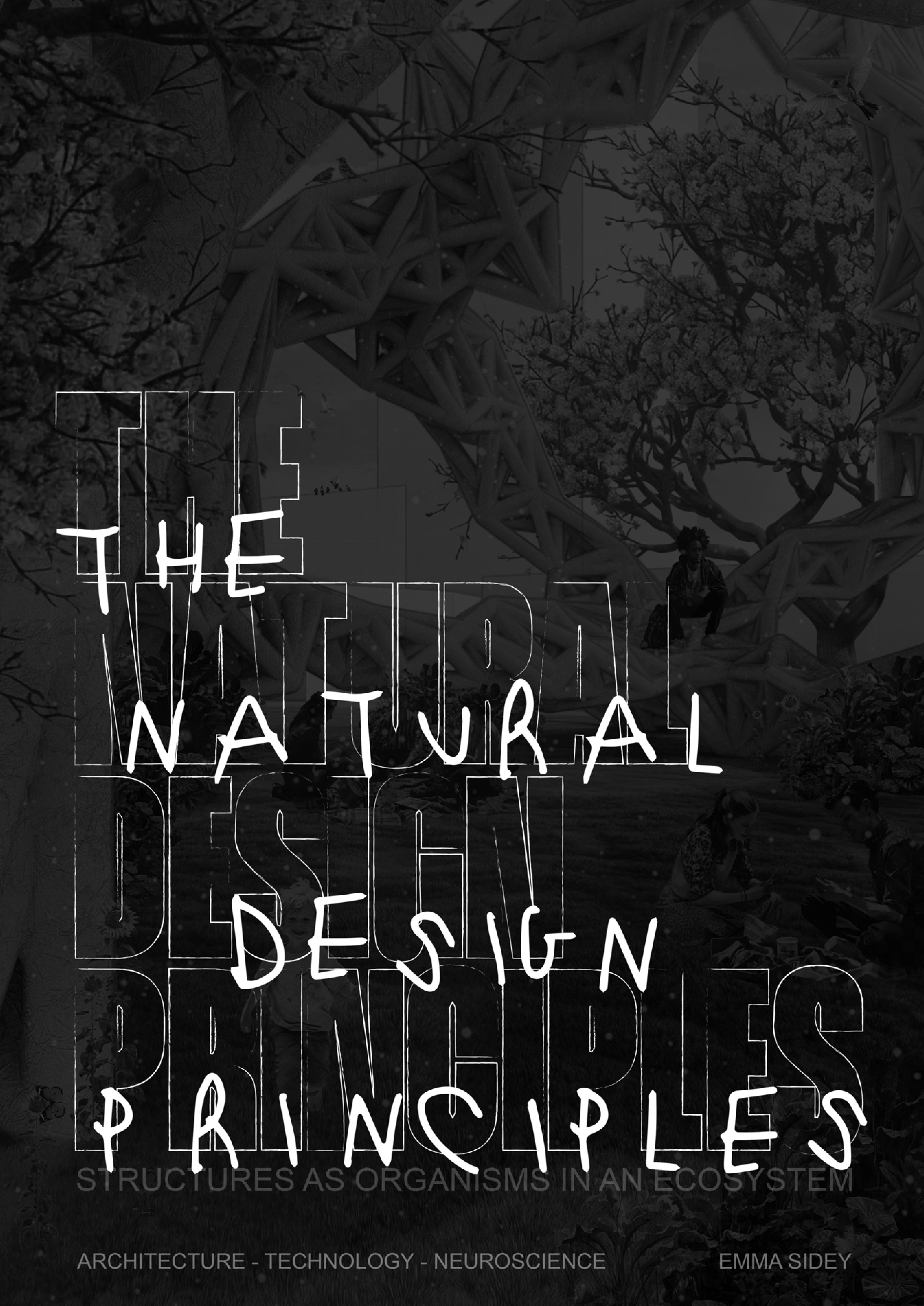

THE NATURAL DESIGN PRINCIPLES

STRUCTURES AS ORGANISMS IN AN ECOSYSTEM

ARCHITECTURE - TECHNOLOGY - NEUROSCIENCE

EMMA SIDEY

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Statement of Originality

This dissertation, The Natural Design Principles: Structures as Organisms in an Ecosystem, is submitted to the Division of Architecture at London South Bank University in partial fulfilment of the requirements for the MArch Architecture RIBA Part 2 postgraduate degree.

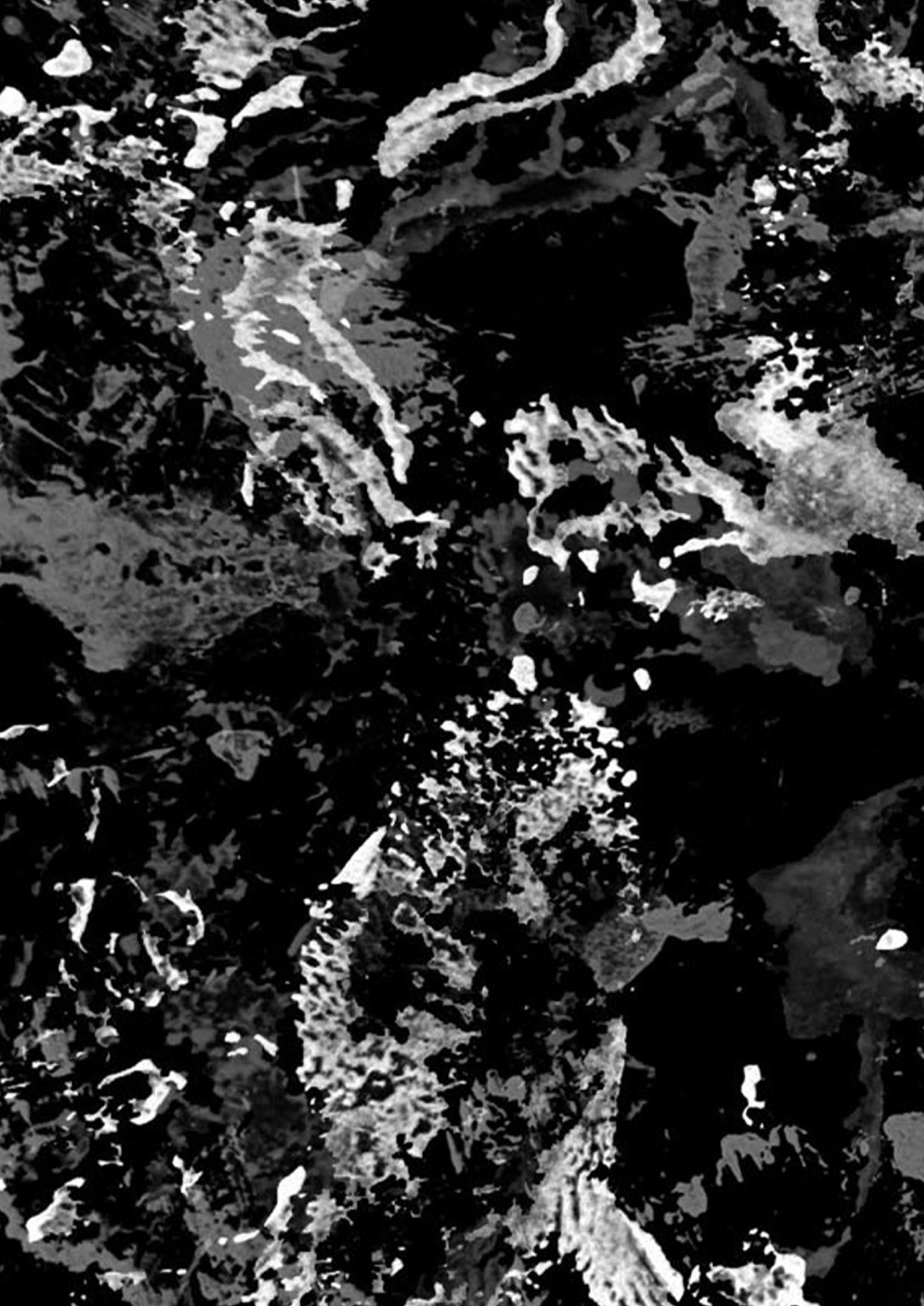
I certify that the intellectual content of the dissertation is the result of my original work and independent research, except where stated otherwise. All sources referenced or utilised have been appropriately cited and acknowledged.

I confirm that I did not utilise Generative AI in any capacity throughout the development, composition, or editing stages of this assignment.

This dissertation has not been submitted for any other academic qualification or to any institution.

E. Sidey

Emma Sidey



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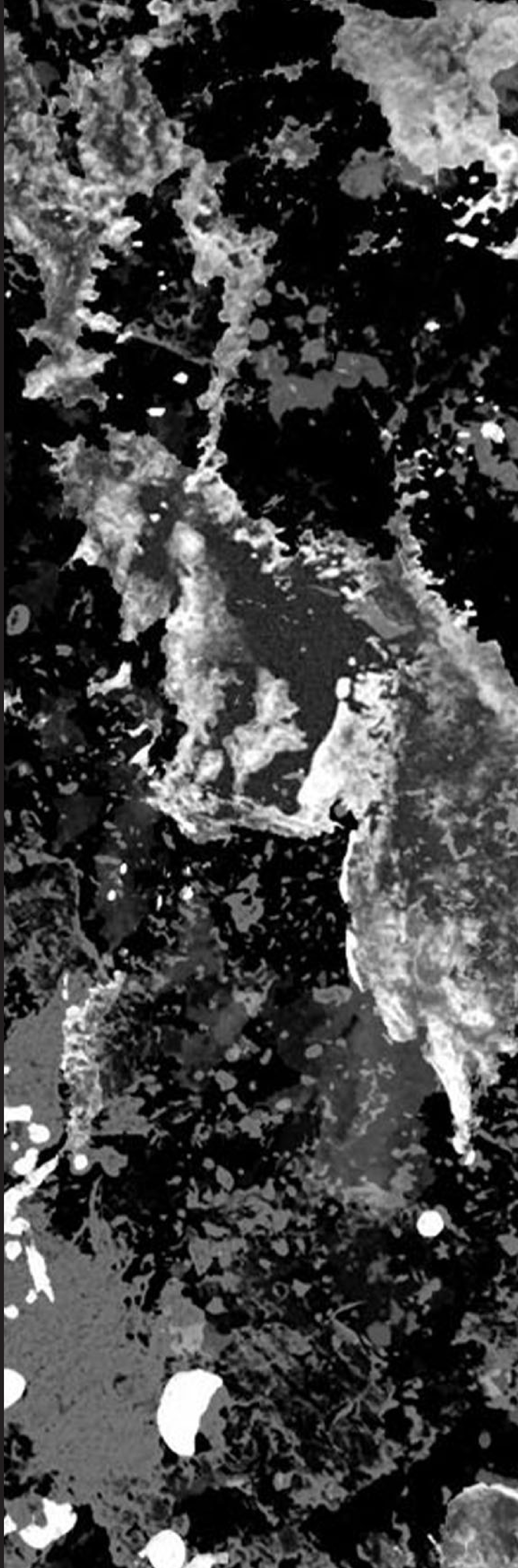

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THE CITY AS A LIVING, BREATHING ECOSYSTEM OF ORGANISMS

ABSTRACT

Throughout the centuries, architecture has come to serve as more than merely a form of protection; buildings, roads, and cities as a whole have started to influence how we move, interact, and experience the world. One of the most significant challenges facing urban development and architecture in the coming centuries is determining how to make cities livable by accommodating a growing population in smaller areas without significantly impacting the quality of life. This moment in London's architectural history presents an opportunity for change. As technologies merge, they offer promising prospects for the future of urban design. The chance to cultivate more sustainable, adaptable, and nature-integrated cities is now attainable. Reassessing the natural design principles that previously shaped urban environments - principles recognising the city as a living, breathing ecosystem of organisms - and aligning them more closely with the needs of its residents facilitates the creation of structures that meet the city's functional requirements while also enhancing the emotional and psychological well-being of its inhabitants. Developing an interdisciplinary approach to design incorporating architecture, neuroscience, and technology offers innovative possibilities for the interplay of buildings and urban environments. The interdisciplinary approach to this dissertation employed a research-by-design methodology to further emphasise the influence of each field.

This research explores the intersection of Variable Property Design (VPD) and Physarum Computational Intelligence (PCI), employing these concepts to guide the development of adaptive, responsive urban structures that connect with nature. The research argues **how can the principles of Variable Property Design be applied to urban architecture through Physarum Computational Intelligence?** Examining the underlying issues inherent in the current urban architectural design process: the standardised division of form, function, structure, environment, and materials, central to modernist design theory. With the advancement of digital fabrication technologies, the architectural discipline stands on the threshold of a new era. One in which design synthesis and analysis can coincide. Current technological advancements allow us to incorporate nature's refined processes, enabling structures to evolve and adapt like living organisms. Nature, as we examine it, does not generate form in isolation. Geometry emerges from the interaction of material distribution, spatial reconfiguration, and environmental forces. One of the most insightful natural structures informing the theoretical framework of Variable Property Design is the neuron, a fundamental component of the human brain. By incorporating Physarum polycephalum, an organism that exhibits intelligent behavioural patterns similar to human neurological structures, we obtain a powerful tool that simulates natural growth processes and can be utilised in designing adaptive urban environments. Through PCI, we can integrate the principles of VPD into urban architecture, effectively bridging the gap between natural systems and architectural design while challenging the conventional disconnection between form, structure, materials, and environment. This approach advocates for a cohesive strategy that views these elements as interconnected components of a dynamic whole. This dissertation establishes the foundation for a new era of urban architecture that honours the symbiosis between humanity, nature, and technology within a rapidly evolving world.

Keywords

Research-By-Design (RBD), Variable Property Design (VPD), Physarum Computational Intelligence (PCI), Urban Architecture, Built Environment

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01 INTRODUCTION

OUR 'ENVIRONMENT' AND RELATIONSHIP WITH THE NATURAL WORLD

'ENVIRONMENT'

STOP.

TAKE A MOMENT TO LOOK AROUND YOU.

WHAT DO YOU SEE?

HOW DO YOU FEEL?

OUR 'ENVIRONMENT' WITH THE

As you reflect on your answers, circling in thought, each will stand alone. However, one element that will be guaranteed is that you are within the built environment. Experienced in various forms, urban, suburban, rural, and industrial, the space we occupy is not merely constructed in the physical sense; it has been shaped through a series of decisions, intentionally integrating elements into a harmonious configuration. As we progress through the 21st century, with the human population continually rising, over 90 percent of inhabitants reside in some form of an artificial environment. (Goldhagen, 2019) When referring to the term 'Environment', I am not addressing climate or nature as one might typically associate. In this context, the word is used to denote surrounding spatial conditions. Architecture ought to be regarded as an art of the highest importance to which all inhabitants are entitled, an art that influences our buildings, landscapes, and cityscapes, thereby shaping our environment. Our awareness of our environment is predominantly subconscious, experienced indirectly through our senses. As a survival mechanism, our responses are triggered directly, whether positively or negatively. In context, if an individual finds themselves in an urban environment characterised by a significant volume of information to process, they might feel overstimulated. Conversely, one would experience a sense of internal peace in a setting featuring calming colours and nature. Consequently, our experience of our environment is not merely a passive reception of stimuli; rather, it is a dynamic process of emotional interpretation that our minds actively devote. Before the construction of the built environment, humans were inherently accustomed to the natural world, relying on sensory and physiological responses for navigation and survival.

