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The Architect's Measure: Constructing a character and influence for data in practice.

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Christopher Edward Bamborough, declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy in the faculty of Design, Architecture and Building at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Abstract

In our technologically saturated world, architects increasingly rely on data to inform their practice. Despite a wealth of research in other disciplines about data's character and influence, architecture has only a limited understanding. This research examines data from the perspective of the architect, exploring how they conceptualise, produce, and use data as part of their practice. The thesis is motivated by a need to challenge and address the culture in architecture that promotes 'data-driven', 'data-centric', and 'data-aware' approaches with limited critical attention to the assumptions placed on data. Additionally, the topic emerged from a recognition that few research texts understand data as anything other than a technological by-product. Scratching beneath the surface of the techno-innovation language reveals an opacity about what data is and why it exists in the architect's consciousness. The research finds that by locating data at the centre of practice, significant shifts in practical actions and thinking correlate to distinct changes in its character, defined by its architectural use.

Through discourse and case study analysis, this research identifies distinct historical moments when architects have assigned contrasting conceptual understandings and uses, complicating the notion that data is exclusive to digital practice. It traces and critically examines data's architectural shifts, testing the hypothesis that data is not a recent phenomenon. The thesis argues that data has always been part of the architect's practice, but has taken on different forms in each period, giving the architect different abilities. Beyond the technological and innovation discourse that emphasises data's computational value, this research offers an alternative understanding, considering the architect's evolution through how they comprehend, create, and apply abstract measurement.

The research offers a novel perspective on data's role for the architect, and encourages a much-needed critical examination and awareness. Its implications are that, with a heightened understanding of data's role and influence, architects are better-equipped to work in future data-rich environments and negotiate project demands. This research provides a solid foundation to spur future discussions and reflections on the architect's relationship with data.

Introduction

At the 2014 Venice Biennale, the exhibition's director, Rem Koolhaas, stated that 'every architectural element is about to associate itself with data-driven technology' (Davis, 2014). According to Koolhaas, an impending wave of sensors would embed into architecture, giving it the capacity to collect and react to data; in the process, architecture's elements would 'be profoundly influenced by its connection to the digital world' (Davis, 2014). Daniel Davis's article used Koolhaas's words to argue that architects were ignoring data's future influence, in the same way they ignored technological advancements in the twentieth century. For an architectural technologist like Davis, the prospect of a door, toilet or floor measuring inhabitation is a logical progression in tool making. However, for the average practising architect, it is unclear why or how architecture would associate itself with data and what affordances and limitations it provides.

The Problem Context

Architecture's present-day relationship with data primarily relates to how practice invites and utilises digital technologies. This technology relationship also exists outside of architecture, locating data within a broader cultural context of digital tool use. In technologically advanced societies, governments and businesses increasingly form and justify decision making around data. To remain competitive, many fields seek risk-averse decision making through computational 'data-driven' techniques that exceed the limitations of human cognition and intuition. However, there are drawbacks. While the data-driven produces many benefits, Steve Lohr identifies a new cultural condition of 'data-ism', whereby humans increasingly base decision making on data and analysis and less on intuition and experience (Lohr, 2015). Scientific decision making has a critical role in human life, but Lohr highlights that increasingly the world becomes managed through what is easiest to measure rather than what is most meaningful (Lohr, 2015). The potential consequence of data-ism is that humans increasingly organise around non-human computational representations rather than human sensory registration, leading to actions and innovations that benefit economics rather than human survival (Lohr, 2015).

Similarly, scholars in other disciplines recognise an emerging drive for data, such as 'data-fication' (Cukier & Mayer-Schoenberger, 2013), an attempt to quantify all aspects of the world, or specifically for architecture, 'datatisation' (Deutsch, 2015), the act of turning information into comparable quantities. More and more, data provides authority for government policies, setting procedures on public health and medical practice, and guiding finance and capital-based decisions (Gitelman & Jackson, 2013). Research from various fields understands data's influence on society; for instance, capitalism's thirst for personal data (Couldry, 2016); its impact through social media (Briscoe & Marble, 2016); its importance in establishing market advantage (Mason, 2015), its significance in infrastructural control (Sterling, 2013); and even its role in triggering dopamine and physiological changes in humans (Greenfield, 2017).

