption in high-rise buildings. As global fuel prices surged and concerns over energy security intensified, governments and architects began to implement stricter building regulations aimed at improving thermal efficiency and reducing reliance on fossil fuels. This period saw the transition from highly inefficient, fully glazed buildings to energy-conscious skyscrapers that

4. Main sustainable design strategies for high-rise buildings



Figure 45 - View on the large glazed facade of the Seagram Building

integrated passive design strategies, improved insulation and mixed-mode ventilation systems.

A major development during this era was the introduction of **double-glazed façades**, which significantly improved thermal performance and energy efficiency. Unlike the single-layer glass curtain walls of the third generation, double-glazed systems reduced heat loss in winter and minimized solar gain in summer, thereby lowering cooling and heating demands. Additionally, the incorporation of shading devices, external louvers and reflective coatings became more common, helping to control solar radiation and glare.

Despite these improvements, many fourth-generation skyscrapers remained heavily dependent on mechanical climate control, as the push toward fully integrated sustainable solutions was still in its early stages. Notable examples from this period include **Tour Elf** in Paris. Initially envisioned as a twin tower to the adjacent **Tour Fiat** ^[Fig. 46], completed in 1974, the project was later redesigned with a stronger emphasis on energy efficiency and ultimately completed in 1985. A comparison between these two buildings highlights key differences between third- and fourth-generation skyscrapers.

4. Main sustainable design strategies for high-rise buildings

The Tour Fiat represents a third-generation skyscraper, characterized by its monolithic, black granite-clad façade and deep floor plates, which limited natural daylight penetration due to the use of dark-tinted glazing. In contrast, the redesigned Tour Elf prioritized increased natural lighting for office occupants, achieved through the selection of high-performance glazing that offered improved light transmittance while maintaining insulation efficiency. This advancement reflected significant progress in façade technology, particularly in response to the energy crises, which prompted innovations in glazing materials and thermal performance.

The decline of black skyscrapers was not limited to the Tour Elf project but was a broader trend during this period. Buildings with dark-colored exteriors became increasingly unpopular, as they were recognized for their poor energy efficiency, particularly in relation to solar heat absorption and cooling demand. At the



Figure 46 - Tour Fiat on the left and Tour Elf on the Right, enhancing the original design of the Tour Elf

4. Main sustainable design strategies for high-rise buildings

peak of this trend in 1971, 17 black skyscrapers were constructed in major American cities. However, following the first energy crisis, this number dropped significantly, with only three black high-rises completed in 1976, and none the following year.

The **fifth and current generation** of skyscrapers represents the culmination of decades of innovation in sustainable design, energy efficiency and smart building technology. Unlike previous generations, where energy consumption was an inevitable byproduct of high-rise development, contemporary skyscrapers aim to minimize environmental impact while maximizing energy efficiency, resource conservation, and occupant well-being.

A defining feature of fifth-generation high-rises is their integration of bioclimatic design principles, which optimize building orientation, passive solutions and daylighting. Advanced façade technologies, such as double-skin façades, dynamic and kinetic facades and photovoltaic-integrated glazing, allow buildings to respond dynamically to environmental conditions, reducing reliance on mechanical heating and cooling systems. One of the most notable aspects of fifth-generation skyscrapers is their use of intelligent *building management systems* (BMS), which employ real-time data analytics, AI-driven automation and IoT (Internet of Things) connectivity to optimize energy consumption and enhance occupant comfort. Smart sensors regulate lighting and security systems based on occupancy patterns and external climate conditions, ensuring that resources are used efficiently without compromising functionality.

Several landmark skyscrapers exemplify the principles of the fifth generation. The Shanghai Tower (2015), as mentioned before, integrates a double-skin façade, sky gardens and a wind turbine system, reducing energy consumption by more than 50% compared to conventional high-rises. The Commerzbank Tower (1997) in Frankfurt, cited as the world's first ecological skyscraper, employs natural ventilation and green atria to create a low-energy office environment. The Burj Khalifa (2010) in Dubai incorporates passive cooling strategies and a condensate recovery system, showcasing how climate-responsive design can enhance energy efficiency in extreme environments.

The future of skyscrapers lies in fully self-sufficient, carbon-neutral developments, where tall buildings generate as much energy as they consume, actively contribute to urban ecosystems and enhance quality of life for their occupants.

4.5 A prime example of sustainable skyscraper: The Shanghai Tower

‘The Shanghai Tower establishes a new paradigm for tall buildings and vertical urbanism. Innovation and new technology play a strong role in the superlative aesthetic, structural, and environmental achievements of this “disruptive” building, while reinforcing timehonored maxims of design that still hold true.’

Source: Gensler.



View on the Shanghai Tower

4. Main sustainable design strategies for high-rise buildings

The Shanghai Tower, designed by Gensler and completed in 2015, represents a milestone in sustainable skyscraper design. As China's tallest building and the second tallest in the world, standing at 632 meters with 128 stories, it is a prime example of how contemporary high-rise architecture can integrate energy efficiency,

structural optimization and occupant well-being. The tower was conceived as part of a broader urban development strategy, responding to Shanghai's dense metropolitan environment, high wind loads and extreme climate conditions. Its design incorporates passive sustainability strategies, high-performance building systems and innovative material applications, setting a new standard for eco-friendly vertical urbanism.

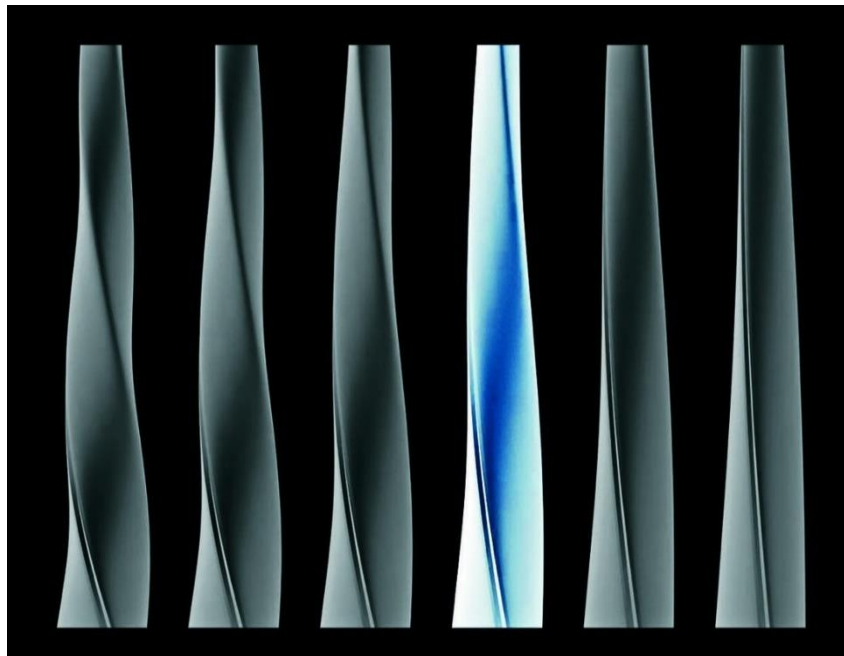


Figure 47 - Diagram of the spiral rotation of the design of the Shanghai Tower

One of the defining characteristics of the Shanghai Tower is its twisting, tapering form, which plays a crucial role in both aesthetic expression and structural performance.

Unlike traditional rectilinear skyscrapers, its **120° spiral rotation** ^[Fig.47] significantly reduces wind resistance, cutting down wind loads by up to 24%. This aerodynamic strategy minimizes lateral forces, thereby reducing the need for heavy structural reinforcement and decreasing material consumption, particularly in steel and concrete.

Shanghai's seismic activity and typhoon-prone climate necessitated an advanced damping system to mitigate wind-induced oscillations. The tower is equipped with a **1,000-metric-ton tuned mass damper** ^[Fig.48], strategically positioned near the top floors to counteract sway and improve overall stability. This system enhances

4. Main sustainable design strategies for high-rise buildings



Figure 48 - 1000 metric-ton tuned mass damper that would not only provide an extra guarantee of occupant comfort on the upper floors, but also serve as a tourist attraction

occupant comfort, ensuring that even at extreme heights, the building remains stable and resilient against external forces.

From the outset, Shanghai Tower was envisioned as one of the most sustainable and high-performing skyscrapers globally, designed to meet the Chinese Green Building Standard and achieve LEED Platinum certification. To accomplish this, the building incorporates 47 advanced energy-saving technologies, which, despite increasing the project's investment by 3% to 5%, deliver significant energy efficiency gains. Specifically, Shanghai Tower achieves an energy-saving rate of 54% above China's national efficiency standard and 22% above the American efficiency standard.

A series of active sustainability solutions have been integrated into the tower's design. These include:

- **A double-skin curtain wall**, which improves energy efficiency by 50% compared to conventional single-layer façades.
- **A combined cooling, heating and power (CHP) system**, supported by two dedicated energy centers located at Level B2 and Level 82.

4. Main sustainable design strategies for high-rise buildings

- **A wind turbine system** capable of generating 1.19 million kWh of electricity annually.
- **A greywater and rain water recycling system**, reusing 25% of wastewater for toilet flushing and landscape irrigation.
- **A sustainable materials strategy**, sourcing 92% of construction materials within an 800-mile (1,287 km) radius.
- **A waste management program**, ensuring 60% of construction waste is recycled or reused.
- **A high-efficiency LED lighting system**, equipped with automatic on/off controls and brightness sensors to optimize illumination and energy savings.

During its operational phase, the Shanghai Tower will continue to implement real-time monitoring and optimization of energy performance. The *Central Energy Management Control System* (CECS) integrates seasonal and time-based energy demand patterns to optimize operational schedules for mechanical systems. With the implementation of CECS, the building is expected to achieve an additional 10% to 15% reduction in energy consumption. Notably, Shanghai Tower represents the first large-scale deployment of CECS in a mega-tall, highly complex building worldwide, setting a precedent for intelligent energy management in high-rise architecture.

Additionally, The tower's façade-integrated ventilation system allows for natural airflow, reducing the need for artificial climate control. These elements, combined with high-performance glazing, contribute to a 53% reduction in overall energy consumption compared to conventional skyscrapers of similar scale.

Matter of fact, Shanghai Tower stands as a paradigm of smart building technology, seamlessly integrating cutting-edge digital advancements into its design and operation. Its construction coincided with significant breakthroughs in information technology, including cloud computing, the Internet of Things (IoT) and Building Information Modeling (BIM)—making it one of the first commercial high-rises to fully incorporate these innovations.

All of these systems are interconnected through an Internet Protocol (IP)-based transmission network, allowing for efficient communication and seamless data

exchange. A 10-GB backbone and a 1-GB IP network facilitate the operation of 90% of the building's intelligent subsystems, enabling Shanghai Tower to function as a fully responsive, energy-efficient, and technologically advanced smart skyscraper.

Beyond its structural and environmental innovations, The Shanghai Tower introduces an innovative approach to high-rise design by integrating the concepts of **"Vertical Community," "Community Square,"** and **"Sky Gardens."** The Vertical

Community concept reimagines the traditional horizontal urban layout by stacking functional zones into nine distinct vertical communities, each designed to offer private and shared spaces that enhance livability and connectivity.



Figure 49 - Rendered detail of the Community square between the layers of the double-skin facades

key element of this strategy is the Community Square, a unique participatory space situated within the 10-meter-wide interstitial zone between the layers of the double-skin façade [Fig.49]. Each vertical community is anchored by three sky lobbies, referred to as Community Squares, which vary in height between 50 and 60 meters. In total, the tower incorporates 21 Community Squares, which serve multiple purposes beyond facilitating energy efficiency, vertical circulation, fire safety, and life protection. These spaces are also designed to accommodate relaxation areas, social hubs,

observation decks, dining facilities, and financial services, thereby fostering a dynamic and interactive high-rise environment.

The Vertical Community concept is further reinforced through the integration of greenery at various heights, with flowers, trees, and landscaped gardens incorporated into the Community Squares. This approach enhances air quality, improves thermal performance, and promotes biophilic engagement, transforming the tower into a living ecosystem rather than a conventional commercial structure. The systematic introduction of community-oriented spaces, public squares, and sky gardens

4. Main sustainable design strategies for high-rise buildings

represents a pioneering step in skyscraper design, distinguishing Shanghai Tower as a global benchmark for vertical urbanism.

In alignment with its "*vertical mixed-use strategy*," the tower's functional zoning extends beyond traditional high-rise programs. In addition to a retail podium (Zone 1), office spaces (Zones 2–6), a luxury hotel (Zones 7–8) and an observation deck (Zone 9), the tower integrates versatile multi-use spaces that enrich the urban experience within the building. These include a public museum on the 37th floor, art galleries and lifestyle centers on B1, the 52nd, and 53rd floors, fitness facilities on the 22nd floor, as well as art exhibitions and cultural activity venues within the Community Squares. By embedding diverse amenities within its vertical framework, Shanghai Tower redefines skyscraper functionality, transforming it from a static architectural landmark into a self-sustaining, multi-dimensional urban environment.

4.6 Conclusions

The research of sustainability in high-rise architecture represents both a challenge and an opportunity for the future of urban development. As cities continue to grow vertically, the integration of sustainable design strategies and advanced technologies is crucial in minimizing the environmental impact of tall buildings while maximizing their efficiency and resilience. This chapter has explored a range of solutions, from the relationship between height and sustainability and passive design strategies to renewable energy integration and advanced structural systems, demonstrating how high-rise buildings can achieve significant reductions in operational energy demands and carbon emissions.

Despite the inherent challenges posed by increased energy consumption per unit area, limited access to solar and wind resources, and the evolving urban context, the potential for net zero energy performance in skyscrapers is becoming increasingly viable. However, achieving true sustainability in vertical architecture requires a total different approach—one that extends beyond individual buildings to embrace entire urban environment. Future developments must not only consider current environmental conditions but also anticipate changes in urban morphology, technological advancements and evolving sustainability standards.

4. Main sustainable design strategies for high-rise buildings

The success of sustainable high-rise architecture will depend on a paradigm shift in design philosophy—moving from isolated, self-sufficient towers to interconnected, energy-efficient urban ecosystems. Through integrated planning, adaptive design and the continuous refinement of sustainable technologies, the skyscrapers of the future have the potential to become not just symbols of human ambition, but key contributors to a more resilient and ecologically responsible built environment.

“Renewables are sexy but energy efficiency is not . . . the cheapest watt you can generate is the watt you avoid using.”

Tony Isaacs, from Hannam, 2018 ⁴⁴

⁴⁴ **Tony Isaacs** is a consultant specializing in energy efficiency and a former public servant who has contributed to the development of various energy assessment tools and building standards in Australia. He underscores his emphasis on prioritizing energy efficiency as a cost-effective strategy in energy management. This perspective highlights the importance of reducing energy demand through efficiency measures before investing in renewable energy generation.

5. Kinetic Façades: The Dynamic Skin of Future's Architecture

5.1 Introduction

“Our present task is to unfreeze architecture, to make it fluid, vibrating, changeable backdrop for the varied and constantly modes of life. An expanding, contracting, pulsating, changing architecture would reflect life as it is today and therefore be part of it”.

William Zuk & Roger Clark, *Kinetic architecture*, 1971.

“Deformation, juxtaposition, superimposition, absence, disturbance, and repetition are just a few of the techniques used by architects to express virtual motion and change”.

Kostas Terzidis.

The capacity of a built environment to dynamically respond to human desires holds transformative potential in shaping experiential quality. A substantial body of built precedents demonstrates the application of interactive systems designed to enhance emotional, social and pedagogical engagement. Within the public realm, artistic interventions—sculptures, fountains, and kinetic façades—increasingly incorporate interactivity as an intrinsic element, ensuring audience captivation through participatory engagement. The synthesis of interactivity and spatial adaptability proves particularly effective in accommodating transient exhibitions and evolving user interactions.

The incorporation of kinetic systems into the built environment carries significant implications for architectural aesthetics, design methodology and functional performance. As observed by architectural theorists: *"While the aesthetic value of virtual motion may always be a source of inspiration, its physical implementation in buildings and structures may challenge the very nature of what architecture really is..."* Crucially, adaptive design transcends mere utilitarian fulfillment. As architect Cheng-An Pan articulates: *"Needs and desires change, permitting new options to be employed, allowing greater freedom of geographical movement, accepting personal whim, recognizing changing roles and functions, encouraging personal identity,*

reflecting mutations in economic levels, and adapting to any change which affects architectural form.."

The ramifications of kinetic architecture extend beyond structural performance into the realm of phenomenological aesthetics. Emerging technologies—including artificial intelligence, autonomous robotics, and adaptive logistics—are poised to redefine infrastructural systems, necessitating architectures that embody circularity and dynamic responsiveness. This paradigm is not novel; historical precedents such as medieval drawbridges exemplify early adaptive structures, transitioning seamlessly between defensive barriers and accessible pathways. Contemporary architecture must now synthesize these principles with advanced technologies to address the ceaseless flow of human and environmental variables.

5.2 The Origin of the Dynamic Façades

The discourse on kinetic architecture and its application to building façades reveals a rich yet underexplored intersection of mechanical engineering, aesthetic theory and environmental responsiveness. While the conceptual foundations of kinetic design were laid as early as the 1970s by **William Zuk** and **Roger H. Clark**, who examined mechanical systems as solutions to spatial challenges, the architectural discipline has yet to fully develop a comprehensive framework for kinetic façades that respond dynamically to environmental stimuli. Jules Moloney's notion of "*kinetic composition*" provides a valuable lens through which to examine this gap, encompassing the interrelated elements of kinetic control, structural adaptability and active surface dynamics. However, despite its potential, the discussion remains largely confined to mechanical engineering, with limited translation into architectural practice.

The historical trajectory of kinetic design finds its roots in Franz Reuleaux's 19th-century mechanistic classifications, which proposed that optimal mechanical forms could be derived through systematic analysis of constituent parts. While these principles informed early kinetic arrangements, their application to contemporary architectural façades remains largely theoretical. This disconnect persists even as scholars like **Antonino Saggio** and **Jules Moloney** highlight the dual imperative of kinetic design: to negotiate between technological functionality and

5. Kinetic Façades: The Dynamic Skin of Future's Architecture

aesthetic intentionality. As Zuk observed, kinetic architecture demands an intrinsic sensitivity to motion itself—a principle vividly demonstrated in the works of kinetic artists such as **Reuben Margolin** and **George Rickey**: Margolin's "*Nebula*", a 45m installation in the air at Hilton Anatole Hotel, in Dallas, with its intricate cable systems

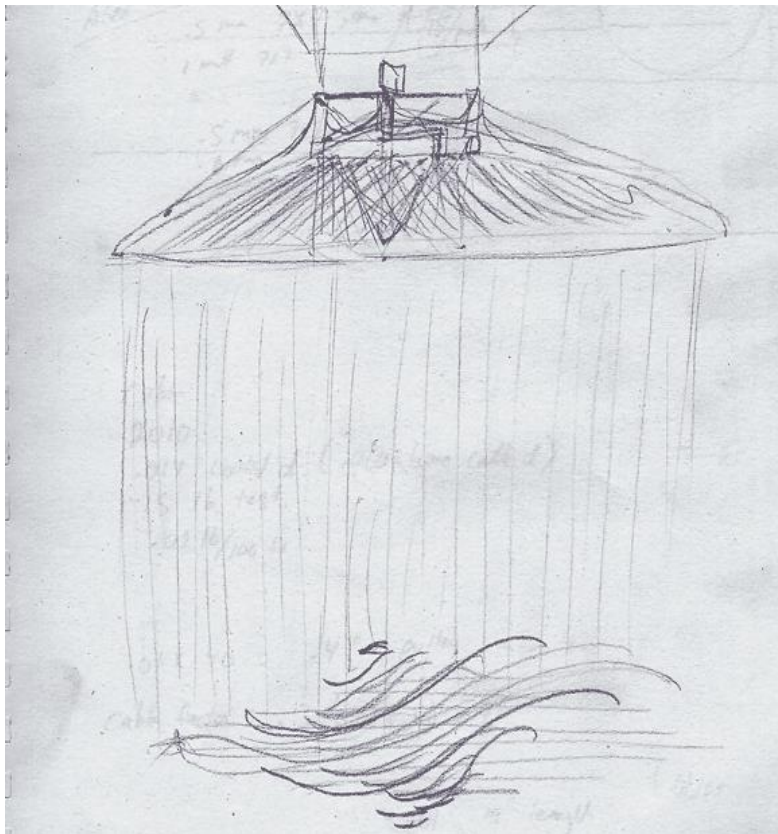


Figure 50/51 - Nebula installation (on the TOP) and its conceptual design (BOTTOM LEFT).

mimicking natural wave patterns, and Rickey's delicately balanced sculptures, activated by air currents and gravity, exemplify sophisticated kinetic composition. Yet, these works remain within the realm of artistic expression, prioritizing visual spectacle over architectural utility or environmental responsiveness.

[Fig. 50 - 51]

The transition from kinetic art to architecturally integrated systems has been gradual but significant. Projects like Asif Khan's "**MegaFace Pavilion**" [Fig.52] and Ned Kahn's "**Wind Arbor**" [Fig.53] demonstrate the potential for kinetic principles to bridge aesthetic and functional domains. Khan's interactive façade, composed of thousands of actuator-driven pistons, creates real-time volumetric representations of visitors, while Kahn's wind-responsive installation at Marina Bay Sands serves simultaneously as a solar shade and a dynamic visualization of airflow. These examples underscore the capacity of kinetic systems to operate at the intersection of environmental adaptation and spatial experience. However, they also reveal a persistent challenge: the absence of a coherent theoretical framework that systematically links kinetic mechanisms to architectural performance criteria.

This gap points to a broader need for the architectural discipline to develop a more rigorous approach to kinetic façade design, one that synthesizes historical mechanistic principles with contemporary advancements in materials science, computational design and environmental analysis. The iterative methodologies



Figure 52 - The MegaFaces pavilion – a 2000 sqm cube created for Russian telecom company Megafon – features a vast kinetic façade that contorts into 3D recreations of visitor's faces, relayed via digital scans made in nearby photo booths.

5. Kinetic Façades: The Dynamic Skin of Future's Architecture



Figure 53 - Wind arbor, a facade of a hotel lobby in Singapore covered with a cable net structure composed of a half a million hinged element

employed by kinetic artists—prototyping, material testing, and pattern abstraction—offer valuable models for architectural experimentation, suggesting a pathway toward more responsive and adaptive built environments. The evolution of kinetic façades will depend on the discipline's ability to reconcile the aesthetic dimensions of motion with the practical demands of performance, durability and environmental integration.

Although various kinetic patterns are employed in the design and aesthetic expression of kinetic facades, the continued exploration and classification of motion mechanisms responsive to environmental stimuli remain essential. Kinetic design serves a pivotal function in the development of adaptive building envelopes that dynamically interact with fluctuating external conditions. Despite the seemingly straightforward appearance of kinetic systems, their effective implementation to achieve appropriate environmental responsiveness entails considerable complexity.

Existing literature and case studies reveal multiple manifestations of kinetic motion, including *folding*, *expanding*, *sliding*, *shrinking*, and *transforming*. While the terminology used to describe these movements may be various, the underlying behavioral principles of motion in kinetic facade applications often exhibit significant similarities.

Pavilion 67, designed by Buckminster Fuller in 1967, stands as an early exemplar of kinetic architecture applied to environmental adaptation through scaling mechanisms. The structure incorporates a self-regulating shading system equipped with sensors and actuators, enabling thermostatic control of interior conditions. Serving as a large-scale prototype, the pavilion embodies Fuller's conceptualization of buildings as "*environmental valve*" mediating energy, light, air, and moisture exchange while delineating interior and exterior boundaries.

The hexagonal panels are embedded with light sensors, dynamically adjusting to solar variations to mitigate direct exposure while optimizing transparency. Although some accounts attribute the shading system to computerized control, evidence suggests it operated primarily through direct solar responsiveness rather than programmed feedback. A technical analysis by George F. Eber during Expo 67 details the system's mechanics: "*consists of mechanically actuated, triangular sunshades controlled by 600-odd motors (one mounted over the center hub of each group of three interior hexagonal frames). The sun's rays striking it at a predetermined angle activate each of the motors. When the motor goes into action, it starts to pull at three sets of cables (six cables per set). These cables, in turn, are wrapped around window-shade-type rollers overlaid on the interior hexagons.*" [Fig.54]

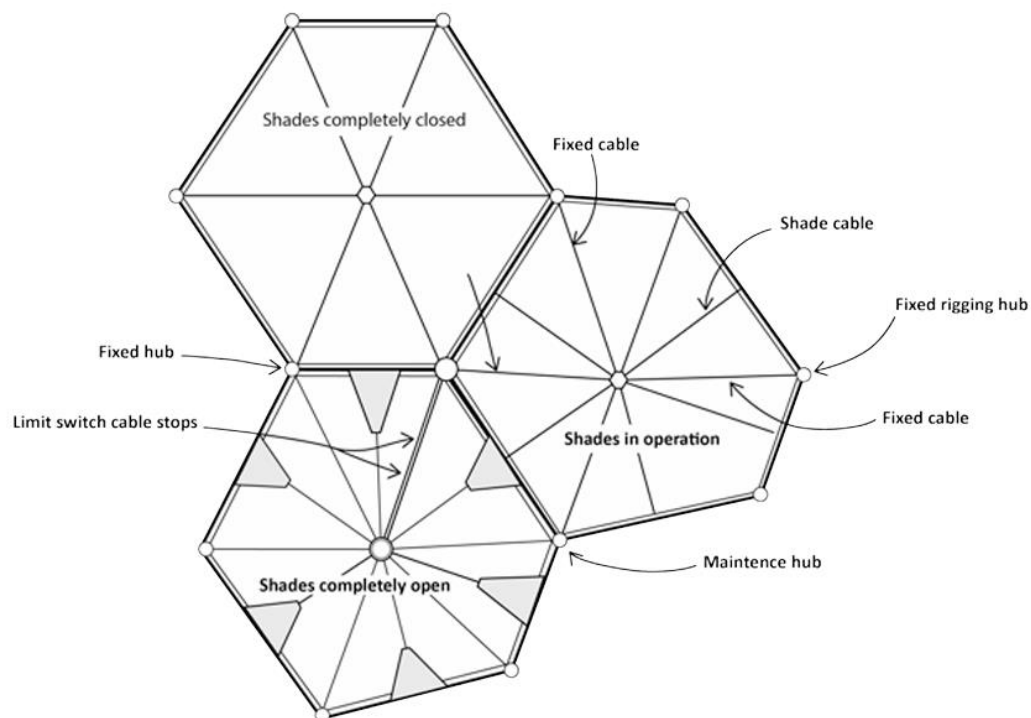


Figure 54 - Design of the facade of the US Pavilion in the Expo 67, Buckminster Fuller, 1967 (Source: Author of the book "Kinetic Facades: Towards design for Environmental Performance")

5. Kinetic Façades: The Dynamic Skin of Future's Architecture

Fuller's design integrated centralized computer coordination, permitting system-wide recalibration six times daily to align with solar trajectory. His pioneering vision of an environmentally adaptive architectural skin was technologically advanced for its era, yet its principles align with contemporary feasibility.

The kinetic facade of the **Institut du Monde Arabe** (1987), designed by Jean Nouvel, presents a similarities to the kinematic principles first explored in Buckminster Fuller's US Pavilion at Expo 67. While differing substantially in scale and cultural context, both projects share a fundamental approach to environmental responsiveness through mechanized architectural surfaces. The Institut du Monde Arabe exemplifies this through its sophisticated arrangement of approximately 25,000 light-sensitive diaphragms, each functioning with precision comparable to a camera's iris mechanism.

The southern facade of the building features a designed 24×10 matrix of square modules, each containing a complex arrangement of circular and rectilinear shutters. This geometric configuration draws direct inspiration from traditional Arab *mashrabiya* screens, reinterpreting their passive environmental modulation through contemporary kinetic technology. As Moloney (2006) observes, the facade's kinetic behavior primarily manifests through rotational movements of these shutters, creating dynamic patterns of aperture and closure that produce visually striking scaling effects across the building's surface.

The system's operation generates a pulsating rhythm of contraction and expansion across the facade, with the shutters' coordinated movements creating a continuously transforming architectural skin. This kinetic performance was originally designed to respond in real-time to varying light conditions, theoretically optimizing interior illumination while providing solar protection. However, post-occupancy evaluations reveal significant operational challenges, with many of the kinetic components having ceased functioning over time. [Fig.55]

This operational failure highlights a critical consideration in kinetic architecture: the inherent tension between mechanical complexity and long-term durability. The case of the Institut du Monde Arabe underscores how even meticulously designed kinetic systems face substantial challenges in maintaining functionality over a building's lifespan. This raises important questions about the practical implementation

of responsive architecture, particularly regarding maintenance requirements, mechanical wear and the integration of moving components with static building systems.

Furthermore, the project's technological ambition must be contextualized within its historical moment. Designed in the 1980s, the facade represented a remarkable feat of architectural innovation, pushing the boundaries of what was technically achievable at the time. The system's partial failure in subsequent years speaks not to flawed design principles, but rather to the rapid evolution of building technologies and changing expectations regarding architectural performance and maintenance.

The *Institut du Monde Arabe* thus occupies a significant position in the history of responsive architecture. It serves simultaneously as a groundbreaking achievement in kinetic design and as a cautionary case study about the practical challenges of maintaining complex mechanical systems in architectural applications. Its legacy continues to inform contemporary discussions about sustainable design, adaptive building skins, and the integration of advanced technologies in architecture.

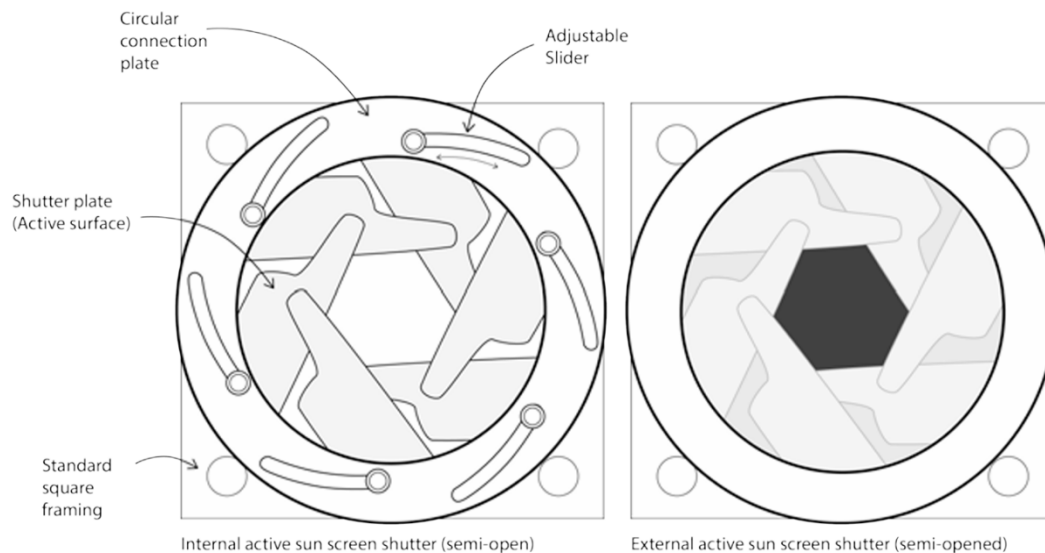


Figure 55 - Kinetic Shutter panel of Institute Monde Arabe, Jean Nouvel (Source: Author of the book "Kinetic Facades: Towards design for Environmental Performance")

Kinetic facades represent one of architecture's most fascinating technological advancements, blending traditional design principles with cutting-edge engineering. A prime example is **Abu Dhabi's Al Bahr Towers** (2012), where Aedas Architects created a dynamic reinterpretation of the classic Islamic mashrabiya screen.

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Imagine 1,049 hexagonal panels gracefully opening and closing across the twin towers' 150-meter facades - it's like watching a giant, intelligent organism breathing in response to the desert sun. The system operates through three elegant positions: fully closed for maximum shade, partially open for balanced light, and fully open for views and ventilation. However, behind this technological marvel lies a cautionary tale. The complex piston mechanisms, while impressive, face significant challenges in Abu Dhabi's harsh climate - from mechanical wear to substantial maintenance needs. What's particularly interesting is how this project highlights the delicate balance architects must strike between innovation and practicality. Yes, we can create buildings that move and adapt, but at what cost? The energy required to operate these systems, combined with their long-term reliability issues, raises important questions about their sustainability. That's why, combined with the right sustainable techniques, it's considered as a stunning improvement.

Yet despite these challenges, Al Bahr Towers remain a groundbreaking project, pushing the boundaries of what architecture can do while teaching us valuable lessons for future kinetic designs. Perhaps the real innovation will come when we develop systems that maintain this responsiveness while being as durable and low-maintenance as traditional building elements. [Fig.56]

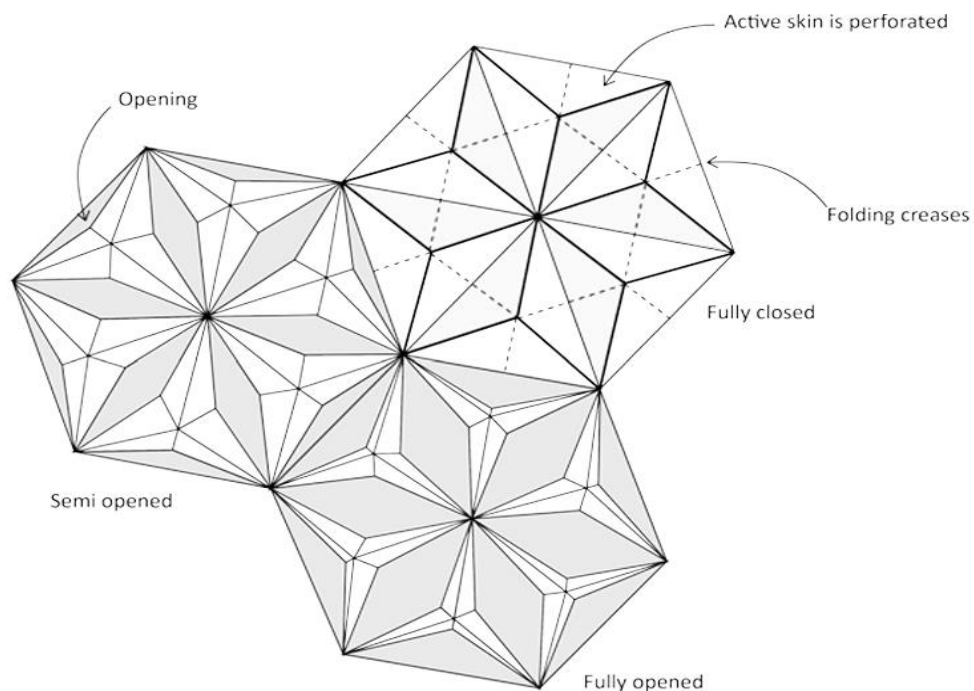


Figure 56 - Abu Dhabi's Al Bahr Towers kinetic facades panels, AEDAS Architects (Source: Author of the book "Kinetic Facades: Towards design for Environmental Performance")

This project will be studied more deeply in the next subchapter “case studies” to have a complete idea and information on it.