Architecture ought to be regarded as an art of the highest ences our buildings, landscapes, and cityscapes, thereby

AND RELATIONSHIP NATURAL WORLD

Our ancestors depended entirely on their responses to environmental stimuli, recognising emotional elements of discomfort, fear, panic, relief, and safety as survival instincts. During this period, the human body was subconsciously conditioned for instant reactions to its rapidly changing environment. Their interaction with the natural world was influenced by the need for shelter, food, and resources, while the human body is designed to respond to emotional triggers. In this context, **human hands had yet to shape our environment; it was a landscape of experiences determined by nature's force.** The development of the built environment signified a change in how we, as humans, relate to our surroundings. During societal development, permanent settlements were established, and the natural environment was modified to fulfil our needs and aspirations. In the process, we have created spaces that serve a functional purpose while eliciting an emotional response.

Throughout the centuries, architecture has come to serve as more than merely a form of protection; buildings, roads, and cities as a whole have started to influence how we move, interact, and experience the world. Our subconscious and psychological experience of our environment has become increasingly complex; surpassing the survival instincts of our ancestors, we are now instinctual, automatic, and emotionally evolved, as evidenced by the spaces we have created for ourselves. Therefore, the built environment we inhabit today extends our early relationship with the natural world. In this sense, **architecture is not merely about constructing a physical space; it involves designing an environment that resonates with our deep-seated need for connection to nature, comfort, and survival.** Our bodies and minds continuously engage in a dialogue with our environment, influenced both by nature and human creation.

importance to which all inhabitants are entitled, an art that influ-
shaping our environment.

CHAPTER 01.1

METHODOLOGY

This dissertation presents a methodical approach that harmonises theory with practice to comprehend how natural elements influence human habitation. Grounded in the essential premise that nature significantly influences the built environment and human experience, this research employs a methodology informed by principles of Research-by-design.

Research-by-design (RBD) is a methodological approach to academic investigation that connects research and design. It recognises design as a process of experimentation through the application of knowledge, along with theoretical and conceptual inquiry. The Natural Design Principles: Structures as Organisms in an Ecosystem applies an interdisciplinary approach bridging architecture, technology, and neuroscience through RBD, where the individual modes of research conduct an interactive and coordinated sequence between the disciplines. It should be recognised for its efforts to unite disciplinary strands, thereby enabling an analysis of individual research hypotheses, with the understanding that design is an activity that assists research. (Fraser, 2021) RBD is an emerging method of high-level research that facilitates new intelligence through continuous outputs. In this dissertation, I will illustrate my development as a researcher and designer, presenting a novel approach to traditional practices in investigating urban architecture.

The theoretical framework of this dissertation is Variable Property Design (VPD). This framework considers design constraints and explores functional, structural, and environmental factors to develop an adaptable system that responds to variable demands. The framework aims to encourage a methodical re-evaluation of design, one that is not form-focused but driven by behavioural properties to explore the potential of a structure without the constraint of a predefined form. VPD will be a guiding principle when evaluating design research methods in this context. This dissertation will research how the principles of VPD can be applied to urban architecture through Physarum computational intelligence. To investigate how VPD can be efficiently used, I will incorporate a collection of RBD methods that provide a theoretical and conceptual framework for exploration.

To analyse the absence of natural elements in London's built environment, I developed a dialectogram that visually represents the area surrounding London South Bank University in the Southwark district. This methodology examines how the urban landscape contrasts underutilised green spaces and the natural environment. Additionally, the mixed-media paintings produced in this dissertation provide crucial insights into the adaptive and responsive qualities of natural systems, particularly neurological structures. They have also enabled me to explore the dynamic interaction between structure, material, and function.

A key component of the research-by-design methodology is the application of Physarum computational intelligence (PCI). By employing Physarum as a computational model, urban structures can be designed to embody the organism's adaptive, self-organising, and responsive characteristics. Additionally, I will utilise a series of two-dimensional drawings that depict the progression of a structure applying the principles of VPD within PCI. These drawings detail the stages of structural growth, in which material distribution is controlled by the input parameters set by the algorithm. I will further investigate digital fabrication, employing 3D-printed models to offer a tangible, physical representation of dynamic, adaptive systems as they manifest in real-world applications. This will bridge the gap between digital simulation and physical manifestation. The structure is concluded through a final rendering to visualise the adaptability within an urban environment. The rendering demonstrates how this responsive architecture has the potential to revitalise the city by integrating nature and technology to compose a dynamic, sustainable space.

Graphic Design Language

Each dissertation component has been intentionally designed to illustrate and support the central argument. This includes the graphic layout, which plays a representational role in conveying the underlying concept. The application of a dual typeface throughout the headings, subheadings, and graphical elements has been carefully considered. The structured typeface reflects the modern design process: systematic, predetermined, and often detached from its context. Conversely, the sketched typeface symbolises the principles of natural design, which emerge from contextual responsiveness rather than formal constraints. Collectively, this visual contrast demonstrates the tension and interaction between artificial structures and organic evolution.

Employing the methodological approach of RBD to literature review and research provides the opportunity to engage with the theoretical framework directly. I conduct a comprehensive review of the existing literature, particularly referencing the influential analysis by Antonelli and Bruckhardt on Neri Oxman's "Material Ecology" (2020), as it provides valuable insights into biometric design principles and the incorporation of natural elements within architectural contexts. Oxman's research, titled "Material-based Design Computation" (2010), establishes a fundamental framework in computational design that is essential for understanding the technological foundation of VPD. In conjunction, the philosophical insights of Keats in "You Belong to the Universe: Buckminster Fuller and the Future" (2016) offered a broader perspective on holistic design methodologies and the application of an interdisciplinary approach to architecture and technology. Lastly, Eberhard's groundbreaking research in "Architecture and the Brain: A New Knowledge Base from Neuroscience" (2007) provided critical insights into how neuroscience can inform architectural practices, thereby offering a scientific foundation for architects to understand the neurological structure, neural processes, and functions, thus interconnecting neuroscience and architectural design. The literature referenced here constitutes a subset of the extensive literature examined in this dissertation, selected for their significant contributions to the comprehension of architecture, neuroscience, and technology. This review establishes a robust theoretical framework by integrating diverse perspectives to investigate the impact of VPD on contemporary urban architecture.

The research explores the possibility of an urban structure that can be recognised as a living entity that coexists with the environment, establishing a foundation for investigation into the practical applications of VPD through PCI. The following chapters will examine case studies and design methodologies intended to investigate and integrate these principles into the design process. This dissertation analyses the role of natural design principles in shaping the built environment, with a particular emphasis on London. The review provides a comprehensive foundation for advancing the discussion on VPD in urban architecture. It synthesises theoretical insights from interdisciplinary sources and delineates a pathway for designing adaptive, resilient, and harmonious structures with their natural surroundings. This research will yield a set of design principles that can be applied to position urban architecture as part of a living ecosystem, illustrating how urban architecture can evolve in response to environmental and human stimuli.

Figure 1: Roofscape of the City of London.

CHAPTER 01.2

THE ROLE OF NATURE IN LONDON

As cities and societies like London evolve, the built environment experiences an urban transformation that emphasises industrial progress, efficiency, and economic growth, often at the expense of human needs and the natural world. The rise of urbanisation, characterised by vibrant streets, towering structures, and concrete landscapes, has shaped this division. Cities have emerged as centres of culture, commerce, and innovation. However, they have also become spaces where nature is often relegated to the margins, replaced by steel, glass, and asphalt. In London, the impact of this shift is particularly evident, as illustrated by Figure 1. The Roofscape of the City of London, captured in 1986, reveals a city once adorned with green spaces and parks, now presenting a skyline dominated by steel and concrete structures rising above the horizon. Once essential to urban life, public parks have transformed into isolated islands amidst a vast expanse of urban sprawl, often neglected or inadequately maintained.

Disconnection from nature in urban areas has significant consequences for our well-being. Our bodies and minds remain profoundly linked to the natural world and our ancestral environment. The lack of nature in our current surroundings can contribute to feelings of tension, isolation, and mental exhaustion. Humans possess an inherent need for environments that provide not only physical shelter but also psychological comfort a sense of tranquillity that nature delivers through soothing sounds, natural light, and organic forms. (Goldhagen, 2019) Indeed, numerous studies have demonstrated that exposure to natural elements, whether a park, a tree-lined street, or even a view of greenery from a window, significantly influences our mood, productivity, and overall mental well-being. Integrating nature into urban areas can reduce stress, improve focus, and promote well-being. However, many of the world's most populated cities, including London, favour concrete over greenery and prioritise design effectiveness over human connection.

One of the most significant challenges facing urban development and architecture in the coming centuries is determining how to make cities livable by accommodating a growing population in smaller areas without significantly impacting the quality of life. **Twenty-one per cent of London's population experiences an increase in anxiety disorders, thirty-nine per cent experience mood disorders, and together, there is a 50 per cent chance of an increased risk of schizophrenia.** (Williams, 2017) As a city that has experienced rapid growth, it stands at a crossroads. The challenge now is not only to design spaces that accommodate the population but to create environments that actively nurture them. What if the next stage of urban architecture could not only emphasise enhancing infrastructure but also reintegrate nature into the heart of the city?

This integration isn't simply about adding a few new trees; it entails reimagining how we design structures within the urban landscape to promote health, connection, and harmony with the natural environment. By reintroducing nature into our urban landscape, we can create spaces that address our inherent need for natural stimuli, like the environments our ancestors once inhabited. With the opportunities presented by technological advancements, we could redesign urban architecture so that inhabitants not only reside in urban settings but also flourish in their surroundings, where architecture and nature coexist through technology and science in a manner that supports both our physical needs and psychological well-being. This shift in perspective for architects working on urban environments requires recognising nature's role in our cities as a fundamental element and rethinking the approach to urban architecture to create spaces that promote health and well-being.

Figure 1: Hunter, A. (1986). Roofscape of the City of London.
(Source: RIBApix, RIBA Ref No: RIBA6272) [Photograph]

02

THE ORIGINS OF NATURE'S DECLINE

NATURE'S
DECLINE

CHAPTER 02

THE ORIGINS OF NATURE'S DECLINE

As we contemplate the modern challenges emerging in the urban landscape, it is vital to reflect on the historical development of urban architecture. As discussed, the built environment has always been intricately linked to human societies' needs, desires, and functions therefore, its evolution provides valuable insights into how we can reshape cities, particularly London, for the future. Historically, London was envisioned with a clear awareness of the relationship between human beings and the spaces they occupied. In 2012, Spiro Kostof, an American architectural historian, presented a compelling metaphor in his literary work, The City Shaped, in which he inaugurates a captivating connection between urban form and human anatomy. Kostof suggests that cities can be seen as extensions of the human body, with streets functioning as arteries, green spaces serving as lungs, and buildings acting as protective skin. From this viewpoint, urban planning and development aim to enrich the human experience. Just as the body requires circulation, breathing, and shelter to thrive, so too does the city. (Kostof, 2012) Kostof's metaphor underscores how, throughout history, the ideal of the urban environment was crafted with a profound understanding of human needs—physical, social, and psychological—intended to nurture the health and well-being of its inhabitants.

In London's early history, this human-centric approach was evident in the design of public spaces and the organisation of the city. Particularly during the Georgian era, urban design embraced green spaces and human-scale architecture, which fostered social interaction and enhanced physical well-being. However, with the advent of industrialisation and the growth of London, nature gradually disappeared from the urban core. To comprehend the gradual shift depicted in Figure 2, A Historical Timeline of the Architectural Evolution of London, I have represented the key elements integrated into the city's typology from the Roman Era to the present day, emphasising the origins of nature's decline.

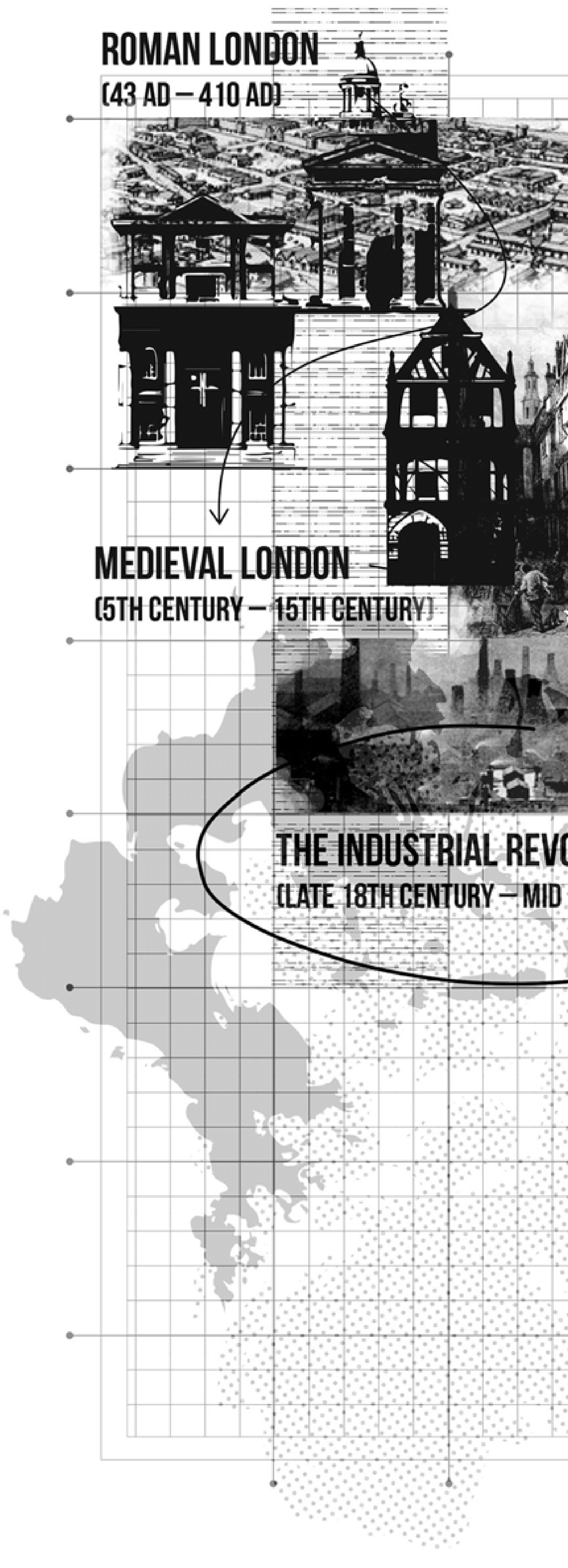


Figure 2: Sidey, E. (2025)
A Historical Timeline of the Architectural Evolution of London. [Diagram]