Today, social science disciplines such as geography and sociology trace and recognise different culturally constructed identities associated with information technology (IT) and knowledge production and their impact on everyday life. Within this, data increasingly imparts a material influence through the ways 'data comes to matter, in and through practical action, collective imaginaries, or biological conditions' (Rogers & McKim, 2018). Other literature highlights how data's existence and function require social agreement and imagination into how it is produced and interpreted (Gitelman & Jackson, 2013, p. 3). Additionally, to Steve Lohr's data-ism problem, Kenneth Neil Cukier and Viktor Mayer-Schoenberger recognise that computer analytics introduce expectations of certainty, precision, accuracy, objectivity and prediction, which are often better understood as inherently unpredictable, intuitive, risky, accident- and error-prone, due to the serendipitous nature of human beings (Cukier & Mayer-Schoenberger, 2013). Often data's existence in present day data analytics discourse acts to signify that knowledge is highly objective and accurate when it is not.

As architecture's expertise lies in designing and realising material assemblies that spatially organise social life, data-ism is potentially a context that influences how architects conceptualise and produce built outcomes. While much of present-day discussion on data occurs within digital theory and practices, it is not exclusively a digital phenomenon. The term 'data' originates from the seventeenth century and originally referred to the factual basis used within argumentation before becoming associated with information in numerical form in the twentieth century (Rosenberg, 2013). Rosenberg's abridged history, discussed in the next chapter, uncovers different disciplinary concepts existing over time. Rosenberg's findings suggest that architecture may similarly hold unique and contingent perspectives.

From the perspective of architectural knowledge, data-ism forms a macro-problem where automated data pattern recognition increasingly stands in for human decision making. Does architecture similarly experience the pressures of data-ism, or does it push back against its assumptions and desires? The research focuses on two key themes to contribute to this larger question; the first is the conceptual understanding produced by architects and the second is data's influence in practical applications. These two themes seek to problematise the assumed uniqueness of digital practice by tracing data as a consistent presence throughout architecture. The research contextualises today's cultural attitudes to the digital and its material consequences by reframing historical practice.

Knowledge Gap

The following literature review brings together existing research in the architectural field through institutional and digital scholarly databases. While many studies locate data's influence exclusively within digital tools and techniques, other work highlights alternative discourse trajectories. The following summarises ideas organised around recognisable themes: the architect's need to construct and transmit information, the degree scientific inquiry infiltrates practice, and the cultural images carried by data in communication.

Encoding information

A keyword search across architectural publications predominately uncovers digital practice and computation research scholarship. Across this scholarship, a common interest lies in data's encoding quality in producing and controlling information. The architectural historian and critic Mario Carpo earns special mention as he provides the most extensive take on data across multiple publications. In *The Alphabet and the Algorithm* (Carpo, 2011), Carpo explores the impact of communication technology on the architect and spends some time discussing the role of quantity to encode and transmit information through technical apparatus. For Carpo, using quantity to abstract information speaks directly to the authorial role of the architect and the power of accurate instruction in identical mechanical replications. The work of Yale School of Architecture associate dean Phillip Bernstein holds a similar technological focus, arguing that digital media replaces drawing when architects apply data to produce 'information, insight and prediction' (Bernstein, 2018, p. 12). While both Carpo and Bernstein explore digital technology through history and describe its impact as producing radical changes for the architect, neither consider data as a constant to technological progress, it is always a by-product.