Before speaking about the principles of the dynamic and kinetic facades, we can say that the design of kinetic facades has evolved far beyond static architectural elements, becoming an increasingly sophisticated process that responds to ever-changing environmental conditions. Today's facade systems are no longer mere barriers between interior and exterior spaces, but active, intelligent interfaces that dynamically interact with their surroundings. This paradigm shift has transformed how we approach facade design, requiring architects to consider complex systems of sensors, actuators and control mechanisms rather than just materials and aesthetics.

At the heart of this transformation lies the integration of cutting-edge technologies like **Wireless Sensor Networks (WSN)**, **Internet of Things (IoT)** and **Artificial Intelligence (AI)**. These systems turn buildings into responsive organisms - imagine tiny sensory modules embedded throughout the facade, constantly monitoring environmental conditions like sunlight intensity, temperature, and wind patterns. When paired with actuators and smart programming, these sensors enable facades to adapt in real-time, adjusting shading elements or ventilation openings automatically.

What makes modern kinetic facades particularly remarkable is their ability to handle complex, dynamic conditions through the seamless integration of multiple systems. Mechanical components work in concert with electronic controls, while advanced material systems contribute to both functionality and aesthetics. The result is architecture that doesn't just stand against the environment, but engages with it in an ongoing dialogue - opening here, shading there, constantly optimizing building performance while creating ever-changing visual effects.

However, this technological sophistication comes with its own set of challenges. Designers must now consider not just the physical form, but the entire ecosystem of sensors, control algorithms and mechanical systems that bring kinetic facades to life. It's a multidisciplinary endeavor that blends architecture with robotics, materials science, and computer programming - pushing the boundaries of what buildings can do while raising important questions about maintenance, energy use and long-term reliability.

As we continue to develop these responsive building skins, we're not just creating smarter facades - we're redefining the very relationship between architecture and its environment. The buildings of tomorrow won't just occupy space; they'll actively negotiate with sunlight, wind, and temperature to create optimal conditions inside while presenting a dynamic face to the world outside.

5.3 Typology of Façades

In the current era, the rapid diffusion of knowledge and the accelerating transformation of social dynamics demand a more adaptable and responsive architectural paradigm. Buildings must be conceived with inherent flexibility to accommodate the evolving requirements of an increasingly mobile and service-oriented society. This flexibility must extend beyond the mere functional adaptability of completed structures to encompass the entire lifecycle—from conceptualization and design to planning and construction management. The integration of emerging technologies, including artificial intelligence, autonomous systems and robotics, along with the evolution of mobility and logistical infrastructures, is set to redefine the nature of architectural production. In light of these developments, it becomes necessary to envision future architecture as resilient and transformable systems, capable of operating within a circular life cycle and dynamically engaging with the ever-changing flows of societal and technological advancement.

The desire for more adaptive buildings that are able to accommodate the perpetual flux of life by providing corresponding flexible structures is not a new idea. The drawbridges of medieval castles, for example, were already able to actively change function from being part of the defensive walls to being a means of passage.

The concept of “*adaptivity*” is frequently paired with the notion of *changeability*; however, its implications extend further to encompass the ability to respond actively to external stimuli. Within the realm of architecture and construction, such responsiveness can be manifested across multiple scales: the material, the physical performance of the building and its structural configuration. In this context, adaptivity means a comprehensive and integrative design methodology where in architecture is **not merely conceived as a static end-product, but rather as an evolving spatial**

process. This perspective unites traditional understandings of adaptability with the levels described above.

Two primary motivations underpin the advancement of adaptive architecture. The first involves the potential to significantly reduce material consumption through the deployment of self-regulating systems. Rather than relying on additional mass or static components to resist environmental forces or enhance performance—such as thermal insulation or structural reinforcement—adaptive mechanisms utilize transient energy inputs to achieve similar or improved results, thereby preserving scarce natural resources; the second motivation shifts the focus of architectural planning towards the users themselves, ensuring comfortness and wellness. Adaptive architecture aspires to tailor spatial environments in direct response to the occupants' individual preferences and needs, making human-centered design a central pillar of this innovative approach.

The movable elements integrated into adaptive facades constitute the primary mechanism through which buildings respond to fluctuating environmental conditions and evolving user needs. These components bring architecture to life, imbuing it with kinetic qualities that enable physical transformation. The design of such facades necessitates a deep comprehension of the interdependent relationship between functional performance, material characteristics, geometric form, environmental context and architectural expression. Achieving this synthesis calls for advanced technical expertise and interdisciplinary coordination.

The successful realization of an adaptive facade relies not only on accurately sizing its mobile components and selecting construction methods suited to the intended function but also on the detailed specification of materials, surface finishes and connection techniques. Equally crucial is the precision achieved in the fabrication and assembly phases, as even minor discrepancies can compromise the facade's operational integrity and performance over time.

Adaptive facades can be classified typologically in terms of their:

- Methods and mechanisms of movement;
- Operating and control modes and user interfaces;
- Dimension or scale;

- Materials and surfaces.

In architectural applications, motion systems are commonly realized through mechanical elements such as hinges and actuators, which may function with or without integrated gearing systems. These mechanisms play a critical role in determining not only the functional efficiency of a dynamic component, but also the extent of its maintenance requirements over time. Depending on the design intention and operational context, components may be actuated manually, mechanically, through mechatronic systems, or powered by electric motors, either as individual units or in coordinated clusters. Control strategies vary in complexity, ranging from manual operation to automated or regulated systems, and may govern movement across a single axis, a designated interior zone, an entire floor or the full facade envelope. The interface used to activate or adjust these systems—whether it be a physical handle, switch, touchscreen, or more advanced modalities like voice commands, gesture recognition, or facial identification—significantly influences user interaction and operational intuitiveness. Moreover, the choice of materials and surface treatments applied to these components greatly affects their performance characteristics. These include levels of optical transparency or translucency, as well as their permeability to air, humidity, and smoke, and their capacity to mediate the transfer of heat and solar radiation. The precision of material processing and the methods used for joining elements are therefore fundamental to the functional and environmental performance of dynamic facades.

Adaptive facades can be classified typologically into **agile**, **dynamic** and **mobile** facades.

Responsive facades, or the so called ‘*agile facades*’, are systems inherently complex and designed to respond autonomously to fluctuating environmental conditions as well as to the specific needs of individual users. They are composed of numerous interconnected components that interact dynamically, often utilizing similar movement strategies and mechanical principles as those found in conventional dynamic facades. However, their actuation and control mechanisms are significantly enhanced by the opportunities offered through digital transformation. This evolution also extends to user interfaces, which have become increasingly sophisticated and cost-effective due to advances in digital integration.

Today, embedding digital technologies—such as microchips, sensors, and cameras—into previously non-digital objects has become economically viable. These enhanced physical systems can now integrate microcontrollers, communication modules, identification systems, sensors and actuators, all of which can exchange data through short-range communication protocols such as **NFC** (Near Field Communication), **RFID** (Radio-Frequency Identification), **WLAN**, or via cellular networks. Moreover, their functionality can be expanded or customized over time through software updates, allowing for post-installation reconfiguration and personalization.

Agile systems, in particular, are characterized by the incorporation of subsymbolic or neural-based artificial intelligence⁴⁵. These architectures consist of multiple semi-autonomous subsystems—such as digitally augmented physical components, often referred to as “digicals”—which operate collaboratively. Through distributed signal processing and real-time data exchange, these elements are capable of responding instantaneously to environmental stimuli, enabling the system to behave in an adaptive and coordinated manner.

These systems are capable of operating with a high degree of flexibility, initiative, and adaptability. They not only respond reactively to environmental stimuli, but also act in a proactive and anticipatory manner. Each component possesses the capacity to learn autonomously—not only from its own interactions and experiences, but also through communication and knowledge exchange with other elements in the system. Research increasingly reveals that both biological organisms and advanced technical systems operate based on comparable principles when engaging with their surroundings. The effectiveness of such systems is significantly enhanced by the amount and quality of information gathered regarding building performance and user behavior—whether based on general user groups or individualized patterns. This data can be instrumental in optimizing current operational strategies and guiding the development of future products and intelligent control systems.

⁴⁵ **Subsymbolic or neural-based artificial intelligence** refers to a category of AI systems that do not rely on explicitly programmed symbolic logic (e.g., rules or if-then statements) to process information, but instead operate through **data-driven learning and pattern recognition**, often inspired by the **structure and function of the human brain**.

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Due to the decentralized nature of agile systems, each component can function independently, allowing for context-specific decisions about which elements operate simultaneously, and in what configurations. These decisions may be driven by functional demands or aesthetic intentions, thereby enabling entirely new architectural expressions. Control systems can be programmed to follow predetermined sequences—such as choreographed movements⁴⁶—or they can respond dynamically and in real time to changing internal or external conditions. Furthermore, the variation of natural light throughout the day and the use of artificial illumination at night, including changes in light angle, intensity, and color, can be harnessed as integral design features to enrich the architectural experience.

On the other side, **Dynamic facades** offer significant benefits, primarily due to their ability to adjust in real time to fluctuating weather conditions. Although they may employ similar materials, movement types, and mechanical systems as responsive facades, dynamic systems are typically characterized by smaller-scale components and lighter structural elements. These movable parts are most often motorized and programmed to react automatically to external environmental changes.

The extent to which users are allowed to override automated controls can greatly influence not only user comfort and satisfaction but also the building's overall energy performance—particularly in terms of heating, cooling, or natural ventilation. Moreover, the physical positioning of these movable elements—whether embedded within the facade layer or located on its interior or exterior surfaces—has implications for both the functional behavior and the aesthetic qualities of the facade. It also affects operational aspects such as ease of maintenance, cleaning frequency, and the long-term durability and efficiency of the system.

To function optimally, the building must possess real-time awareness of both its internal condition and the surrounding environment. This is achieved through intelligent control systems that analyze contextual data to determine the most

⁴⁶ Rather than reacting spontaneously to environmental stimuli, choreographed systems **execute movements in a controlled and harmonious manner**, often based on programmed scripts that consider factors like time of day, season, or desired visual impact. This concept transforms facade operation into a form of **architectural performance**, enhancing both user engagement and spatial experience.

appropriate adaptive response. These systems are capable of responding not only to predictable environmental inputs—such as solar trajectories—but also to irregular and unforeseen factors, including dynamic weather patterns and unexpected human occupancy beyond regular operating hours.

Two alternative approaches exist, which can also be used in combination:

- The building is equipped with sensors for external as well as internal conditions and has an access control system on a personal and possibly room level.
- The control system is connected via the internet to regional weather forecasts and to the GPS of the smartphones of a building's possible users.

As a rule, the subsystems that constitute the building envelope and the building services are interdependent and function together as a cohesive system. The various elements of dynamic facades are typically mechanically linked along specific axes, rooms, floors or entire facades, and are powered by electric drive systems in coordinated groups. This configuration allows for a range of functional and visual effects. Consequently, the manner in which the movable components of the building are connected plays a significant role in shaping the architectural aesthetic, as well as its symbolic or iconic representation.

5.4 Impact on the comfort and sustainability

With rising environmental consciousness and technological advancement, the facade has become an active interface that can intelligently manage daylight, thermal loads, air movement, and even energy generation. The comfort and sustainability gains of such kinetic systems are evident not only in theoretical studies but also in empirical experiments and practical applications documented across various projects and scholarly research.

From a comfort standpoint, dynamic facades significantly improve interior environmental quality by regulating daylight penetration and thermal conditions. According to **Kamil Sharaidin's** *Kinetic Facades*, the kinetic response—movement triggered by environmental changes like light intensity or heat—enables a façade to

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self-adjust in real-time. For instance, systems with photo-resistors and temperature sensors can detect excessive solar radiation and activate shading elements to reduce glare and overheating, thereby optimizing visual and thermal comfort. This is particularly impactful in climates with intense solar exposure, such as those found in North Africa or the Middle East. Sharaidin's empirical testing through both digital simulations (e.g., Autodesk Ecotect) and full-scale prototyping underscores how kinetic designs can dynamically control daylight levels and interior temperatures, achieving not only energy efficiency but also occupant satisfaction. The experiments demonstrated that kinetic facades with programmable elements like rotating panels or inflating membranes could maintain interior illuminance within acceptable visual comfort thresholds while minimizing reliance on artificial lighting.

The sustainability implications of such responsive behavior are equally profound. Energy consumption in tall buildings—especially due to HVAC systems and artificial lighting—means a significant portion of global emissions. By employing kinetic facades that actively manage solar heat gain and natural lighting, buildings can drastically reduce their dependency on mechanical systems. For example, kinetic facades with shape memory alloys or pneumatic actuators can open or close in response to external temperatures, functioning as passive thermal regulators. This adaptability reduces both cooling loads during summer and heating demands in winter. The dynamic nature of the facade essentially converts the building skin into a performative system, not just a static barrier. Sharaidin's full-scale prototype studies, including thermal reticulation testing, revealed that adaptive facades could modulate indoor temperatures with remarkable consistency, contributing to long-term operational energy savings.

One notable example is the use of shape memory alloys (SMAs), which alter form based on thermal stimuli, enabling seamless movement without traditional motors or actuators. These materials imbue the facade with a form of embedded intelligence, allowing the skin to “learn” and “remember” environmental conditions. Projects like *HygroSkin* from the ICD University of Stuttgart ^[Fig.57], which uses the hygroscopic properties of wood to react to humidity levels, show how materials can serve both structural and responsive functions. Such integration of material behavior and environmental interaction enhances the sustainability profile of the architecture while maintaining simplicity and elegance in movement.



Figure 57 - HygroSkin from the ICD University of Stuttgart

The performance of kinetic facades is not merely limited to heat and light control but extends to psychological comfort and emotional engagement. The poetic choreography of moving architectural components introduces a new layer of spatial and experiential dynamism. Buildings like Jean Nouvel's *Institut du Monde Arabe* or the *Al Bahar Towers* exemplify this phenomenon. In both, dynamic mashrabiya-inspired elements respond to solar conditions throughout the day, creating ever-changing patterns of shadow and light while recalling traditional Arab architectural motifs. Such contextual sensitivity not only enhances thermal comfort but also fosters cultural resonance and visual delight—factors that greatly influence occupant well-being.

Despite these advantages, the implementation of kinetic facades is not without challenges. Issues such as mechanical complexity, cost, long-term maintenance, and reliability remain significant barriers to widespread adoption. Moreover, post-occupancy evaluations are critical yet underreported in current literature, which makes it difficult to quantify the full lifecycle benefits of kinetic systems. Nevertheless, the evolution of soft robotics, responsive textiles and modular kinetic components suggests that future facades will be increasingly adaptable, cost-effective, and user-friendly. These developments can potentially offset the initial capital investment by improving energy performance and occupant productivity over the building's life.

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The synergy between comfort and sustainability in kinetic facades lies in their capacity for contextual adaptability. As Sharaidin argues, **performance-based design** is key: facades must be conceived not as artifacts but as processes, dynamically engaging with their environmental and cultural surroundings. By using multi-performance criteria—simultaneously evaluating daylight, thermal response, aesthetics, and constructability—designers can make informed decisions early in the design phase. Rapid prototyping combined with digital simulation empowers architects to test hypotheses, iterate solutions, and achieve optimized outcomes. This methodological rigor is essential for bridging the gap between experimental design and practical implementation.

In conclusion, dynamic facades represent a transformative approach to sustainable architecture, where performance, comfort, and aesthetics converge. By adapting to environmental stimuli through kinetic movement, these systems mitigate energy consumption, enhance indoor comfort, and elevate architectural expression. As technologies evolve and interdisciplinary tools become more accessible, kinetic facades will likely become integral to sustainable design paradigms in urban environments.

5.5 Case Study

This section examines examples of buildings that incorporate facades capable of dynamically responding to environmental and climatic conditions, enhancing energy efficiency and interior comfort. Dynamic facades, with their ability to adapt to changing weather conditions, represent one of the most promising solutions for sustainable architecture, reducing energy consumption and increasing the resilience of buildings. Through the study of these cases, the potential of such solutions for the design of modern and sustainable towers will be explored, with a focus on construction strategies and environmental impacts.

5.5.1 Al Bahr Towers, Abu Dhabi

When seeking innovative designs for skyscrapers, both nature and culture consistently serve as key sources of inspiration. The **Al Bahar Towers** exemplify this

dual influence. The integration of an advanced detection system was designed to align the building with its cultural surroundings while addressing the specific demands of the local climate. *The mashrabiya screens*, a traditional form of wooden lattice shading, are deeply rooted in the Islamic architectural heritage of the Middle East. Additionally, the dynamic motion of each individual screen mirrors the natural response of indigenous plants to the shifting position of the sun. The architects employed advanced parametric modeling techniques and algorithms to support their design process, enabling them to fine-tune the concept through computational tools while maintaining the ambitious vision of the project.

Design teams are often confronted with the significant challenge of creating buildings that provide users with the necessary comfort in an efficient and cost-effective way, all while adapting to a constantly evolving environment. Over the past twenty years, the use of exposed glass has become predominant in the facades of both conventional and iconic office towers, particularly in the Persian Gulf region. This trend has set the standard for client and user expectations, largely driven by local governmental support and encouragement. Consequently, altering these expectations and educating the market will take time. The design team at Aedas regarded the implementation of the dynamic mashrabiya screen as a move away from the prevalence of fully transparent glass facades and a step toward reconsidering this commitment to transparency.

The design brief for the towers was driven by the ambition to create a structure that would embody the values of the Abu Dhabi Investment Council (ADIC), which occupies one of the buildings, while simultaneously using a contemporary architectural language that honors the cultural traditions. The design concept for the Al Bahr towers is built upon three main pillars: Islamic and regional architecture, sustainable technology and inspiration drawn from nature.

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Figure 58 - View on the Al Bahr Towers with the dynamic facades, Aedas Architects

The design carefully avoids both the superficial imitation of traditional styles and the direct replication of natural systems, instead seeking to reinterpret and integrate some of these time-tested sustainable strategies while adopting bio-inspired approaches to enhance the building's performance.

The strength of the concept lies in the computational algorithm, which integrates various design principles and translates them into a performance-driven form, coupled with an automated system capable of adjusting to the dynamic environment.

The geometric design of the towers is based on the intersection of infinite combinations of circles (2D) and spheres (3D), generating an endless array of nodes that, when connected, follow a mathematical logic.

The core structure of the towers is composed of a honeycomb pattern, applied uniquely to enhance efficiency and redundancy. The envelope features a series of smart, folding kinetic shading elements that serve as a protective layer over the weathering glass skin, preventing excessive solar heat gain. A transparent glass curtain wall forms the outermost layer, providing weatherproofing, while a secondary layer consists of automated, intelligent shading components. These components open and close via centrally located linear actuators, linked to a computerized control system that tracks the sun's path.

The shading screen functions as a dynamic mashrabiya, effectively reducing solar heat gain and glare while enhancing visibility. Unlike dark-tinted glass or blinds, which can obscure the view, this system avoids such distortions. It intelligently distributes natural diffused light, optimizes artificial lighting usage through dimmers connected to sensors, and lowers air-conditioning loads. In doing so, it contributes to a significant reduction in overall energy consumption, carbon emissions, and the size of mechanical rooms.

The dynamic mashrabiya is a unique kinetic shading system composed of triangular units, each divided into six triangular flat frames that fold like an umbrella at different angles. This creates fins and louver-like geometries in multiple directions and positions. The design was inspired by natural adaptive mechanisms found in leaves, flowers, and skin spikes, which open and close in response to environmental changes, particularly sunlight. The flexible and intelligent folding geometry was meticulously

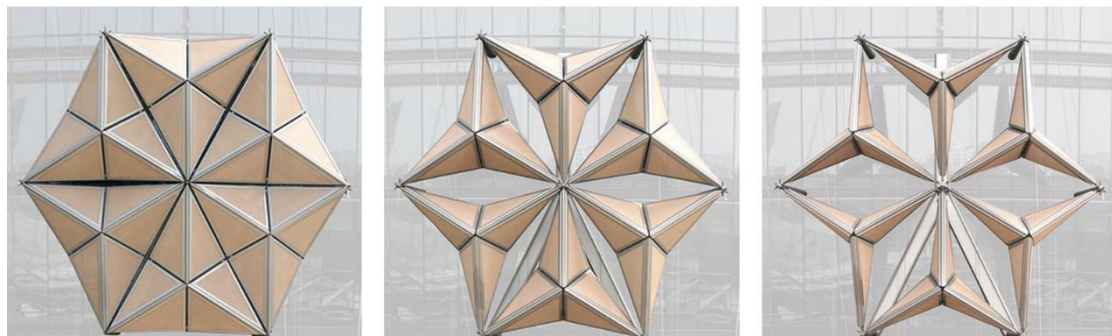
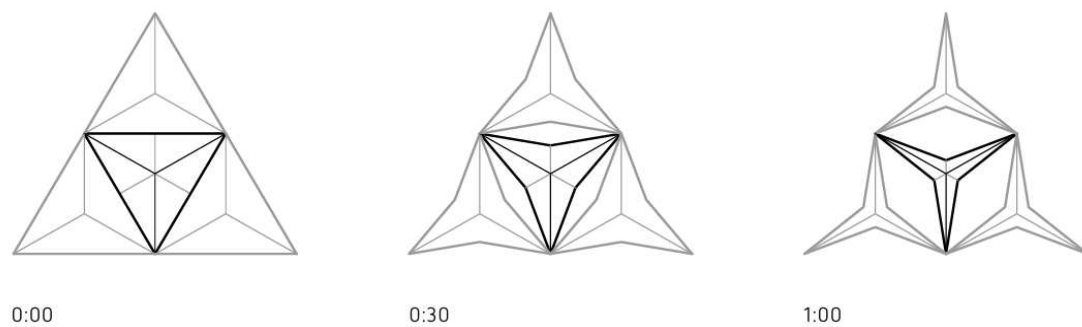


Figure 59 - Opening sequence of a sun screen module and the timing of the whole operation.

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developed to address the limitations of traditional vertical and horizontal louvers, especially in the context of geometrically complex buildings.

Each tower is equipped with 1,049 mashrabiya units positioned along the east, south, and west façades, while the north face—being naturally shaded from direct solar exposure—remains uncovered. When direct sunlight strikes a particular section of the façade, the mashrabiya elements in that zone automatically transition into their deployed, or closed, configuration, effectively shading the underlying

glazing system. As the sun progresses along its daily path, the individual mashrabiya modules gradually retract.

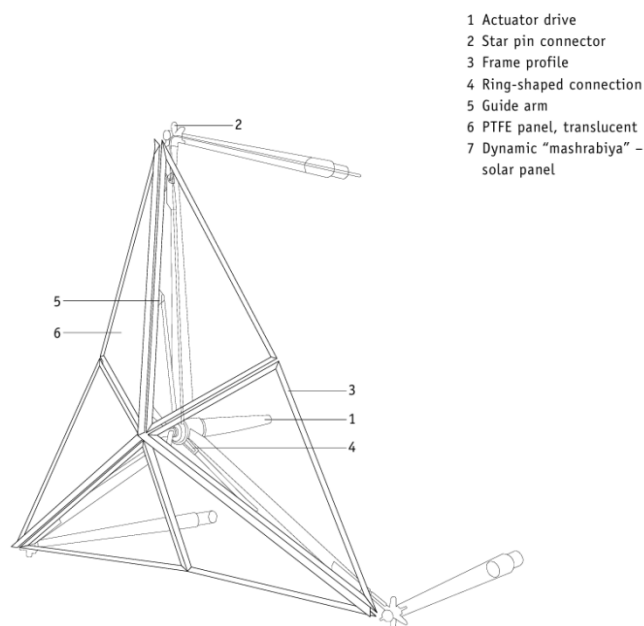


Figure 60 - Detail on the single sun screen element.

The movement of each unit is powered by a centrally positioned electric screw-jack linear actuator, engineered to operate reliably in harsh, sand-laden environments. With a stroke length of up to 1,000 millimeters, the actuator enables the mechanism to fold efficiently, achieving an open area ratio of up

to 85 percent. Each floor provides the necessary electrical supply for both actuators and control units. Communication between the central control system and the actuators is facilitated through a dedicated Ethernet network, utilizing Programmable Logic Controllers (PLCs) and Supervisory Control and Data Acquisition (SCADA)

protocols⁴⁷. To maintain a streamlined and discreet appearance, power and data cables are routed internally through the structural struts and Y-shaped support arms.

The responsive façade offers a range of significant benefits, particularly in enhancing the quality of the indoor environment for occupants. These include increased access to natural daylight, unobstructed external views, a reduction in the need for traditional blinds, enhanced thermal comfort through diminished reliance on air-conditioning systems, and the added value of an architecturally dynamic and visually engaging feature. Beyond improving user experience, the dynamic facade system contributes notable advantages at the building scale: it achieves up to 20% overall energy savings (with office spaces seeing savings of up to 40%), reduces carbon emissions by 20%, lowers plant capital expenditure by approximately 15%, and has supported the achievement of LEED Silver certification.

Moreover, the integrated approach from concept to realization may serve as a model for the development of innovative architectural strategies that genuinely advance sustainability in both design and performance.

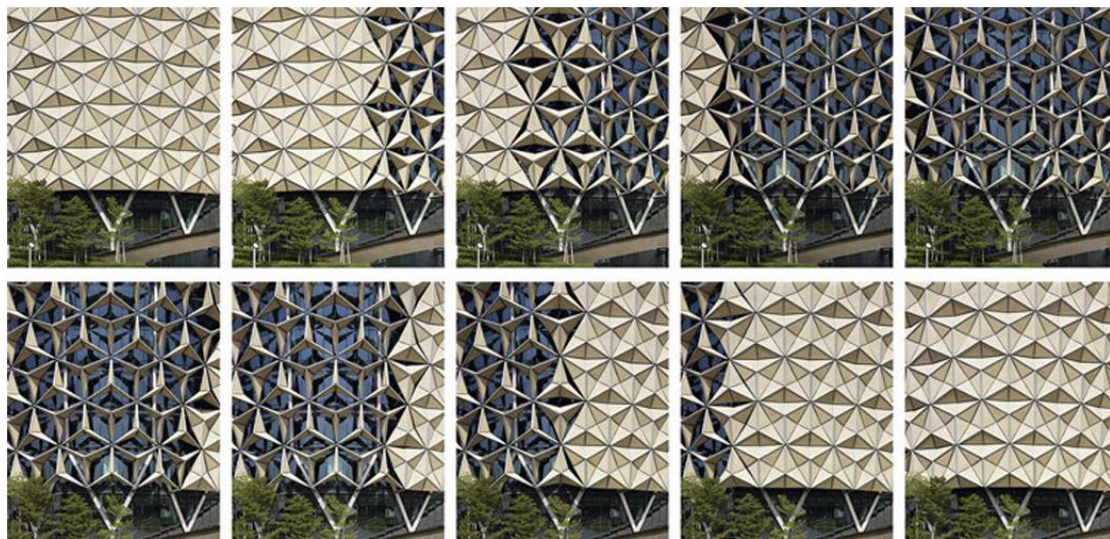


Figure 61 - Different situations with opening and closing sun screen system.

⁴⁷ **Supervisory Control and Data Acquisition (SCADA)** is a type of industrial control system used to monitor and control infrastructure and facility processes in real time. In the case of Al Bahr Tower, this protocol serves to collect environmental data (like sunlight levels), to send instructions to the mashrabiya actuators and to ensure the kinetic façade system operates efficiently and in real time, adapting to changing solar conditions.

5.5.2 One Ocean Pavilion, Yeosu

The kinetic media façade constitutes a fundamental component of the Thematic Pavilion, a significant and enduring structure built for Expo 2012 in Yeosu, South Korea, designed by the Vienna-based firm SOMA Architecture.^[Fig.62] The application of glass-fiber-reinforced polymer (**GFRP**) facilitates extensive reversible elastic deformations, permitting a novel conceptualization of transformable architectural systems. In biological systems, plants have developed diverse kinetic mechanisms relying solely on elastic deformation—without the need for hinges—to regulate processes such as floral blooming, foliar movement, and related functions. The examination of these natural principles informed the development of the kinetic façade system implemented in the Yeosu Pavilion.



Figure 62 - View on the One Ocean Pavilion, SOMA Architecture

The façade spans 140 meters in length, with a variable height ranging from 3 to 13 meters. It is composed of 108 kinetic glass-fiber-reinforced polymer (GFRP) louvers, each anchored at the top and bottom edges by fixed supports on one end and adjustable actuators on the opposite end. These actuators exert compressive force on the upper and lower edges, inducing elastic deformation and lateral rotation of the GFRP components. Despite their considerable length of 13 meters, the louvers have a slender thickness of just 9 millimeters. To enhance structural rigidity, their longitudinal edges are reinforced with a 200 mm rib and a secondary 30 mm rib, the latter

incorporating a hard rubber buffer bar. This rubber element serves as a protective interface when the louvers are in a closed position, preventing direct contact between adjacent GFRP surfaces.

Under extreme wind conditions—a periodic occurrence along the South Korean coastline—the façade automatically transitions to a closed and secured state. Wind tunnel simulations were conducted to determine the required pressure thresholds for various open configurations. During standard operation, each louver is independently actuated, generating dynamic patterns across the façade surface. The range of possible choreographies extends from subtle, localized motions to large-scale undulating waves that propagate across the entire elevation. [Fig.63]

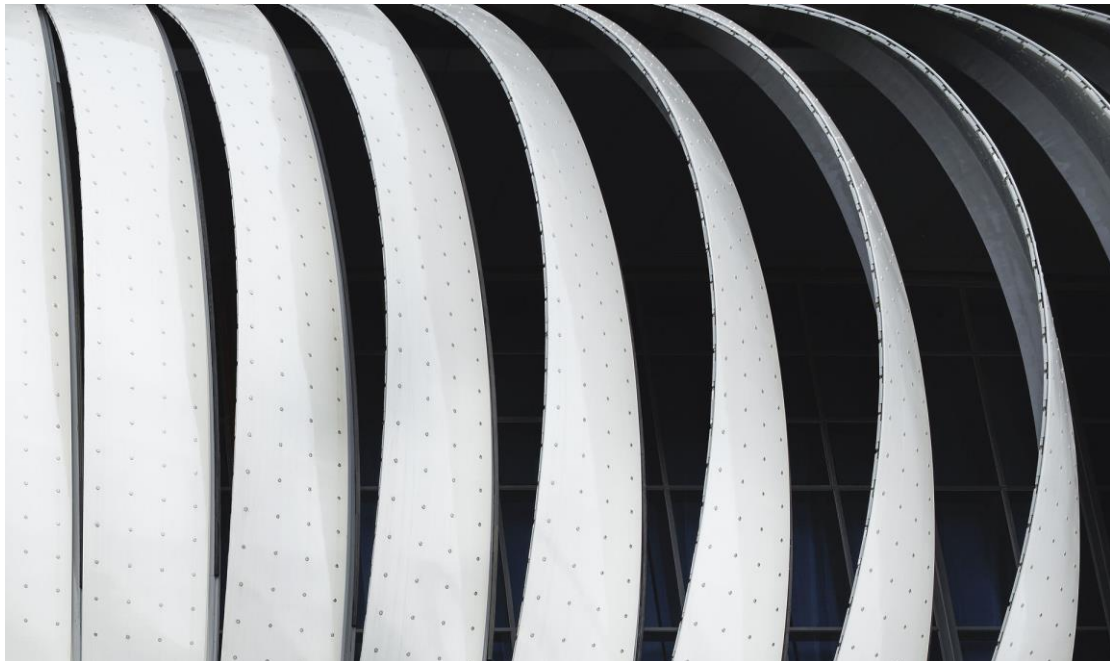


Figure 63 - Detail on the kinetic elements made of glass-fiber-reinforced polymer

The kinetic louvers serve a climate-responsive function, adapting their operation to meet varying user requirements. During active operation, each louver is individually controlled, generating dynamic patterns across the façade. These patterns can vary in scale, from localized, subtle movements to synchronized undulations that propagate along the entire façade length.

After dark, the analog visual effect of the moving louvers is enhanced by integrated linear LED bars, positioned along the inner front edge of each louver. When opened, these LEDs cast light onto adjacent louvers, with the intensity and spread

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modulated by the opening angle. To optimize light control, continuous GFRP flanges are incorporated, significantly reducing the infiltration of both artificial and natural light when the system is in the closed position.

The louvers are actuated by motorized mechanisms positioned at their upper and lower edges, which apply compressive forces to generate controlled elastic deformation. By decreasing the span between the support points, these forces induce a bending moment that produces a lateral rotation of each louver. The actuation system employs servo-driven screw spindles, synchronized via a centralized digital bus network. This configuration enables individual control of each louver, facilitating diverse kinematic choreographies and operational modes.

The control system relies on real-time positional feedback from the servo motors, enabling precise motion coordination. Additionally, it features network connectivity, allowing for remote updates of movement algorithms and transmission of façade performance data to maintenance providers. Notably, the upper and lower motors frequently operate in opposing modes (drive versus brake), creating opportunities for regenerative energy recovery. This energy can be recycled within the local system, enhancing overall energy efficiency. [Fig.64]

The opening procedure of a 13m louver requires a movement of 450mm for an opening angle of 60°. The maximum movement speed of one actuator is about

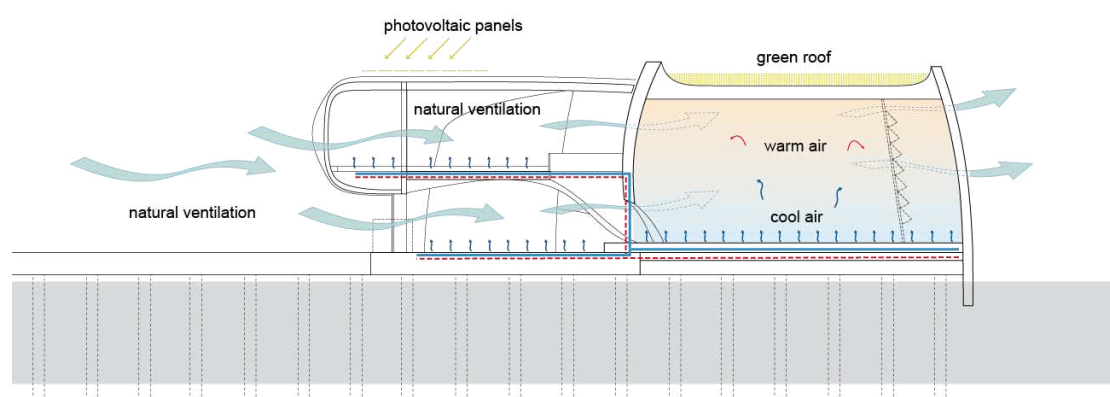


Figure 64 - Section of the One Ocean Pavilion

3,80m/minute. Short louvers open less. A detailed geometrical analysis of the movement has been carried out in order to determine potential collisions. Those have been solved by minor adjustments of the movement paths and bearing locations.