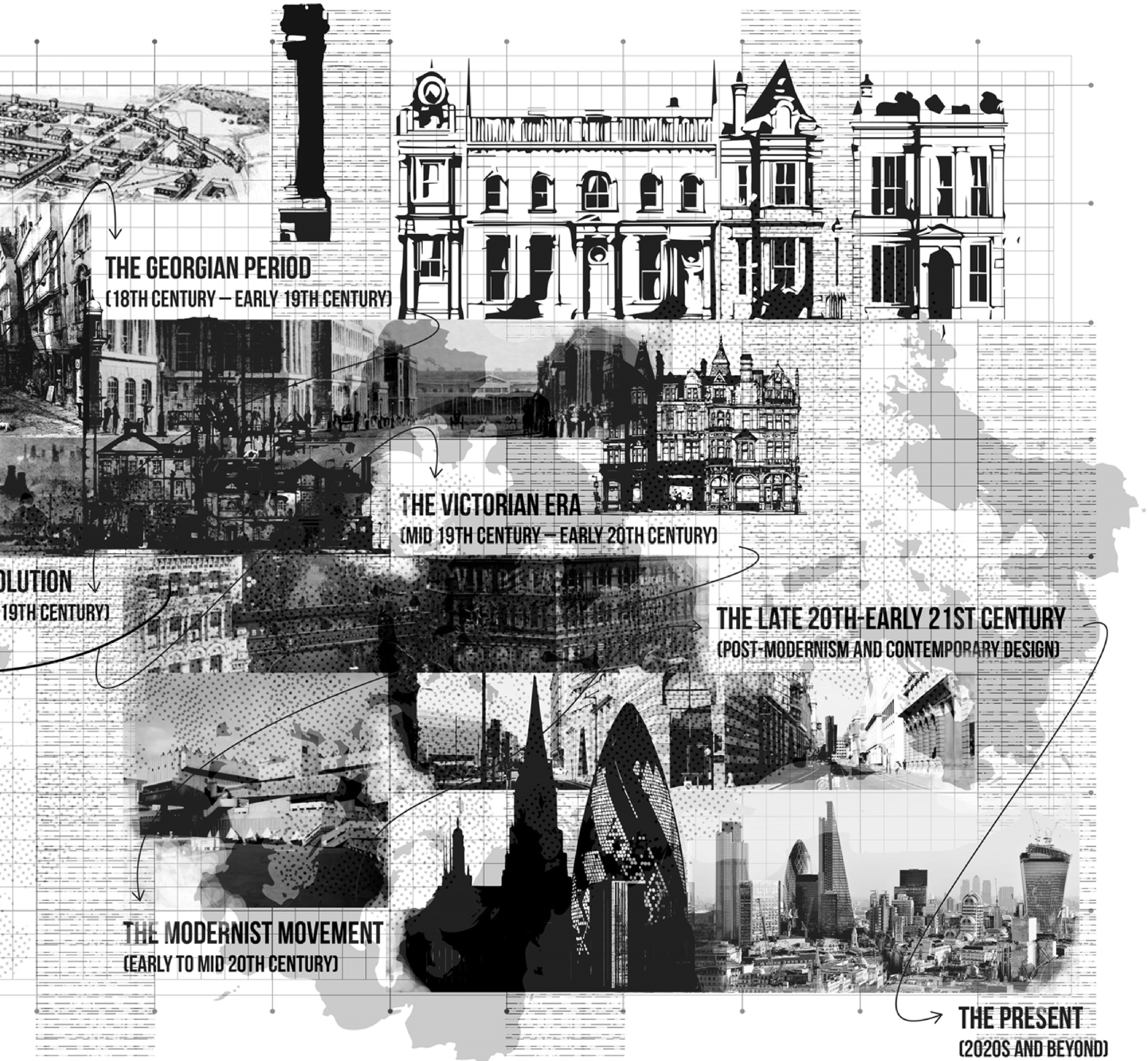
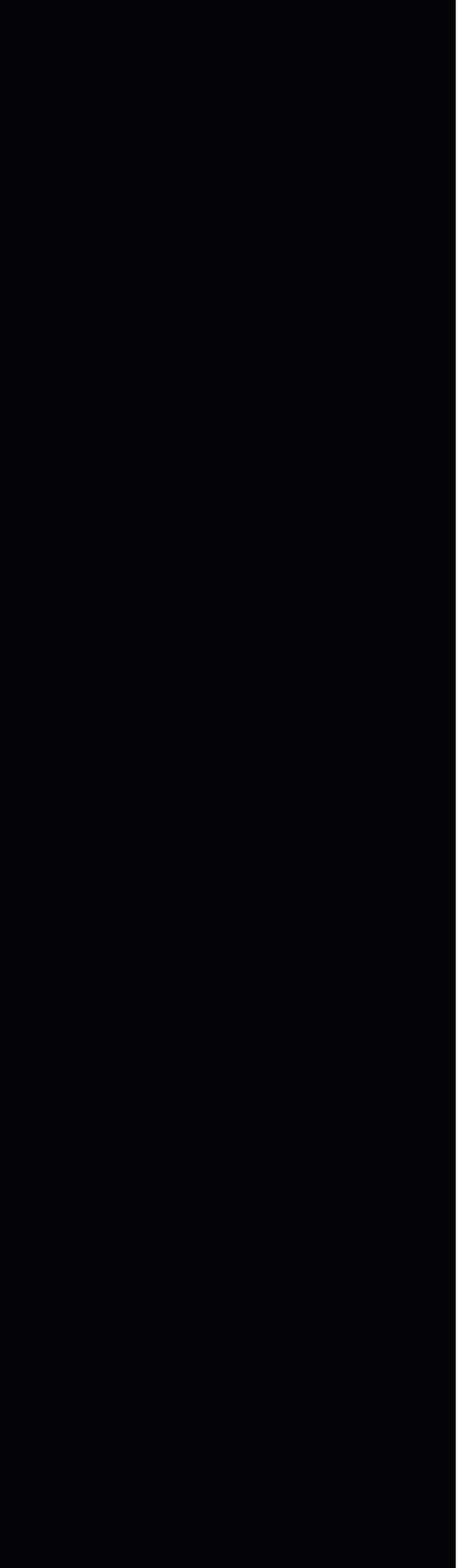


Figure 2: A Historical Timeline of the Architectural Evolution of London



During the medieval period, the city's narrow, winding streets were bordered by buildings that, though not always architecturally refined, created a sense of intimacy and accessibility. The heart of London, the squares, markets, and streets were designed to encourage human interaction and cultivate a sense of community. In the 19th century, at the height of the Industrial Revolution, rapid urbanisation introduced a new set of priorities. London's population grew significantly as individuals migrated to the city for employment. (Menga, 2022) The city's expansion was driven by the demands of industry and commerce, leading urban planning to favour efficiency over human comfort. The construction of extensive railway stations, industrial warehouses, and large housing estates prioritised functionality over aesthetics and the psychological well-being of residents. Illustrated in Figures 3 and 4, the West India Docks exemplify the architectural advancements that arose during the Industrial Revolution, characterised by engineering innovation, brick and stone construction, and iron structures. The focus has shifted from nature and community-centred design to productivity, industry, and economic growth. (Cannadine, 1984) Once integral to the city's fabric, green spaces are now regarded as luxuries, and parks have become increasingly detached from the densely populated urban areas. Although these changes aimed to accommodate the increasing population and improve infrastructure, they also resulted in the fragmentation of communities and the alienation of individuals within the city. In reference to Kostof's metaphorical body, London's urban form started to detach from the human experience, evolving into a mechanical system instead of a living, breathing organism. Increased pollution, inadequate sanitation, and overcrowded living conditions worsened the disconnection between people and nature. (Mayhew, 2009) The city's expansion led to the loss of natural elements as factories, warehouses, and industrial buildings became prominent urban landscape features. This period signalled the beginning of nature's decline, as the city transformed into a space primarily designed to facilitate industrialisation rather than enhance human well-being.

Figure 3: The London Archives. (1953). North Quay Warehouses, West India Docks. Source: LCC Photograph Library, Ref No: 343215 [Photograph]

Figure 4: The London Archives. (1977). West India Docks Warehouses. Source: LCC Photograph Library, Ref No: 281452 [Photograph]

Figure 3: North Quay Warehouses, West India Docks.

Figure 4: West India Docks Warehouses.

THE MODERN CITY REFLECTS A BUILT ENVIRONMENT PRIMARILY CENTRED ON EFFICIENCY, PRODUCTIVITY, AND ACCOMMODATING EXPANDING POPULATIONS.

Figure 5: Metcalfe, H. (1980). Broadwater Farm Estate, London. (Source: RIBApix, RIBA Ref No: RIBA34332) [Photoprint]

Figure 6: Hodgkinson, P. (1971). The Brunswick Centre, Bloomsbury, London: O'Donnell Court seen from Bernard Street. (Source: RIBApix, RIBA Ref No: RIBA18576) [Photograph 35mm Transparency]

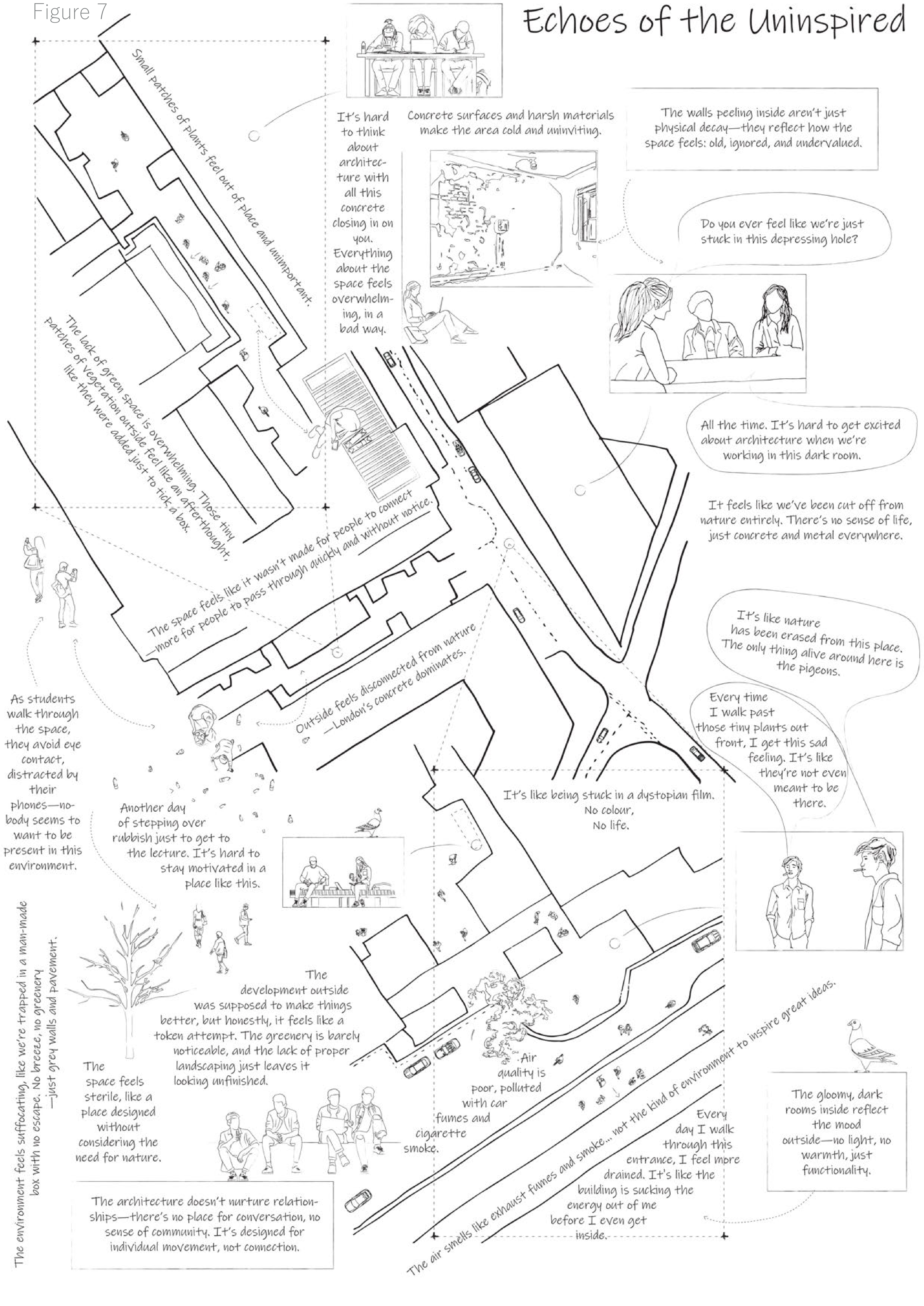
During the Victorian era, the city continued to expand, now in a more structured, although segregated, approach. The emergence of large housing estates designed for the working class, alongside the rise of middle-class suburbs, led to spaces that prioritised function over a connection to nature. The densely populated industrial regions contrast with middle-class developments, which, while more comfortable, were often disconnected from the working-class districts and the natural environment. Public parks, including Hyde Park and Regent's Park, were implemented during this period to reintegrate nature into the urban environment. (Summerson, 1977) However, these green spaces were frequently regarded as separate and detached from the city's industrial heart rather than being integrated into the urban fabric. Greenery had shifted from central to the city's design; instead, it was pushed to the periphery, widening the growing divide between the natural environment and the built landscape.

This trend persisted into the 20th century with the emergence of modernist architecture, which created an even greater separation between the city and the human scale. Brutalist buildings, such as the Broadwater Farm Estate (Figure 5) and Brunswick Centre (Figure 6), prioritised bold and functional design, often at the cost of the human experience. With their strident concrete forms, these structures lacked the warmth and connection to nature that characterised earlier architectural practices. (Harwood, 2022) Public spaces increasingly prioritised movement and efficiency, neglecting the human need for social interaction and emotional ties to place. The construction of high-rise buildings and large, impersonal public housing estates led to a significant disconnection; with little regard for natural elements, the environment became more reminiscent of industrial and mass housing. (Banham, 1999) As the late 20th century progressed, the increasing awareness of environmental issues, such as climate change and biodiversity loss, began to reshape perspectives on urban design. However, despite this awareness, much of London's urban landscape still lacked integration with nature. Some isolated efforts to integrate green spaces into development projects, urban sprawl and the prevalence of concrete and glass persisted. Urbanisation advanced swiftly, and economic growth demands led to a preference for developing buildings, roads, and infrastructure over incorporating parks and green space. **The modern city reflects a built environment primarily centred on efficiency, productivity, and accommodating expanding populations.** The human need for nature is largely overlooked, with the existing green spaces often being underused, fragmented, or overshadowed by the concrete expanse of the city.

Figure 5: Broadwater Farm Estate, London.

Figure 6: The Brunswick Centre, Bloomsbury, London

Figure 7



Echoes of the Uninspired
Small patches of plants feel out of place and unimportant.
It's hard to think about architecture with all this concrete closing in on you. Everything about the space feels overwhelming, in a bad way.
Concrete surfaces and harsh materials make the area cold and uninviting.
The walls peeling inside aren't just physical decay—they reflect how the space feels: old, ignored, and undervalued.
Do you ever feel like we're just stuck in this depressing hole?
All the time. It's hard to get excited about architecture when we're working in this dark room.
It feels like we've been cut off from nature entirely. There's no sense of life, just concrete and metal everywhere.
The lack of green space is overwhelming. Those tiny patches of vegetation outside feel like an afterthought, like they were added just to tick a box.
The space feels like it wasn't made for people to connect—more for people to pass through quickly and without notice.
It's like nature has been erased from this place. The only thing alive around here is the pigeons.
Every time I walk past those tiny plants out front, I get this sad feeling. It's like they're not even meant to be there.
Outside feels disconnected from nature—London's concrete dominates.
As students walk through the space, they avoid eye contact, distracted by their phones—nobody seems to want to be present in this environment.
Another day of stepping over rubbish just to get to the lecture. It's hard to stay motivated in a place like this.
It's like being stuck in a dystopian film. No colour, No life.
The environment feels suffocating, like we're trapped in a man-made box with no escape. No breeze, no greenery—just grey walls and pavement.
The development outside was supposed to make things better, but honestly, it feels like a token attempt. The greenery is barely noticeable, and the lack of proper landscaping just leaves it looking unfinished.
The space feels sterile, like a place designed without considering the need for nature.
Air quality is poor, polluted with car fumes and cigarette smoke.
The air smells like exhaust fumes and smoke... not the kind of environment to inspire great ideas.
Every day I walk through this entrance, I feel more drained. It's like the building is sucking the energy out of me before I even get inside.
The gloomy, dark rooms inside reflect the mood outside—no light, no warmth, just functionality.
The architecture doesn't nurture relationships—there's no place for conversation, no sense of community. It's designed for individual movement, not connection.