Henriette Bier and Terry Knight also recognise data's encoding quality but consider data more varied as quantitative and qualitative parameters. Their data understanding centres around the human architect programming and interacting with 'artificial agents' that incorporate information and knowledge regarding 'geometry and pre-materialisation behaviour' (Bier & Knight, 2014, p. 2). For Bier and Knight, data's ability to algorithmically encode information and knowledge through digital logic gives the architect a communication channel with non-human abilities of computation that extend control between concept and material realisation. This source of non-human intelligence also appears in Anthony Burke's take on data acting as a 'material within the network' (Burke, 2006, p. 90), existing in vast amounts across the public and dark web internet. Burke brings us closer to considering data directly and argues that an unprecedented availability and access provides the architect with a new 'partner in design' (Burke, 2006, p. 90). Burke's focus remains within the digital but provides an alternative view of data as a thing in itself, something that alters design profession methodologies and business management practices (Burke, 2006).

Beyond the consensus that digital tools radically change the architect's role and practice, some question the limitations of the digital and are concerned with its detachment from human meaning and material practice. Roberto Bottazzi's unease lies with how much of architectural technology discourse misses that data today exists as something very different from analogue practices. Rather than numbers or words, data exists as 'combinations of physical properties' and 'purely a quantitative phenomenon, unrelated to qualitative, sematic concerns: it can claim no meaning, and even less truthfulness' (Bottazzi, 2018, p. 329). Bottazzi's recognition is significant as it opens up the possibility that the digital confuses understanding between semantic and statistical origins.

These studies show how data's character and influence tie intimately with information technology. Work exploring data's encoding role and quality often concentrate on its affordances in improving human capabilities; apart from Roberto Botazzi's contribution, most studies predominantly miss what architects potentially lose in the process.

Scientific inquiry

The second theme of literature concerns architecture's relationship with scientific inquiry. Mario Carpo continues his interest into this topic and recognises the crucial role data plays in knowledge production. In his book chapter 'Digital Indeterminism' (Carpo, 2013) and subsequent book *The Second Digital Turn* (Carpo, 2017), Carpo develops his data conceptualisation as a scientific product applicable for architectural practice. Rather than assigning influence on data through information encoding, Carpo recognises a secondary influence via the techniques and assumptions inherent in modern science. For Carpo, much of architecture maintains a legacy of scientific thinking that sought general rules and mathematical formulas in response to a lack of data. A lack of specificity from data scarcity necessitated universal causal and deterministic models. Carpo argues a 'post-human complexity' will transcend a human friendly 'small-data logic' (Carpo, 2017, p. 33) as technical sensing and sharing increase availability. This shift in scientific thinking points to a significant gap in knowing data's historical change in architecture. Carpo concedes this when noting, 'our data-rich present prompts us to look at our data-starved past from a different vantage point' (Carpo, 2017, p. 33).

Rather than looking back, some look into the future of automated technology in practice and enthusiastically predict data-rich environments and workflows in architectural design practices. For Martin Tamke, Paul Nicholas and Mateusz Zwierzycki, advances in non-human pattern recognition will mean architects change from 'architectural representations of unconnected data to practices with an overwhelming amount of information-rich data' (Tamke et al., 2018, p. 123). Data becomes the primary design material within their prediction, and the architect's role shifts to extracting and producing meaning through extreme technology leverage. The issue associated with this uncritical techno-innovation focus is that there is no consideration of what this data represents. If Botazzi is correct and data increasingly has no connection to truth or meaning, then optimistic promotions of data technology have a blind spot.

In these studies of data's scientific role and origin, a similar trend to the digital encoding discourse emerges, wherein abstract measurement portrays beneficial human practices, with less attention on its limitations. There is a clear need to balance technological innovation and progress with a critical awareness of what may be lost in the process.

Cultural change

While some scholars explore data with an overt technical bent; others accentuate the cultural change data imparts, becoming part of the architect's design environment. Of these culturally facing scholars, some place greater importance on the patterns found in data and how they become the basis for new knowledge, rather than encoding and manipulating information. An example is Yanni Alexander Loukissas's work on how architects employ simulation models to test and share their imagination. Loukissas highlights that within simulation, data has two roles. On the one hand, capture and analysis lead to agreed rules and axioms that help explain phenomena; at the same time, they become justification to coordinate, manipulate and speculate on new outcomes. The consequence, for Loukissas, is that data has a critical cultural influence through how social distributions of people and machines occur in architectural work (Loukissas, 2019). Loukissas's ethnographic research recognises how numerically describing architecture provides the architect with a means to command and control organisation but argues that data also imparts a cultural influence on how architects collectively construct and share ideas through images (Loukissas, 2019). Loukissas work implies that data's character and influence is not a simple division between digital or analogue forms, it provides architecture with agreed rules and axioms that become culturally accepted and applied in practice.