5.6 Conclusions

Kinetic façades represent an essential advancement in contemporary architectural design, offering a responsive interface between the built environment and its surrounding climatic conditions. Through their capacity to adapt in real time to environmental stimuli—such as sunlight, temperature, and airflow—these dynamic systems enhance both occupant comfort and the building's overall energy performance. As demonstrated in the preceding analyses, kinetic façades not only reduce reliance on mechanical heating, cooling, and lighting systems, but also contribute to the architectural expression and cultural resonance of high-rise buildings.

By integrating technologies ranging from programmable mechanical elements to biomimetic materials, dynamic façades transcend the limitations of static envelopes, aligning with principles of sustainability, adaptability and user-centric design. Case studies such as the Al Bahar Towers and One Ocean Pavilion illustrate the successful application of kinetic systems, bridging traditional architectural motifs with innovative engineering solutions. Despite challenges related to cost, maintenance, and technological complexity, the growing maturity of design tools and smart materials is progressively overcoming these barriers.

In conclusion, kinetic façades are more than a technological novelty; they are emblematic of a broader paradigm shift toward environmentally responsive, culturally informed, and performative architecture. As cities confront escalating climatic and urban challenges, the implementation of dynamic façade systems will be increasingly instrumental in shaping the future of sustainable and resilient vertical architecture.

6. The Arab-islamic Architecture

6.1 Introduction

“Search for identity could give us a much greater sensitivity not only to our environment but to ourselves and to the society in which we live.”

C. Correa, *Quest for identity*, in Proceedings of the Seminar: Exploring Architecture in Islamic Culture; Architecture and Identity, 1983.

Arab-Islamic architecture constitutes one of the most diverse and symbolically charged architectural traditions in the world. Rooted in the early centuries of islamic religion, this architectural language emerged not merely as a stylistic expression but as a spatial and environmental response to the religious, social, and climatic needs of Muslim communities, starting from the early times. Its influence spans across regions, from the Maghreb to Central Asia, adapting to local conditions while retaining core symbolic and functional principles. This chapter aims to investigate the legacy and contemporary relevance of Arab-Islamic architecture, focusing particularly on its passive environmental strategies, spatial compositions, symbolic values and adaptability to modern high-rise buildings. The analysis is conducted with a critical and evaluative approach, aiming to identify applicable strategies for sustainable vertical development.

6.2 Passive Cooling Systems and Spatial Diversification

Arab-Islamic architecture demonstrates a deep, intuitive understanding of environmental design. Among its most impactful innovations is the incorporation of passive cooling strategies within building form, materiality and urban planning. These systems were conceived not only for thermal regulation but also as responses to cultural norms surrounding privacy, social hierarchy and spiritual life, rooted within its people.

The **courtyard house** – *dar* – stands as the primary archetype in traditional Arab-Islamic residential design [Fig.65]. Often rectangular and inward-facing, its open-air *sahn* (central courtyard) functions as the thermal and social heart of the home. This configuration significantly improves thermal comfort: the inner courtyard was found to lower the ambient temperature by 4–6°C in summer conditions due to shading and evaporative cooling. Courtyards typically feature vegetation, shaded arcades, water basins and reflective surfaces that contribute to heat mitigation and enhance the sensory



Figure 65 - Different climate and ventilation in the courtyards during the day (TOP) and the night (BOTTOM) (Source: Ernest, R., & Ford, B. (2012). *The role of multiple courtyards in the promotion of convective cooling*. *Architectural Science Review*, 55(4), 241-249.)

quality of the domestic environment, and even for the natural ventilation of the inner spaces.

Spatial diversity was also inherent in the way rooms were arranged around the courtyard. Summer rooms and winter rooms were designated based on their solar orientation, as typical homes responded dynamically to seasonal changes. The layering of semi-private and private zones within the house was not only culturally appropriate but allowed for staggered thermal thresholds, gradually

buffering external conditions.

These internal strategies were mirrored in a very specific urban fabric distribution. **Compact urban layouts**—narrow streets, high-walled buildings, and shaded passages—reduced direct solar exposure and facilitated air movement. According to Shahda (2020), "*the urban masses were arranged to reduce the heat island effect and maximize shading on pedestrian routes*"⁴⁸. Such compactness created urban canyons

⁴⁸ **Merhan M. Shahda**, a researcher affiliated with Port Said University (Egypt). She is the author or co-author of several academic publications on sustainable architecture and traditional environmental treatments in Arab-Islamic contexts.

that channeled breezes and encouraged convection, while also preserving privacy and defense.

Thermal mass played a pivotal role in this bioclimatic performance. Traditional materials like brick and limestone, with their high heat capacity and low thermal conductivity, absorbed heat during the day and released it at night. This thermal lag created stable interior conditions even as external temperatures fluctuated sharply. Shahda explains, *"mud brick walls acted as climate moderators, reducing both temperature peaks and lows through delayed heat transfer"*.

Building **orientation** was also key. In many cases, main facades faced north or northeast to avoid the intense western sun. Openings were limited on sun-exposed walls and generously placed on shaded ones, encouraging cross ventilation. Where possible, buildings were sunken slightly into the ground, further enhancing thermal inertia.

A particularly refined spatial device was the **takhtabüsh**—a semi-open, roofed space placed between two courtyards, one shaded and one exposed to the sun. This setup used natural pressure differentials to drive ventilation [Fig.66]. As stated in the source, *"hot air rising from the sunlit court created suction that drew in cooler air from the shaded zone, facilitating continuous airflow"*. It consist in a very sophisticated method to channel cold air between inner space without the use of any kind of mechanical devices.

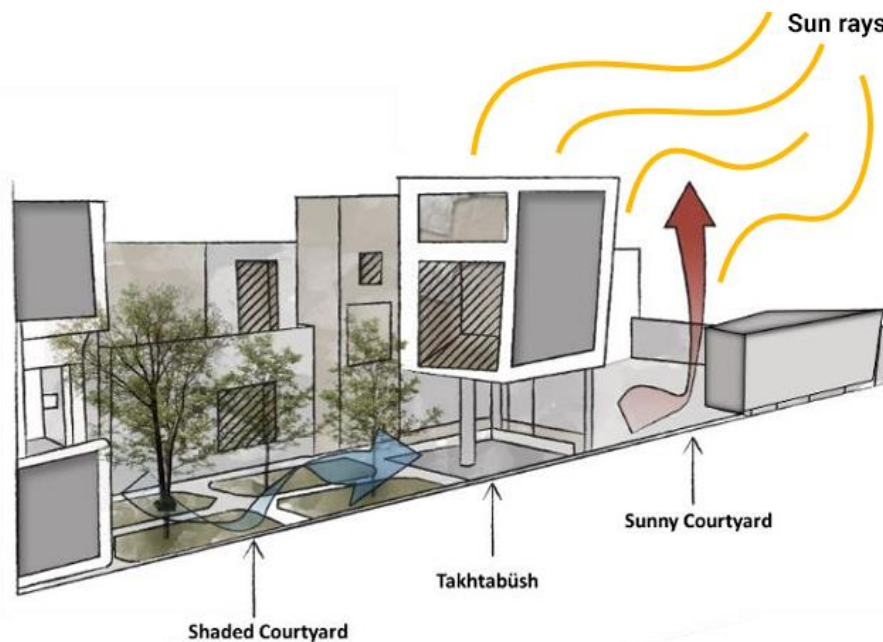


Figura 66 - Takhtabush functioning method

Windows and openings has to be carefully calibrated. High-set windows prevented glare and facilitated hot air exhaust. Decorative elements like **shamsiyat** (colored glass) and **alqamariyat** (latticed oculi) filtered light without introducing excess heat. Small, deeply recessed windows not only improved shade but also preserved privacy—an essential value in Islamic domestic culture, introducing the usage of the Mashrabiya in different kind of ways.

In larger buildings, **rooftop elements** such as domes and ventilation holes (al-Omarah) served to evacuate accumulated heat. These features allowed warm air, which naturally rises, to escape efficiently. Combined with the use of tall interior volumes, they promoted stratified ventilation, ensuring fresher, cooler air at occupant level.

The use of **color and texture** also had an environmental function. Light-colored plasters and tiles reflected sunlight, reducing surface temperatures. Polished stone or ceramic finishes inside courtyards and rooms helped to diffuse light and lower radiant heat.

From the urban scale point of view, **transition spaces** such as loggias, porticos, atrias and narrow passageways enhanced spatial diversification and passive performance. These buffer zones provided shaded resting areas and delayed thermal gain when moving from hot exteriors to cooler interiors. As described in the literature, "*semi-outdoor spaces offered a gradient of thermal experiences, enabling residents to adapt gradually to external conditions*".

Environmental comfort in Arab-Islamic architecture was not incidental—it was deliberate, measured and dynamic, and also well calibrated to stay in a constant relationship with the exterior environment. It did not rely on centralized mechanical systems but instead wove climate logic into every layer of the built environment, from the urban plan to the window grille. Experimental reconstructions of these environments demonstrate that passive systems could maintain interior temperatures between 24–27°C with relative humidity near 40–50%, and air movement between 0.3–0.7 m/s, all within optimal comfort zone. In other words, with simple yet very effective methods, it can be reached both comfortness and energy saving at the same time.

Beyond performance, these passive strategies carried cultural significance. They embodied the Islamic principle of **hikma** - *wisdom in action* - by aligning ecological

sensitivity with architectural elegance. As summarized in Abusaada and Elshater (2020)⁴⁹, "*the Arab-Islamic spatial model offers not only sustainable practice but an ethical and symbolic approach to inhabiting place*".

In contemporary practice and era, these principles are increasingly relevant. With rising temperatures and energy scarcity, designers are revisiting traditional techniques as valid alternatives to energy-intensive systems, searching for some cultural identity and innovative techniques based in the tradition. Advanced simulations, climate-responsive software and new material technologies allow for the adaptation of these time-tested strategies to today's needs.

Reintegrating passive systems and spatial diversification into urban architecture—especially in hot climates—offers a promising direction for sustainable design. Rather than mere aesthetic motifs, these elements can serve as active agents in reducing environmental loads, enhancing human comfort, and preserving cultural memory.

6.3 Innovation in Tradition: Mashrabiya and Wind Towers

The Mashrabiya and wind towers, historically integral to Arab-Islamic architecture, exemplify sophisticated passive climate-control mechanisms. These traditional architectural elements embody a deep understanding of climatic conditions, social needs, and cultural identity, continuously adapting and evolving through contemporary innovation.

6.3.1 The Mashrabiya

The **Mashrabiya**, a traditional latticed screen typically made of intricately carved wood, is one of the most distinctive architectural features in Arab-Islamic culture. Historically prominent in the Middle East, particularly in Egypt, Saudi Arabia, Yemen, and Iraq, the Mashrabiya was conceived as a functional response to the region's harsh climate and cultural emphasis on privacy. Derived from the Arabic root "*shariba*" meaning "*to drink*," its name originally referred to the practice of placing water jars

⁴⁹ Abusaada and Elshater have co-authored several influential works focusing on urban design, affective atmospheres, and the integration of cultural and emotional dimensions into architectural practice.

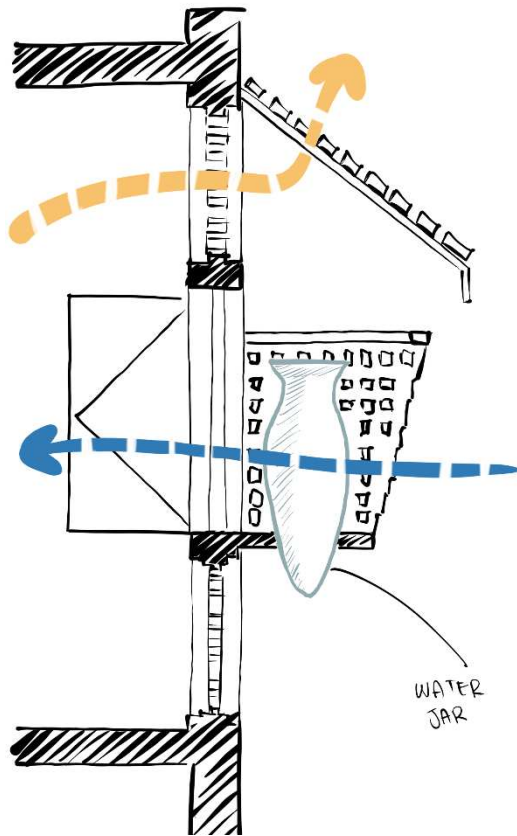


Figure 67 - A porous clay water jar used to cool the air as it passes through the Mashrabiya and into the building behind.

behind these latticed screens, thereby cooling the incoming air through evaporation [Fig.67]

Mashrabiya's fulfill multiple environmental functions, including shading, ventilation, humidity control, temperature regulation, and privacy. Their finely carved geometric patterns not only serve aesthetic purposes but are meticulously designed to regulate sunlight penetration and air movement. By controlling glare and diffusing harsh sunlight, Mashrabiya's significantly reduce indoor temperatures, improving thermal comfort and reducing the need for mechanical cooling systems. Allothman (2017) notes that the Mashrabiya's intricate latticework allows gentle, filtered daylight into interiors, creating serene and

comfortable indoor environments while maintaining visual privacy, crucial in densely populated urban areas.

Furthermore, the Mashrabiya's environmental function extends to humidity control. Historically, water jars were placed behind the latticework to induce evaporative cooling, a strategy highly effective in hot, arid climates. The porosity of the

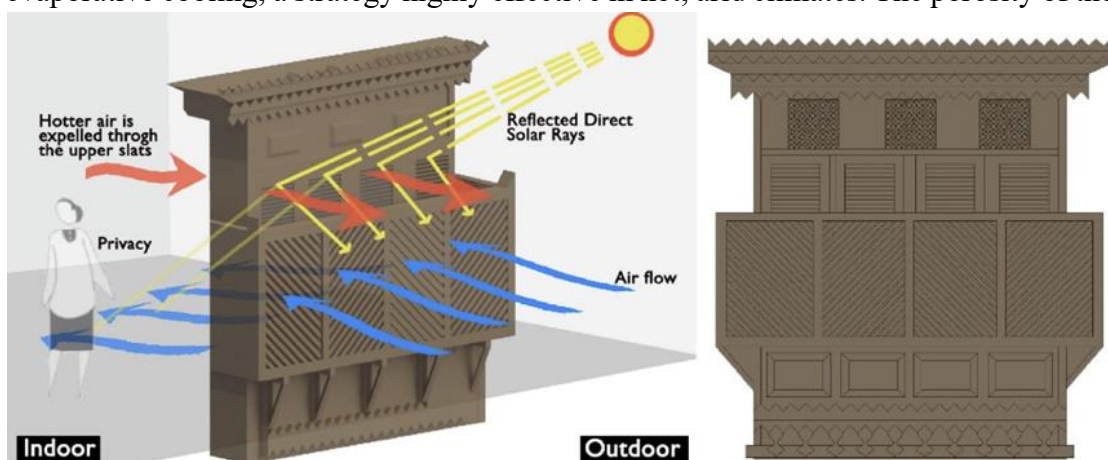


Figure 68 - Diagram showing the functionality of the Mashrabiya

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screen promotes airflow while controlling moisture levels, ensuring a balanced indoor climate ideal for human comfort. [fig.68]

Culturally, Mashrabiya symbolize Islamic principles of modesty and privacy. Their design enables occupants, particularly women, to observe street life without being visible from the outside. This function aligns with the social norms prevalent in Islamic cultures, embedding profound cultural significance within their physical structure.

In contemporary architecture, the Mashrabiya has seen a resurgence, driven by increased interest in sustainable design practices and cultural heritage preservation. Modern adaptations employ new materials such as aluminum, stainless steel, and high-performance glass to enhance durability and maintenance ease, allowing broader application in contemporary buildings. As seen in the previous chapters of this thesis, examples include Jean Nouvel's Doha Tower, which features a metallic screen inspired by traditional Mashrabiya, effectively balancing aesthetic beauty with environmental performance. Similarly, the Al Bahr Towers in Abu Dhabi employ dynamic Mashrabiya-inspired facades with motorized elements that adjust automatically to solar exposure, significantly enhancing energy efficiency and thermal comfort.

Another great example of the usage of this technique is the **The Doha Tower**, designed by *architect Jean Nouvel*, provides a compelling contemporary reinterpretation of the traditional Mashrabiya within a modern high-rise context. Located in Doha, Qatar, this skyscraper is enveloped in an intricately designed metallic façade inspired by traditional wooden Mashrabiya. The tower's external skin consists of aluminum panels featuring geometric patterns derived from Islamic art, which serve both aesthetic and functional purposes. These panels effectively filter sunlight, significantly reducing solar gain and glare, and thus decreasing cooling loads within the building. Moreover, the façade provides essential privacy for occupants, a vital cultural consideration aligned with the original Mashrabiya concept. By integrating traditional design principles with advanced materials and modern fabrication techniques, the Doha Tower demonstrates the effective contemporary adaptation of historical passive cooling and shading strategies. [Fig.69]



Figure 69 - View of the Doha Tower (LEFT) and detail on the Mashrabiya facade in aluminium (RIGHT)

Technological advancements have further extended Mashrabiya applications through computational design and digital fabrication techniques. These modern tools allow architects to simulate and optimize lattice patterns for maximum environmental performance, tailored specifically to local climatic conditions and building orientations. By leveraging **computational fluid dynamics** (CFD) and parametric design software, contemporary Mashrabiya achieve unprecedented levels of precision in airflow and light management.

6.3.2 The Wind Tower or ‘Windcatchers’

Wind towers, also known as "*badgir*,"⁵⁰ represent another iconic and highly effective passive cooling element deeply rooted in Arab-Islamic architecture, with origins traceable to ancient Persia. The wind tower has been extensively used in hot, arid regions of the Middle East, particularly Iran, Iraq, Egypt, and the Arabian

⁵⁰ Badgir literally means "**wind catcher**"—combining the words "**bâd**" (باد), meaning "**wind**," and "**gir**" (گیر), meaning "**catcher**" or "**grabber**." The term originates from Persian language.

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Peninsula. These towers function by capturing cooler air at elevated levels and channeling it downward into building interiors, creating a natural ventilation system without reliance on mechanical energy.

Structurally, wind towers typically feature vertical shafts with openings at the top to capture prevailing winds. The captured wind travels down the tower, cooling as it moves, before dispersing into interior spaces. Additionally, the warmer indoor air rises and escapes through other tower openings, effectively enhancing air circulation and maintaining a comfortable internal environment. This mechanism significantly reduces indoor temperatures and provides fresh air circulation, crucial in densely populated urban areas where natural ventilation can greatly improve air quality and occupant comfort [Fig.70].

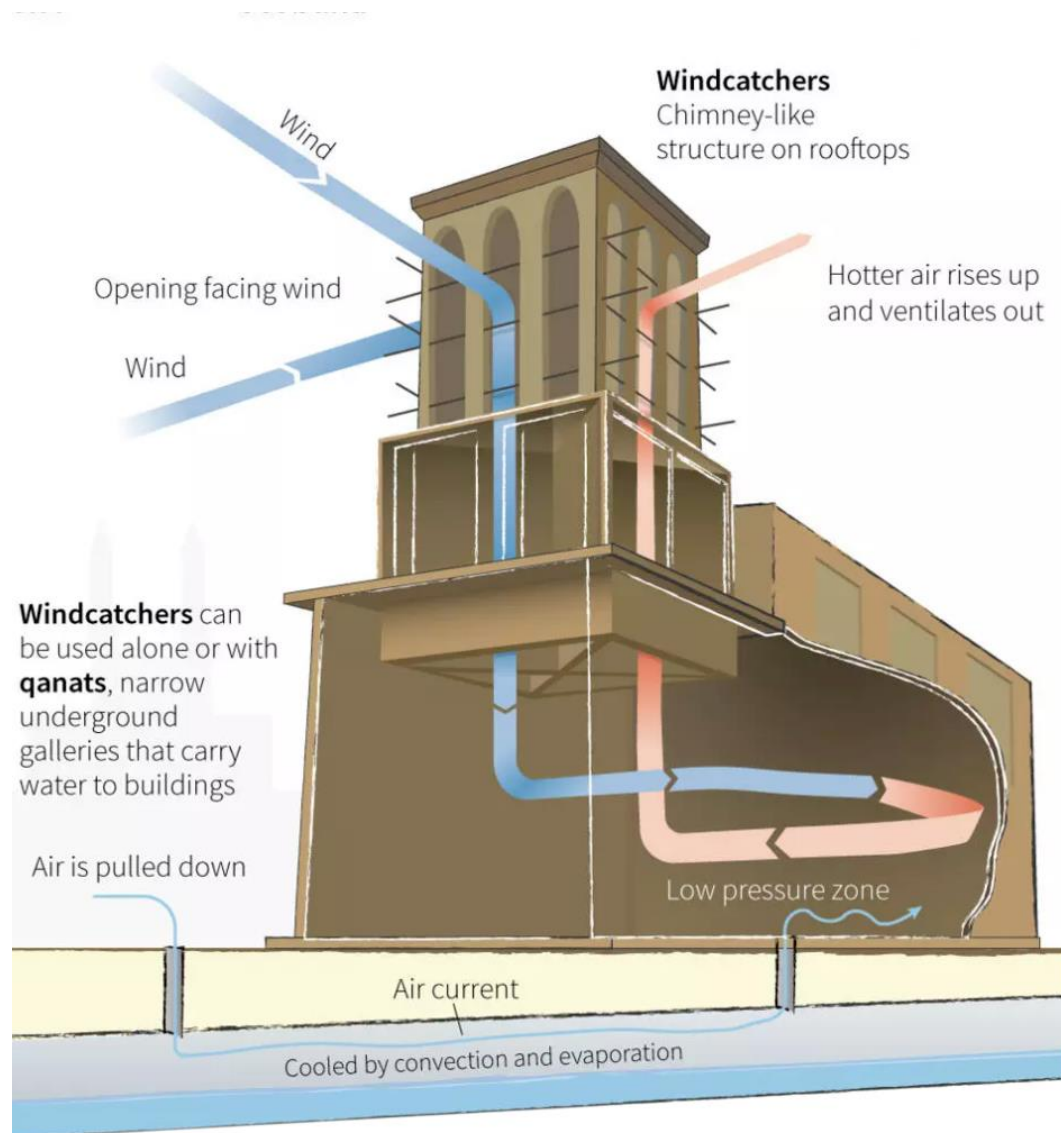


Figure 70 - Operating principles of the Wind Towers

The effectiveness of traditional wind towers has encouraged their modern adaptations. Contemporary architects and researchers have begun integrating wind towers with advanced technologies such as computational fluid dynamics (CFD) - just like the modern Mashrabiya - simulations and hybrid ventilation systems. It has been highlighted that the recent innovations in wind tower designs, emphasizing the integration of modern technologies that improve performance in varied environmental and urban contexts. Computational modeling enables the precise optimization of wind towers' shape, orientation, and internal structure, significantly enhancing their efficiency and adaptability to contemporary buildings, keeping its prime functionality.

Hybrid systems represent an important advancement in wind tower technology, combining traditional passive cooling methods with modern mechanical elements. These systems integrate wind towers with complementary technologies such as evaporative cooling, solar chimneys, and geothermal heat exchange. Such hybrid solutions extend the functional viability of wind towers to regions with low wind speeds or variable climatic conditions, broadening their applicability.

A notable contemporary reinterpretation of the traditional wind tower can be found in the **Masdar Institute of Science and Technology** in Abu Dhabi, designed by **Norman Foster**. This institute forms a key part of **Masdar City**, envisioned as the world's first **carbon-neutral, zero-waste, and car-free urban development**. The symbolic foundation of the project was laid in 2008, by Sheikh Mohammed bin Zayed Al Nahyan, Crown Prince of Abu Dhabi. Masdar City spans over 1,483 acres and integrates commercial, industrial, residential, and academic spaces aimed at fostering the development of sustainable technologies. The masterplan includes the headquarters of the Future Energy Company, which leads the initiative. Organized around two central plazas, the project's first phase featured the construction of a 60-megawatt photovoltaic power plant, designed to generate the electricity required for building the rest of the city. Completed in part by 2010, this phase includes the Masdar Institute buildings, which incorporate a contemporary version of the wind tower, adapting traditional cooling techniques to the needs of modern, sustainable urban design [Fig.71].

Despite its uniqueness and useful capacity as a natural "air cooling system", the wind tower is not largely used or designed as it should be in the contemporary era

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Figure 71 - A modern interpretation of the Arabian wind tower at the Masdar Institute of Science and Technology

and its mainly used as an artificial adornment on buildings to somehow flavour the building with traditional heritage sentimentalities.

Additionally, contemporary wind towers utilize new materials such as reinforced concrete, steel, and composite materials, allowing them to be seamlessly integrated into modern architectural aesthetics and structural systems. These advanced materials improve the durability, structural integrity and thermal performance of wind towers, ensuring long-term sustainability and effectiveness.

In summary, wind towers illustrate the enduring innovation embedded within Arab-Islamic architectural tradition. Their historical efficiency combined with contemporary technological integration underscores their potential as key elements in

sustainable, climate-responsive architecture. Through strategic adaptations and modern refinements, wind towers continue to offer viable solutions for enhancing energy efficiency and environmental comfort in modern buildings.

6.4 Symbolism and Aesthetic Principles in Arab-Islamic Architecture

Symbolism and aesthetics in Arab-Islamic architecture reflect profound spiritual, cultural, and intellectual traditions expressed through architecture's visual, spatial, and experiential dimensions. These architectural expressions embody core Islamic philosophical and theological principles, deeply influencing form, structure, ornamentation and spatial organization.

A defining characteristic of Arab-Islamic architecture is the intricate use of geometric patterns. These patterns, known as **arabesques**, symbolize infinite continuity and reflect Islamic concepts of divine unity (*tawhid*). The use of repetitive geometric shapes such as stars, hexagons, and tessellations creates visually captivating designs that represent the boundlessness of creation, suggesting infinite divine creativity and perfection. It can be identified the geometric patterns in Mashrabiya as a symbolic manifestation of unity in multiplicity, reflecting broader cosmological beliefs prevalent in Islamic culture.

Calligraphy is another significant aesthetic and symbolic component integral to Arab-Islamic architecture. Quranic inscriptions and poetic verses intricately engraved or painted on architectural surfaces elevate these buildings beyond mere physical structures into vessels of spiritual contemplation. Calligraphy, therefore, not only embellishes buildings aesthetically but also reinforces Islamic spiritual and ethical values, creating immersive environments where spiritual and visual experiences intertwine seamlessly. Mosque, palaces and even houses have this kind of calligraphy, which gives a sense of identity to the environment itself, suggesting a kind way of social inclusion.

Spatial hierarchy in Arab-Islamic architecture further embodies symbolic significance. Islamic structures often guide visitors through sequentially ordered spaces, moving from public or semi-public zones into progressively private or sacred areas. This spatial transition reflects spiritual journeys towards increased

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sanctity, echoing the Islamic belief in the journey towards greater spiritual awareness and closeness to the divine.

Architectural elements such as domes and arches hold symbolic meanings deeply rooted in Islamic traditions. Domes symbolize the celestial vault, a direct representation of heaven, thus emphasizing the spiritual dimension of architectural spaces. Arches often signify transitional spaces, denoting a passage between the worldly and the spiritual realms. Minarets, prominent vertical elements, symbolize humanity's spiritual ascent and aspiration towards the divine. So, as shown, each singular element represents something related to each other with a logical sense. These architectural forms consistently reinforce a visual and experiential dialogue between human existence and spiritual transcendence.

Materiality in Arab-Islamic architecture also carries symbolic significance. Traditional materials such as stone, mudbrick, and wood not only respond practically to environmental conditions but also convey cultural authenticity and continuity. Modern adaptations have incorporated contemporary materials like steel, glass, and concrete, thoughtfully integrating traditional motifs and forms to maintain symbolic relevance in contemporary architectural practices. The integration of water elements in Arab-Islamic architecture further enhances the symbolic depth, representing purity, life, and paradise as described in Islamic texts. Courtyards often feature water elements such as fountains and reflective pools, creating serene microclimates while symbolizing spiritual and physical refreshment, emphasizing environmental comfort.

One of the most intricate and iconic Moroccan contributions to Islamic decorative arts is the **zellij**, a type of mosaic tilework formed by assembling individually chiseled pieces of glazed terra-cotta. The resulting geometric compositions are both visually and spiritually meaningful, emphasizing the principle of infinity and divine unity through repetition and complexity. The craftsmanship behind *zellij* speaks to centuries of refinement in mathematical precision and an enduring reverence for the non-figurative aesthetic embraced in Islamic art. These patterns are often used to adorn floors, walls, fountains and columns, seamlessly integrating ornament with architecture [Fig.72].

Another profound element is the **muqarnas**, a three-dimensional architectural ornament resembling stalactites or honeycombs. These intricate, layered vault-like forms are often used in the transitional spaces between walls and domes or to articulate niches and entryways. In Moroccan architecture, muqarnas are typically made from carved plaster or stone, arranged in cascading tiers. Their rhythmic, cellular geometry serves both a decorative and symbolic purpose—suggesting ascension, transformation and the divine order. They visually soften structural transitions while symbolically guiding the eye and spirit upward, from the earthly to the celestial realm.



Figure 72 – View on the Moroccan Zellij with some calligraphy components



Figure 73 - View on the Muqarnas beautifully adorned

Together, *zellij* and *muqarnas* exemplify the synthesis of mathematics, spirituality and aesthetics in Arab-Islamic architecture—particularly in its Moroccan expression. These elements, while deeply historical, continue to inspire modern interpretations that seek to honor traditional forms while embracing contemporary materials and technologies, trying to find innovative solutions in traditional elements and techniques.

Color is also central in Moroccan aesthetics: **blues** signify protection and tranquility, **greens** are tied to paradise and Islam, while **earth tones** reflect the natural desert landscapes. Carved plasterwork (*stucco*), intricately carved wood (*such as in mashrabiya and cedar ceilings*), and the repetitive use of symmetrical garden plans further reinforce the Islamic principle of harmony and reflection.

In Moroccan riads—homes structured around an internal courtyard totally open to the sky—the layout itself embodies Islamic ideals of privacy, inward reflection, and harmony between the built environment and nature. The courtyard, often with a fountain at its center, is simultaneously a practical cooling device and a spiritual sanctuary. It is similar to the Atriums previously seen and studied, which can be considered as the “*Openair Atria*”.



Figure 74 - View on the Moroccan Riad with the Water Element as an essential component

6.5 How can it be Applicable in High-Rise Buildings?

Translating the principles of Arab-Islamic architecture into the vertical format of contemporary high-rise buildings presents both opportunities and challenges, especially now that we have the sustainable crises era and the research for an innovative way to build in a carbon-free way. Tall buildings often prioritize structural efficiency, high-density occupancy and technological systems, which can seem strange with the human-scale intimacy and passive environmental strategies inherent in traditional Islamic design. However, with thoughtful adaptation and technological integration, the cultural and environmental intelligence of Arab-Islamic architecture can significantly inform and enhance high-rise design.

One of the most effective strategies for high-rise buildings is the reinterpretation of traditional **shading devices**, particularly the **mashrabiya**, into advanced responsive façades. These systems can be digitally controlled to adjust to solar orientation and ambient conditions, minimizing heat gain and reducing energy demand for cooling. Precedent analyzed projects like the **Al Bahr Towers** in Abu Dhabi demonstrate the success of this approach. Their dynamic façade system, inspired by the geometry and function of traditional mashrabiya, opens and closes in response to solar intensity, improving thermal comfort and achieving substantial energy savings. Such facades are scalable and adaptable to tall buildings, allowing for both performance efficiency and cultural continuity. Another good project is the Doha Tower, which uses the mashrabiya elements to create its facade even if its static, giving the building an identity status and a very innovative approach.

Another avenue is the application of **courtyard logics** to vertical typologies: while traditional Arab-Islamic architecture is inherently horizontal, the courtyard's role as a thermal buffer and social nucleus can be reimagined as **sky gardens**, **atriums**, or **vertical voids** within skyscrapers. These elements not only contribute to passive ventilation and natural lighting but also create biophilic environments that improve occupants' well-being and offer communal spaces that echo the social functionality of traditional courtyards. Even the use of the water element inside and outside the vertical building can result in something interesting, towards society comfortness and the overall building performances.

Wind towers, although historically used in low-rise structures, can also inform vertical applications. When reinterpreted through modern technologies, wind towers can be transformed into **ventilation chimneys**, **solar chimneys**, or **hybrid shafts** that enhance air circulation throughout the building. When combined with CFD-based design and smart control systems, such strategies become viable even in dense urban environments where traditional wind tower geometries are spatially constrained.

Symbolic elements of Arab-Islamic architecture—such as geometric motifs, calligraphic panels, and ornamental screens—can also be integrated into high-rise facades, lobbies, and interiors, maintaining a sense of identity and spiritual resonance. This integration helps prevent the loss of cultural specificity in increasingly globalized skylines and reinforces a connection to local heritage.

Moreover, vertical architecture can benefit from the **material palette** and **construction logics** of Arab-Islamic design. High thermal mass materials, modular construction inspired by traditional geometries, and earth-toned or glazed ceramic finishes rooted in Islamic art can be applied to the building envelope to improve energy performance and reinforce aesthetic continuity.

The Moroccan context, and specifically a site like **Casablanca Finance City**, presents a unique opportunity to hybridize traditional Arab-Islamic principles with the demands of a globalized urban financial hub. Here, incorporating passive strategies like **double-skin façades with decorative latticework**, **north-oriented openings**, and **controlled ventilation corridors** can offer both functional and symbolic value. Ornamented panels inspired by Moroccan *zellij* or *muqarnas* could be abstracted into shading modules or acoustic elements within office interiors, providing not only environmental benefits but also contributing to the cultural narrative of the space.

6.6 Conclusion

Overall, it can be said that this chapter has explored the enduring relevance of Arab-Islamic architecture through a multifaceted lens, examining its climatic intelligence, symbolic richness, and adaptability to contemporary design challenges. From passive cooling systems and spatial configurations to the symbolic intricacy of elements such as the mashrabiya, wind towers, *muqarnas*, and *zellij*, Arab-Islamic architecture emerges as a deeply contextual and innovative design language.

These elements, while historically grounded, are far from obsolete. Their reinterpretation in modern architecture—particularly in high-rise buildings—demonstrates a growing appreciation for context-driven, culturally embedded, and environmentally responsive design. Case studies like the Doha Tower and Al Bahr Towers illustrate that traditional principles can not only coexist with modern technologies but also elevate architectural expression by rooting it in identity and place.

Furthermore, the Moroccan context adds a vital regional layer, showcasing how local expressions of Islamic aesthetics, especially in materiality, ornamentation, and spatial logic, can give something more to contemporary projects in cities like Casablanca. As architects increasingly seek sustainable and culturally

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resonant solutions, Arab-Islamic architecture offers a wellspring of strategies, symbols and typologies that are both time-tested and forward-thinking.