CHAPTER 02.1

ECHOES OF THE UNINSPIRED

UNINSPIRED

Figure 7 illustrates a dialectogram that visually represents the area surrounding London South Bank University in the Southwark district to analyse the absence of natural elements in London's built environment. This analysis examines how the urban landscape, characterised by vast expanses of concrete, glass, and steel, contrasts sharply with underutilised green spaces and the natural environment. The findings from this dialectogram reinforce earlier observations regarding the widespread neglect of humanity's need for nature in modern urban planning practices that prioritise economic and industrial growth. This issue is particularly apparent in areas such as Southwark, where natural environments are often fragmented or entirely obscured by the extensive concrete landscape of the city. Humans have an intrinsic need to connect with nature, an essential component of mental health and physical well-being, and a source of inspiration. However, Southwark's environment illustrates how the scarcity of readily accessible green spaces in urban areas significantly undermines this crucial requirement. As noted in the photographs in Appendix A, the existing green spaces are fragmented, uninspiring, and frequently overshadowed by the prevailing dominance of urban structures. This results in underutilisation and a sense of disconnection among local students. These individuals live, work, and study in the area, and a more integrated urban ecosystem could provide substantial benefits. The dialectogram reveals that this urban environment does not promote a healthy relationship between individuals and nature.

This urban condition is not unique to Southwark; it reflects a broader issue in many metropolitan areas of London. It is crucial to recognise that the internal environment of the buildings also contributes to the overall sense of neglect. An analysis of the data obtained from the dialectogram indicates that the structures in the area seem disconnected internally and externally, providing little to improve the quality of life for the inhabitants. There are many reasons to harbour scepticism regarding the aspiration to design exceptional architecture. It is uncommon for buildings to reflect the efforts necessitated by their construction as a result of the economic influence. As observed, it is evident that even when we have achieved our goals, our buildings tend to deteriorate at an alarming rate, leaving those who inhabit them disheartened by the decay. (De Botton, 2014)
The dialectogram highlights the absence of a cohesive design that harmoniously integrates the components of nature, human needs, and architectural design in Southwark, underscoring the necessity to reevaluate urban architectural practices.

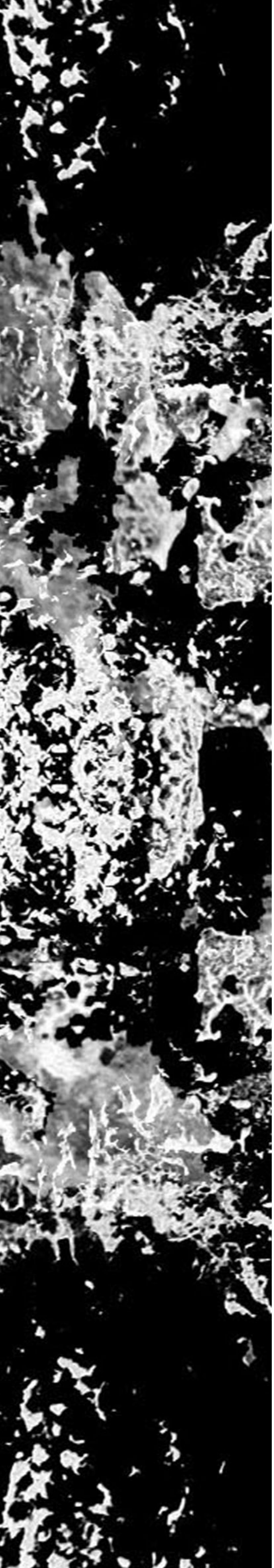
Figure 7: Sidey, E. (2025) Echoes of the Uninspired. An Analysis of the Built Environment at London South Bank University. [Dialectogram]

03

ARCHITECTURE - TECHNOLOGY - NEUROSCIENCE

AN INTERDISCIPLINARY APPROACH TO ARCHITECTURE

INTERDISCIPLINARY



CHAPTER 03

AN INTERDISCIPLINARY

Today, in the 21st century, London still contends with the consequences of its historical neglect of nature and human needs in urban design. We are confronted with a new reality where technological advancements pose both a challenge and an opportunity to transform the built environment. London, characterised by its dense population and mounting pressure on space, necessitates innovative solutions to tackle its challenges. These solutions must concentrate not only on improving efficiency and sustainability but also on prioritising human well-being. Technology can play a vital role in this transformation, offering new tools to weave nature into the urban fabric while meeting human needs in previously unachievable ways.

Richard Buckminster Fuller, an American Architect, Systems Theorist and Inventor, was a distinguished visionary whose interdisciplinary approach to architecture and technology has significantly influenced contemporary design philosophies. The design principles he advanced, exemplified by geodesic domes and tensegrity structures, encapsulate the ethos of integration by conceptualising architecture as static edifices and dynamic systems that respond harmoniously to environmental demands and human requirements. Fuller's methodology regarding technology transcended conventional boundaries, advocating for the harmonious integration of mechanical and environmental controls within architectural designs. Buckminster Fuller envisioned design not merely as a means to facilitate life but as a mechanism to cultivate it in accordance with ecological principles. Organisms would not only influence their environment but would also be moulded by it in reciprocation. (Antonelli, 2020). He asserted that due to designers' failure to cultivate their capacity for world-changing innovations, they did not exercise their influence responsibly. The design profession has excessively emphasised creating aesthetically pleasing products, while insufficient attention has been accorded to the social and political context within which design operates. (Keats, 2016). His philosophy redefines the constructed environment, concurrently influencing and embracing contemporary transformative changes at the junction of technology and architecture.

APPROACH TO ARCHITECTURE

Technological advancements, including artificial intelligence (AI), green building technology, and smart cities, offer promising pathways for a more sustainable, human-centred urban environment. Innovations such as green roofs, living walls, and biophilic design integrate natural elements into building construction, reshaping our perception of incorporating nature. At the forefront of these technologies lies the promise of data-driven urban planning and smart cities, enabling AI to analyse and optimise urban areas in real-time, thus creating more adaptable environments that cater to the needs of their residents. (Quan et al., 2019) By employing AI to monitor factors such as air quality, traffic patterns, and energy consumption, cities can enhance sustainability and be better equipped to support the well-being of their inhabitants.

However, the potential of technology extends beyond creating efficient, sustainable cities. It also paves the way for exploring new approaches in architectural design. One such approach is Variable Property Design (VPD), a concept grounded in natural design principles that examines how structures can adapt to their environment over time. With the support of new technologies, spaces can respond to various demands, whether accommodating more people during peak times, altering room configurations based on their function, or adjusting to environmental conditions in real-time. (Oxman, 2010) This approach fosters a dynamic and flexible urban environment, effectively supporting the evolving needs of humanity.

In this context, we can also consider Physarum Computational Intelligence (PCI) — a biometric approach inspired by the behaviour of slime moulds that have shown the capacity to adapt and optimise complex networks in search of food. We can employ analogous algorithms in urban architecture by examining how these organisms address complex problems through straightforward, distributed processes. Physarum-based systems offer insights into how cities may adapt and evolve organically, responding to changing needs and environmental conditions without rigid top-down control. (Mayne, 2015) This computational intelligence promotes the development of self-organising, adaptive urban systems that can mimic natural processes and cultivate a more harmonious relationship between the built environment and the natural world.

Nonetheless, this moment in London's architectural history presents an opportunity for change. As these technologies merge, they offer promising prospects for the future of urban design. The chance to cultivate more sustainable, adaptable, and nature-integrated cities is now attainable. Reassessing the natural design principles that previously shaped urban environments, principles recognising the city as a living, breathing organism, and aligning them more closely with the needs of its residents facilitates the creation of structures that meet the city's functional requirements while also enhancing the emotional and psychological well-being of its inhabitants. This research explores the intersection of Variable Property Design and Physarum Computational Intelligence, employing these concepts to guide the development of adaptive, responsive urban structures that connect with nature. The question, then, is **how can the principles of Variable Property Design be applied to urban architecture through Physarum Computational Intelligence?**

HOW CAN THE PRINCIPLES OF VARIABLE PROPERTY DESIGN BE APPLIED TO URBAN ARCHITECTURE THROUGH PHYSARUM COMPUTATIONAL INTELLIGENCE?

CHAPTER 03.1

THE MODERN DESIGN PROCESS: A FRAGMENTED APPROACH

A FRAGMENTED APPROACH

To address this question, we must first grasp the underlying issues inherent in the current urban architectural design process. The standardised division of form, function, structure, environment, and materials, central to modernist design theory, together with a systematic segmentation of modelling, analysis, and fabrication, has produced geometric form-based architecture. (Oxman, 2010) A key outcome of this separation is the emergence of a design process driven by geometric forms, disregarding the interdependent relationship between these elements. This has resulted in buildings that often fail to satisfy the complex needs of inhabitants and the environment. By examining the interaction of these elements and how their separation leads to inefficiency and disconnection, we can pinpoint the route to a more integrated and adaptive approach to urban architecture. This understanding will assist us in exploring the potential of technologies like VPD and PCI to integrate these elements and cultivate urban environments that respond more effectively to the evolving needs of humanity and the natural world.

ARCHITECTURE IS CONCEIVED IN ISOLATION, DEPENDING ON PREDETERMINED FORMS AND TECHNICAL SPECIFICATIONS RATHER THAN INFLUENCED BY ITS CONTEXT AND THE LIVING, BREATHING WORLD IN WHICH IT RESIDES.

Modernist architecture was grounded in the principle that form should follow function, with the rational use of materials and structure as the primary factors influencing design. Although this belief was revolutionary at the time, it institutionalised a separation between key design components. **FORM** evolved into a purely geometric pursuit driven by aesthetic and functional considerations that often diverged from the building's materiality and supporting structure. In this approach, the **STRUCTURE** was refined to meet functional requirements assessed independently of the expressive potential of the form. Simultaneously, the **MATERIALS** were selected for their practicality, cost-effectiveness, and performance characteristics, frequently with little consideration for their aesthetic, tactile, and environmental impacts. Urban architecture evolved into a system of modular, standardised components, emphasising the geometric purity of form over the engagement with spatial environments.

The methodological partitioning extended into the design process, whereby the various design stages—modelling, analysis, and fabrication—became distinct tasks. **MODELLING** primarily focuses on creating geometric representations of forms, often abstracted from the project's material and structural realities. The **ANALYSIS** subsequently took precedence, concentrating on technical calculations like load-bearing capacity and environmental performance. However, these assessments were frequently detached from the design's aesthetic or experiential qualities. **FABRICATION**, the concluding phase, transforms these conceptual forms and technical calculations into a physical entity. (Brown, 2018) The delineation between the stages of the design process has led to a fragmented relationship between form, function, structure, environment, and materials.

The assumption that geometric forms can be designed initially and then applied to materials and structures without thoroughly considering their materiality or structural logic has led to buildings that, while functional, frequently fail to integrate form and materials meaningfully. The construction process became increasingly mechanical as design tools and workflows solidified this separation. Architects conceive a design, draft it, select materials, and then assess how it endures physical forces, frequently without permitting the material and structural properties to inform or inspire the form.

Today, the tools architects use to create forms are still greatly influenced by this geometry-driven methodology. Software programmes such as CAD (Computer-Aided Design) and BIM (Building Information Modelling) enable the rapid and efficient production of complex geometric forms. These tools presume that the superiority of geometric forms is assumed, that form must serve as the foundation for design, and that all other aspects, including materiality and structure, should be considered secondary. The design process often appears straightforward: conceive a form, sketch it, apply materials, analyse its performance, and proceed to construction. Nevertheless, this approach has its limitations. It simplifies architectural design to a mechanical, linear process that overlooks the dynamic interconnections between form, material, and structure. It allows minimal space for organic, adaptive qualities that arise from the natural world, where material and environmental characteristics inform and structure develops in response to its context. Within this framework, **architecture is conceived in isolation, depending on predetermined forms and technical specifications rather than influenced by its context and the living, breathing world in which it resides.**

This is evident in Foster and Partners' recent design proposal for 18 Blackfriars Road, which was developed in collaboration with Hines and Lipton Rogers. The proposal reflects a complex intersection of modern sustainability objectives and the enduring legacy, highlighting the fragmentation of the contemporary design process. Situated in Bankside, Southwark, London, this development endeavours to revitalise a two-acre brownfield site that has remained vacant for 20 years and to convert it into a mixed-use project. Despite setting a goal to achieve a net-zero carbon status and incorporating ground-source heat pumps while supporting affordable housing and local businesses (Foster+Partners, 2024), it simultaneously illustrates the challenges of differentiating form, structure, material, and environment, embodying modernist design principles. Although the building's aesthetics and structural efficiency are undeniably impressive, they illustrate how these distinctive design elements, often isolated from human experience and nature, can create functional urban spaces that lack deeper connections to the environment and the well-being of their inhabitants.

18 Blackfriars Road follows a standard contemporary model in which the building's form is conceived first, followed by considerations of materials and structural elements. As illustrated in Figure 8, the building's sleek glass and steel façade, which rises above its urban environment, exemplifies a direct continuation of the approach established by modernist architects, where the design comprises a series of distinct steps. However, this linear process fails to recognise the interdependence of these elements, limiting the building's ability to adapt to its surroundings and meet its inhabitants' emotional and psychological needs. While undoubtedly a notable achievement in energy efficiency, the building's net-zero carbon strategy continues to depend on the promise of this fragmented methodology. Rather than allowing the materials, structure, and environmental forces to dictate the form, the form is conceived first and subsequently refined with technologies that reduce environmental impact. This approach, although effective in reducing operational carbon emissions, misses the chance to fully integrate environmental considerations at the most fundamental level of design. The building exemplifies sustainability by utilising ground-source heat pumps to decrease energy demand. It operates on a fossil fuel-free, 100% electric system, and it incorporates a comprehensive biodiversity enhancement strategy, which includes planting 100 new trees and aims for a 150% increase in biodiversity on-site. (Spocchia, 2024) However, it fails to explore how the structure could have been more harmoniously integrated with its environmental context. Conversely, the ecological response remains marginalised in the design process.

Figure 8: Spocchia, G. (2024). Aerial View of Foster + Partner's Tower Scheme for Hines. (Source: DBOX, The Architects' Journal). [Photograph]

The building includes green terraces and outdoor spaces intended to provide occupants with access to nature. Nonetheless, these areas are regarded as tertiary elements, primarily added after establishing the main form and structure. The concept of biophilia is apparent in the terraces and proposed green spaces; however, it is not integrated into the architectural fabric of the building. These elements do not influence the design or dictate how the structure interacts with the environment. This portrayal of nature as an accessory highlights a more significant issue within modern urban developments, where sustainability, although increasingly prioritised, is still frequently implemented in a manner that does not fundamentally transform how buildings are integrated into the environment.

While 18 Blackfriars Road provides a range of community-oriented amenities, including affordable workspaces and public mixed-use areas, these facilities are not intrinsically linked to the building's form or structure. The proposal does little to enhance social cohesion or encourage human connection within the broader context of the site. The building's imposing structure, characterised by the verticality of its tower, creates a psychological distance between the edifice and the surrounding community, further highlighting the deficiency of interactive green space.

The challenges posed by 18 Blackfriars Road accentuate the pressing necessity to rethink our approach to urban architecture in today's context. The building's notable sustainability measures represent progress; however, they are still governed by a linear and fragmented design process that prioritises aesthetics over practicality, structural elements over material considerations and treats the natural environment as a secondary concern. We must reverse the conventional design process to develop thoroughly integrated, adaptive, and responsive urban structures. Rather than starting with a preconceived form, we should allow materials, structural elements, and environmental factors to shape and influence architecture. (Oxman, 2010) In this reimagined process, the structure would evolve according to its environment and the needs of individuals. Utilising the principles of VPD allows buildings to adapt over time to meet growing environmental and social needs. By employing PCI, inspired by the adaptive behaviour of natural organisms, we can create urban structures that develop organically. These systems would enable real-time feedback, thereby ensuring that the building remains attentive to the needs of its occupants and the changing climate, all while promoting a more profound connection to nature. By reversing the design process and allowing the fundamental principles of nature to guide the evolution of form, structure, materials, and function, we can create sustainable and adaptable designs that focus on human needs, with nature intricately integrated into the fabric of the design.