Danelle Briscoe similarly recognises data's influence on culture through its observational and communicative capacity. Briscoe argues that data imposes an alternative image onto practice, operating on a different temporal register to material architecture. Consequently, Briscoe theorises data's cultural role through how media overlays could individualise architectural communication and bring information dynamism (Briscoe & Marble, 2016). Although data's cultural role recentres it within the digital and technological fold, its influence on and through communication technology has an external influence on how we understand and experience architecture, which potentially becomes part of the architect's spatial and material concerns.

Mark Jarzombek argues that when we interact with present-day personal technology, we encounter data far from the stable entity experienced in the 'old days of empiricism' (Jarzombek, 2017). Today, technology designed to encourage user input give data a dynamism and produce a surplus that social media platforms collect, manage and monetise through advertising (Jarzombek, 2017). An example of this surplus exists in

Facebook's business model that relies on stimulating user data input through attention maintaining techniques, such as manipulating emotion. Jarzombek refers to the source of dynamism as the new 'Industrial Data-Civilianization Complex', which reconstructs human identity and their sense of self in the service of surplus. Consequently, architects and designers need to recognise the ontological shift data causes, how humans understand themselves and how this understanding is manipulated by those who can control data flow (Jarzombek, 2016). Jarzombek demands we notice how data acts outside of architecture while remaining central to its intentions, rather than the narrow concern with digital tool use. Through a more human lens, Jarzombek argues that our present-day data experience is not about information; it is an endless desire to feed an expanding networked attention complex.

Collectively, these studies outline a critical role for data in cultural formation in and outside design disciplines, which offers an alternative viewpoint to the information-rich discussion stemming from digital practice.

Contextualising practice

The literature covered so far mainly focuses on moments of identified characters and influences, despite some recognising that shifts occur and will continue to do so, such as Mario Carpo (Carpo, 2017). Some studies partly address a gap in connecting moments and contextualisation of our present-day understanding. Two studies address data's changing character and influence in two disciplines, visual design and information architecture, by connecting past trends and accounts. Orit Halpern traces data through the advances in information technology of the twentieth century and demonstrates that designers understood data as both organic and artificial and that its utility was related solely to an ability to detect patterns (Halpern, 2015). Halpern's argument disrupts the established narrative that data only became significant after the uptake of personal computing and shows how data was critical to how some designers operated during this time. Halpern offers a profoundly different take to the prevailing 'data as a technology by-product' by demonstrating its vital role in producing innovations. This reinterpretation of data as catalyst connects to the ways designers absorb knowledge production techniques and then apply them as sources of creativity, from early twentieth century taxonomy, ontology and archiving to late twentieth-century concerns with organisation, method, and storage.

Molly Wright-Steenson similarly disrupts a data narrative, but one found in the history of the internet and web interface design. Through tracing early architectural approaches to data, Wright-Steenson argues that architects influenced the development of the modern digital landscape. Wright-Steenson recognises how data's dynamic and transient quality from observation imparted ideas of responsive and flexible organisation onto architecture (Wright-Steenson, 2017). The consequence for Wright-Steenson is that data's dynamism, employed as a metaphor in architecture, foregrounds a need to re-engage with meaning which contrasts with the prevailing narrative of rational information abstraction and scientific calculation. Both Orit Halpern and Molly Wright-Steenson's work contribute to a much-needed contextualisation of the dominant present-day digital understanding. Each caters for a particular design discipline without explicitly considering the change and impact in architecture, leaving a knowledge gap.

In summary, these studies outline that most architectural research attention directed at data sits within broader digital technology interests. Firstly, there is a gap in understanding data's limitations in digital practices, which often gets lost in technological innovation discourse. Scholars from other disciplines who recognise data's shifting character and influence disrupt the narrative that data is a purely digital phenomenon. As these studies do not explore the specificities of architectural practice, a clear need exists to bring a similar approach to the topic.