In conclusion, the legacy of Arab-Islamic architecture is not confined to the past; it is a living tradition that, when skillfully adapted, can guide the future of architectural design. Its relevance in high-rise contexts lies in its capacity to respond greatly to climate, culture, and human experience elements that are more crucial than ever in the construction of resilient, meaningful and inclusive urban environments.

7. Design Proposal

7.1 Introduction

“Designing a tall building is not just about reaching the sky—it’s about how the building breathes, how it lives.”

Ken Yeang.

After the accurate research stage, which we have seen that covers different topics and arguments, the thesis design proposal represents the culmination of a broader investigation into architecture's ability to mediate between tradition and innovation, climate and culture, permanence and adaptability. Building upon the theoretical foundations outlined in the previous chapters—including the critical analysis of vernacular strategies, contemporary technologies, and regional climatic dynamics—the project seeks to synthesize these principles into a coherent and performative architectural form.

Set in the evolving urban landscape of **Casablanca Finance City**, in Morocco, the proposed tower is more than a high-rise: it is envisioned as a **vertical organism**, one that responds actively to its environmental context while resonating symbolically with the cultural memory of place. The project challenges the notion of the generic skyscraper by embedding within its structure and skin a series of spatial and climatic logics drawn from traditional Moroccan architecture—such as the **riad**, the **mashrabiya**, and the **wind tower**—and reinterpreting them through a contemporary lens.

This part of the thesis outlines the full development of the design proposal, moving from urban analysis to spatial strategies, structural systems, environmental performance and technical detailing. Each decision—formal or functional—is framed not as an isolated gesture, but as a component of an integrated architectural ecosystem.

The objective is to propose a model for **climatic and cultural sustainability**, rooted in place yet open to global discourse—a project that performs, adapts and communicates. In this sense, the tower becomes not just a building, but a

statement on the future of architecture in contexts of rapid urbanization and climatic urgency.

7.2 Casablanca Finance City

7.2.1 A brief history of Moroccan urbanism

Beginning in the early 2000s, Morocco underwent a gradual yet decisive transformation in the way urban planning policies were conceptualized and implemented. This period marked the institutional foundation for the rise of **urban megaprojects** such as **Casablanca Finance City**, situated at the intersection of strategic planning, economic liberalization, and governance reform.

A key milestone came in 2001 with the government's initiation of a **nationwide territorial reflection**, which sought to address spatial inequalities between metropolitan cores and their surrounding peri-urban and rural zones. This led to the development of a new generation of regional planning tools—most notably the *Schémas Régionaux de l'Aménagement du Territoire* (SRAT). In the case of Casablanca and Rabat, these cities were grouped under a centralized metropolitan planning scheme known as the **Schéma d'Organisation Fonctionnelle et d'Aménagement pour l'Aire Métropolitaine Centrale** (SOFA). The SOFA reoriented Casablanca's urban agenda around macroeconomic priorities, including the enhancement of port infrastructure, the promotion of tourism as a vehicle for employment, and the strategic branding of the Casablanca-Rabat axis as an internationally competitive investment corridor.

This reconfiguration of territorial governance was reinforced in 2002 by a sweeping reform of the **Charte Communale**, Morocco's legislative framework for municipal management. The reform promoted the idea of “*urban unity*” in large cities—those with populations exceeding 750,000 people—through the consolidation of administrative structures. In Casablanca, this led to a significant administrative overhaul: the city was reorganized from 27 separate communes into a single municipality supported by 16 municipal districts. While this centralization was framed as a means to increase efficiency, it also had the effect of **diminishing the autonomy of local authorities**, concentrating decision-making power for large-scale urban projects in the hands of a central administrative body. This shift streamlined approvals

and facilitated the prioritization of projects deemed to have high economic potential, often at the expense of public consultation and participatory processes.

Parallel to these institutional reforms, a new planning mechanism was introduced: **urban exemption**, called in french “**dérogation**”. Beginning in 1999 and codified throughout the following decade by a series of ministerial circulars, this system allowed certain developments to bypass existing land-use regulations, ostensibly to overcome regulatory rigidity and stimulate investment. In practice, this led to the integration of underutilized or informally managed land parcels into formal real-estate markets, particularly those with strategic geographical, scenic or symbolic value. Exemptions quickly evolved into a **parallel mode of planning**, frequently employed alongside conventional tools and, in some cases, replacing them altogether.

While presented as instruments of economic rationalization, these exemption procedures disproportionately favored **large private real-estate projects**, many of which offered limited public benefit. Case studies reveal that such developments often rely on precarious labor conditions and contribute little to sustainable urban growth or long-term employment. The decade from 2000 to 2010 thus represents a critical moment in Morocco’s urban policy history: a shift from regulatory frameworks rooted in territorial equity toward a **market-oriented model of urban development**, one that privileged megaprojects as tools for urban transformation and global positioning.

Located directly adjacent to the dense and popular district of **Hay Hassani**, the *Casa Anfa* megaproject—initiated in 2004—embodies the city’s strategic ambition to shift its urban core westward ^[Fig.75]. Designed as a mixed-use development spanning over **400 hectares**, the project integrates high-end residential complexes, extensive green areas, a designated business and economic zone (**Casablanca Finance City**), and a variety of upscale institutional and commercial facilities including schools, healthcare centers, hotels and cultural venues.

What distinguishes the Anfa redevelopment from its urban context is not only its **monumental scale** but also its **highly formalized urban layout**, characterized by wide boulevards, open plots, and a deliberate emphasis on landscape design—particularly in the eastern and central zones. This stands in marked contrast to the informal, compact morphology of the surrounding neighborhoods, where density is higher, public space is fragmented and infrastructure is under strain.

7. Design Proposal

These morphological and spatial disparities are mirrored in economic terms. A comparative analysis of property values between Anfa and the adjacent districts—particularly Hay Hassani—reveals a **stark divide in real estate pricing**. The average

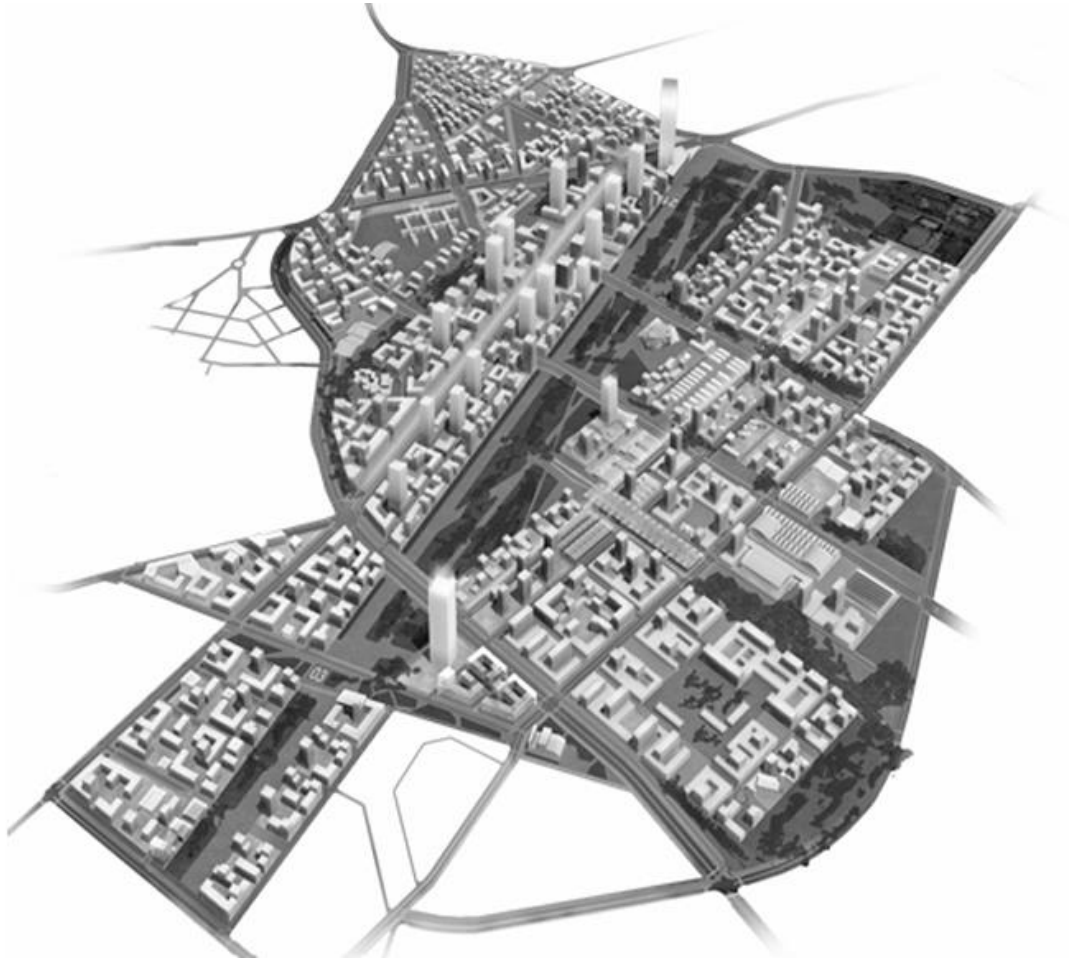


Figure 75 - A rendering giving a general impression of the built density of the Anfa business and residential district (Source: Casablanca's Megaprojects: Neoliberal Urban Planning and Socio-Spatial Transformations - A Journal for Planning and Building in a Global Context Vol. 4/2018 April 2020)

cost per square meter of built residential space in Anfa is nearly **double** that of neighboring areas, underscoring the selective socio-economic targeting of the development. So it can be understood how social-spatial matters in this new kind of urban and architectural point of view matters, and how the general design is afflicted by these aspects.

7.2.2 Urban and climate analysis

The site selected for intervention is strategically embedded within the newly defined perimeter of **Casablanca Finance City (CFC)**, yet it remains in close

proximity to socially and morphologically contrasting neighborhoods such as **Hay Hassani** and **Aïn Chock**. This juxtaposition underscores the fragmented nature of Casablanca's urban fabric, where neoliberal megaprojects often coexist with under-resourced districts that lack access to basic services, integrated mobility, or quality public space. The tension between these urban layers reveals a planning paradigm that privileges symbolic capital over inclusive urban development.

The **Anfa-CFC area** sits on a vast plateau of approximately **400 hectares**, previously occupied by the historic Anfa Airport. Its transformation began in the early 2000s under the national agenda of urban modernization and economic liberalization. The area was earmarked as a *Zone d'Aménagement Concerté* (ZAC), meaning that private-public partnerships would oversee its rapid development, with relaxed planning constraints. Today, the CFC zone is characterized by low urban density (~40-60 inhabitants per hectare), extensive green and vacant parcels, and a skyline in transition—punctuated by isolated towers, yet lacking cohesive street-level vitality. This morphology is in stark contrast with the adjoining **Hay Hassani**, which exceeds **200 inhabitants per hectare** and is marked by a tight urban grain, active street fronts, and dense social interaction.

The site's **triangular geometry**, situated at the confluence of major vehicular flows and future transit-oriented development, provides a unique opportunity to redefine this threshold between urban isolation and civic connectivity.

From a climatic point of view, Casablanca is situated within a Mediterranean climate zone with strong Atlantic influence, characterized by mild, humid winters and hot, dry summers. The city receives an average annual solar irradiation of approximately 1,800–2,000 kWh/m², making solar exposure a critical parameter for both passive and active energy strategies. The site experiences **prevailing winds from the northwest**, particularly in late afternoon and evening hours, which are intensified by the ocean's cooling effect. Wind speeds average **4–6 m/s**, offering a consistent and exploitable source of natural ventilation, particularly in mid- and high-rise applications. All these factors are essential to design a high-rise building that considers environment

These environmental forces have been interpreted not as constraints, but as **form-generating elements** in the design process. The **south, southwest, and**

7. Design Proposal

southeast façades of the tower are the most exposed to direct solar radiation, necessitating the integration of **adaptive shading systems**—in this case, a kinetic mashrabiya-inspired façade designed to modulate daylight, reduce thermal gain, and maintain visual permeability. In contrast, the **northwestern orientation** is harnessed to drive a **passive ventilation system**, utilizing an eccentric vertical shaft that behaves as a modern reinterpretation of the traditional *wind towe* or also called *windcatcher*. This allows for a stack-effect mechanism that extracts hot air upward, drawing cooler breezes through operable lower-level inlets.

Crucially, the project is conceived in alignment with **bioclimatic architecture principles**, wherein the building's orientation, massing and skin are actively calibrated to local environmental data. The objective is to reduce reliance on mechanical systems and maximize **passive environmental performance**, in accordance with both contemporary sustainability standards and the region's vernacular intelligence. Rather than adopting generic sustainability certifications, the project seeks to root its performance in **site-specific climatic strategies**, integrating traditional logics with modern technologies in a way that is both culturally resonant and environmentally effective.

The site of the proposed tower is strategically positioned within a rapidly consolidating urban framework, bordered by a range of significant civic, commercial, and cultural destinations that enhance its **connectivity and symbolic visibility**. To the north lies the emerging core of CFC, composed by a landmark office towers, international headquarters and diplomatic institutions, many of which are under construction or nearing completion. This evolving skyline provides the project with both a **prestigious context and an opportunity to contribute a unique architectural identity** to the ensemble.

To the northeast, within a radius of 1.5–2 kilometers, are several **key institutional and recreational nodes**, including:

- The **Parc de la Ligue Arabe**, one of the city's largest urban green spaces, recently revitalized as a cultural and leisure destination;
- The **Grand Théâtre de Casablanca**, designed by Christian de Portzamparc, acting as a new center for performance arts and civic gathering;

- The **Twin Center** towers and **Maarif commercial district**, which remain active economic and retail hubs;
- The **Casablanca Marina**, offering luxury amenities, seafront promenades, and international hotels.

To the west, the **Anfa Park** and its surrounding residential developments establish a new urban polarity centered on landscape and high-end housing, offering a softer urban experience than the dense city center. The **Mohammed VI Polytechnic School**, located just beyond the Anfa redevelopment zone, adds an educational and innovation-oriented layer to the site's proximity.

From a transportation standpoint, the future extension of **Tramway Line T3** will significantly improve soft mobility access, connecting the site to the **Casa-Port** train station, the historic medina, and the university campuses to the south. This infrastructural evolution is expected to increase **foot traffic, visibility, and multimodal accessibility**, reinforcing the site's potential as a **new urban landmark**.

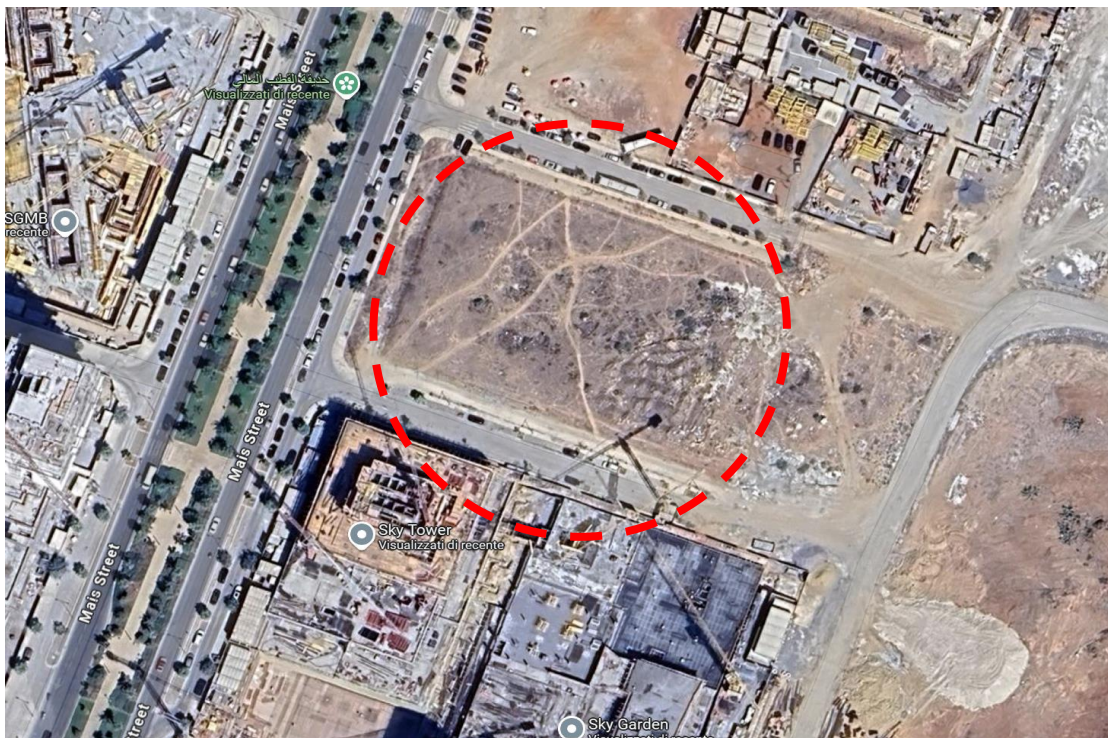


Figure 76 - Project area inside the CFC District

Importantly, the tower is not conceived in isolation from these attractors, but rather as a **connector and amplifier** of existing and future urban flows. Its location at the intersection of institutional prestige, cultural activity, green infrastructure, and

residential growth positions it as a pivot between Casablanca's **past, present, and speculative future**.

7.3 Design Concept

The design concept for the proposed tower within Casablanca Finance City, which takes the name of **Vertical Oasis**, is rooted in the ambition to articulate a vertical structure that not only meets the demands of global performance standards but also resonates deeply with local environmental conditions, cultural memory, and urban identity.

Far from being identified as a sculptural icon, the tower is conceived as a performative and responsive organism, an architectural system capable of negotiating between climate, culture, structure, and public life. The climatic conditions of Casablanca, shaped by its Atlantic-influenced Mediterranean climate, provide the primary drivers for form generation. Starting with the high solar exposure on the south, southeast, and southwest façades, coupled with prevailing northwesterly winds and significant daily thermal variations, informed the development of a passive environmental strategy where the building mass tapers and rotates—0.7° per floor, accumulating to 30° overall—to reduce wind pressure, minimize vortex shedding, and optimize solar orientation. The building's soft triangular floorplate, inspired by the geometry of the riad and traditional courtyard houses, centers around a vertical void that functions as a stack-ventilation system, simultaneously acting as a climatic lung and symbolic core.

This eccentric void facilitates passive airflow, daylight penetration, and visual continuity, reinterpreting the typology of the arabic wind tower through contemporary performance logic. Structurally, the tower is articulated through a **diagrid** exoskeleton that enables large-span, column-free interiors and provides high torsional resistance in response to the building's rotational geometry. **Belt trusses**, strategically positioned along structural nodes and levels of tapering, are integrated seamlessly within the diagrid modules to maintain formal consistency and mechanical performance without disrupting the façade rhythm. The external envelope is composed of a double-skin system in which the inner curtain wall provides thermal insulation, and the outer kinetic layer operates as a reinterpretation of the traditional mashrabiya. This kinetic skin is composed of triangular panels that respond to solar intensity through mechanical actuation, dynamically adjusting to reduce heat gain, control glare and animate the façade as a breathing surface, marking the focus on the '*moving architecture*'.

The pattern of the mashrabiya is inspired by Islamic geometric principles, creating a culturally resonant architectural language that remains legible across scales. Functionally, the tower is vertically stratified: the base levels house public and semi-public programs including a shaded civic plaza, exhibition spaces, and commercial areas connected through sunken gardens and reflective water features that support evaporative cooling; intermediate levels are dedicated to flexible office spaces and co-working hubs; upper levels transition into temporary residential units and are punctuated by sky gardens and technical floors that provide both ecological breaks and infrastructural efficiency. These sky gardens serve as pockets of greenery and informal socialization zones in the vertical ascent, while technical floors concentrate MEP systems to ensure minimal horizontal distribution and reduced energy consumption.

At the urban scale, the tower's ground plane engages the public realm through a porous base that extends into a landscaped plaza, adopting the logic of the riad in section and civic openness in plan. Vegetation, shaded arcades, and urban furniture create a microclimatic condition that contrasts with the often sterile ground planes of megaprojects, offering spatial generosity and inclusiveness. The project positions itself as a critical response to the typology of the generic high-rise, resisting both the homogenization of global corporate architecture and the privatization of urban ground. It proposes instead a model of climatic and symbolic verticality—an architecture that is at once technologically advanced and culturally situated, capable of forming a dialogue between modern structural innovation and the timeless intelligence of vernacular form, material, and climate. The tower thus becomes not only a spatial landmark but a performative civic artifact, articulating a new vision for sustainable high-rise architecture in North Africa.

At the base of the tower, the public plaza has been reimagined not as a conventional hardscape, but as a **dense urban jungle**—a richly vegetated and climatically responsive ground plane that blurs the boundaries between architecture and landscape. This approach subverts the typical sterility of megaproject plazas by introducing biodiversity, microclimatic regulation and multifactor experience into the urban fabric. Rather than applying greenery as surface decoration, the landscape strategy is structured as an immersive ecological system: tall native vegetation, layered planting beds, integrated water features and shaded walkways create a spatial atmosphere closer to that of a tropical courtyard than a corporate forecourt. This “urban jungle” not only

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mitigates the heat island effect and supports evaporative cooling, but also serves as a spatial transition between the density of the city and the verticality of the tower, allowing users to inhabit the base of the building in a way that is both informal and

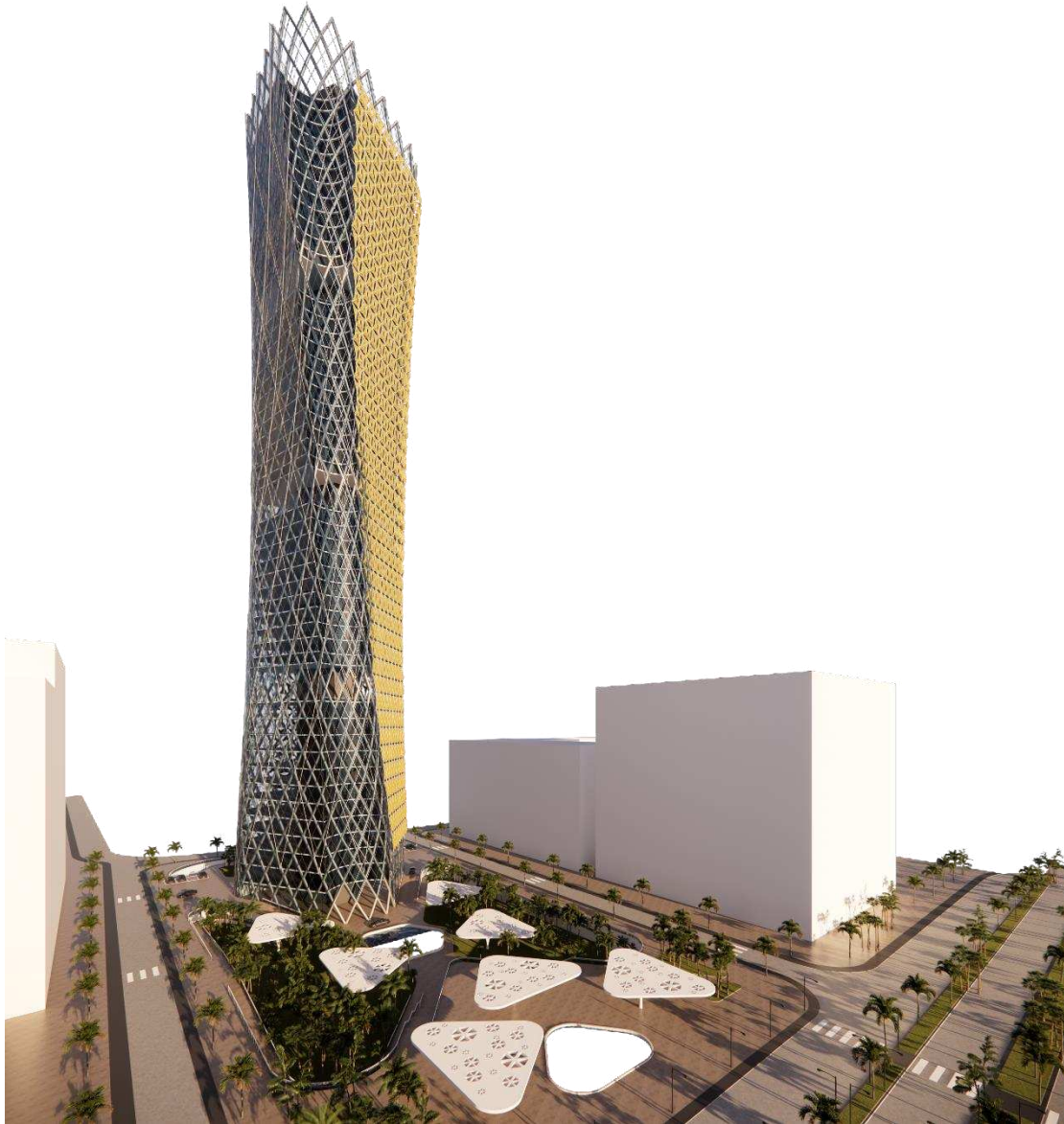


Figure 77 - Rendered view of the design proposal

restorative. By embedding this living landscape at the heart of a high-density financial district, the project reclaims urban space for public interaction and challenges the binary between nature and the artificial, offering a model of vertical urbanism grounded in ecological and human-scale principles.

7.4 Structural system solution

The structural system of the tower is conceived as a direct response to its **formal complexity, climatic performance and programmatic flexibility**. Given the building's rotational geometry, tapering mass and vertical stratification, a conventional post-and-beam skeleton would have proven inefficient, both spatially and structurally. Instead, the tower is supported by a **diagrid exoskeleton**, an innovative structural strategy that merges architectural expression with engineering efficiency. This diagrid system is composed of a lattice of diagonally intersecting steel members, forming a triangulated structural mesh that envelops the building's envelope by using circular sectioned tubular pillars of 70 cm diameter.. Unlike conventional orthogonal systems, the diagrid distributes both **gravity and lateral loads** across its inclined elements, reducing the need for internal columns and allowing for large, unobstructed floorplates adaptable to a wide range of uses.

The tower's geometry—defined by a **progressive rotation of circa 0.7 degrees per level** and a **tapering profile** near mid-height—introduces complex torsional forces and differential loading conditions. To address these, the diagrid is designed with **variable module dimensions**: larger modules are employed at the base where structural demand is highest, while smaller, tighter modules occur in the upper third of the tower, where the reduced floor area and wind exposure permit finer articulation. At critical height, particularly near the mid-section where the floorplan tightens inward by 3.5 meters, **belt trusses** are created: these are horizontal ring-like structural bands that stiffen the diagrid and transfer loads around the building's core. In this case, the belt truss is **concealed within the diagrid pattern**, allowing for continuity of the façade language and avoiding any break in architectural rhythm. In order to maintain continuity and elegance from outside, especially on the facade, these structural elements are hidden inside the MEP floors.

The central **reinforced concrete core** plays a complementary structural role: it houses the vertical circulation systems (elevators, stairwells, service shafts) and contributes to the overall lateral stability of the tower, especially during seismic events. The core is **centrally positioned**, aligning with the natural geometry of the triangular plan and maintaining the balance of gravitational loads. The walls of the core are thickened enough for the Moroccan Emergency rules, creating “passive” areas for the emergency

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situations. The elevators and the stairs are protected by REI doors that can protect the inner space of the core for 120 minutes from fire calamities.

Foundation design responds to the geotechnical conditions of the site, which lies on the former Anfa airport plateau—a relatively stable and compact terrain. A **deep-pile foundation system** has been adopted, anchoring the tower with high-capacity bored piles capable of absorbing vertical loads and resisting overturning moments induced by wind and seismic activity.

Materially, the diagrid is constructed from **high-performance steel** with a corrosion-resistant finish suitable for Casablanca's humid coastal climate. Joints between members are fully welded at the workshop and bolted on site to ensure ease of assembly and precision during construction. The core is poured in situ with reinforced concrete and supplemented by shear walls at mechanical levels to limit deformation under lateral loads.

In addition to its mechanical and structural advantages, the diagrid system also performs a key **architectural function**: it becomes the tower's visual identity, conveying rhythm, hierarchy and elegance. The triangulated grid references Islamic geometric logic while optimizing structural behavior, resulting in a façade that is both expressive and rational. The façade grid also integrates seamlessly with the **dynamic shading system**, allowing structural nodes to act as anchoring points for the kinetic mashrabiya panels.

7.5 Façade design and adaptability

The façade of the tower is more than a protective envelope; it is a **responsive, performative interface** that simultaneously mediates between climate, light, privacy and cultural identity. As a key component of the building's environmental strategy, the façade is designed as a double-skin system, composed of an inner high-performance curtain wall and an outer kinetic shading layer inspired by the traditional mashrabiya. This dual configuration provides both thermal regulation and symbolic articulation, ensuring that the building's skin actively participates in the tower's sustainability and cultural positioning.

From an environmental point of view, the outer kinetic layer operates as a **climatic filter**: composed of ETFE panels mounted on a lightweight metallic substructure, the

façade responds dynamically to solar radiation levels through mechanical or AI controlled actuation. Located primarily on the **south, southeast, and southwest façades**, where solar exposure is most intense, these panels rotate or fold to modulate daylight penetration and reduce internal heat gain. This mechanism is governed by a sensor-integrated system connected to the building's environmental control platform, enabling real-time adaptation to solar position, external temperature, and interior comfort thresholds. As a result, the façade reduces reliance on mechanical cooling systems, contributing significantly to the building's energy efficiency and reducing operational carbon emissions.

The pattern and geometry of the kinetic skin are derived from **Islamic geometric motifs**, reinterpreted through parametric design tools to optimize solar shading while maintaining visual porosity. Unlike historical mashrabiya, which were often handcrafted from wood and fixed in place, this system embraces technological precision and dynamic performance, creating a living façade that breathes, adapts and evolves throughout the day. Each module varies in density and opening ratio based on its specific solar orientation, producing a heterogeneous yet harmonious expression across the building's height.

Behind the kinetic layer lies the inner curtain wall, a double-glazed, low-emissivity glass system supported by aluminum mullions and thermally broken frames. This layer provides air-tightness, thermal insulation and acoustic performance, as well as uninterrupted views toward the Atlantic coast and the urban growing skyline. The cavity between the two skins functions as a ventilated buffer zone, where heat accumulation is minimized and natural airflow can be modulated. Maintenance access is integrated through operable service catwalks concealed within the shading framework, ensuring long-term operability without compromising aesthetics.

The façade design also plays a role in **cultural expression**: while the overall form of the tower is contemporary, its surface becomes the medium bridge between historical architectural logic is made relevant to the present. The mashrabiya—a device traditionally associated with privacy, ornament and passive cooling—is reactivated here as a technological and ecological component, bridging centuries of design evolution. This strategy resists the global trend of homogenized glass skyscrapers, instead offering

a regionally specific architectural language that speaks to Casablanca's climate, culture and aspirations.

In conclusion, the façade is conceived not as a static cladding, but as a **multilayered system of adaptability and resonance**. It performs across multiple registers: environmentally, by responding to climatic forces; structurally, by integrating with the diagrid frame; and culturally, by embedding regional memory into a high-performance envelope. The result is an intelligent skin that not only protects but also expresses, modulates and connects, establishing the façade as a central agent in the tower's architectural identity.

7.6 Sustainable strategies

The sustainable vision of the tower is not limited to the application of high-efficiency technologies, but is rooted in a climate-specific design process that fuses passive environmental principles, vernacular intelligence, and renewable energy integration. The project responds to the increasing demand for sustainable high-rise typologies that are not only efficient in performance but also contextually aware, socially inclusive, and materially responsible. In a city like Casablanca, where rapid urbanization and energy dependency challenge environmental resilience, the tower becomes a **prototype of adaptive sustainability** for the North African climate.

At the core of the project's environmental strategy is its bioclimatic massing and orientation. The tower is aligned to maximize exposure to prevailing winds from the northwest, enabling the use of **passive ventilation systems** through an eccentric vertical shaft—an evolved wind tower—that facilitates stack-effect air circulation across all levels. The tapered and twisted form of the building is not only a response to wind loads and aesthetics but is also strategically shaped to reduce solar gain on the most exposed façades and to break down wind vortices at upper heights. The **eccentric void** acts as a thermal chimney, enabling vertical air movement and pressure equalization, reducing the need for mechanical air handling.

The façade further reinforces the building's environmental adaptability. The **kinetic mashrabiya system**, operating on the sunniest orientations, adjusts dynamically to modulate solar radiation, reduce glare and maintain interior thermal comfort, reducing cooling loads especially during summer peaks. Coupled with a **high-performance low-**

e glazed curtain wall, this system enables a balance between transparency, insulation, and solar control.

In terms of **renewable energy**, the tower integrates a system of **photovoltaic panels** placed primarily on the rooftop technical level and across select horizontal shading elements. The available surface area dedicated to PV modules is approximately 800 m², which enables the annual generation of around **136,000 kWh**, covering a significant portion of the tower's common area electricity demand. These energy savings are further supported by **geothermal energy** systems located at the fourth basement level, where deep geothermal wells provide low-grade heating and cooling support for HVAC systems through heat exchange loops. These systems drastically reduce the building's dependence on fossil fuels and help stabilize indoor thermal conditions throughout the year.

Water management strategies play an equally vital role. A **rainwater harvesting system** is integrated into the tower's roof and plaza-level landscape, channeling runoff into a cistern located at the first basement floor, separated from the technical and mechanical equipment rooms, enhancing safety and organization. The collected water is filtered and reused for irrigation and greywater systems, feeding the public restrooms and planted surfaces around the site. Additionally, native and drought-resistant vegetation has been selected for the public plaza and sky gardens to minimize irrigation needs while supporting urban biodiversity and microclimate regulation.

Sustainability speaking, the structure employs **locally sourced concrete and steel**, where possible, with high recycled content. Finishes in interiors and public areas favor low-VOC materials, acoustic insulation and demountable assemblies that facilitate future disassembly or maintenance. The construction strategy also aims to minimize waste on site by prefabricating components of the façade and diagrid structure, ensuring tighter control over energy and material use.

Ultimately, the tower positions itself as a model for context-specific sustainable architecture—not through imported strategies, but through a calibrated mix of passive design, renewable energy, and architectural intelligence rooted in local climate and culture. It demonstrates that high-rise buildings in rapidly developing regions can be more than symbolic statements: they can become functional infrastructures for ecological balance, energy independence and cultural continuity

7.7 Functional Mixed-Use and Social experience

For the functional point of view, the organization of the tower is conceived as a **layered vertical ecosystem**, where diverse programs are spatially and socially integrated across height, creating a continuous sequence of experiences that redefine the tower as a civic, cultural, and inhabitable infrastructure. Rejecting the model of the monofunctional skyscraper, the project embraces the logic of hybrid use, allowing for temporal, demographic, and programmatic overlap that generates intensity and openness within the vertical fabric of the city.