04 VARIABLE PROPERTY DESIGN (VPD)

THE NATURAL DESIGN PRINCIPLES

THE NATURAL DESIGN PRINCIPLES

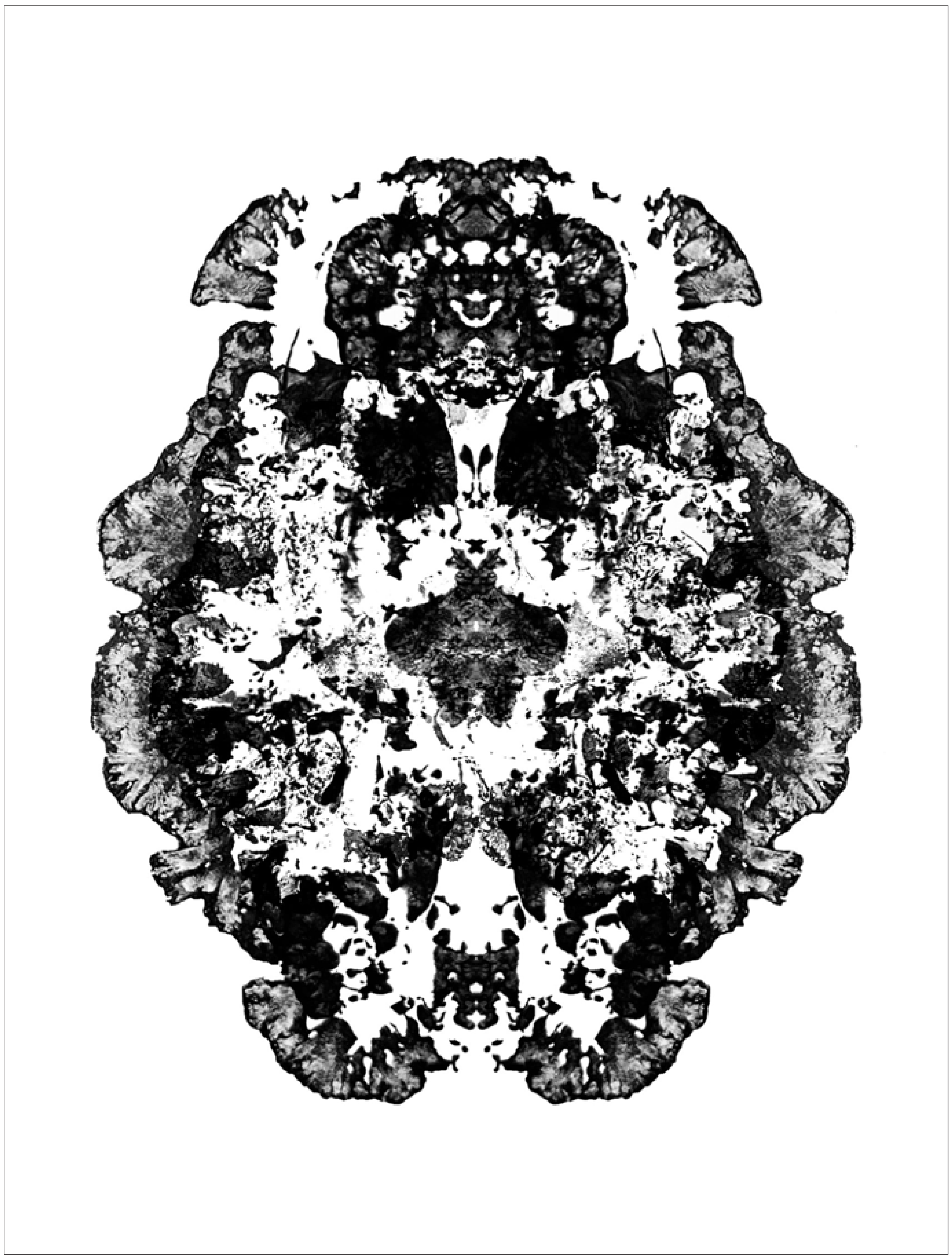
CHAPTER 04

THE NATURAL DESIGN PRINCIPLES

To transcend the limitations of the fragmented design process that has characterised modern architecture, we must look to nature to understand how VPD can transform urban architecture. One of the most insightful natural structures informing this theoretical framework is the neuron, a fundamental component of the human brain. Neurons' ability to adapt, optimise material properties, and respond to environmental demands is a direct analogy for how urban structures could function. The neuron exemplifies a self-organising system wherein its structure, behaviour, and material components are cohesively integrated. This integration facilitates continuous adaptation, performance optimisation, and resilience. Within the context of VPD, the neuron embodies the design principles that allow urban structures to be adaptive and responsive. The neurological system, particularly its neurons, functions as a self-organising system without an external controller directing the arrangement of its components during development. Instead, the system naturally arranges itself based on internal processes. (Eberhard, 2007) This self-organisation represents a significant concept in urban architecture, suggesting that structures can be designed to evolve, thereby adapting to the needs of their inhabitants, the surrounding environment, and even unforeseen changes. Much like the network of neurons within the brain operates independently of external commands, the structure has the potential to function dynamically, assimilating information from its surroundings and adjusting autonomously to optimise its performance.

To comprehend how the neuron aligns with the principles of VPD, it is imperative to examine its structural properties, material optimisation, and adaptive behaviour. Similarly, just as neurons integrate structure and function, urban structures should embody this duality by enabling a building's form to respond to environmental stimuli. Neurons optimise materials by transmitting signals and adjusting their structural properties to perform specific tasks based on the environment. Implementing VPD in an urban structure would improve material distribution in response to external demand, optimising performance while maintaining configuration. This suggests that form is not predetermined but shaped by the synergy of natural design principles. Examining the modifications that occur in a neuron during a learning phase is also pertinent. As connections strengthen or weaken in response to experience, the neuron alters its internal structure, both forming and reforming connections to optimise its performance. This process, known as synaptic plasticity, enables neurons to enhance their responses to stimuli. Similarly, urban structures should be capable of evolution, with building materials and architectural designs adapting to their environmental context. Through RBD, I have produced acrylic paintings to emphasise the importance of representation in research as a method that encourages a visual comprehension of the research topic. (Hatch, 2008) While art may not conform to traditional notions of functionality, it can be positioned to play a crucial role in providing instruments for representation and critical analysis. (Rendell, 2006) Each painting metaphorically embodies the principles of VPD while contextualising the influence of the neurological system on the distribution of materials and spatial reconfiguration within a specific framework.

Figure 9: A Plan View of the Neurological Structure



ARCHITECTURE
SHOULD NOT BE LIMITED BY
FIXED GEOMETRICAL FORMS; RATHER,
IT SHOULD BE SHAPED BY
THE FUNCTIONAL AND BEHAVIOURAL
TRAITS OF THE ENVIRONMENT

Figure 9 presents an acrylic painting of the complete neurological system, resembling an MRI scan. These images visually illustrate the intricate neurological network, reflecting the formation of neurons and their connections within the structure. This visual exploration, adopting a plan view, aims to clarify how neurons and their interconnections create a self-organising system in which material and structural characteristics are distributed according to functional necessities. The data from this research methodology indicates that the neural network, shaped by the natural design principles of adaptation, forms connections that optimise its functionality without geometric limitations. The process of capturing this natural structure has demonstrated that architecture can likewise evolve by optimising materials and forms in response to environmental stimuli and the requirements of users. Emphasising how the brain's material distribution and spatial configuration evolve to enhance functionality is a vital aspect of VPD. The neurological structure depicted in this painting represents a system shaped by nature, where form follows function and behaviour. This principle is essential for comprehending how VPD can be applied to urban architecture.

Figure 9: Sidey, E. (2025) A Plan View of the Neurological Structure: MRI Scan. [Acrylic Painting]

Figure 10: Sidey, E. (2025) A Cross-Cut Section of the Neurological Structure: MRI Scan. [Acrylic Painting]

Figure 10, in conjunction with Figure 9, displays an acrylic painting of the entire neurological system, resembling a cross-section that facilitates a more in-depth analysis of the internal organisation of the neural structure. This section clarifies the relationship and restructuring of the framework during the learning phase when confronted with new information. The painting exemplifies the process of synaptic plasticity within the brain. Throughout the artistic process, the data collected substantiates the concept that, like natural structures, architecture can be viewed as a dynamic system that continuously adapts. A key characteristic of the neurological system illustrated through these paintings is the principle of VPD, which states that structure adapts in form and function according to behavioural demands, regardless of geometric constraints. Neurons do not rely on rigid geometric patterns to function. Similarly, **architecture should not be limited by fixed geometrical forms; rather, it should be shaped by the functional and behavioural traits of the environment.** This behavioural principle, where form follows function and behaviour takes precedence over geometry, aligns directly with VPD. Just as neurons reorganise their pathways in response to acquired knowledge and crucial needs, urban environments should be capable of adapting their structures and materials in real time to enhance performance.

Figure 10: A Cross-Cut Section of the Neurological Structure

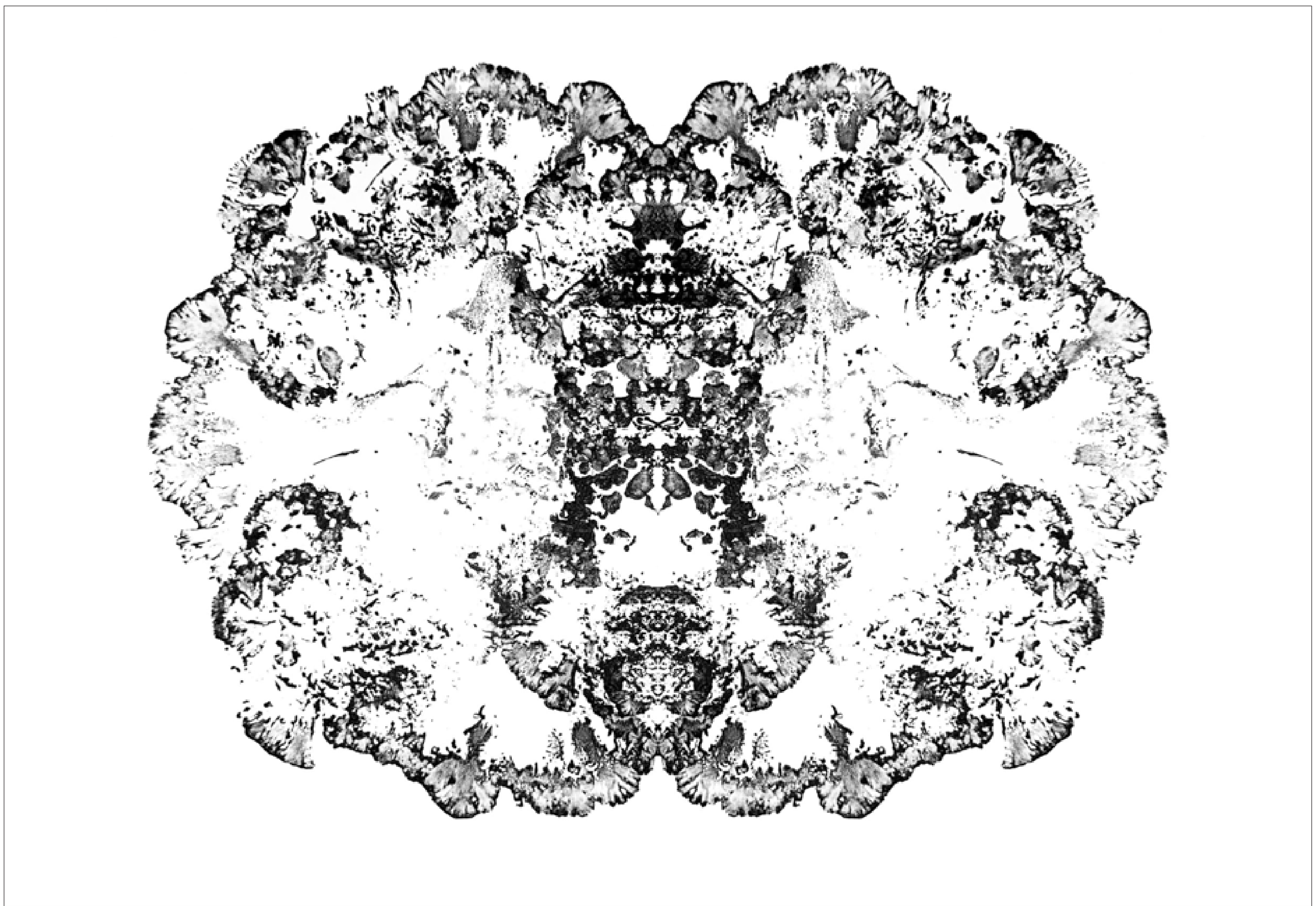


Figure 11 illustrates the initial stage during which neural connections are established, highlighting the earliest distribution of materials as neurons commence the adaptation process. This indicates that architecture, during its initial phases, should emphasise flexibility and adaptability, possessing the capacity to establish connections and disseminate materials that will develop within its environmental context. Figure 12 illustrates the second stage, during which neuronal connections strengthen and adapt. This phase is characterised by the optimisation of structure and the emergence of more defined pathways. In architecture, this indicates that after an initial period of adaptability, the structure should remain unobtrusive to optimise the materials and spaces, which should be finely tuned for their intended function.

Figure 11: Sidey, E. (2025) Stage 1 of the Material Distribution and Spatial Reconfiguration: Immunohistochemistry Scan. [Mixed-Media Acrylic Painting]

Figure 12: Sidey, E. (2025) Stage 2 of the Material Distribution and Spatial Reconfiguration: Immunohistochemistry Scan. [Mixed-Media Acrylic Painting]

Figure 13: Sidey, E. (2025) Stage 3 of the Material Distribution and Spatial Reconfiguration: Immunohistochemistry Scan. [Mixed-Media Acrylic Painting]

Figure 13, the final illustration in the series, depicts the third stage: a fully optimised arrangement of the neurological structure adapted to the environment. The structure has evolved, and the distribution of materials ensures optimum functionality. In line with the principles of VPD in architecture, the paintings exhibit a structure that, although representational, has evolved to optimise the spatial configuration, materiality, and function fully. This is a collection of three mixed-media paintings that examine the distribution of materials and the spatial reconfiguration of the neural network across three distinct stages. Inspired by the immunohistochemistry scan, these paintings depict the evolution and adaptation of the neurological network across different stages, from initial growth to active adaptation and finally achieving optimised performance. Collectively, they provide a visual analysis of how material distribution and spatial reconfiguration can evolve in response to the environment. The paintings developed as a methodology of RBD illustrate that architecture, similar to the neural structure, can be conceptualised as a dynamic system that responds to internal necessities and external stimuli, thereby ensuring efficiency, sustainability, and resilience.

Figure 11: Stage 1 of the Material Distribution and Spatial Reconfiguration: Immunohistochemistry Scan.