Data as a research lens

Since abstract measurement does not exclusively rely on digital technology, there is a need to historically understand data through a balance of human and non-human technical processes. While some endeavour to characterise data within specific technical applications, this approach is often entirely blind to data's practical role and limitations. The lack of architectural attention to tracing data outside digital discourse presents the first knowledge gap: the character of data. This gap requires new knowledge concerning previous data practices to help contextualise present-day understanding. Additionally, a need to critically consider both data's affordances and limitations present the second gap, data's influence on architectural practice. Considering data's influence attempts to problematise current thinking regarding computation in architecture and position data as a significant part of a practice and has done for some time.

No scholar has yet to offer a full engagement with what exactly data is for the architect and why it has become so useful. Subsequently, a gap exists in knowing what data is in the architect’s hands and to trace and unpack its changing role over time. By foregrounding data as an important factor in practice, the research provides an alternative lens for understanding the architect's role and thinking.

Contribution to Knowledge

Aim

The research addresses the identified knowledge gaps concerning data’s character and influence in architectural practice. Consequently, the research traces the multiple characters and influences assigned to data use and identifies distinct shifts used to organise the thesis. Tracing data’s characters and influences across historical and present-day practices contributes to a much-needed discussion on future use. Distinct identified shifts construct an alternative understanding of data as a central part of the architect's practice while problematising an existing and prevalent technology-centric discourse.

Hypothesis

Generally, in architecture, data’s character and influence is poorly understood, and due to the increasing demands placed on the architect, it warrants closer scrutiny. The overarching argument is that data has always held an unseen role in architecture and is not merely a recent phenomenon. The specific hypothesis is that data has always existed in architecture, and it is possible to trace distinct shifts in character and influence over time. Rather than the digital dominating architectural thinking, with data as a side character, the research foregrounds data as a lens to study architectural practice. Therefore, the research tests the notion that data correlates to how architects think and act. We should not frame the digital as something unique and different, but as a continuation of distinct and recognisable changes in character and influence.

Questions

The specific research questions addressed are.

1. How have architects historically characterised data?
2. What influence does data impart on the architect's practice?

Objectives

The research objective is to provide present-day architects with an awareness of what data brings to the architect and to contribute a foundational understanding. This knowledge of data's character and influence aims to release new thinking and discourse from the current digital tooling paradigm. The research identifies and explores shifts in how architecture uses abstract measurement, arguing that each lead to a notable change in the architect's practice. The progression of the chapters demonstrates how data's character changes over time, thus contributing to testing the overarching thesis that data is unique in the hands of architects and contrary to present-day assumptions, it has always existed as part of the architect's practice. The research identifies six data characters that exert unique constraints on practice and correlate to how architects practice. Each character and influence emerge from a critical discussion of existing literature and case study analysis unpacking architectural application.

Although the research considers periods where artificial intelligence, machine learning or robotics became part of a data discourse, the research does not treat these as central concerns. As the research provides a foundational character and influence for the professional architect, it focusses on the ways humans engage with data rather than on automated processes.

Methodology

The research seeks to trace data's character and influence by identifying, discussing, and comparing documented ideas and uses. As the research explores shifts over time it must engage with existing discourse found in architectural literature. Additionally, as the research also seeks to understand data's practical influence, it studies and considers cases of architectural application. With the possible danger of becoming meta in approach, this research about architectural data must consider what data is appropriate to produce knowledge. As the research questions address the architect's experience and thinking, it does not consider collecting quantitative data a suitable approach as that would not lead to a definable character. The research seeks human accounts, therefore, a positivist causality is inappropriate.