From the **base to the eleventh**, the tower anchors itself in the public realm through a porous and inclusive ground floor. These levels act as a civic platform, hosting cultural exhibitions, public art, retail units, cafés and shaded seating areas integrated into a lushly vegetated urban jungle on the ground floor. The public plaza is not treated as a residual forecourt, but as a programmable social surface—a space for interaction, events, performances, and everyday life. Through ramps and sunken gardens, this ground condition continues below grade, connecting with subterranean levels that accommodate multi-purpose halls, technical rooms, and rainwater harvesting infrastructure. Accessibility is ensured through barrier-free design and a looped vertical circulation system, which includes panoramic elevators, escalators, and fire-rated escape stairs.

From the **13th to the 22nd floor**, the tower hosts co-working spaces and innovation hubs, designed with modular layouts to support changing occupancy patterns and diverse workstyles. These levels promote knowledge exchange, entrepreneurship, and flexibility, while ensuring proximity to services and collaborative amenities. Natural daylight and ventilation are maximized through the central atrium, while shared breakout zones spill into double-height lounges that overlook the plaza below. The average height is satisfied by the Moroccan Building Rules, with a 3.30 meters of net height as average for each floor.

Above **the 24th floor**, the building transitions into a core of **premium office spaces**, distributed up to the twenty-fourth floor. These are organized in open-plan layouts with high floor-to-ceiling ratios, enabling tenants to personalize their work environments while benefiting from natural light, acoustic comfort and proximity to vertical gardens. Interspersed among office floors are “**sky lobbies**”—semi-public collective areas that

offer cafes, terraces, and informal meeting spaces, blurring the line between productivity and socialization.

From the **35th-forth to the 46th floor**, the program shifts toward **serviced residential units**, aimed at business travelers, expatriates and short-term professionals. These residences vary in size, from compact studios to double-aspect one-bedroom apartments, and include access to shared amenities such as **laundry zones, lounges, and wellness areas**.

The **uppermost levels** of the tower are dedicated to collective uses and climatic functionality. A panoramic sky lounge, flexible event room, and rooftop observatory are located just below the technical crown, offering **unobstructed views** over Casablanca and the Atlantic. These areas are supported by a vertical garden and a **technical floor housing a tuned mass damper**, which simultaneously ensures structural performance and wind and seismic stability. The top of the tower becomes a social and symbolic apex—a place of elevation, not only in altitude but in shared experience.

Programmatic layering is supported by a **separated vertical core**, which distributes users through distinct elevator banks while maintaining safety and service efficiency. Back-of-house functions (deliveries, mechanical shafts, waste separation, etc.) are isolated from public flows, ensuring functionality without compromising openness. Social integration is also considered at a vertical scale: each programmatic band is provided with interstitial public moments, where users can pause, meet, reflect, or transition between activities. These spaces, often green or open to the exterior, serve as breathing chambers in the vertical circulation of the building.

In terms of inclusivity, the design prioritizes diverse user profiles, from tourists to professionals, residents to casual visitors. Through its mixed-use programming, the tower resists privatization and segmentation, offering layered social interactions that challenge the exclusivity typically associated with high-rise development. In this way, the building supports not just functional diversity, but a diverse urban life.

8. Conclusions and future perspectives

This thesis has been one of both architectural inquiry and personal exploration. Through the design of a high-rise tower in Casablanca Finance City, I have learned not only to synthesize the lessons drawn from case studies, theories and sustainable innovations but also to propose a vision that reflects a deep understanding of place, culture, and climate. The tower does not merely stand as an isolated vertical entity but rather emerges as a porous, adaptive organism—rooted in Moroccan identity and open to global architectural discourse.

Throughout the project, I have critically addressed challenges posed by height, environmental performance, and mixed-use programming, crafting an ecosystem that intertwines urban life with architectural intelligence. From the use of dynamic façades to passive wind-driven ventilation, from the reinterpretation of Arab architectural traditions to the application of advanced structural systems and a tuned mass damper—every design decision has been oriented toward equilibrium: between heritage and innovation, density and openness, iconicity and inclusivity.

At the ground level, the integration of a lush urban jungle and reflective water elements transforms the public realm into a biophilic sanctuary—an urban oasis where architecture heals, breathes, and connects. As we ascend, the tower becomes a vertical narration of collective experience: workspaces, social hubs and temporary residences coexist in dialogue with nature and light. At its summit, the tower culminates not in isolation but in openness—with a panoramic observatory and public terrace that reinstate the idea of architecture as a gift to the city.

This thesis ultimately argues for a rethinking of the vertical paradigm—not as a monument to capital or ego, but as a socially embedded and climatically responsive urban artifact. The tower is envisioned not as a sealed object, but as a breathing, evolving extension of the city itself. In doing so, it becomes a manifesto for a future architecture—one that dares to rise, not only in height but in conscience.

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11. Acknowledgments

I would like to express my deepest gratitude to all those who supported me throughout the development of this thesis.

First of all, I would like to express my sincere thanks to my two academic advisors. To Professor CHEN YI at Tongji University: thank you for your rigorous guidance, your thoughtful criticism and your trust throughout this process. Your perspective helped me frame my research with clarity and precision. To Professor Trabattoni Luca, whose deeply knowledge for architecture, cultural depth, and unwavering support have accompanied me since the early phases of this work, I am especially grateful. Your ability to challenge ideas while nurturing creativity has been invaluable.

I am also thankful to the entire faculty and staff of the **College of Architecture and Urban Planning (CAUP) at Tongji University**, for providing an intellectually rich and internationally open environment where I could explore different perspectives and push the boundaries of my design and theoretical thinking.

I would like to acknowledge the inspiration I drew expetially from **Arab-Islamic architectural heritage**, which shaped not only the content of this thesis but also my personal vision of sustainable and culturally rooted design. The opportunity to study and live between different worlds has been a privilege that expanded my sense of responsibility as an architect.

A heartfelt thanks goes to my **fellow university colleagues and friends**—both in Shanghai and Italy—who have shared with me moments of stress, crazy-fueled nights, academic debates, laughter and hope. Thank you for your honesty, your presence and your patience. This work was often sustained by your energy as much as by my own.

I am infinitely grateful to my **family**, whose love and support have been the most stable foundation throughout this academic and personal path. To my parents, thank you for your unwavering faith in me, for your sacrifices and for teaching me to value both roots and horizons. To my siblings and loved ones, thank you for being my compass and emotional shelter.

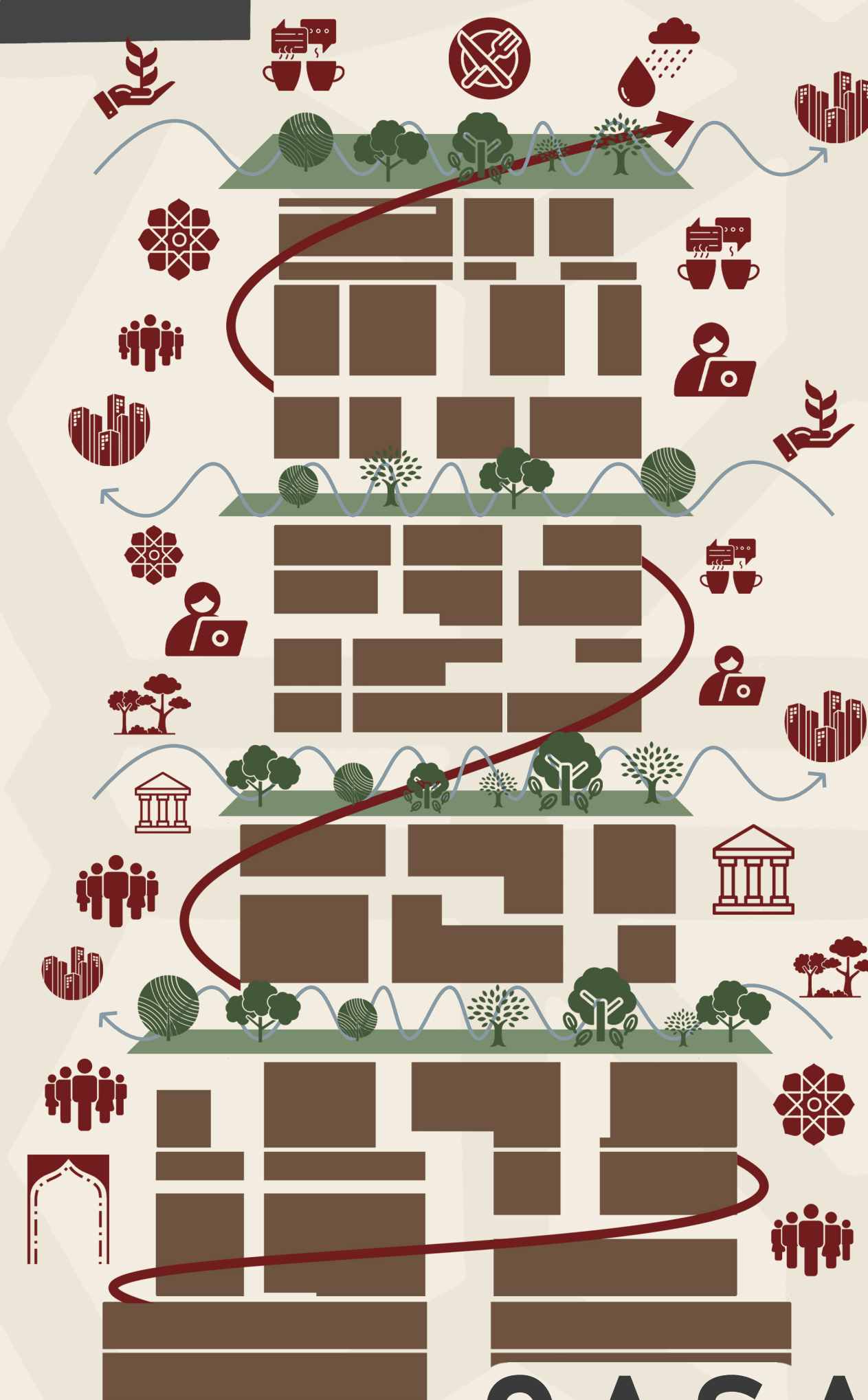
11. Acknowledgments

Lastly, I would like to dedicate this thesis to all those who believe that architecture is far more than a mere technical discipline. To those who see it as a bridge between people, climates, and cultures—a living language capable of having dialogue, preserving memory, shaping transformation and embracing both innovation and bold creativity. This work is for the dreamers, the visionaries, the curious minds who understand that architecture can be both rooted in context and wildly imaginative. May this thesis serve as a small tribute to the idea that spaces are not just built, but felt; not only functional, but deeply human and creative.

Because Architecture has to answer the needs of people.

VERTICAL OASIS: THE DYNAMIC TOWER

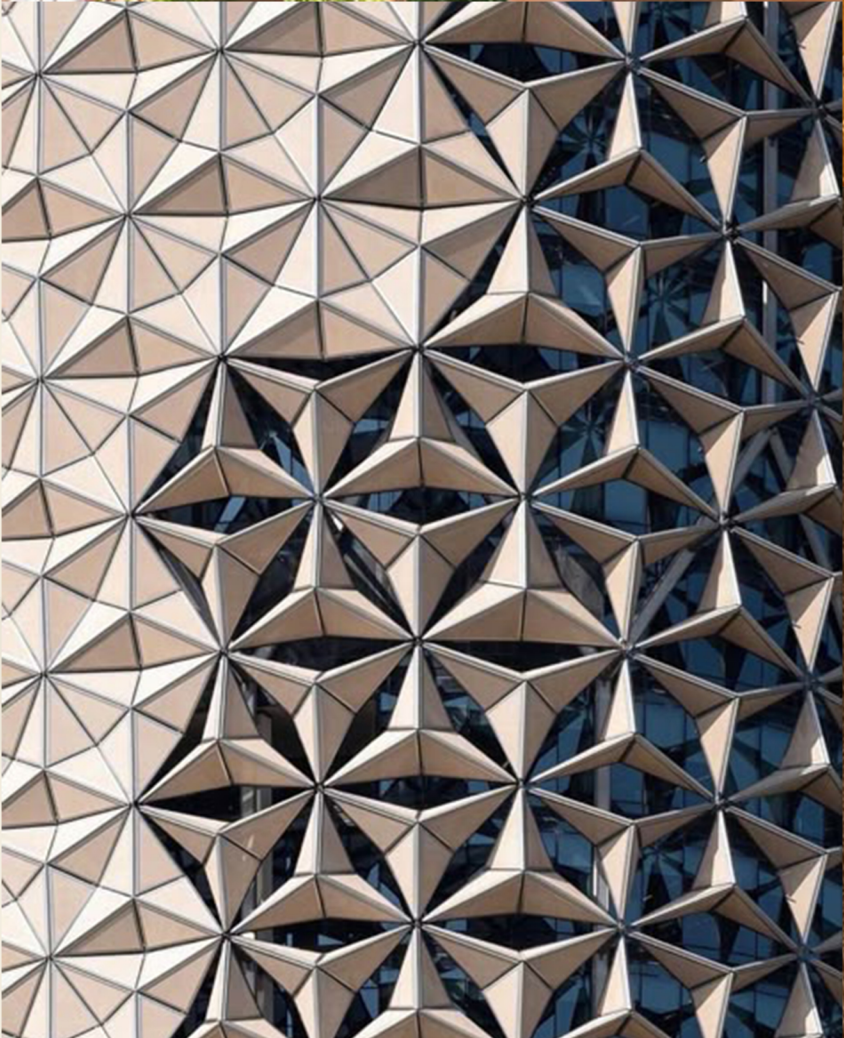
M A G H R E B



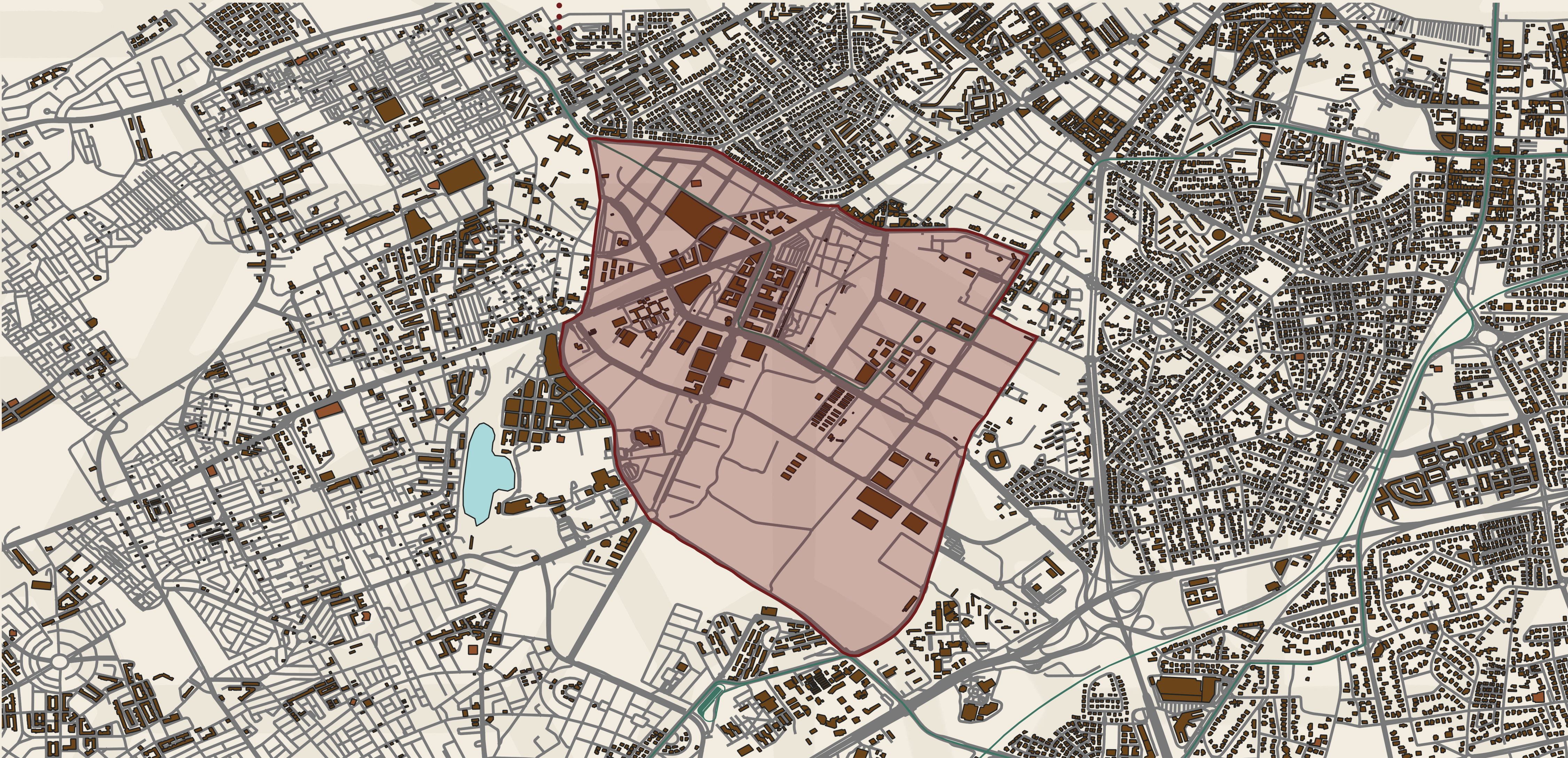
MODERNITY
TRADITION
IDENTITY
FORM
ADAPTATION
BIOClimatic
VERTICAL



VISIONAL
MOODBOARD



CASABLANCA FINANCE CITY

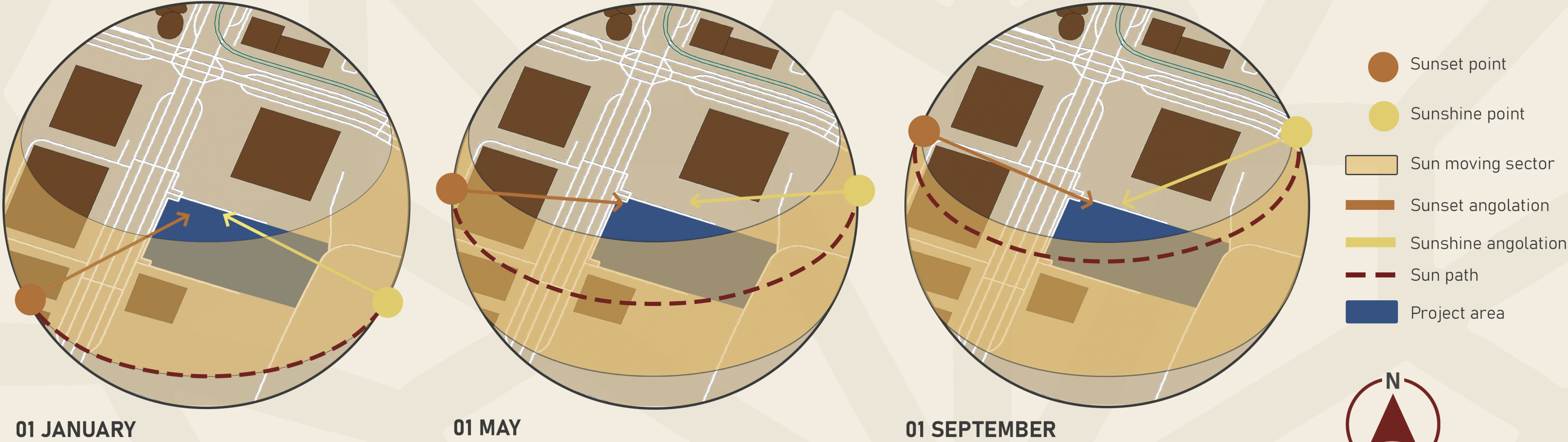


VERTICAL OASIS: THE DYNAMIC TOWER



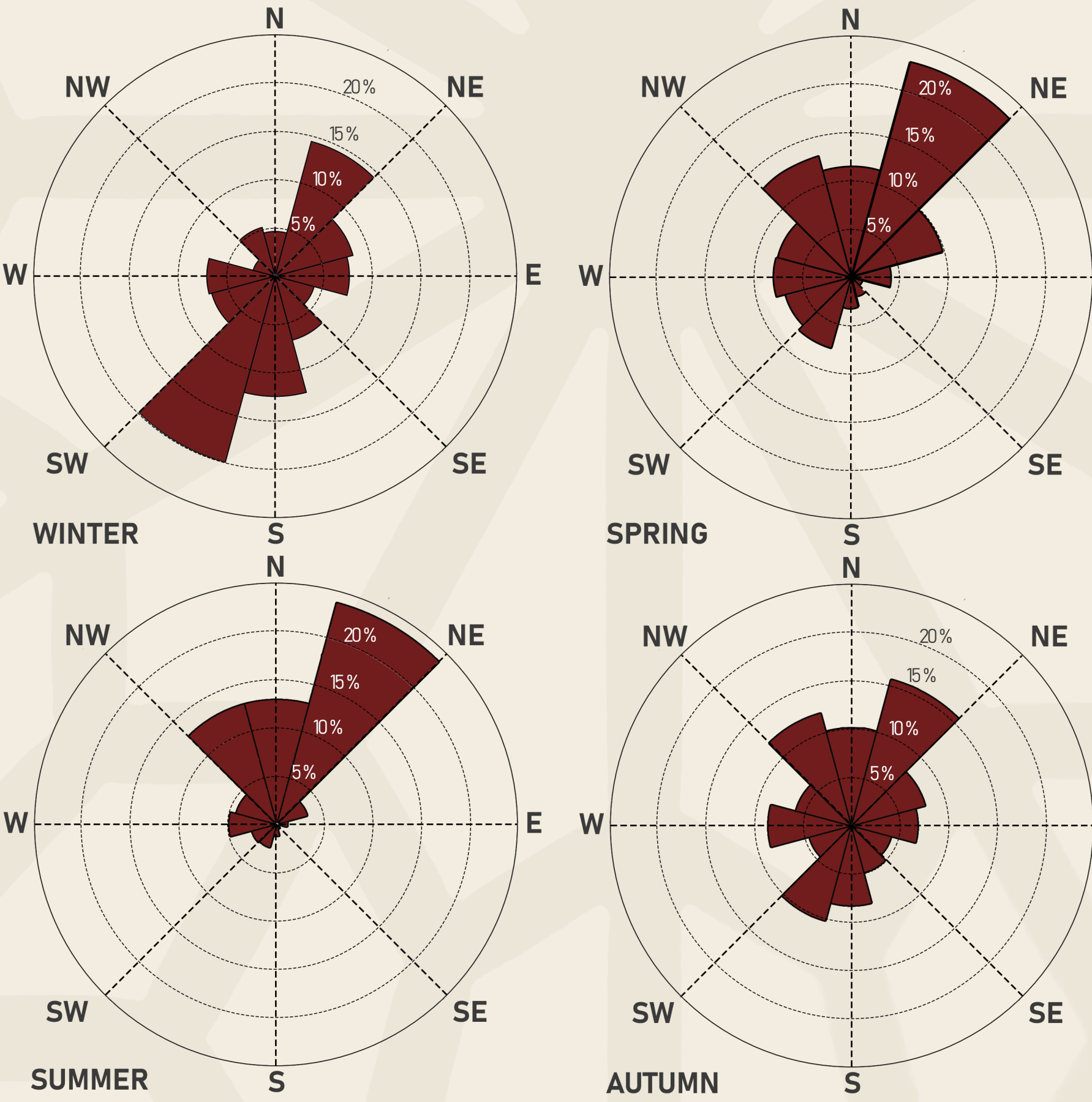
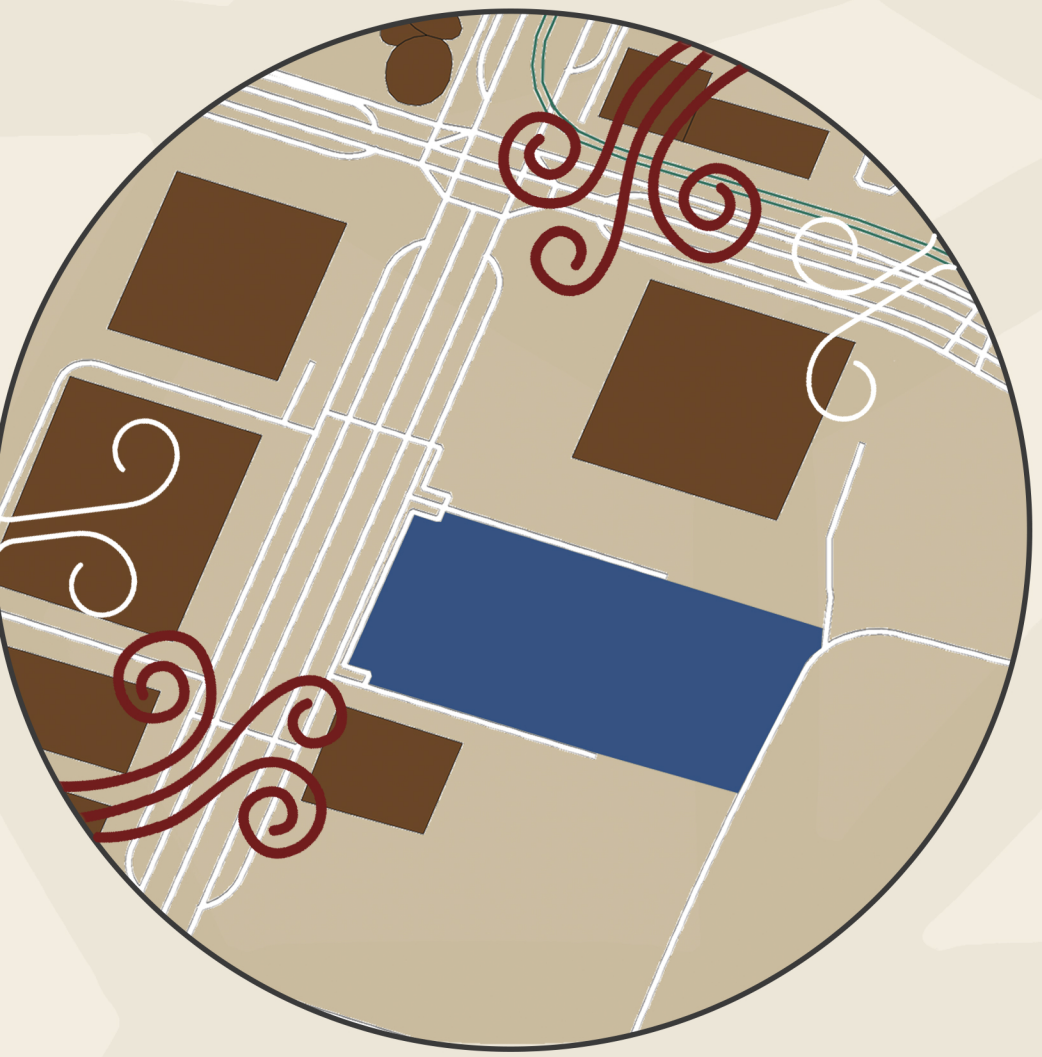
The chosen plot within Casablanca Finance City is strategically located at the intersection of infrastructural efficiency and urban symbolism. Through a careful analysis of environmental parameters and urban dynamics, the site reveals itself as an ideal ground for a high-performance vertical structure. The local microclimate, solar trajectories, and prevailing winds directly inform the building's orientation, passive strategies, and responsive envelope systems.

Sun Path and Solar Exposure



Wind Direction and Speed

Understanding the wind behavior across seasons is fundamental for the design of a high-rise building that aspires to be environmentally responsive. Wind influences not only the structural load and façade articulation but also plays a crucial role in enabling passive cooling strategies and enhancing occupant comfort. This analysis draws from historical climatic data (2009–2023) to investigate the seasonal wind patterns in Casablanca.



According to the **Global Wind Atlas**, the project site in Casablanca experiences a predominant north-easterly wind throughout the year, with an average wind speed of approximately 6.2 m/s at 100 meters above ground level. This makes the site particularly suitable for passive ventilation strategies and reinforces the need for aerodynamic design considerations in the tower's façade system. The radial values indicate the percentage of time during which the wind blows from each direction throughout the season.



VERTICAL OASIS: THE DYNAMIC TOWER



Commerzbank Tower HQ

Location: Frankfurt, Germany
Date: 1997
Architect: Foster & Partners



30 St Mary Axe "The Gherkin" Tower

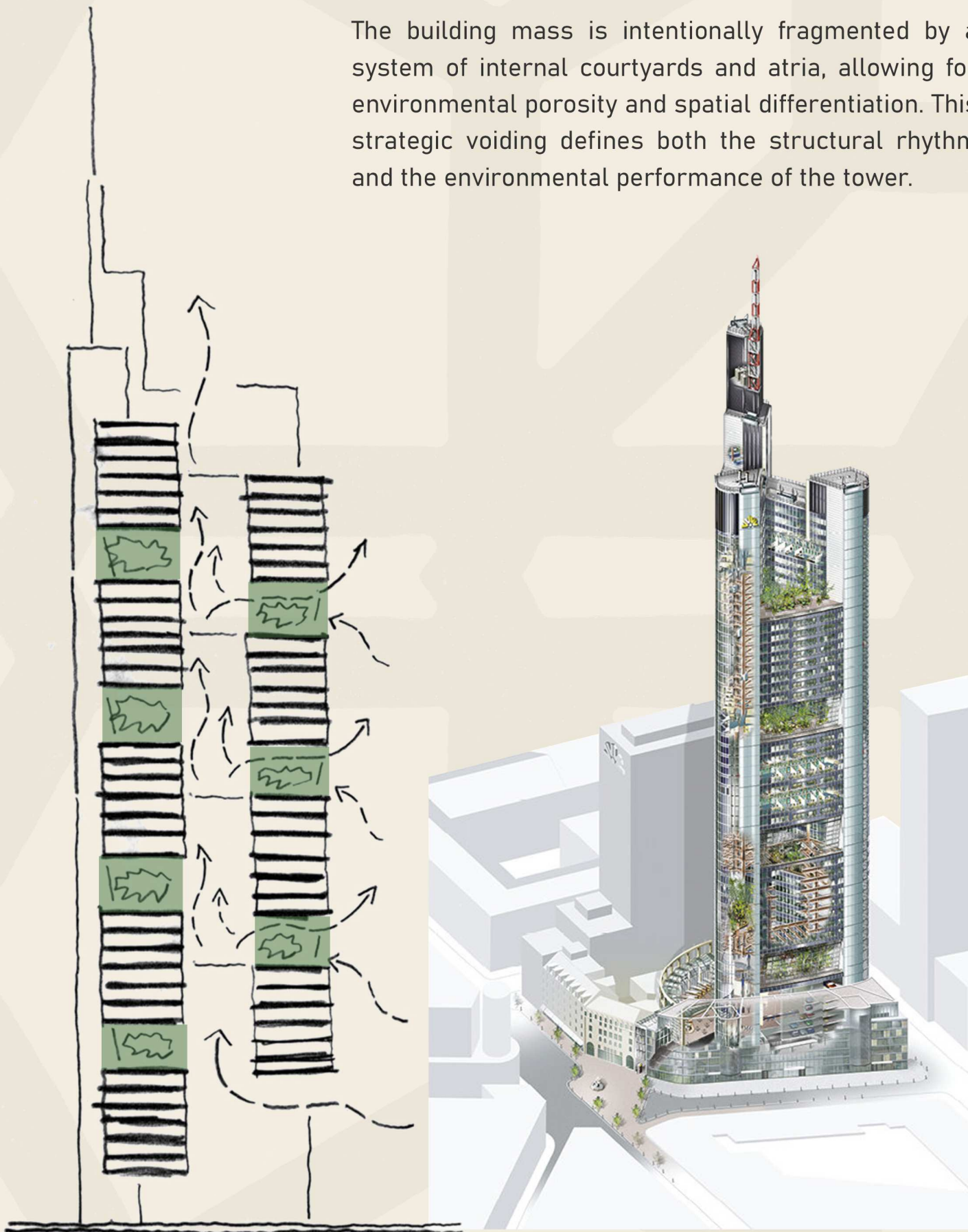
Location: London, UK
Date: 2003
Architect: Foster & Partners



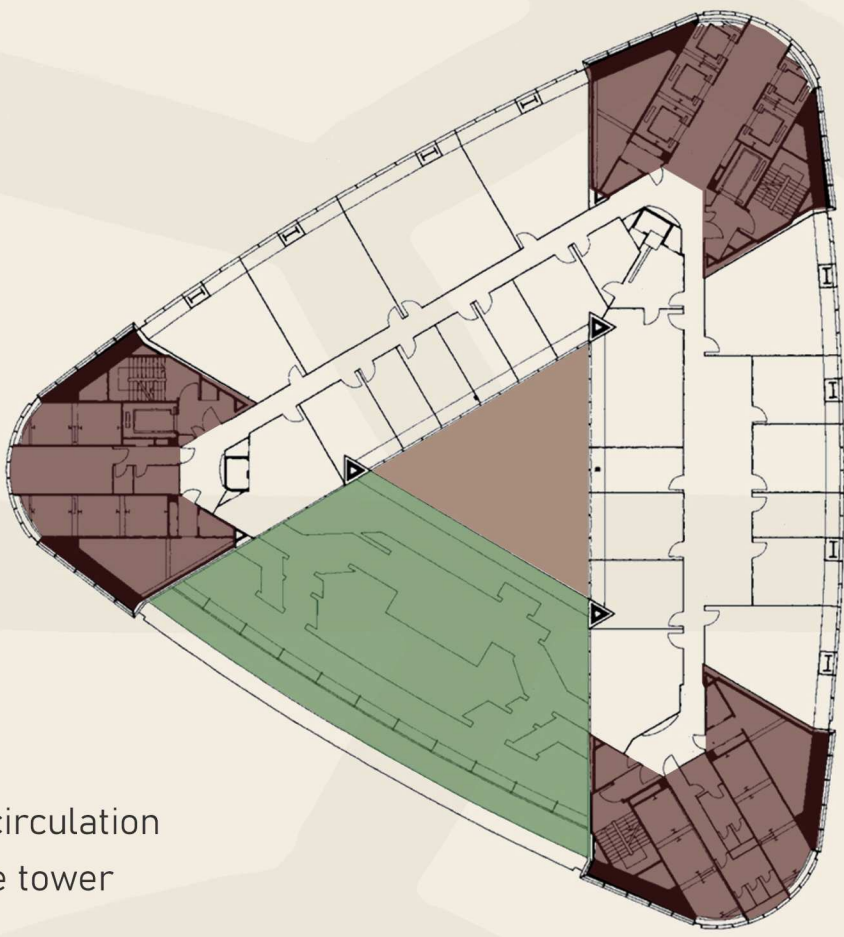
Institute Du Monde Arabe

Location: Paris, France
Date: 1987
Architect: Enrique Jan + Jean Nouvel + Architecture-Studio

The building mass is intentionally fragmented by a system of internal courtyards and atria, allowing for environmental porosity and spatial differentiation. This strategic voiding defines both the structural rhythm and the environmental performance of the tower.



The Commerzbank Tower is structured around a central triangular void that cuts vertically through the tower. Every 12 floors, internal sky gardens are introduced, creating visual and physical connections across levels. These voids allow natural light to penetrate deep into the floor plates, while enabling cross-ventilation, reducing reliance on artificial systems.