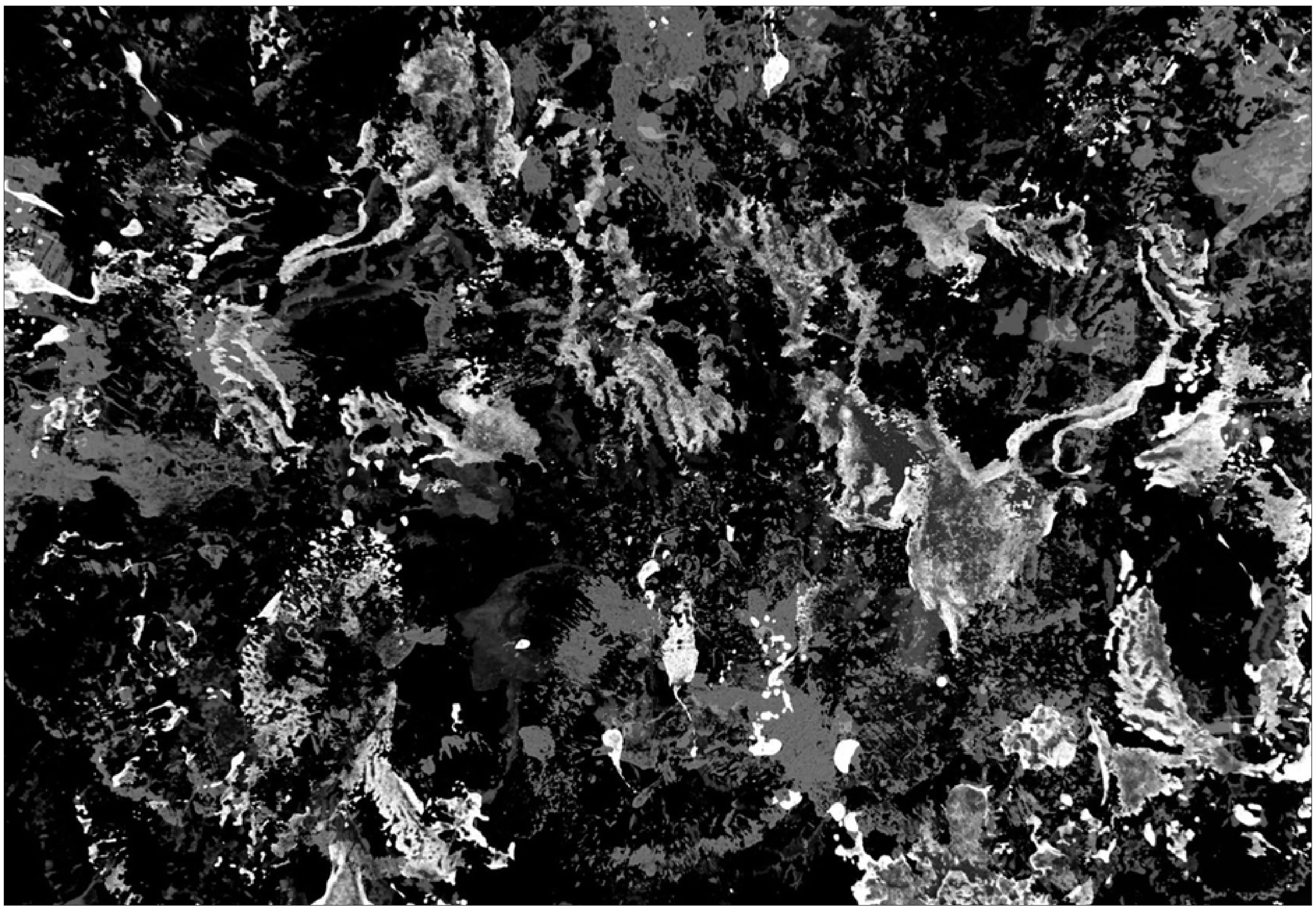


Figure 12: Sidey, E. (2025) Stage 2 of the Material Distribution and Spatial Reconfiguration: Immunohistochemistry Scan.

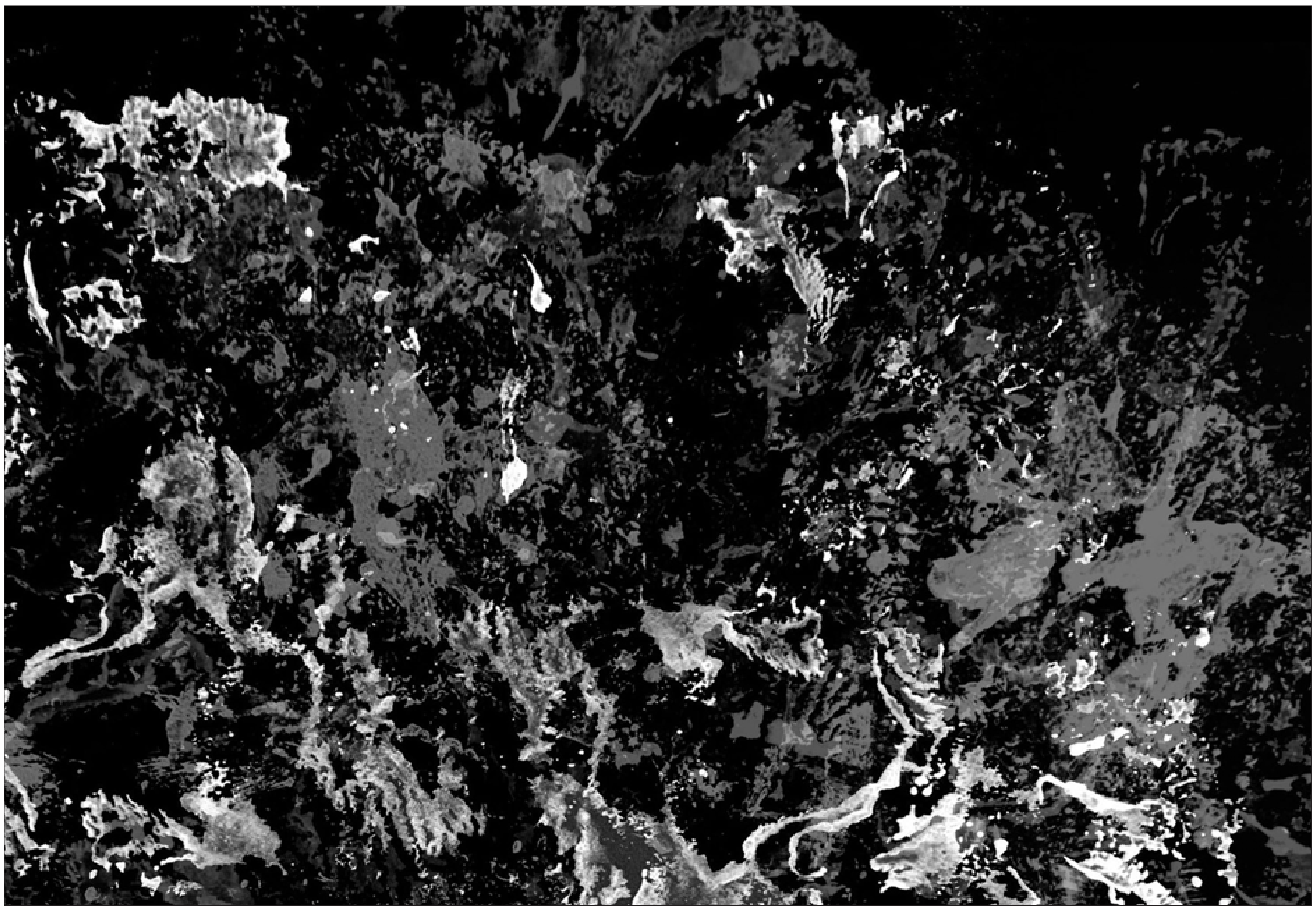
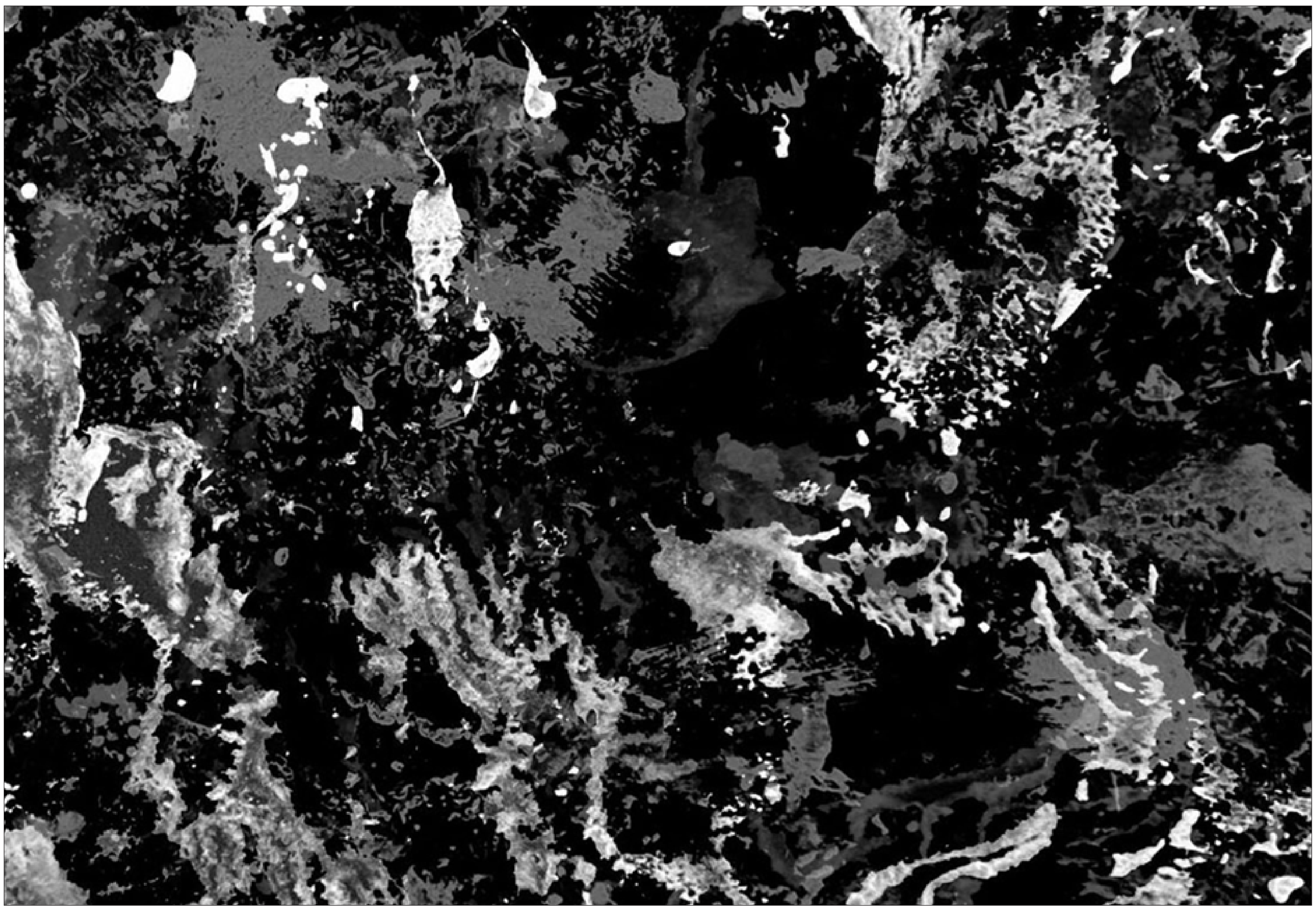


Figure 13: Sidey, E. (2025) Stage 3 of the Material Distribution and Spatial Reconfiguration: Immunohistochemistry Scan.



In urban architecture, it is essential to employ the natural design principles of VPD, as evidenced in neurological structures. This requires careful consideration of how each component within the design process can integrate effectively, thus enabling a structure to adapt, respond, and optimise according to its external conditions. VPD challenges the conventional concept of static architecture, where materials and structural elements are integrated secondarily into the overall form. Instead, VPD advocates for a dynamic approach in which the structure is flexible, allowing for the redistribution of materials and the adaptation of forms according to real-time environmental constraints. Structures evolve into systems of materials optimised for specific tasks, with each component responding and adjusting as necessary, much like the neurons that comprise the neurological system.

To address the challenges presented by the fragmented design process in contemporary architecture, we can take cues from nature, which has refined its problem-solving abilities over 3.5 billion years of evolution, showcasing principles of adaptive and responsive design. (Keats, 2016) In examining neurological structures, I have investigated how natural systems seamlessly integrate generating and evaluating design processes. **In nature, there is no distinction between building a structure and assessing its performance. Instead, the form evolves through continuous feedback loops, adapting to functional and environmental demands.** (Oxman, 2010)

With the advancement of digital fabrication technologies, the architectural discipline is on the threshold of a new era, one in which design synthesis and analysis can coincide. Current technological advancements allow us to incorporate nature's refined processes, enabling structures to evolve and adapt like living organisms. Nature, as we have examined, does not generate form in isolation. Geometry emerges from the interaction of material distribution, spatial reconfiguration, and environmental forces. In this manner, form is a direct outcome of adaptation, a process in which material distribution is continually adjusted to meet specific structural and ecological challenges. This dynamic interaction lies at the heart of natural systems, comprehended via the neurological structure, and offers a model for reimagining urban architecture. Nature's integrated approach, wherein analysis, fabrication and modelling occur as a cohesive process, contrasts the fragmented design methodologies prevalent in modern architecture. For urban architecture to attain comparable levels of sustainability and adaptability, it is imperative to adopt a design philosophy that integrates these fundamental steps, employing material distribution to achieve dynamic performance across diverse contexts. By utilising these natural strategies, urban architecture can move towards a more adaptive and responsive design solution. Similar to how the neurological system optimises its structure and form through ongoing interaction with various materials and the environment, buildings and urban areas can be engineered to evolve and function in response to real-time inputs. Essentially, VPD establishes a framework for a more sustainable approach to urban architecture that mirrors the evolutionary processes found in nature. Architecture transcends its static nature by integrating design, analysis, and fabrication into a harmonious process; it evolves like natural systems, ensuring our built environment remains adaptable and responsive.

NATURE,

AS WE HAVE EXAMINED,

DOES NOT GENERATE FORM
IN ISOLATION.

GEOMETRY EMERGES
FROM THE INTERACTION

OF MATERIAL DISTRIBUTION,
SPATIAL RECONFIGURATION,
AND ENVIRONMENTAL FORCES.

05

PHYSARUM COMPUTATIONAL INTELLIGENCE (PCI)

ARCHITECTURE AS A TECHNOLOGICAL ORGANISM

CHAPTER 05

ARCHITECTURE AS A TECHNOLOGICAL ORGANISM

To implement the principles of VPD and the natural design process, Physarum Computational Intelligence (PCI) serves as a transformative instrument for applying this framework within the realm of urban architecture. This innovative software plugin used in Grasshopper within Rhino simulates the behaviour of Physarum Polycephalum, a living organism that processes information based on experience to adjust its behavioural patterns. The organism is predominantly found in mould. However, its behavioural patterns and processes resemble synaptic network connections in the neurological system, making it a natural parallel for VPD and a robust tool for designing urban structures that are both adaptable and responsive. Physarum polycephalum displays self-organising behaviour while foraging for sustenance, and the resultant growth patterns create networks that optimise the routes between resources, dynamically adapting to their surrounding environment. (Mayne, 2015) By utilising the Physarum plugin, this behaviour is simulated computationally, allowing for the design of structures that evolve in real time and adapt to environmental constraints and performance in a way akin to that of a biological system.

HOW CAN THE PRINCIPLES OF VARIABLE PROPERTY DESIGN BE APPLIED TO URBAN ARCHITECTURE THROUGH PHYSARUM COMPUTATIONAL INTELLIGENCE?

Incorporating PCI into urban architecture facilitates the application of the principles of VPD within a technological framework. This approach permits the development of urban structures that evolve, adapt, and optimise their configuration, material distribution, and spatial organisation. The software simulates the natural growth processes of Physarum polycephalum, thus enabling the design of adaptive and responsive structures that react to environmental inputs analogous to a living organism. These structures are neither rigid nor predefined; instead, they evolve based on real-time data, adapting to the ever-changing conditions of their environment. Through PCI, the design of buildings as organisms within an ecosystem becomes not only feasible but also practical. This approach reconceptualises the role of architecture within the urban landscape, moving from static structures to buildings that actively engage with and adapt to their surroundings. By employing the principles of VPD through PCI, it is possible to establish responsive and sustainable frameworks that align with the natural environment rather than disrupt it.