Groat and Wang's (2013) tripartite framework helps situate the research's methodological position. Their defined 'naturalism' paradigm sets a basic ontological premise that there are multiple socially constructed realities, and that 'value-free' objectivity is neither possible nor necessarily desirable (Groat & Wang, 2001, p33). This research does not wish to uncover an objective and concrete data understanding, it provides an interpretation of existing accounts, which are themselves subjectively embedded in particular settings. In this regard, the research is based on empirical accounts and utilises the authors professional and academic background to interpret discourse and produce what Groat and Wang refer to as poststructuralist 'cultural manifestations of the trafficking of thought' that view practices as 'conditions of formation' (Groat & Wang, 2001, p149). The research anticipates eras of data paradigms, but rather than providing an historical account of formations, it discursively probes the space of formation relationships between architectural practice and data over time. Therefore, the outcome is an interpretive account of how architects think about data and how data helps shape their practice.

Within the qualitative research school of thought, a discursive and case study analysis understands and compares present-day with historical accounts. The study does not employ other qualitative data techniques such as interview, action or field research as they provide good accounts of the now but offer little towards uncovering historical change. As a result, the research uses a mixture of literary review, critical analysis, logical argumentation, and original case study investigation to explore data's character and influence across historical practices. Rather than rigidly subscribing to a specific epistemological framework or paradigm, the research advocates a pragmatic approach that harnesses available evidence to best fit the research question (Foqué, 2010); Linda Groat and David Wang refer to this approach as 'combined strategies' (Groat & Wang, 2013). The proposed strategies combine to 'uncover meanings, phases and characteristics of a phenomenon or process at a particular point of time' (Lähdesmäki et al., 2010), alongside analysis that brings a subjective interpretation to the qualitative data. In this regard, the research uses observation gained from primary case study analysis and from secondary literature sources to trace and follow data's historical changes.

While the research explores changes in architectural culture in relation to data, it is not cultural or theoretical research. Consequently, the research did not employ a disciplinary specific theoretical framework, such as Marxism, Structuralism or Actor Network Theory. Instead, chapter 1 constructs a framework unique to the project to trace thinking and practical action over history and discuss data's role in architectural practice. Each chapter uses the framework to focus attention on identified areas of practice and limit the scope of literature sources. This framework helps locate where data interacts with the architect and assists the research in analysing and comparing relevant discourse and practical use cases.

Scope and Limitations

The study of discourses in this thesis begins from a position of seeking to understand data's relationship to the architectural discipline. The study relies on availability from academic sources which limit the literature to mainly western sources, in particular Europe and The United States of America. Additionally, given the authors position as a UK trained architectural designer and academic, the boundary of the research is set at discussing and understanding data in a northern hemisphere context. The literature sources and scholarly subjects included extend from present-day to the Renaissance, considered the birth of the modern designing architect. The research does not extend further back in time to consider Roman and Greek practices, as the architect held a very different master builder role during these ancient periods.

Outcomes

By tracking data's historical characters and influences in architecture, the research provides architects with a new understanding of what data is and how it plays an essential role in architecture. This new understanding sets a foundation for new critical work that brings awareness to data's role in the future. Fundamentally, this awareness helps architects question the future progression of data within practices and critically understand how the patterns detected or recognised from observation or communication become the rules and axioms used to connect the existing with imagined and materialised realities. The general trend recognised is that computation's radical instability and manipulation give architecture freedom over these rules. However, we must be careful to understand and potentially contest such guiding notions in the future.

In summary, this research contributes to knowledge by identifying and addressing a gap in understanding data's character and influence in architecture. The thesis argues that data is not a purely digital phenomenon, despite data's close relationship with the digital. Different forms of abstract measurement have always been a part of the architect's material practice. The critical outcome of the research is that some practical methods increasingly lose any human relationship to data and that future explorations must address the potentially alienating influence digital abstraction imparts on the built environment.