- Central void for air circulation
- Eccentric core of the tower
- Sky Garden



The Gherkin's structure employs a diagrid system in which triangular steel members form a stiff, self-supporting external skin. This eliminates the need for internal columns and creates open, flexible floor plans. The diagrid absorbs both vertical and lateral loads efficiently, especially important in a high-rise with a curved, tapering geometry.

At its core, the tower includes a passive ventilation shaft that channels warm air upwards, enabling a natural stack effect. This central void supports mixed-mode ventilation strategies and enhances the building's bioclimatic performance. Each floor is shaped to allow perimeter airflow, contributing to energy reduction.

A full circular floor-plate occurs every six floors to act as a firebreak as well as a breakout space for the offices.

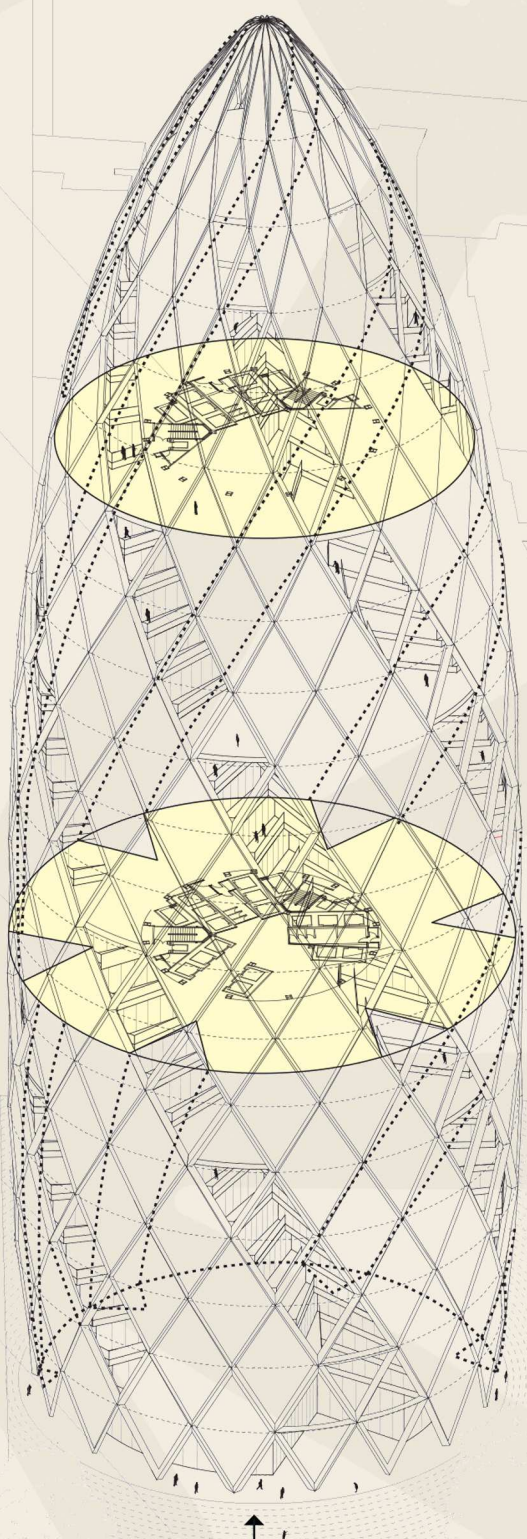
The shafts create a double-glazing effect, pulling warm air out of the building during the summer and warming the building in winter by means of passive solar heating.

The shafts enable sunlight to pass through the building.

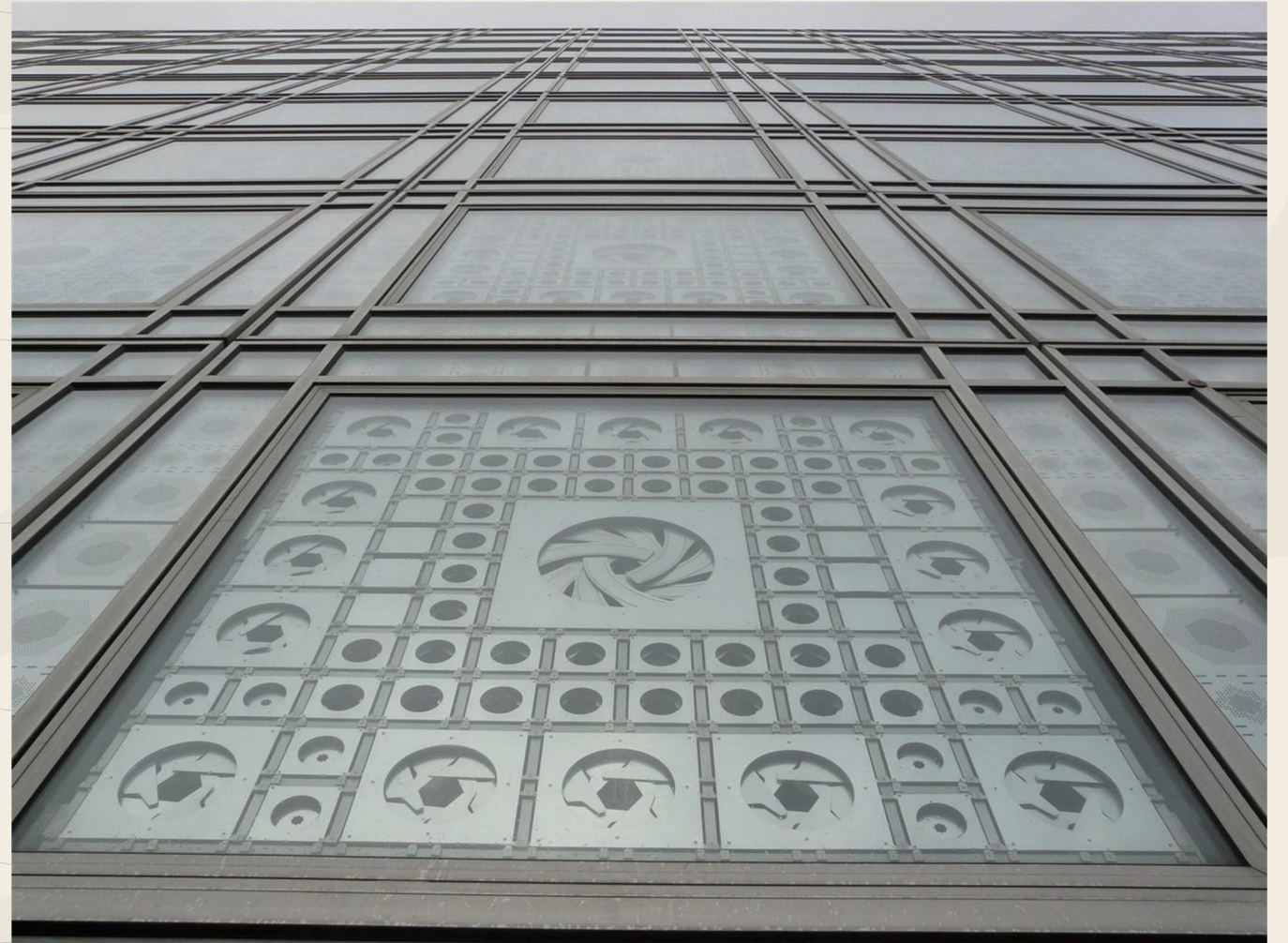
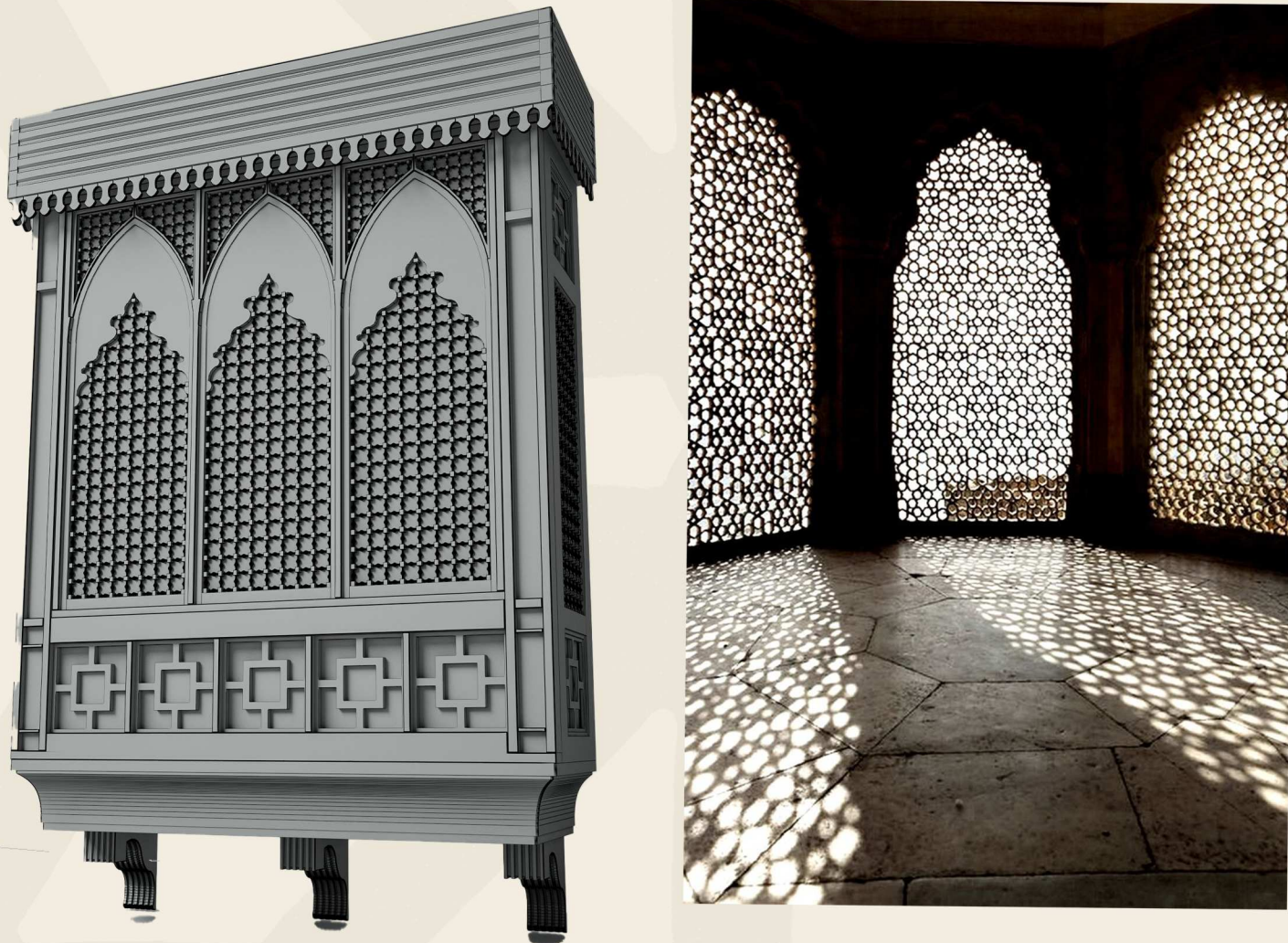
Each floor is rotated 5° from the one below to create diagonal shafts.

The smaller tower profile towards the base maximizes the public realm at street level.

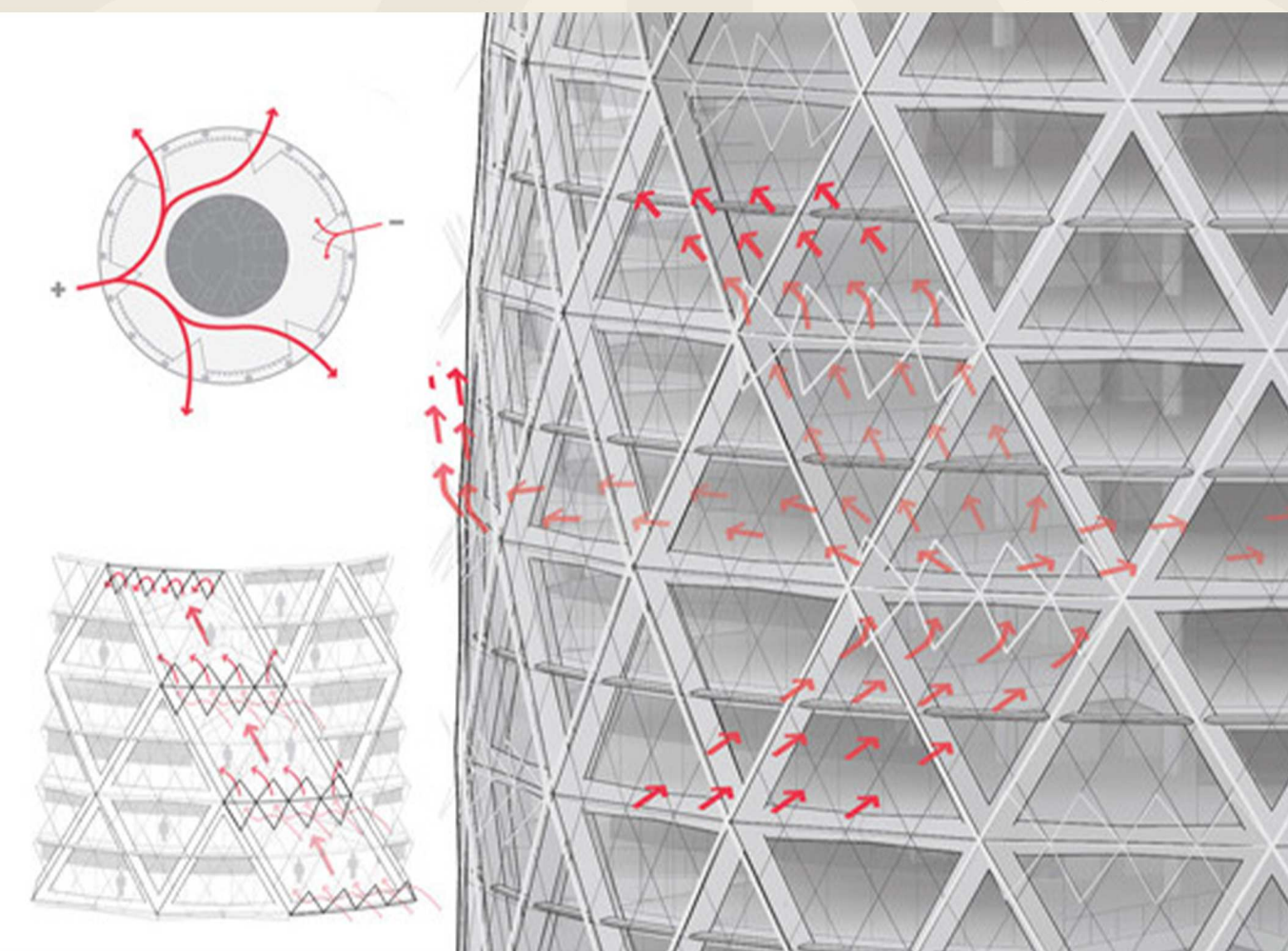
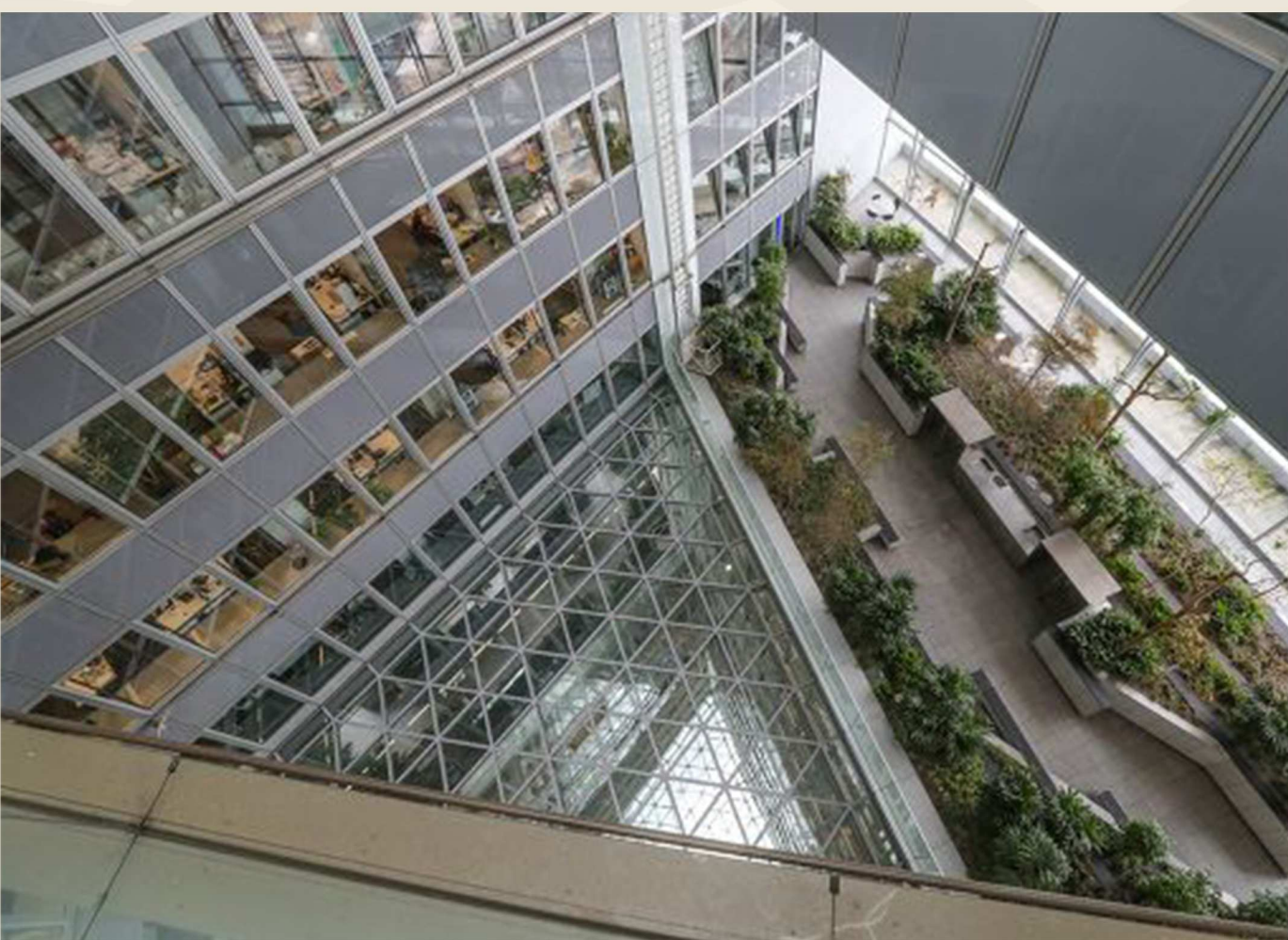
Floor-plate for firebreak and breakout space for offices



Its most iconic feature is the south façade, a technological reinterpretation of the traditional mashrabiya—the patterned screens used in Islamic architecture to filter light and provide privacy. Nouvel transforms this motif into a system of mechanical diaphragms composed of 240 light-sensitive aluminum and glass apertures, each featuring intricate Arab geometric designs. These diaphragms open and close automatically in response to sunlight, forming a responsive environmental skin.

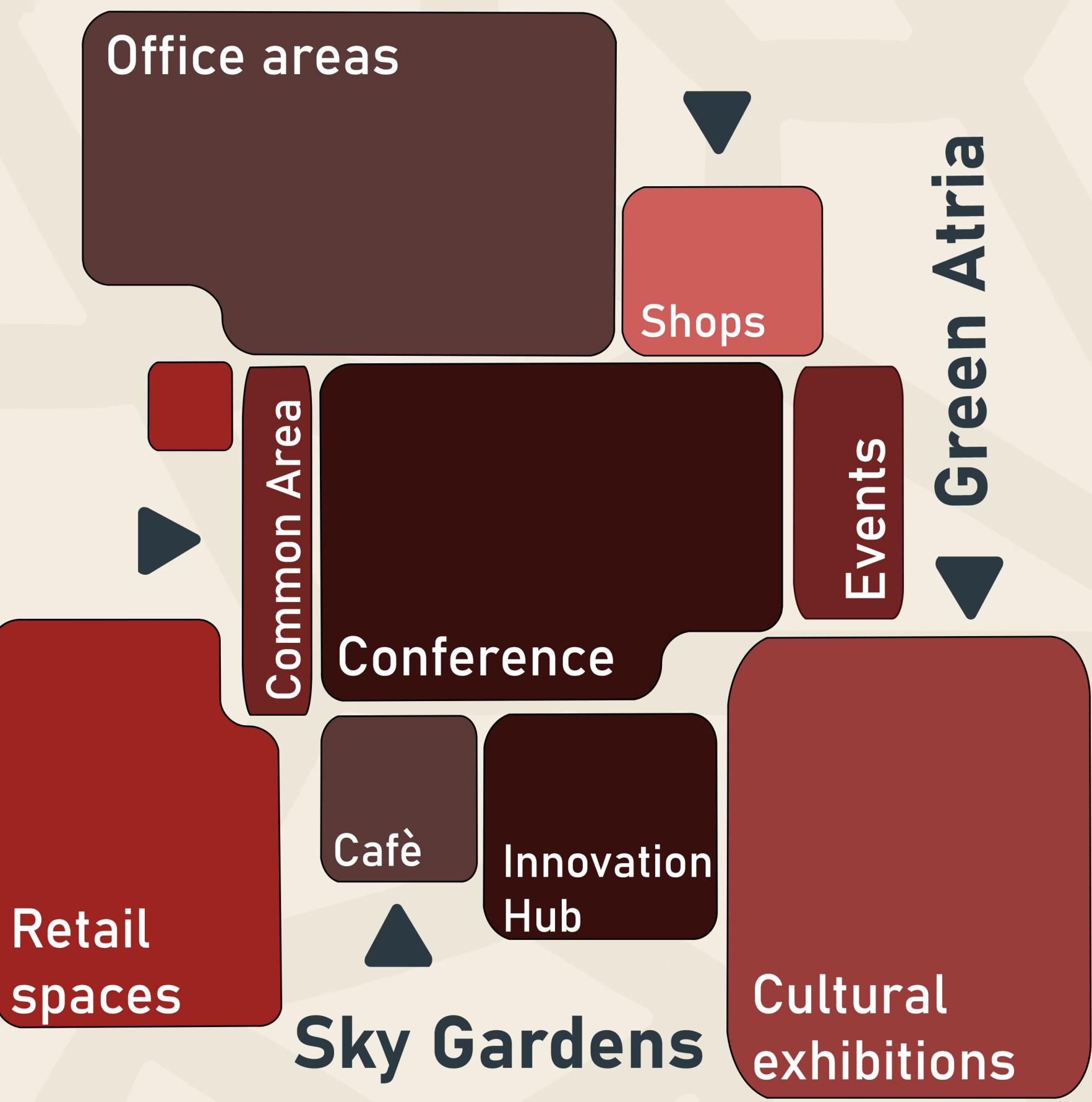


The façade performs a dual role: as an active climatic device, it regulates solar gain and improves interior comfort; as an expression of cultural memory, it abstractly translates Islamic ornament into a high-tech architectural language. Inside, natural light is modulated in a way reminiscent of a Moroccan riad, with filtered shadows and intimate spatial sequences, reinterpreted through modern materials. The building is conceived as a public threshold, blending library, museum, auditorium, and exhibition spaces into a coherent cultural program.

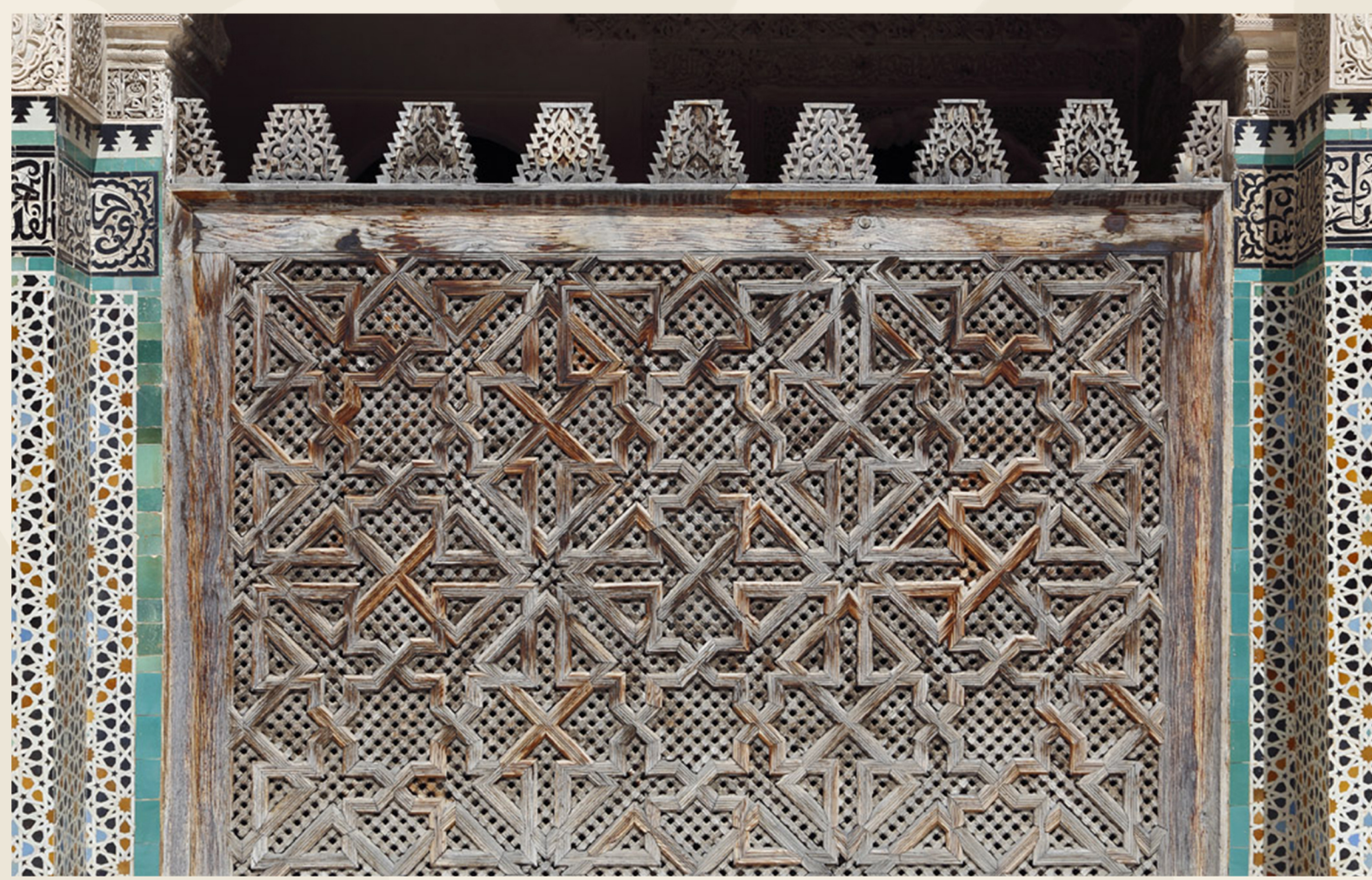


VERTICAL OASIS: THE DYNAMIC TOWER

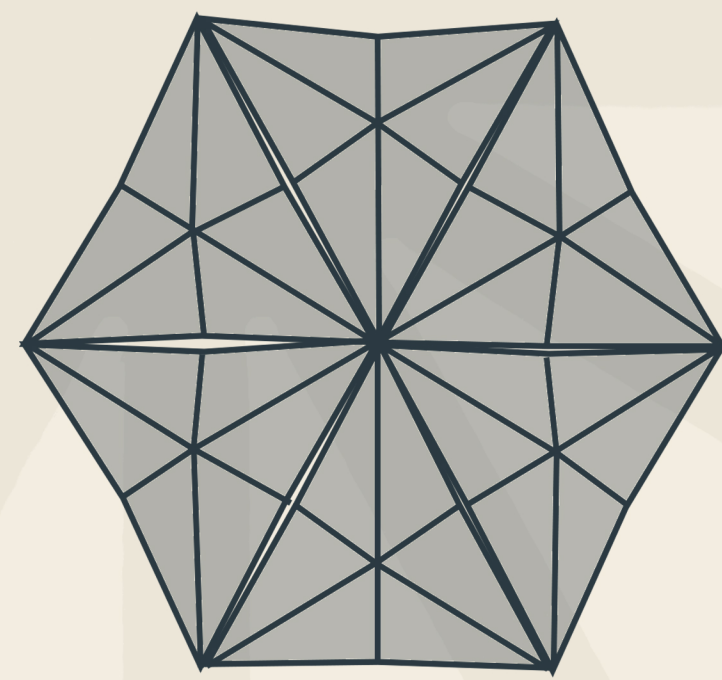
Functional Diagram



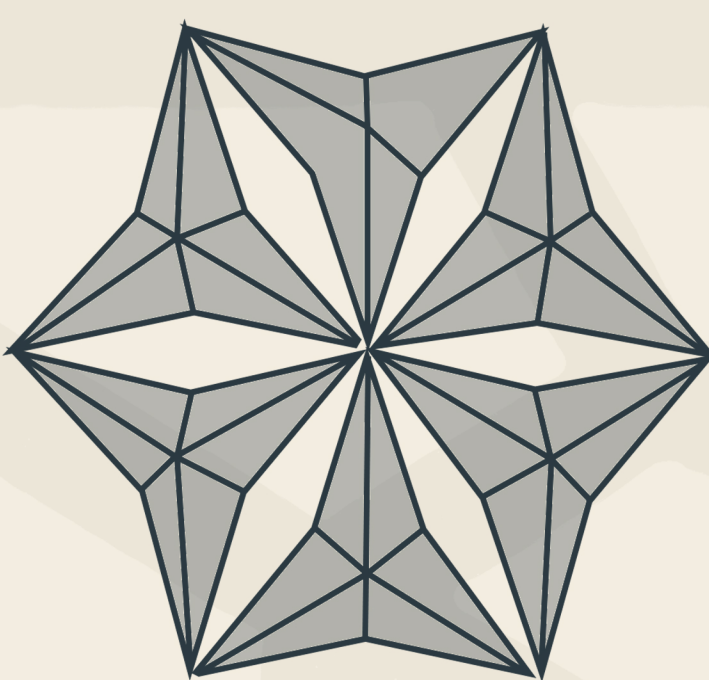
Mashrabiya concept for the façade



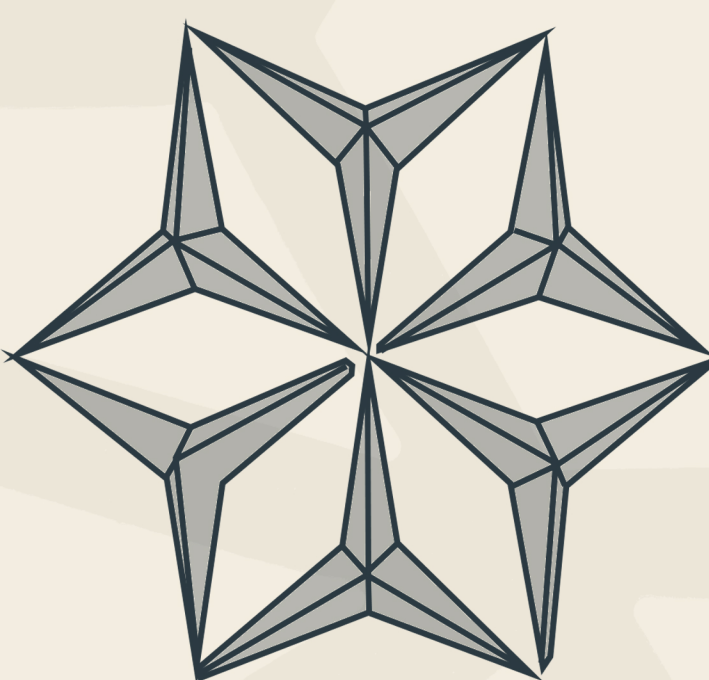
The kinetic façade takes inspiration from traditional Islamic mashrabiya screens, reinterpreted into a responsive skin system. The geometry transitions from closed to open, allowing dynamic control of light, heat, and privacy while referencing cultural identity and craft. Progressive diagram showing the transformation of the modular façade unit in response to environmental conditions. The panels adapt to solar exposure, regulating shading and transparency.