The core of this dissertation is the question of how the principles of Variable Property Design can be applied to Urban Architecture through Physarum Computational Intelligence. Central to this research is the principle that architecture must operate as a dynamic and adaptive system, one that evolves in response to environmental factors as well as human needs, reflecting the behaviour of natural systems. By incorporating Physarum, an organism that exhibits intelligent behavioural patterns similar to human neurological structures, we obtain a powerful tool that simulates natural growth processes and can be utilised in designing adaptive urban environments. Having conducted a thorough analysis, we can recognise that modern urban development often fails to incorporate natural elements, resulting in detrimental consequences such as ecosystem degradation, the loss of green spaces, and a disconnection between the built environment and the natural world. As urban areas continue to expand, the fragmentation in the design process, which creates a disjunction between natural systems and architectural design, threatens the health of urban residents and ecological sustainability. Design and engineering occur in constituent parts at the atomic and subatomic levels. With access to advanced technology, designers can begin exploring methodologies previously only nature could achieve. (Neville, 2019). The solution identified involves collaboration with nature, rather than an opposition to it, through the design of urban areas where architecture adapts to the environment, preserves natural habitats, and facilitates coexistence between the built and natural environments.

THE BEHAVIOURAL COMPONENTS

THE BEHAVIOURAL COMPONENTS

Through PCI, we can integrate the principles of VPD into urban architecture, effectively bridging the gap between natural systems and architectural design. Figure 14 illustrates the design process of VPD within Physarum, demonstrating how PCI functions as a tool for developing responsive, adaptive structures. The diagram illustrates the different stages of the design process, showcasing how Physarum emulates the behavioural patterns of natural systems. Through computational intelligence, the framework is constructed by allowing the system to evolve and optimise itself following input parameters, like the adaptive nature of the neurological system. This figure facilitates the visualisation of the dynamic relationship between the parameters established by the algorithm and how the material distribution evolves in real time, enabling the structure to develop and adapt in response to specific requirements. As illustrated in Figure 14, the behavioural components reflect the neurological structure found in nature, where form and structure emerge from the interplay between the environment and material properties. An essential insight derived from this process is that buildings and urban structures can be conceived through a comparable self-organising system that perpetually adjusts, optimises, and reacts to their environment. Through the integration of this theoretical framework, it becomes possible to develop structures that are not only responsive but also efficient, sustainable, and adaptable, akin to the evolutionary process of natural organisms. This is the foundation for applying VPD through PCI to urban architecture.

Figure 14: Sidey, E. (2025) The Behavioural Components within The Design Process of Variable Property Design, in Physarum. [Diagram]

Figure 14: The Behavioural Components within The Design Process of Variable Property Design, in Physarum.

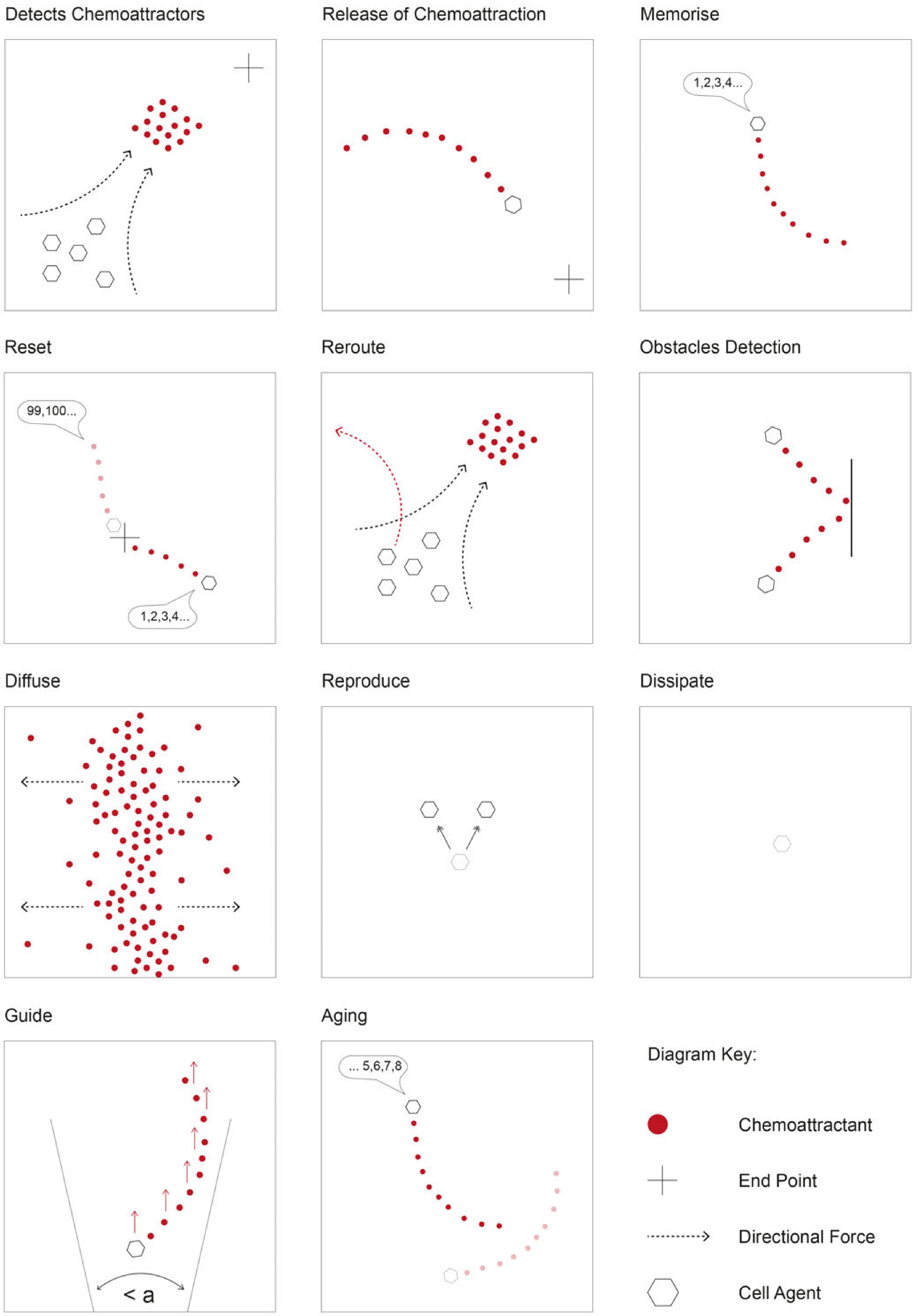
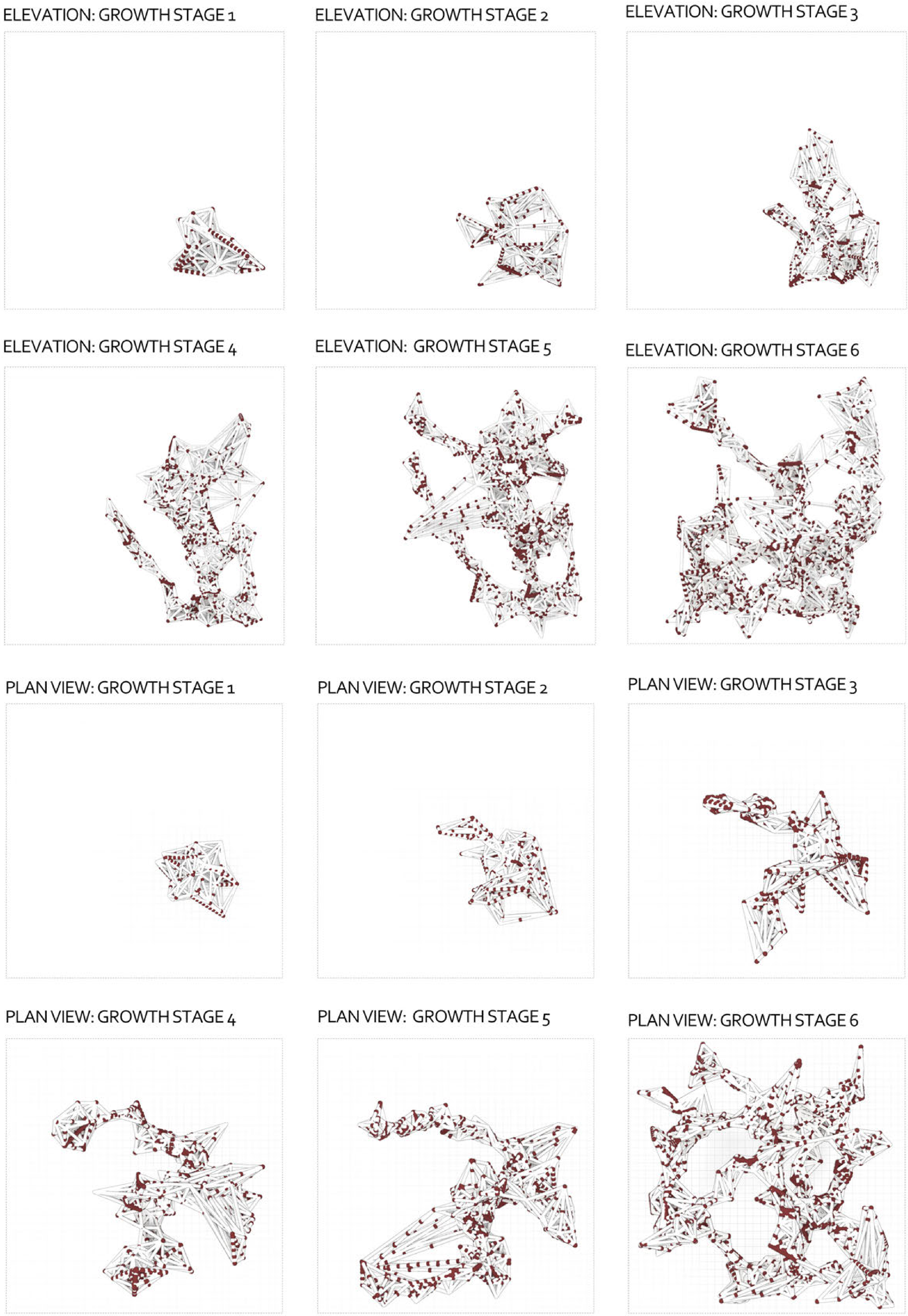


Figure 15: The Staged Structural Growth of Variable Property Design, in Physarum.



Building upon this framework, Figure 15 presents a series of two-dimensional drawings that illustrate the progression of a structure employing the principles of VPD within PCI. These drawings illustrate the stages of structural growth, where material distribution is controlled by the input parameters established by the algorithm. The six-stage computational simulation shown in these drawings represents the evolution of a structural network as it adapts and evolves, imitating the behavioural patterns of the neurological system. The prototype model developed during this process investigates 3D behavioural patterns and enables us to explore the interactions between the algorithm, material properties, and environmental inputs. The model demonstrates how the system consistently adapts the form and material distribution of structures to their ecological context, optimising the design at each stage. This model shows that similar to the brain's ability to adapt and recognise its neuronal pathways, urban structures can self-optimise their form, structure, and material composition to ensure optimal performance within their environmental constraints.

Figure 15: Sidey, E. (2025) The Staged Structural Growth of Variable Property Design, in Physarum. [Digital Drawing]

To investigate further the feasibility and structural properties of the VPD theoretical framework, I 3D printed the structure's staged simulation. Figure 16, supported by the photographs in Appendix B, demonstrates the 3D printed elements, visually illustrating the structural growth and material distribution as they evolve through the stages of computational simulation. These models provide a concrete, physical representation of the operational mechanisms of dynamic, adaptive systems as they may occur in real-world applications, thereby bridging the divide between digital simulation and physical manifestation. By printing these models, we attain a more profound comprehension of how the behavioural patterns, as delineated by the natural design principles observed in PCI simulation, translate into a tangible structure. The models are systematically presented in stages to reflect the progression of material distribution and the evolving network, thereby enabling an examination of how the structure adapts and develops. The staged progression of the three-dimensional printed models illustrates the incremental enhancement of the form, showcasing the flexibility and adaptability inherent in the design—a fundamental principle of VPD. The three-dimensional printed models assist in addressing the primary research question by physically materialising the growth process of a self-organising structure. These models illustrate that adaptive architecture, informed by natural systems and computational intelligence, can indeed be transposed into a tangible built environment. As evidenced by the models, the gradual transformation of architectural form supports the assertion that buildings can evolve and optimise over time in response to internal and external stimuli. This indicates that structures may be designed comparably to adapt and grow in urban architecture, consistently optimising for environmental conditions, human requirements, and sustainability.

STAGED STRUCTURAL GROWTH

STAGED STRUCTURAL GROWTH

Figure 16:

3D PRINTED PHYSICAL
THE STRUCTURAL GROWTH

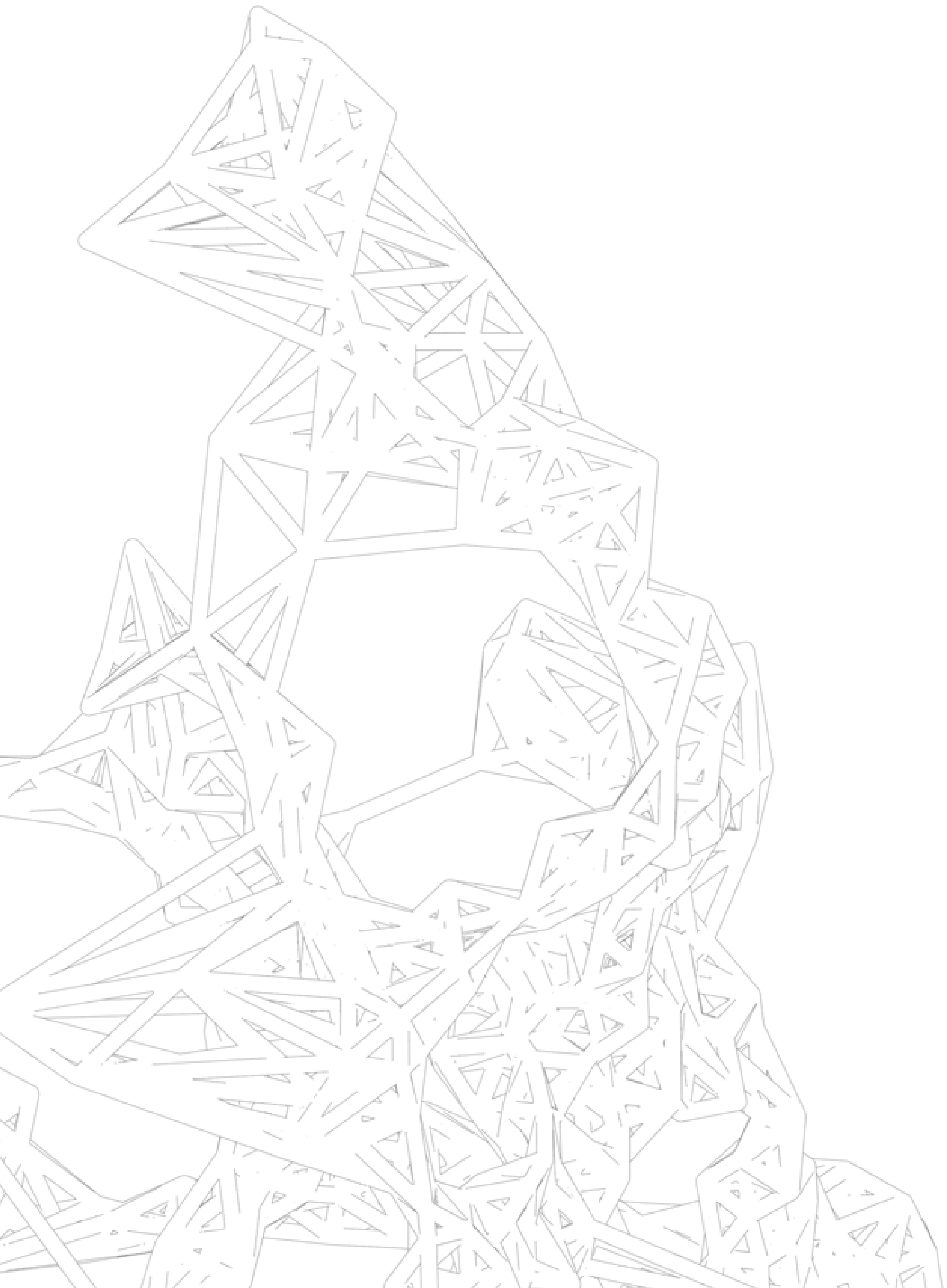
Figure 16: Sidey, E. (2025) 3D Printed Physical Models Illustrating the Structural Growth and Material Distribution. [Photograph: 3D Printed Models]

MODELS ILLUSTRATING AND MATERIAL DISTRIBUTION

By applying the principles of VPD through PCI, we revisit a fundamental argument articulated earlier in this dissertation: the essence of nature in augmenting the built environment is paramount. Nature's capacity to adapt, respond, and self-organise provides invaluable insights for urban architecture. PCI facilitates the integration of these principles within a technological framework, wherein form and function are optimised and adjusted under real-time environmental feedback. The insights derived from Physarum Polycephalum, the neurological structure, and its associated behavioural patterns affirm the potential for buildings to function as organisms within an ecosystem, wherein structures interact with and respond to the surrounding natural world.