Key Terms

Practice(s)

Researching how data exists and exerts influence on practice first requires agreement on 'architectural practice'. From an everyday human perspective, Tim Jordan describes everyday human practice as a feedback relationship between repeated and habitual meanings and actions that create an environment through patterns of interaction between human and non-human actors (Jordan, 2020). Architectural practice refers explicitly to the environment created by repeated and habitual meanings and actions towards the realisation of material structures. The architect's role and practice are closely intertwined, with the term 'architect' originating from the Greek 'chief' or 'master' (arkhi) and 'builder' (tekton) (Cruz, 2013, p. 1988). Many consider the Roman military engineer Marcus Vitruvius Pollio (80BC – 15BC) to be the first architect whose primary skills sat at the nexus of art and science; art signified while science demonstrated significance (Pollio et al., 1914). Through Vitruvius's writings, popularised during the Renaissance, we know that being an architect required practice through 'continuous and regular exercise of employment where manual work is done with any necessary material according to the design of a drawing' (Pollio et al., 1914, p. 5). Vitruvius's 'practice' expected the architect to oversee an entire production process, from drawn information to overseeing construction. This process changed in the Renaissance when drawing became the architect's primary activity, responsible for construction information, or a 'design', rather than directly making architecture. Mario Carpo identifies Alberti as one of the first formal 'architects', as we might understand today, whose creative output provided building instruction rather than involvement in the building process (Carpo, 2011).

In present-day architecture, we understand practice as a creative process, proposing solutions to defined architectural problems, and delivering information documents suitable for construction. While some architects may specialise in output, such as drawing, model making, or research, their practices commonly incorporate varying mixtures of artistic, scientific, and design-led thinking. The mixture employed by an architect relates closely to patronage. Roger Ferris recognises how changing financial pressures have historically changed architectural practices from an *occupation* to a *profession* (Ferris, 1996). The transition from the traditional Renaissance patrons to twenty-first-century commercial investor clients has caused an increased requirement for exclusive and expert knowledge with guaranteed competence and skill. Francesca Hughes recognises a distinct change in practice through this pressure, from once engaging in physical building to today's obsession with coordinating material precision and eradicating error (Hughes, 2014). The relevance for understanding data in practice is that application occurs under commercial pressures that expect specific skills and knowledge and demand a level of accuracy and precision in realising buildings.

The architectural discipline explores and speculates on new and unpredictable futures while paradoxically trying to deliver predictable outcomes, often through contractual evaluative metrics. This paradox results in a tension between public and commercial. A common theme within this tension is how architect's apply their skills and knowledge to serve a benefactor's requirements. As Andy Pressman highlights, this benefactor often exists as someone 'speculating on an as-yet-unseen or unrealised vision' who must negotiate 'continual contradictions and conflicts between the ideal/idea and the reality' (Pressman, 1997, p. 14). These benefactor's expectations place pressure onto practice and influence how architects connect ideas with material reality. For instance, modern-day professional architects who design complex schemes are more likely to deal with separate corporate or institutional entities than practical users and the project's future inhabitants, which Dana Cuff describes as 'real clients' (Cuff, 1992). In the shift from servicing the inhabitant to a stakeholder or investor, Cuff points out that the architects requirements, i.e. the brief, contains less observation from client's first-hand experience and increasingly more abstract statistical data from detached consultants (Cuff, 1992). Therefore, the pressures placed onto architecture's habitual actions and meanings potentially divide between whom the architect perceives as their inhabitant or audience, and commercial stakeholder influence.

In practice, the architect operates between skilfully gaining and applying knowledge towards construction, where architecturally produced information helps shape the constructed world. Alfonso Corona-Martinez et al. describe this space as the 'architectural project', foregrounding how architects practice shaping sensory phenomena into ideas by 'converting mere imaginings into the dimensions of physical reality' (Corona-Martínez et al., 2003, p. 11). From the 'architectural project', an essential basis of practice emerges as describing and imagining reality, one that speaks to Molly Wright-Steenson's description of architectural practice as moving between the imagined and real, between image and language (Wright-Steenson, 2014). Expanding on Wright-Steenson's description, architects really move between reality, imagined reality, and new realities. Stan Allen highlights that, because practice must negotiate reality, it mimics its appearance, tending to be messy and inconsistent; moreover, there is never just one practice; many practices differentiate over time based on agency and resulting actions (Allen & Agrest, 2000). What binds different practices together is the architect's material focus, 'activities that transform reality by producing new objects or new organisation of matter' (Allen & Agrest, 2000, p. XVIII). This material focus means that architectural practice is inseparable from understanding reality, placing importance on observing, imagining, and organising matter.