Fully Closed

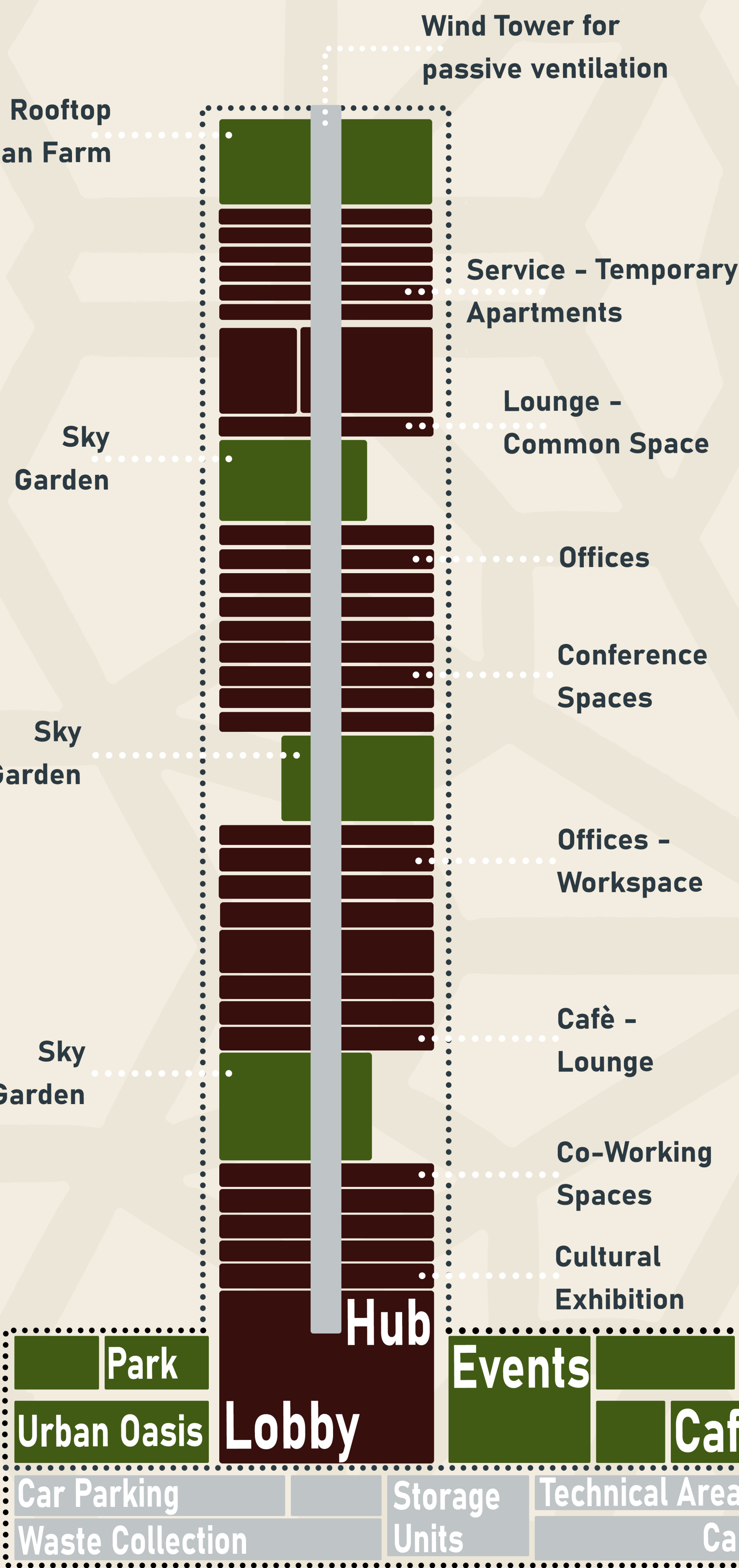


Partly Open



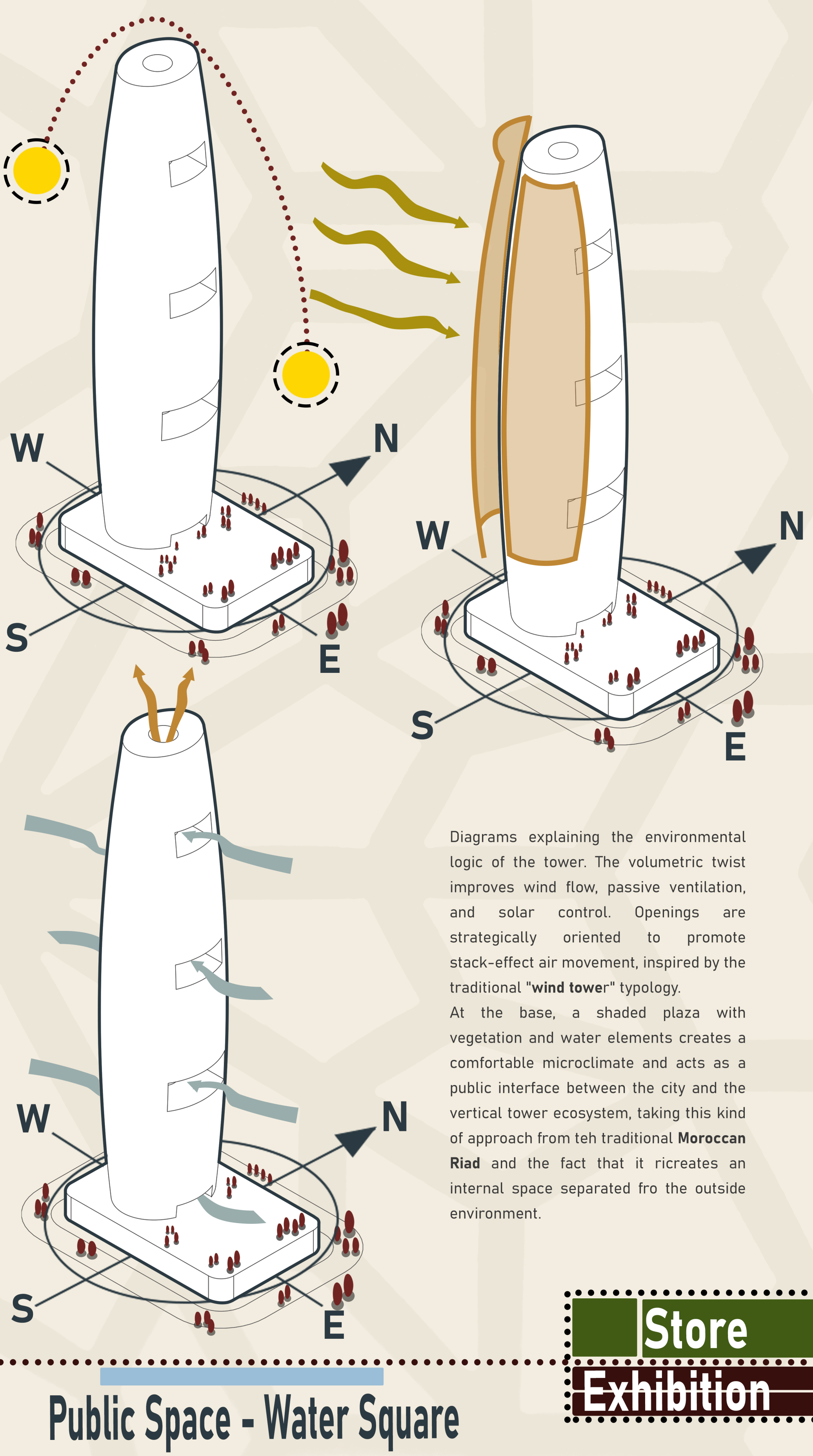
Fully Open

Conceptual Sectioned Diagram



A programmatic distribution diagram illustrating the key public and semi-public functions on the lower levels of the tower. The spaces are organized to activate the ground floor and plaza, including retail, cafés, events, and innovation hubs, all connected by green atria and sky gardens. The tower borrows as a mixed-use building, having the sky gardens as "voids" to connect the building with the urban environment, to create space for society to interact with each other and to guarantee a sustainable approach towards today's green building standards.

Conceptual 3D Diagrams



Diagrams explaining the environmental logic of the tower. The volumetric twist improves wind flow, passive ventilation, and solar control. Openings are strategically oriented to promote stack-effect air movement, inspired by the traditional "wind tower" typology. At the base, a shaded plaza with vegetation and water elements creates a comfortable microclimate and acts as a public interface between the city and the vertical tower ecosystem, taking this kind of approach from the traditional Moroccan Riad and the fact that it recreates an internal space separated from the outside environment.

VERTICAL OASIS: THE DYNAMIC TOWER



The design of the tower is inseparably linked to its base: a public space conceived not as a residual void, but as a performative and experiential landscape. Inspired by the geometry of the **Riad** and the sensory richness of **traditional Arab architecture**, the space is structured around a central water mirror and shaded zones that recreate the microclimatic benefits of an urban oasis.

Strategically placed elements such as cultural exhibitions, retail areas, cafés, and open event zones define a vibrant and inclusive ground floor. The tower's diagrid lifts the base, allowing the public to flow beneath it, reinforcing the idea of permeability and openness.

The layout emphasizes a strong climatic response, with palm trees, water features, and floating canopy structures that diffuse light and cool the air. The plaza is not static: it is an interface between the tower and the city, where movement, wind, shadow, and culture shape a daily-changing environment.

At level -1, indoor spaces host a lobby hub, restrooms, shops, and additional cultural programs, maintaining the active public character even below grade.

- 1 - Cultural Exhibition

2 - Shop

3 - Restroom

4 - Water Mirror

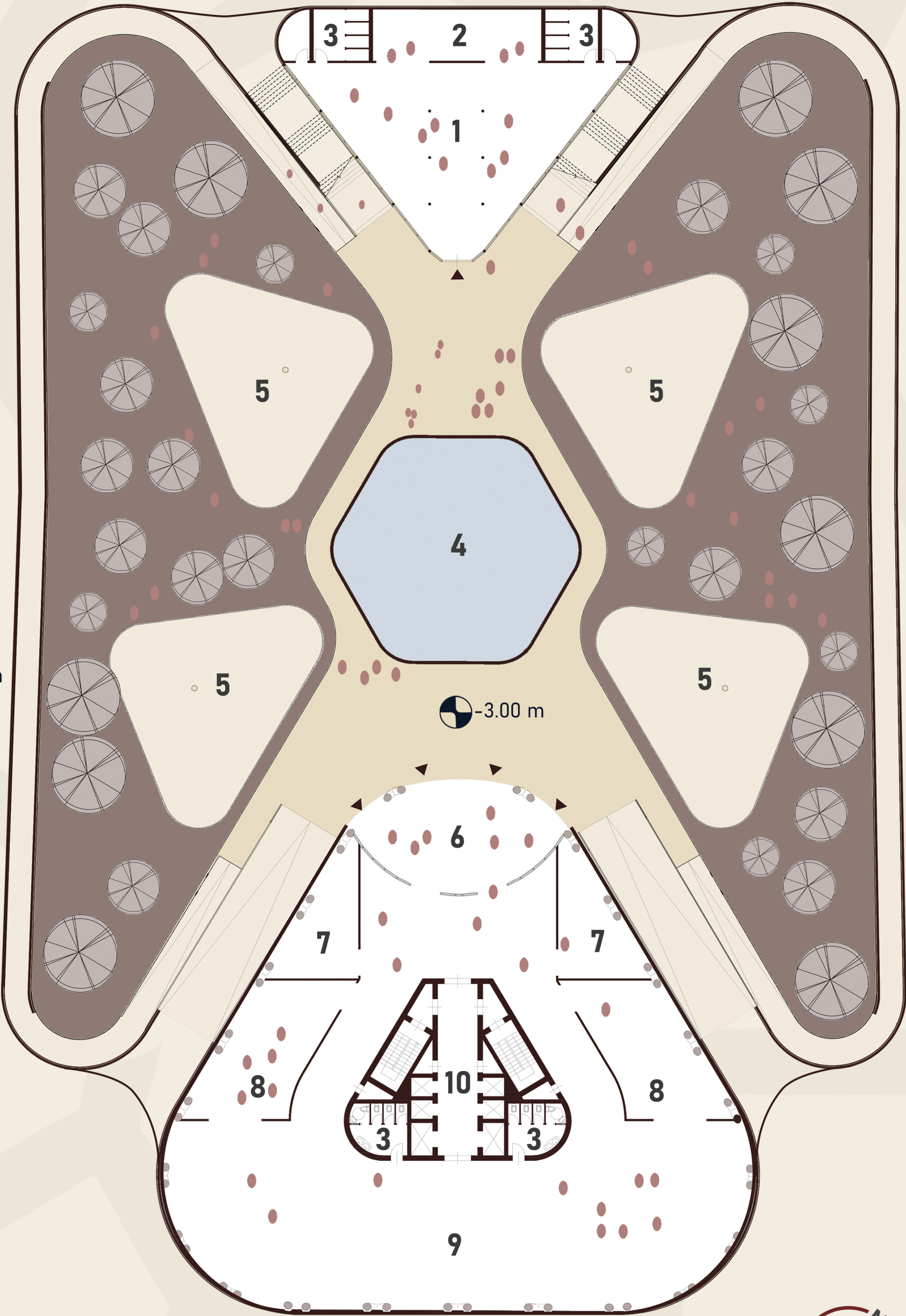
5 - Public Shading Spaces
- 6 - Entrance of the Tower

7 - Lobby Points

8 - Café

9 - Open Event Area

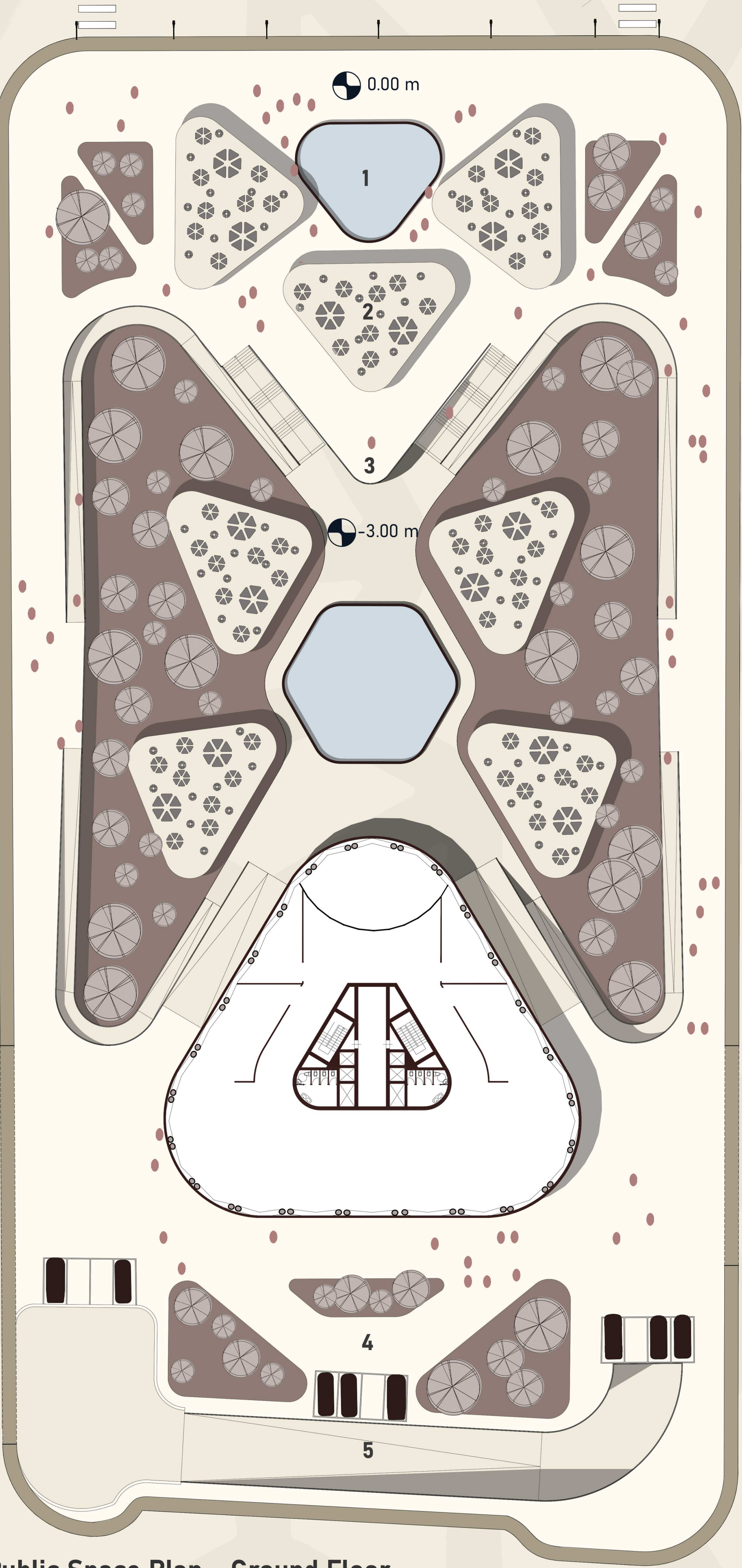
10 - Hall Core



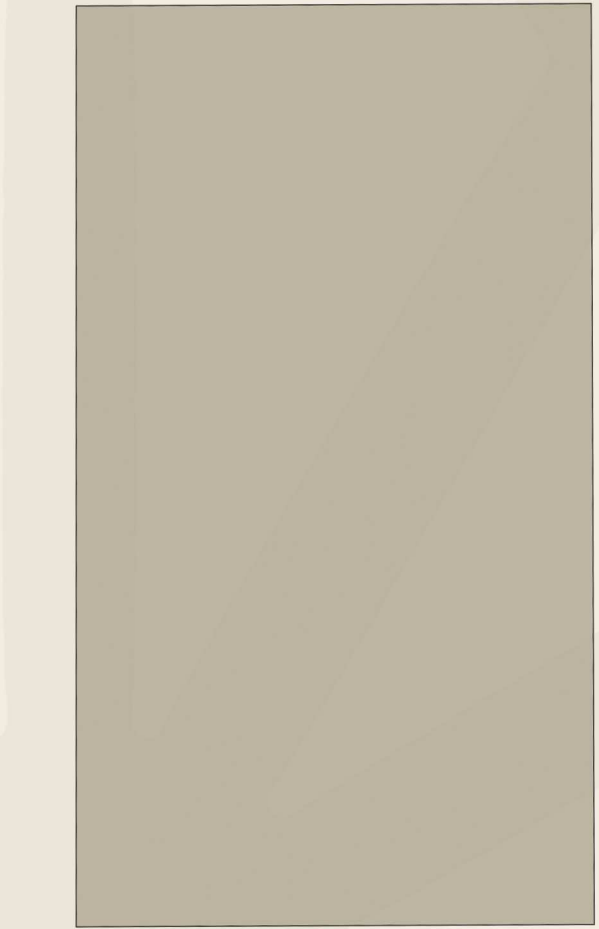
Public Space Plan - -1 Floor
Scale 1:500



VERTICAL OASIS: THE DYNAMIC TOWER



Public Space Plan - Ground Floor
Scale 1:500



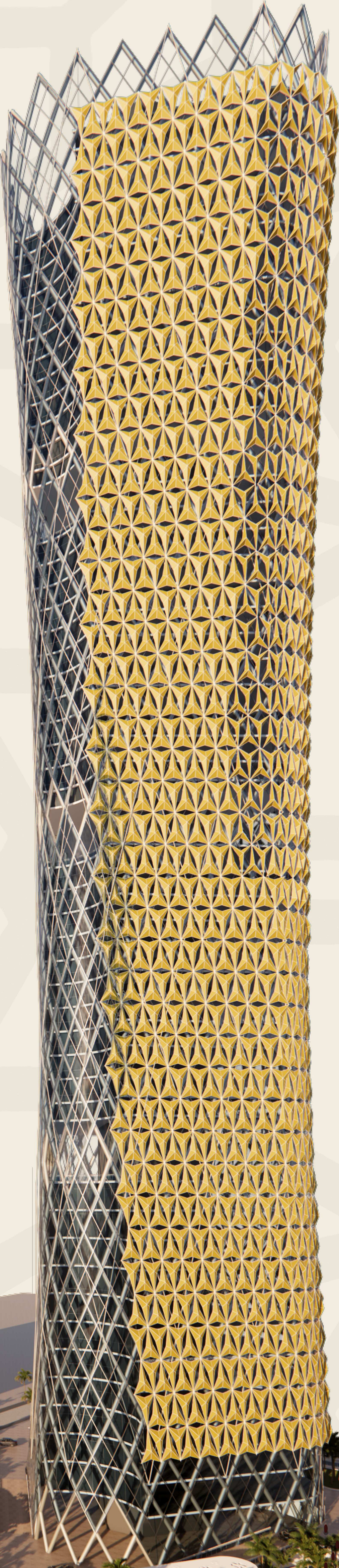
The dynamic façade is strategically positioned along the south, southeast, and southwest faces of the tower—those most exposed to intense solar radiation throughout the year in Casablanca's climate.

Its kinetic geometry, inspired by the traditional mashrabiya, adapts in real time to changing environmental conditions: filtering direct sunlight, reducing glare, and enhancing thermal comfort inside the tower.

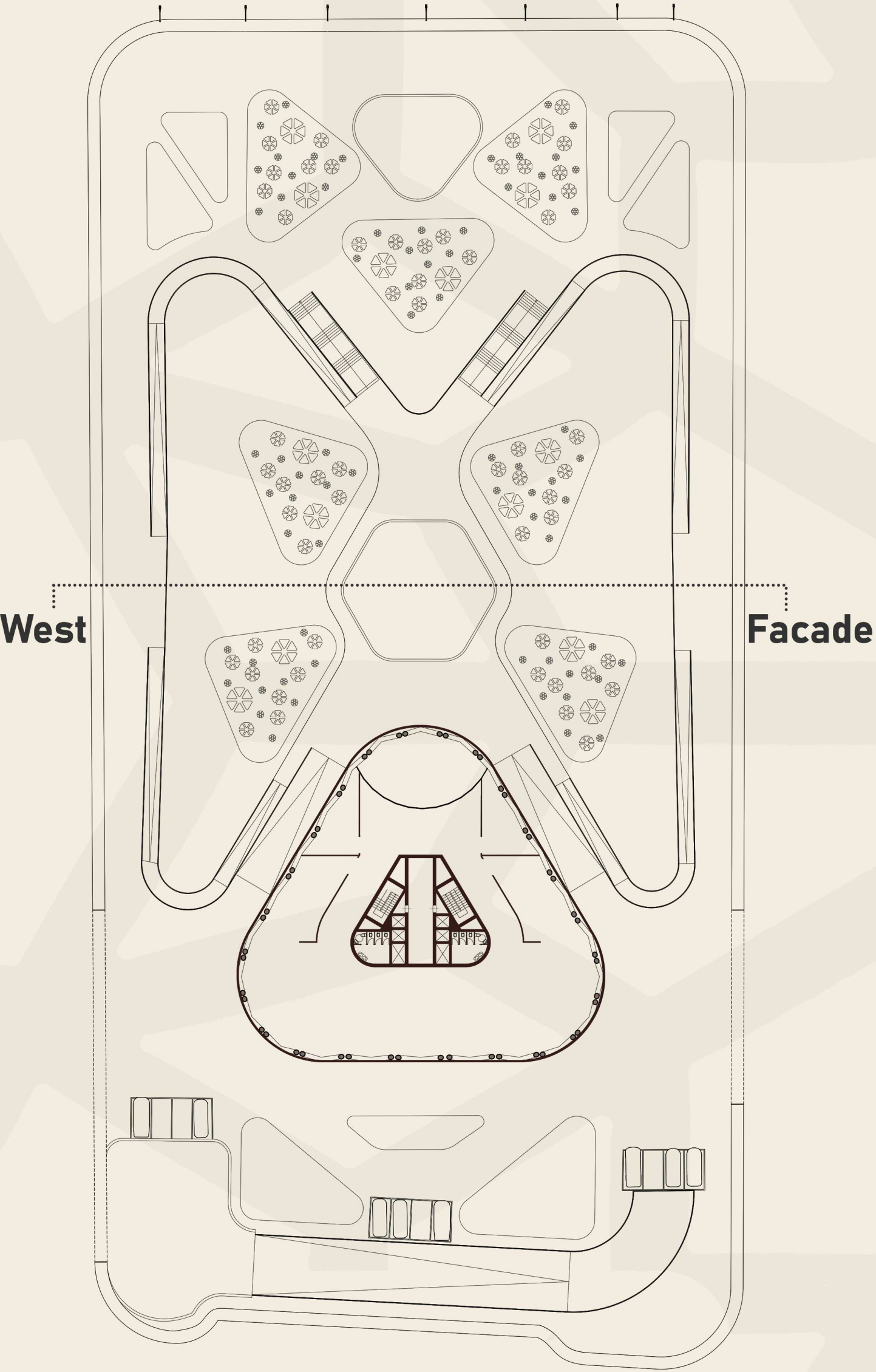
This orientation not only maximizes passive shading efficiency, but also preserves visual permeability and cultural identity through a pattern derived from Arab geometric logic. By concentrating the responsive system on sun-exposed elevations, the remaining facades can remain more open or integrated with photovoltaic systems or diagrid expression.

The dynamic skin becomes a climatic mediator, balancing aesthetics, energy performance, and cultural symbolism—where form and orientation together drive sustainability.

- 1 - Water Mirror
- 2 - Shading Spaces
- 3 - Panoramic view
- 4 - Temporary Parking
- 5 - Basement Ramp



VERTICAL OASIS: THE DYNAMIC TOWER



A clear distinction is made between public, semi-private, and private domains, progressing upward along the tower. Technical floors are integrated at structural nodes to house the building's energy and ventilation systems, and reinforce the diagrid with belt trusses.



Service -
Temporary
Apartments

Semi Private
space

Offices -
Conference
Spaces
Lounges

Common
space

Office -
Workspace
Café

Public
space

Coworking
Cultural
Exhibition
Commercial

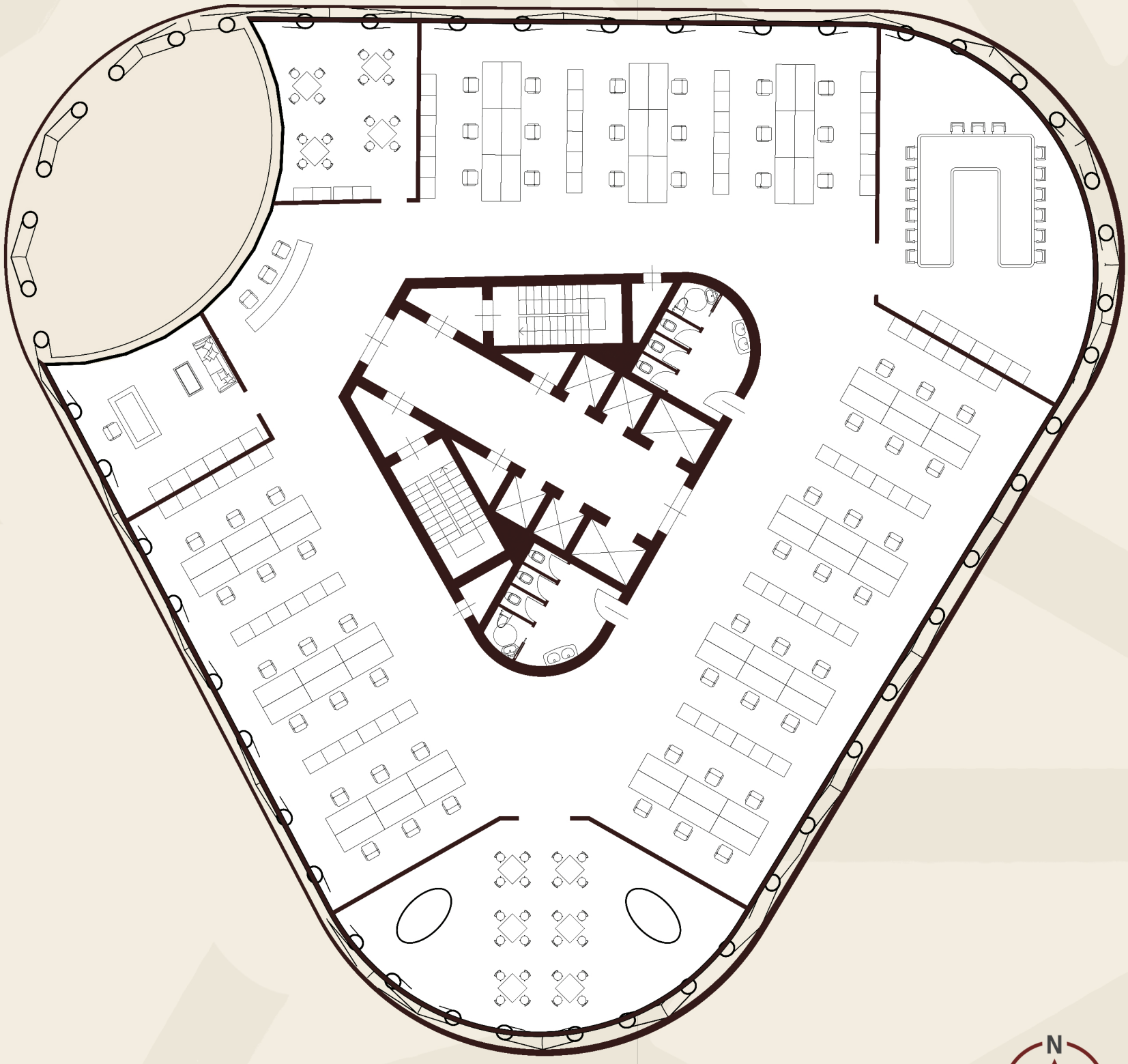
The west elevation reveals the complete vertical layering of the tower's mixed-use program, from the commercial and public base to coworking spaces, offices, lounges, and serviced apartments. Sky gardens act as bioclimatic buffers and community zones at regular intervals.

The dynamic façade system is applied to the sun-exposed southern and southwestern faces, as visualized here in the golden-hued geometry. This responsive skin provides effective solar shading, while preserving visual porosity and evoking the arabesque pattern logic



West Facade - Scale 1:500

VERTICAL OASIS: THE DYNAMIC TOWER



Office Plan - Scale 1:200

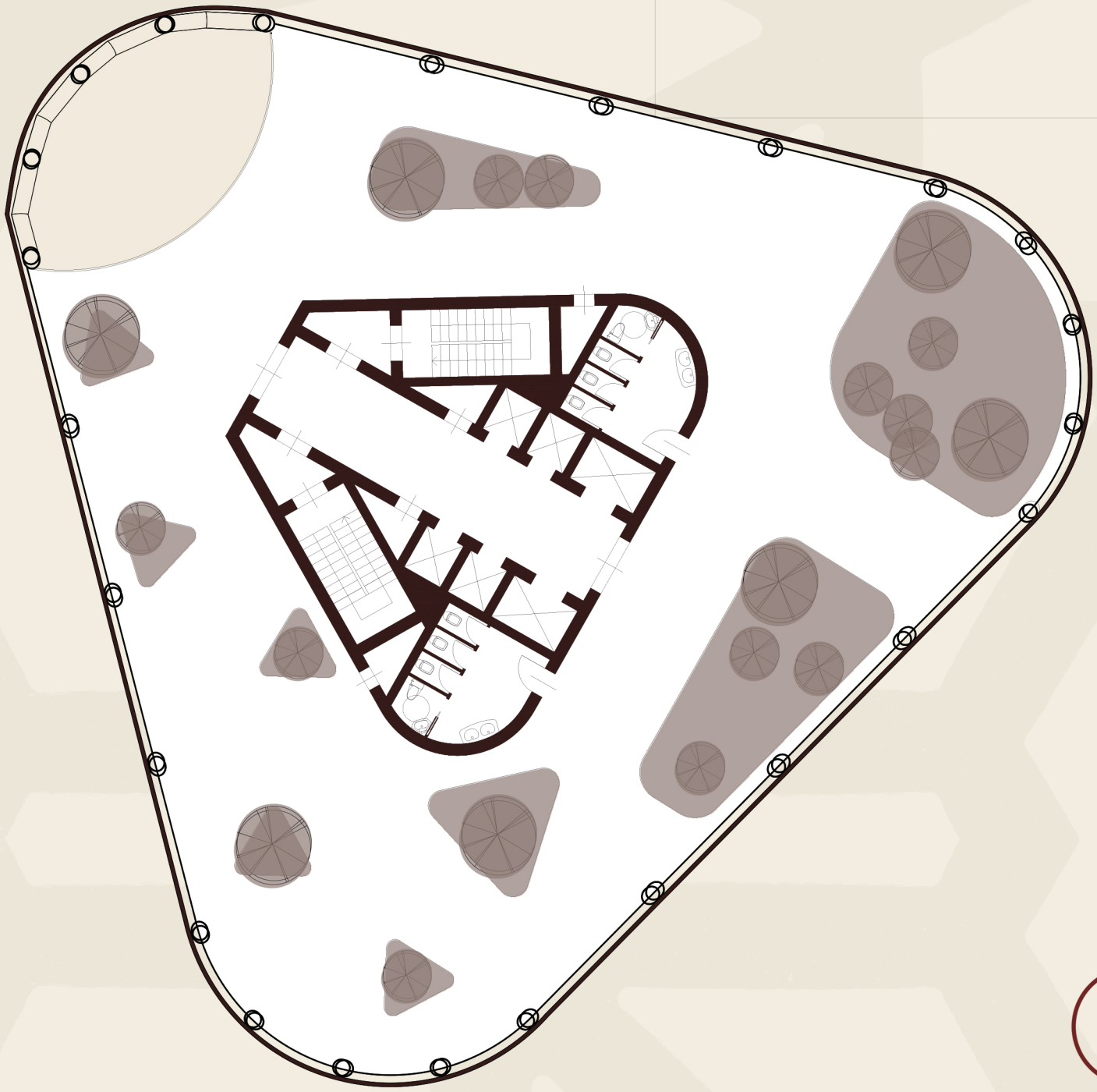


Temporary Apartments Plan - Scale 1:200

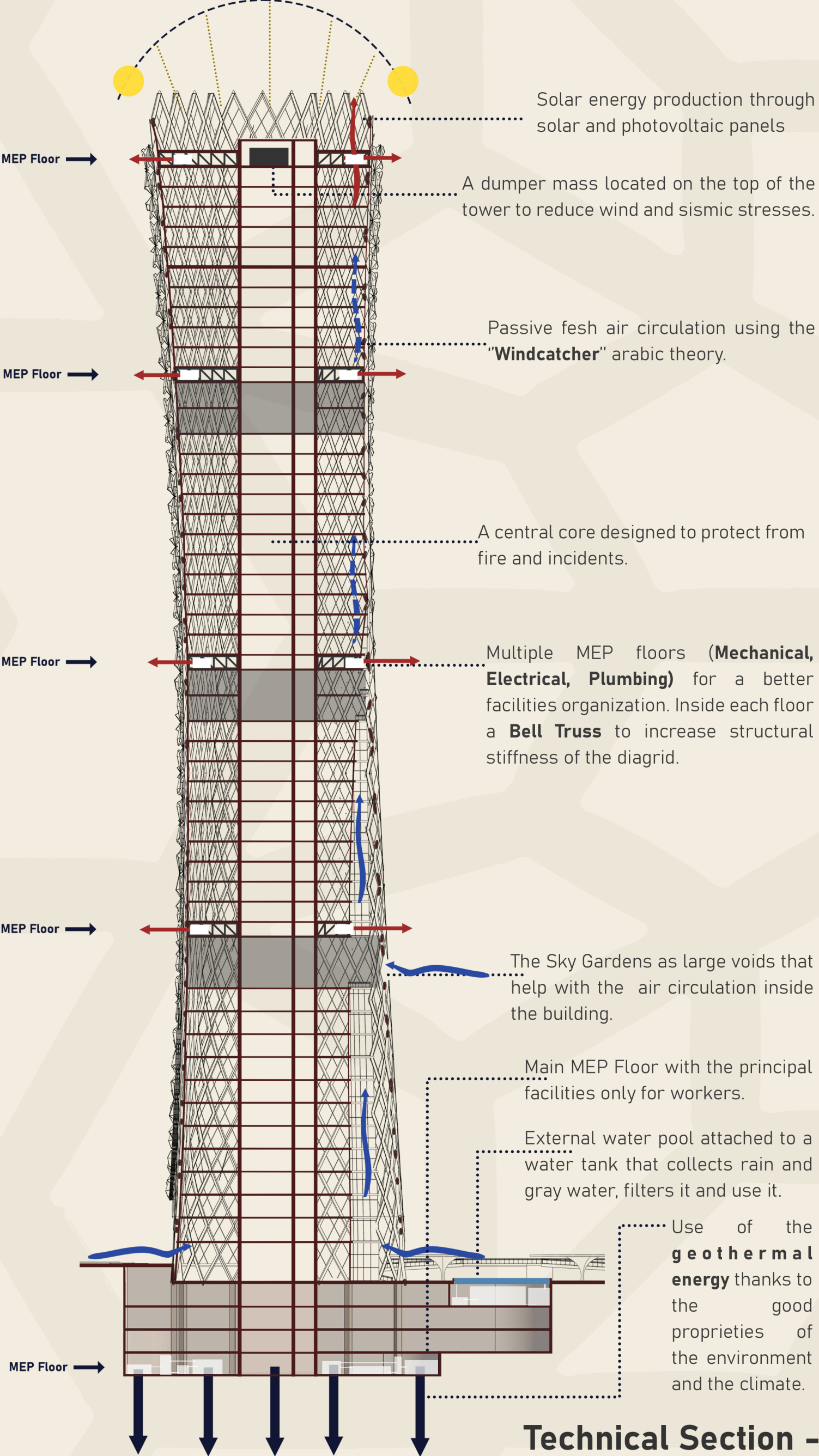
Functional layout for standard **office floors**. The perimeter provides natural lighting and ventilation, while the compact core ensures efficient vertical circulation and structural logic. Open workspaces are combined with meeting rooms and shared service zones.