This approach diverts from the damaging urban processes of ecological neglect. Instead, it permits the built environment to coexist harmoniously with nature, enabling buildings to evolve and adapt around existing natural elements, thereby preserving environmental balance and fulfilling the needs of human inhabitants. The biophilia hypothesis asserts that tranquil or nurturing aspects of nature help restore empathy, serenity, cognitive clarity, and hope, reflecting humans' intrinsic emotional connection towards other living organisms. (Williams, 2017) By utilising PCI, we have shown that it is feasible and essential to develop urban structures that harmonise with the natural environment, where the distribution of materials and spatial configurations are dynamic and responsive to environmental variables. This initiative contributes to the preservation of green spaces and natural habitats. It promotes the creation of sustainable, self-organising urban systems that can adapt to the changing needs of the population and the environment.

Buildings should not be divided into two intellectually distinct components: physical structures and technological properties. A successful approach to architecture involves organic integration. It requires exploring external and internal factors, usage fluctuations, changes in user expectations, strategies for addressing users' needs, and, above all, the building's environmental controls. (Antonelli, 2020) This dissertation employs the theoretical framework of VPD to advocate for a reciprocal attitude, which has been further developed into a novel form of organicism. The algorithm catalyses architecturally controlled growth in this paradigm, transforming the building from a static structure into a living organism.



BUILDINGS SHOULD NOT
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06 CONCLUSION

THE FOUNDATION OF A NEW ERA IN URBAN ARCHITECTURE

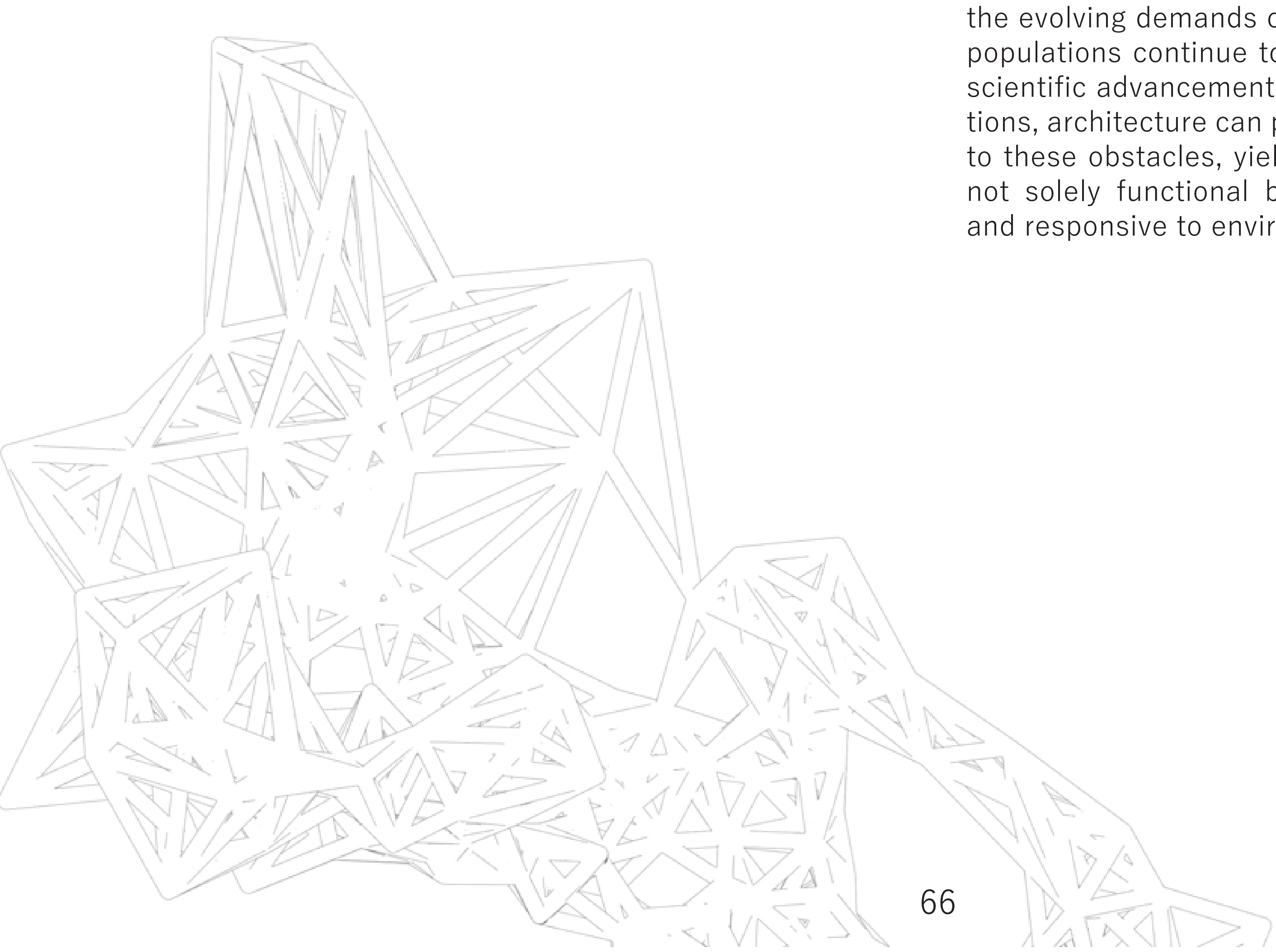
THE
FOUNDATION
OF A
NEW ERA IN
URBAN
ARCHITECTURE

CHAPTER 06

THE FOUNDATION URBAN

In this dissertation, I have identified and critically examined the fragmentation in the modern design process, where form, structure, material, and environment are often regarded as isolated elements. This process has led to fragmented and frequently unsustainable urban developments rooted in modernist design principles that inadequately address human needs and environmental constraints. As previously discussed, this separation results in functionally efficient buildings that lack the ability for genuine adaptability, connection to their environment, and resilience over time. The disconnection among form, structure, material, and environment in modernism has produced rigid, static systems that, while efficient in certain respects, fail to integrate nature into the built environment meaningfully. In addressing this matter, we sought guidance from nature. A thorough examination of the neurological structure revealed a self-organising, adaptive model that integrates structure, function, materials, and the environment into a cohesive process. The neuron, as a fundamental component of the brain, provides a compelling analogy for an integrated approach to design. Just as the neuron adapts and optimises its structure, as well as its interactions with materials and the environment, to perform complex tasks, our approach to architecture should also embody this adaptability. In the natural world, form and function are not separate entities; instead, they emerge from an ongoing feedback loop wherein material properties, structural design, and environmental influences continually adapt to optimise performance.

Examining biological systems and applying biomimicry derived from Physarum polycephalum and the neurological structure offers significant insights: nature presents a paradigm where all design components, structure, form, material, and environment operate independently and collaboratively within a dynamic system. In contrast to traditional architectural design methodologies that view these components as separate entities, the natural design process integrates them, leading to inherently adaptive and resilient systems. Developing an interdisciplinary approach to design incorporating architecture, technology, and neuroscience offers innovative possibilities for the interrelation of buildings and urban environments. Specifically, integrating computational intelligence into the design process introduces an additional layer of complexity, thereby empowering architecture to optimise performance and enhance sustainability, all while preserving the balance between human interests and ecological considerations. The interdisciplinary approach utilised in the research-by-design methodology further emphasises the connection of each field. Using design as a research tool, we have investigated theoretical perspectives and illustrated their practical application using 3D printed models and computational simulations. Integrating physical design with scientific investigation and technological experimentation has established a comprehensive framework for addressing the requirements of future urban structures. Recognising the unprecedented challenges ahead, we understand that sustainable development, resource optimisation, and environmental resilience are essential to meet the evolving demands of the 21st century as urban populations continue to increase. When guided by scientific advancements and technological innovations, architecture can provide pioneering solutions to these obstacles, yielding environments that are not solely functional but also adaptive, resilient, and responsive to environmental feedback.



OF A NEW ERA IN ARCHITECTURE

This research indicates that neurons modify their morphology and structure to meet functional requirements, responding autonomously to environmental stimuli without external direction. The phenomenon of self-organisation and adaptation observed in nature contrasts with modern architecture's rigid and predetermined characteristics. In this realm, external factors, including architects, dictate the form, materials, and structure without regard for the dynamic relationship with the surrounding environment. By examining the neurological structure, we have established that the principles of nature are congruent with the theoretical perspective of VPD and can be effectively translated into urban architecture. This is exemplified by using PCI, which enables the design of adaptive, self-organising structures. These principles of natural growth have been incorporated into the structure as a model of research-by-design, illustrating how architecture can surpass the fragmented design methodology to establish a responsive, integrated system that adapts to its environment. Utilising computational intelligence, the interconnection of form, function, materials, and environment inherent in natural systems is applied to urban architectural design, thereby enhancing structures' resilience, sustainability, and responsiveness to real-time environmental and societal changes.

The structure presented to conclude this dissertation is illustrated through digital renders, Figure 17 and Figure 18, intended to visualise the adaptive structure within an urban environment. The rendering demonstrates how responsive architecture has the potential to revitalise the city by integrating nature and technology to compose a dynamic, sustainable space. The structure is depicted with a texture akin to a tree, symbolising its potential as an organism within urban architecture and signifies growth. When all design elements are synthesised within an integrated process, similar to the neurological system, architecture can transcend its conventional characterisation as a mere aggregation of isolated components. It can evolve and adapt in real-time, engendering a functional and harmonious environment that aligns with the natural world.

Through VPD and PCI, this research has demonstrated our capacity to overcome modernist fragmentation constraints by creating buildings that adapt to their surroundings and develop alongside them, addressing human and environmental requirements. This research endeavoured to question the prevailing standards of urban architecture. It necessitates a transition in design philosophy, promoting an approach that regards the built environment not merely as a collection of isolated components but as a dynamic system in which every element, form, structure, material, and environment collaboratively engages in a continuous adaptation process. By integrating these principles into architectural practice, we advance towards a future in which buildings transcend static, inflexible structures and instead function as adaptive, self-organising systems that evolve and develop in harmony with the natural environment, preserving balance and synergy with the ecosystem in which they exist.

Therefore, the work presented signifies a paradigmatic shift in the approach to urban architecture. It challenges the conventional disconnection between form, structure, materials, and environment by advocating for a cohesive strategy that perceives these elements as interconnected components of a dynamic whole. This research demonstrates that architecture can adapt, optimise, and respond to the needs of both individuals and the surrounding environment, thereby creating spaces that are functional and inspired by nature. As we advance into the future, it shall be imperative to adopt this interdisciplinary and adaptive methodology in the development of cities that are resilient, sustainable, and genuinely integrated with the natural environment. This dissertation establishes the foundation for a new era of urban architecture that honours the symbiosis between humanity, nature, and technology within a rapidly evolving world.

Figure 17: Sidey, E. (2025). The Principles of Variable Property Design Applied to Urban Architecture through Physarum Computational Intelligence. [Digital Render]

Figure 18: Sidey, E. (2025). The Principles of Variable Property Design Applied to Urban Architecture through Physarum Computational Intelligence. [Digital Render]

Figure 17: The Principles of Variable Property Design Applied to Urban Architecture through Physarum Computational Intelligence.

Figure 18: The Principles of Variable Property Design Applied to Urban Architecture through Physarum Computational Intelligence.

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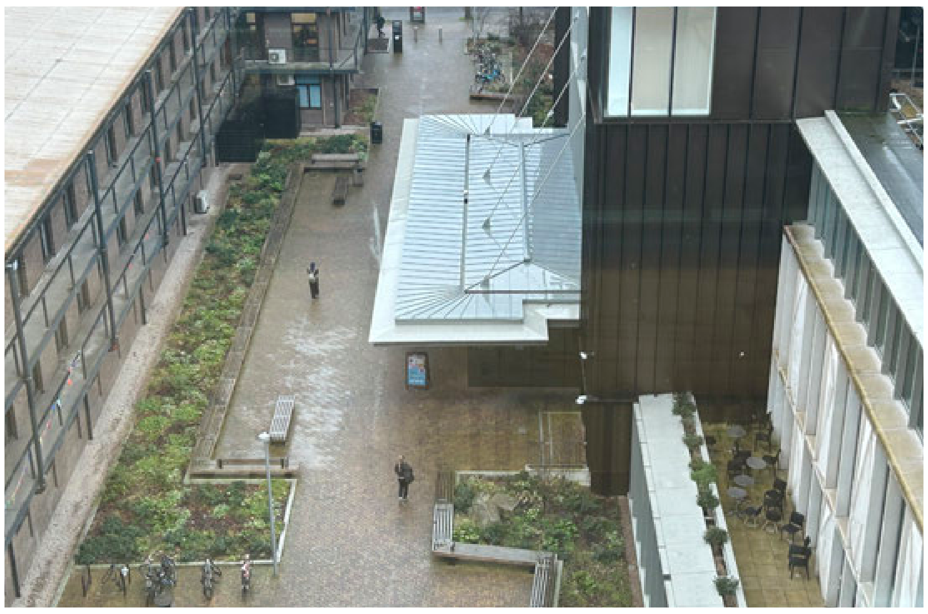
APPENDIX A

This is a photographic study of London South Bank University, located in the Southwark district. This analysis, which supports the data collected from the Dialectogram, explores how the urban landscape, characterised by extensive areas of concrete, glass, and steel, juxtaposes underutilised green spaces and the natural environment.



APPENDIX B

3D Printed Physical Models Illustrating the Structural Growth and Material Distribution.

The materials employed in these models consist of PLA biodegradable filament, which, while not directly representative of the materials that would be utilised in actual applications, provides a practical means to print and assess the structural potential of the design. In the context of this research project, the selection of PLA filament is indicative, as it illustrates the principles of material distribution and structural behaviour rather than serving as the ultimate material for construction. Applying this methodology to urban architecture would involve using natural materials, such as biodegradable or sustainable components. This approach allows structures to breathe, blend seamlessly with their surroundings, and provide ecological advantages.