Residential floor designed for **short-term living units**. The radial layout maximizes facade exposure for natural light and privacy, while shared services and compact modules offer flexibility and modularity for various user needs, resulting in a combination of different kind of accomodations.

Intermediate floor dedicated to collective **green space as the tower's voids**. The garden acts as a bioclimatic buffer, enhancing indoor air quality and offering visual and physical connection to nature. It supports the tower's passive ventilation system and user well-being.



Sky Garden Plan - Scale 1:200



Technical Section - Scale 1:1000

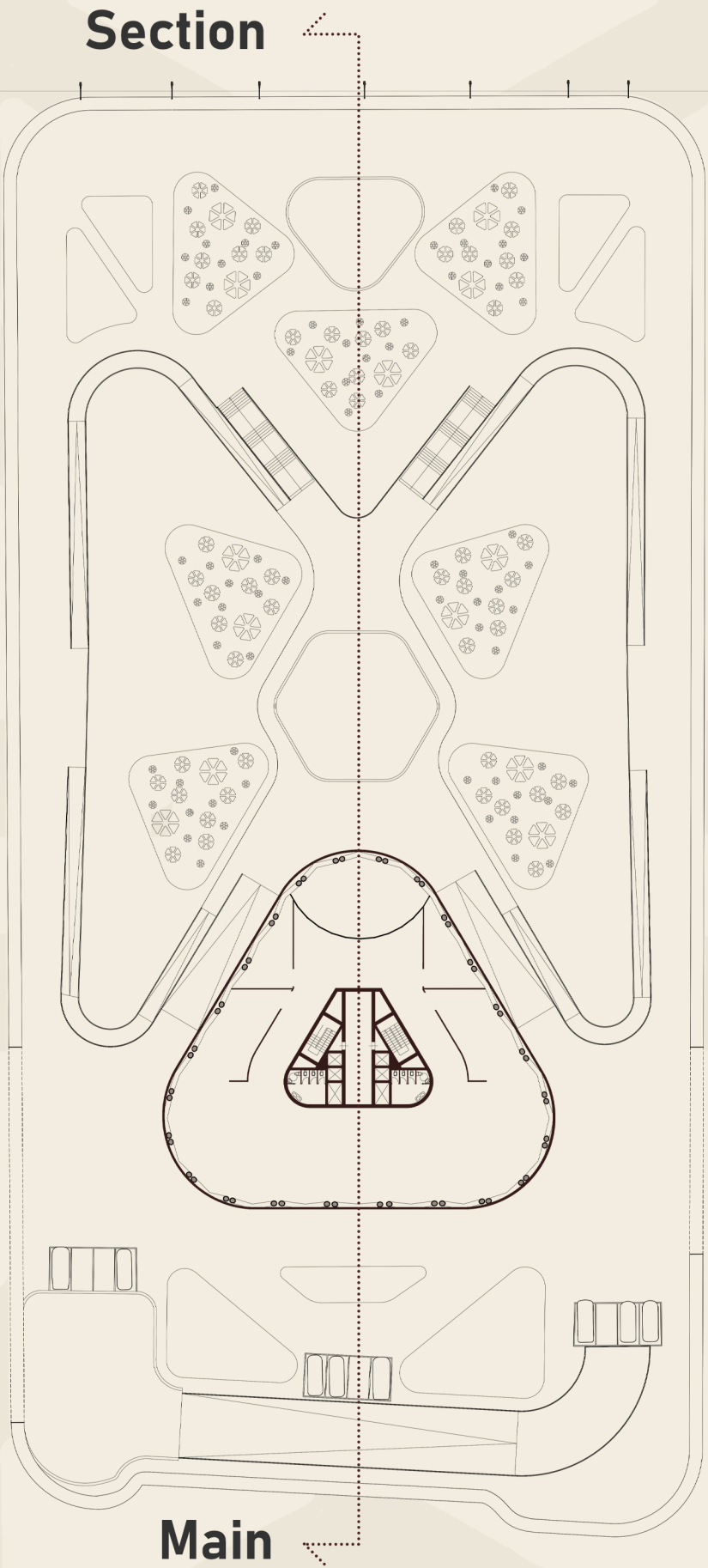
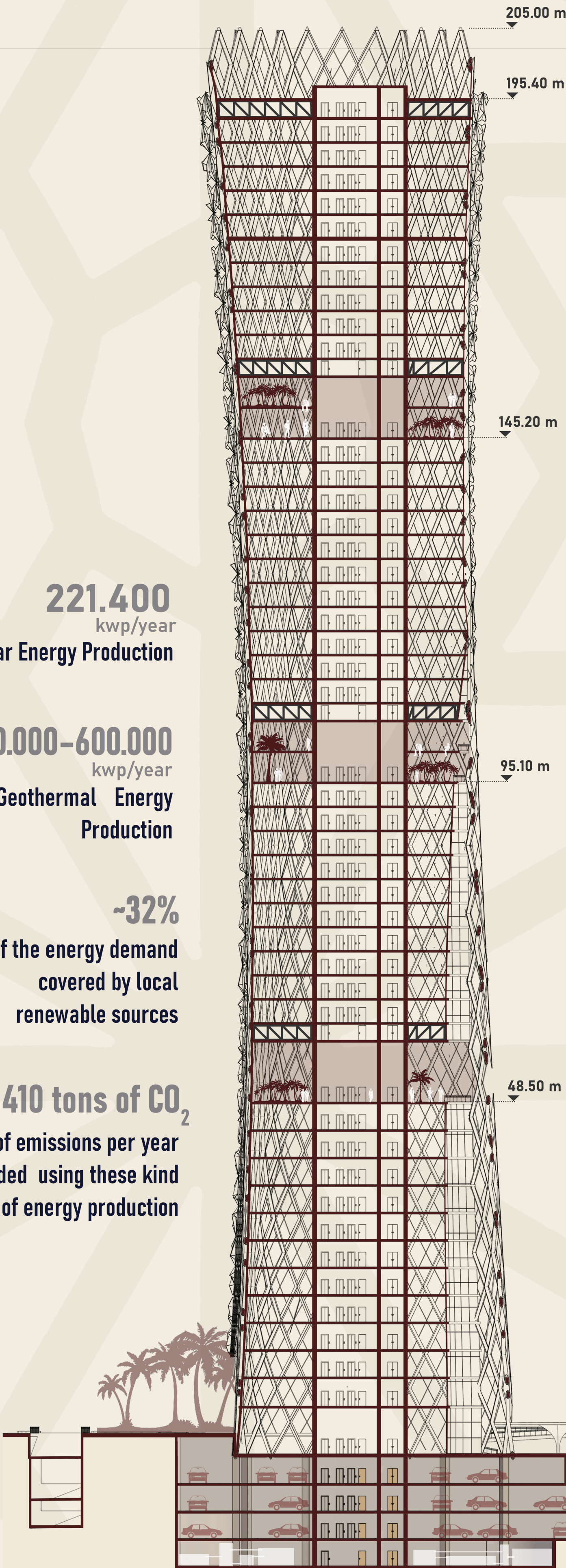


221.400
kwp/year
Solar Energy Production

~ 500.000-600.000
kwp/year
Net Geothermal Energy Production

~32%
of the energy demand covered by local renewable sources

~360-410 tons of CO₂
of emissions per year avoided using these kind of energy production



Vertical section illustrating the full programmatic and technical distribution of the tower. The central void houses the passive airflow shaft, while dedicated MEP floors, sky gardens, and mixed-use levels are integrated to ensure high performance, comfort and spatial richness and structural elements to support the main frame of the building.

Diagram highlighting mechanical and structural integration. MEP floors are strategically positioned to manage services and air movement, with a core for geothermal systems, water storage, and vertical shafts. The belt truss reinforces the diagrid around key technical levels.

Arab Windcatcher-inspired passive air circulation is supported by the central void and sky gardens. A ceramic crown shields the rooftop from solar radiation while housing technical elements. The tower acts as a climate-responsive structure integrated with its environment.

Main Section - Scale 1:500

VERTICAL OASIS: THE DYNAMIC TOWER

09

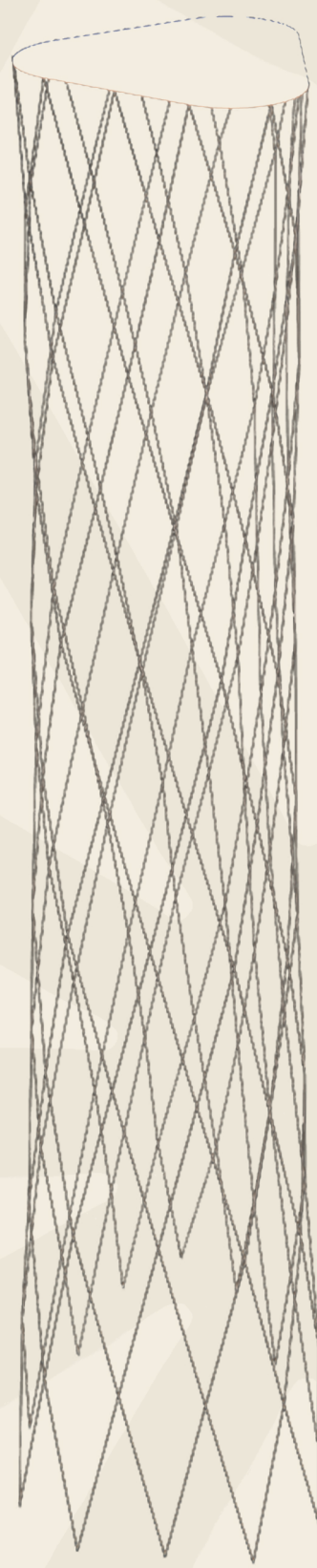
Structure framework of the tower



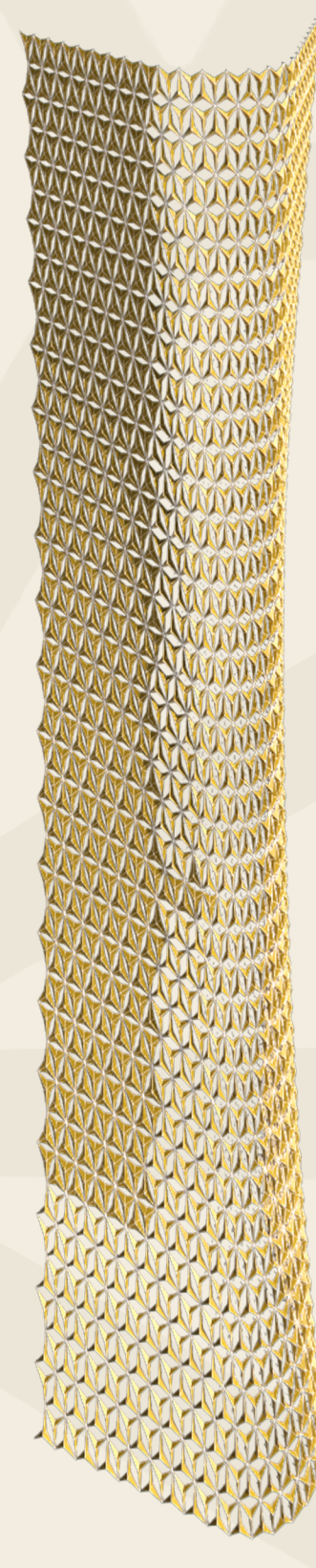
1 - Building structure



2 - Glass Curtain wall



3 - Dynamic Facade's Frame



4 - Dynamic Facades

The tower's structural system is conceived as a high-performance diagrid that works in synergy with the architectural form and environmental strategy. The structural core ensures vertical circulation and stability, while the external diagrid carries both vertical and lateral loads, eliminating the need for internal columns and maximizing spatial flexibility.

A triple-layer system is employed:

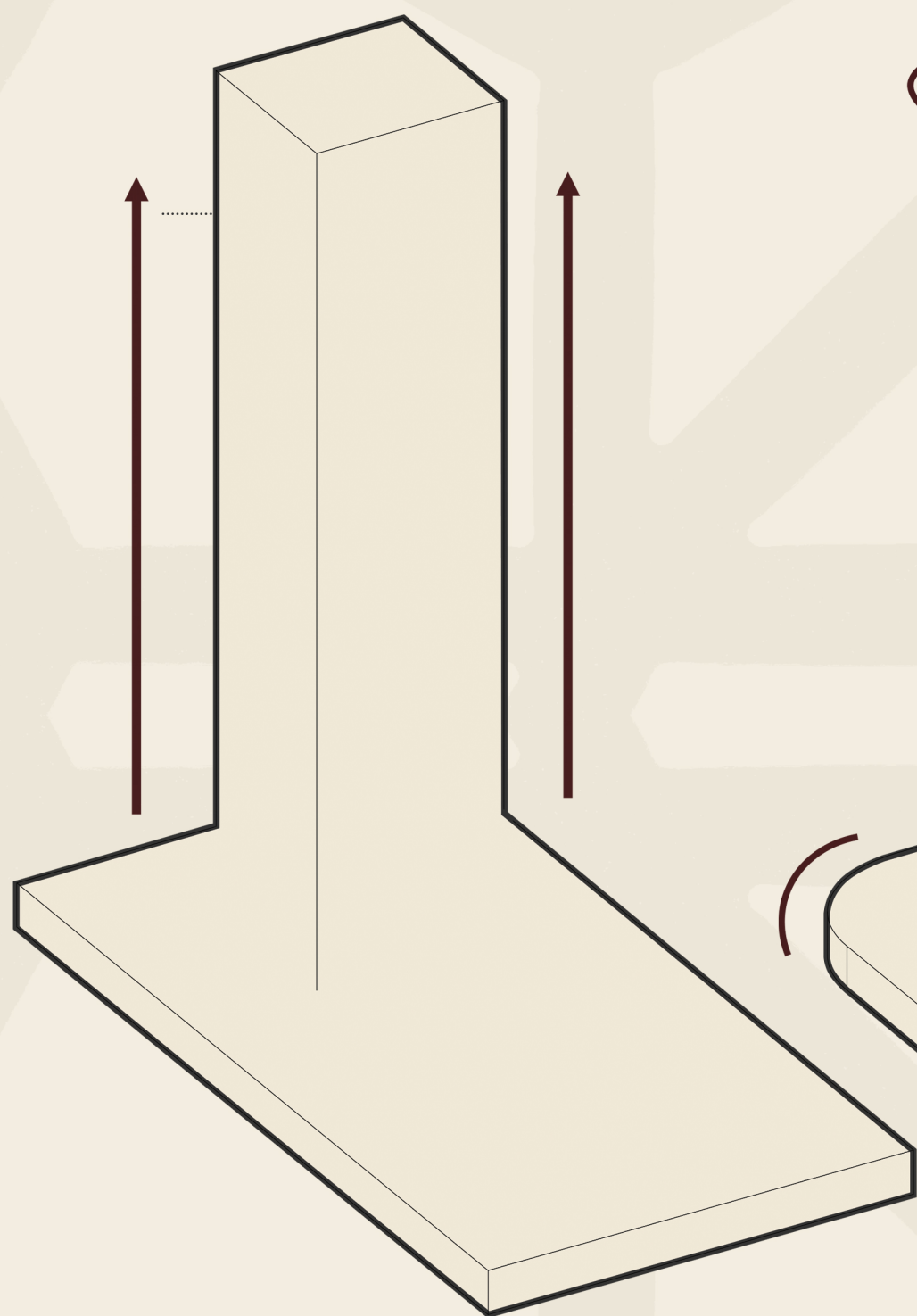
Core and floor slabs for primary load-bearing and circulation;

Glass curtain wall as the inner transparent envelope;

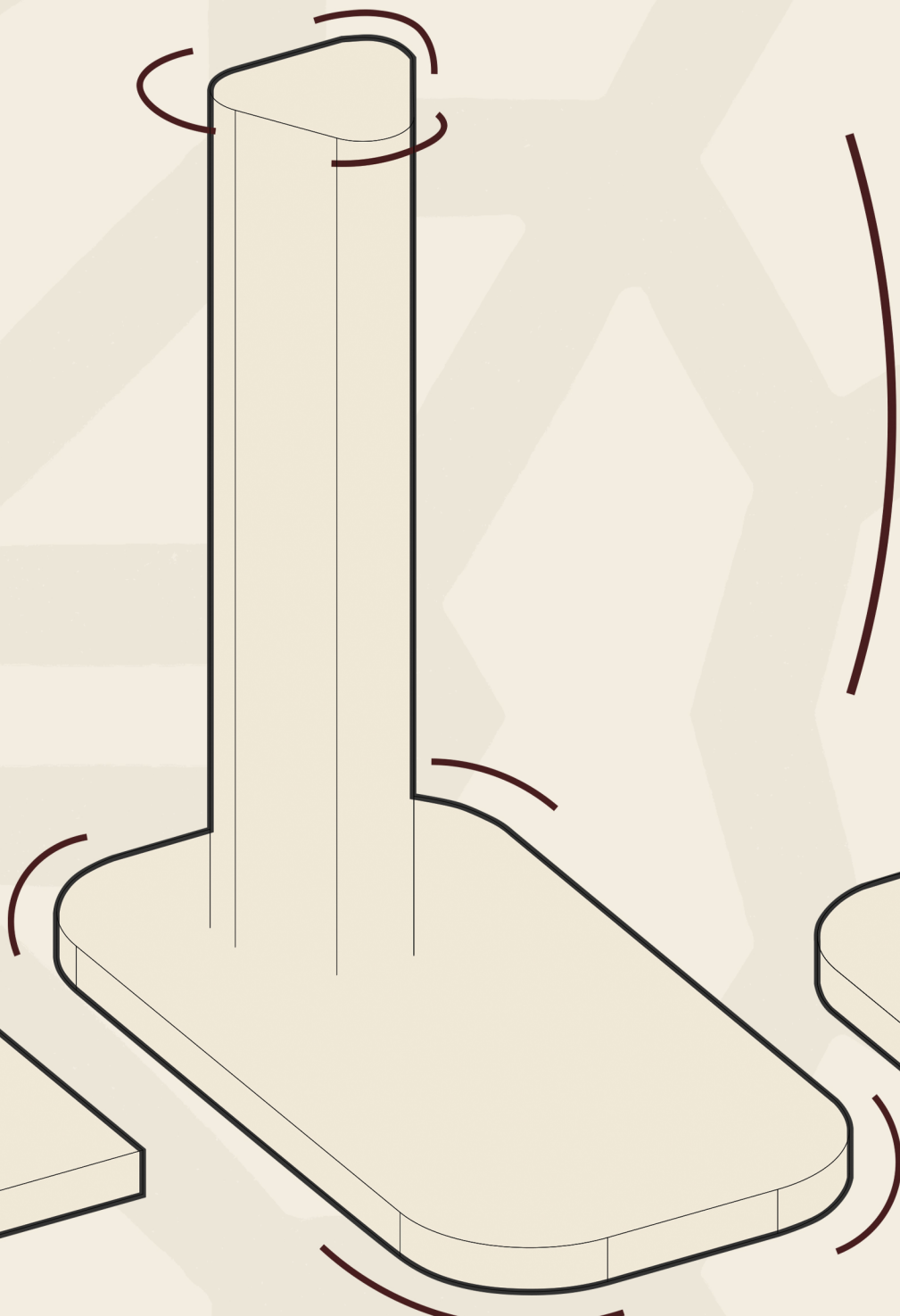
Kinetic façade frame supporting the dynamic mashrabiya skin, providing solar shading and cultural expression.

This integration of structure and skin reinforces the tower's identity as a climate-responsive vertical organism.

Shape evolution



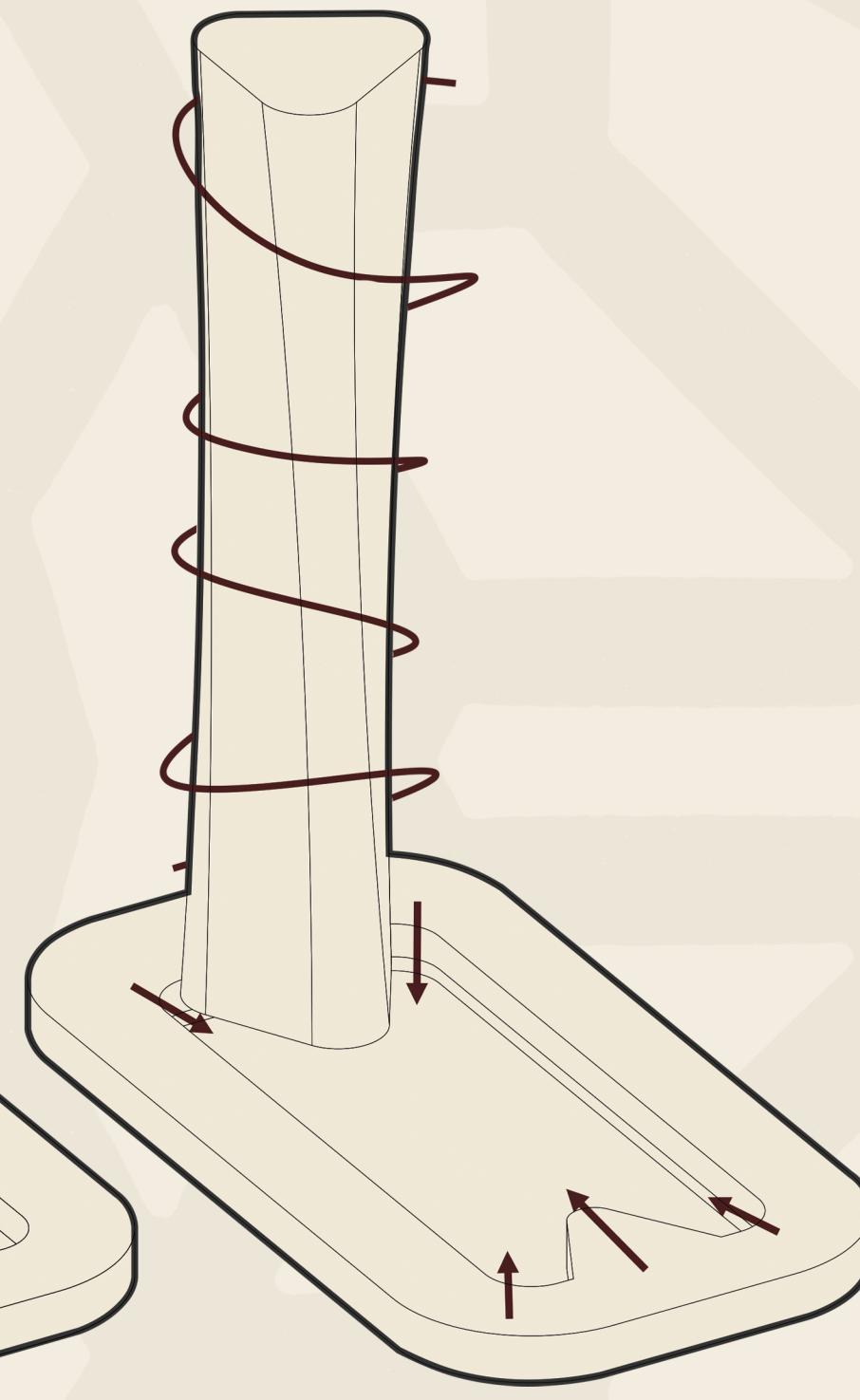
1 - Tower estrusion



2 - Curved Triangular shape like square



3 - Vertical tapering and "Riad" like square



4 - Torsion of 0.70 degree each floor and final shape of the square

The shape of the tower evolves through a series of formal and conceptual operations:

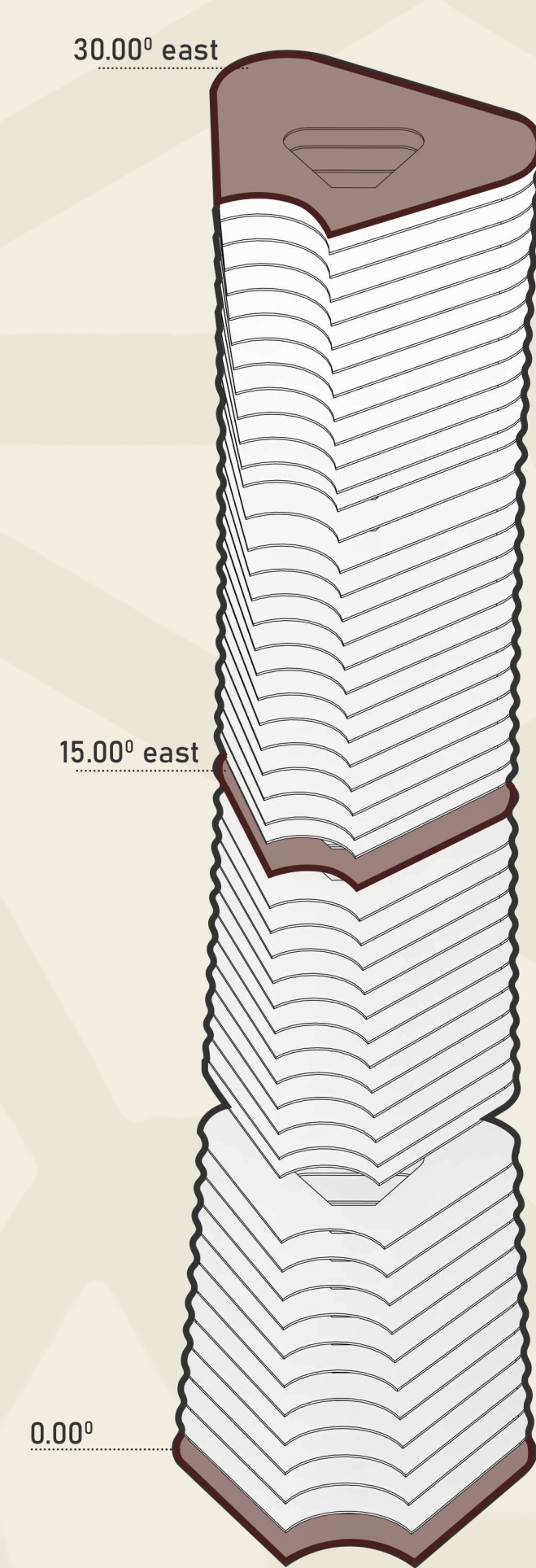
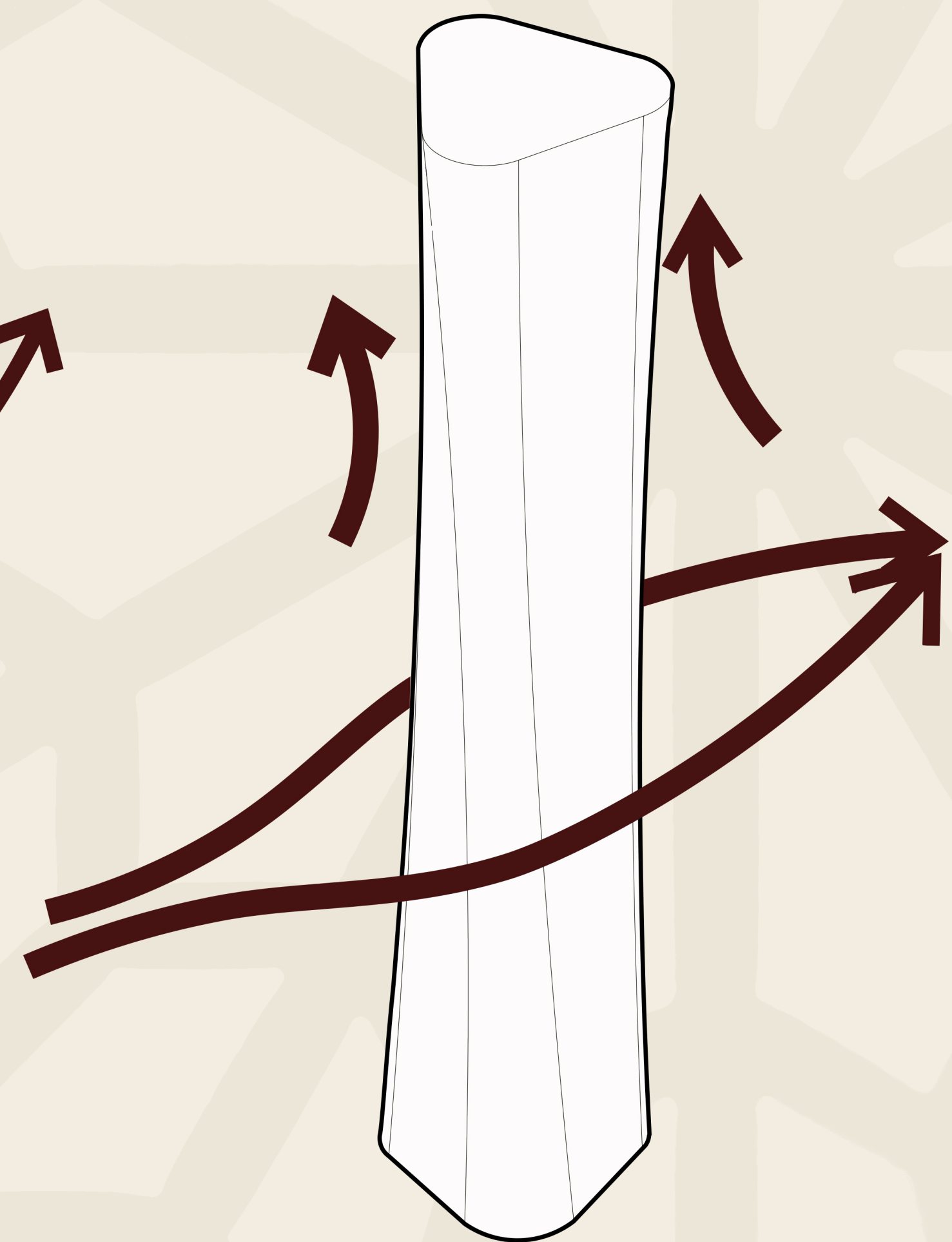
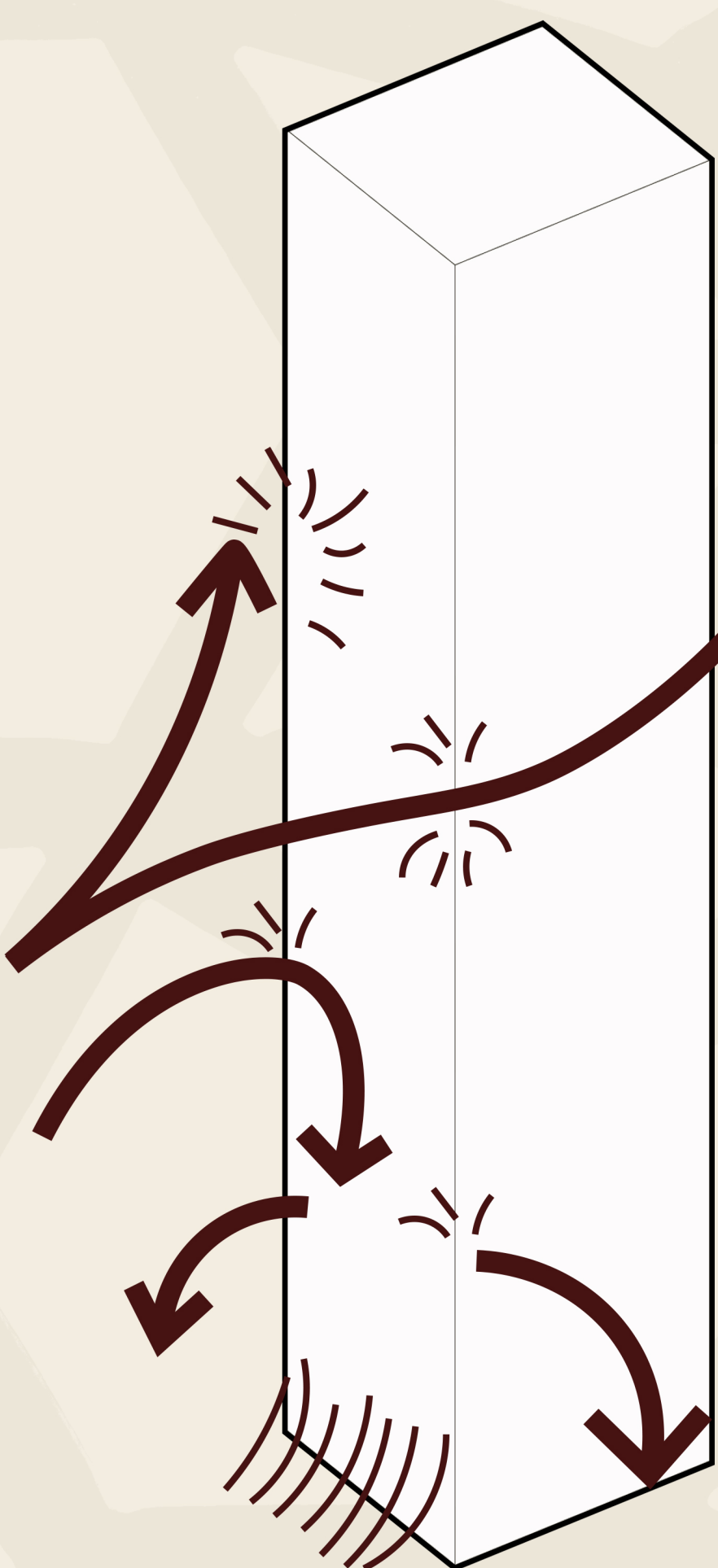
Extrusion of a compact floorplate based on a soft triangular geometry;

Vertical tapering, echoing the internal courtyard proportions of a traditional Moroccan Riad;

Progressive rotation of 0.7° per floor, generating a total twist of 30° at the top.

This spatial manipulation creates a dynamic silhouette that responds to the sun, wind, and urban context. The form is not arbitrary, but derives from environmental performance and cultural resonance, turning the tower into a contemporary reinterpretation of vernacular principles through geometry, rhythm, and light.

Wind based design



The tower's form is not only driven by spatial and cultural intentions, but also shaped by environmental forces—primarily the prevailing winds from the northwest in Casablanca. Through a combination of tapering, curvature, and rotation, the design minimizes wind load, vortex shedding, and ground-level turbulence.

The triangular plan with rounded corners reduces sharp wind deflection, while the progressive twist of 0.7° per floor transforms the vertical airflow into a controlled upward spiral. This effect reduces pressure differentials along the height of the façade and improves structural performance.

At pedestrian level, the lifted base and softened geometry help deflect wind horizontally, creating a more comfortable public space. These passive aerodynamic strategies not only reduce structural stress, but also enhance the building's energy efficiency and urban livability.

The result is a tower that works with the wind, not against it—a vertical form that breathes, adapts, and responds to its environment as an intelligent and performative organism.

VERTICAL OASIS: THE DYNAMIC TOWER