In summary, the research defines practice as the habitual meanings and actions that connect the architect's knowledge, skill and experience with commercial pressures leading to processes of observing, imagining and materialising reality.

Material

The thesis uses the term 'material' throughout, but its use risks confusion, as it can stand as an adjective and a noun. When referring to physical objects, the research situates material as an adjective and refers to the sensory qualities produced by formed matter. When discussing composition or assembly processes, the research uses material as a noun, something to make into something else, providing a simple distinction between the whole — adjective, or the part — noun.

Material outcomes

When used in the thesis, 'material outcomes' refers to the built products of architecture and the elements architects organise to realise coherent spatial conditions. A focus on material outcomes engages with architectural form and encompasses formation processes. Sanford Kwinter draws two parallel understandings of architectural form, one of the object form engaging ideas of aesthetics and meaning, the other of material formations as expressions of embedded forces, deployed logic and ordering actions (Kwinter & Davidson, 2008). The thesis proceeds with both definitions in mind and anticipates data's influence in engaging both meaning and logic for the architect.

Non-Human

When using the term 'non-human' in the thesis, it refers to data sources and uses that do not involve human senses and cognition. Unlike ecological and sociological use of the term to mean organic and inorganic entities apart from humans (Latour, 2005), this research employs the term to mean examples of technical abstraction and computation that occur away from human supervision, sometimes happening autonomously.

Immaterial

The term immaterial also plays an essential role in this thesis and invites as much ambiguity as material. The term immaterial serves as an adjective and categorises things that exist but are not part of physical, sensory experience. Based on this distinction, cognitive processes such as imagining, and visualising are immaterial. The research considers the immaterial to exist where cognitive processes occur, be it organic or technical. When visualisation of thoughts, ideas, and images occur through media and language, they transfer from the immaterial to the material and become part of physical experience.

Environment

The term 'environment' is as slippery as 'material', as it does not relate to a concrete object, more to a concept. Larry Busbea provides a helpful definition from Thomas Carlyle's first use of the term to mean 'a mid-term between natural and spiritual surroundings' (Busbea, 2015, p. 10). In response to Carlyle's pre-modern duality between nature and spirit, Busbea defines the term environment as the 'totality of the psychological, somatic, cultural, technical, and natural aspects' of our surroundings (Busbea, 2015, p. 2). While an environment can relate to what actions it 'affords' using J.J Gibson's ecological perspective (Gibson, 1979), the environment is also a product of larger combined affordances. For instance, while technologies produce an environment for action, technologies themselves result from an environment. This mutual relationship between environments and actions forms an important consideration in understanding data's influence in architecture. Mark Wigley's critique of mid-twentieth-century ecological approaches helps illustrate this point, that while an ecological perspective on the built environment detected the forces at work, it missed that 'the city shapes its inhabitants every bit as much as the inhabitants shape their city' (Wigley, 1998, p. 34). Wrigley highlights that defining an environment helps us understand its shaping influence on our actions, while conversely our actions help shape the environment.

Thesis Structure

The research organises across distinct historical shifts in data's character and influence. Each chapter's title presents the identified character to signpost and assist the reader's comprehension, with each sub-heading describing its relationship to practice. Each chapter's conclusion title highlights data's influence on the architect before discussing the chapter's findings within the context of the overall research.

Chapter 1 moves to produce a foundational definition and construct a framework for interrogating character and influence. The chapter identifies the possible ways architects identify and apply data to detect possible vectors of influence.

The subsequent three chapters identify and explore distinct historical shifts in data for the architect. Chapter 2 identifies Leon Battista Alberti and Jean Nicolas Louis Durand's measurement techniques as two early architectural data attitudes that cause a duality that continues to this day. While Alberti applied abstract measurement to control communication, Durand applied quantitative analysis to uncover, maintain and apply architectural knowledge.

Chapter 3 uses this duality to critically examine early twentieth-century architecture through the discourse of Le Corbusier, the pedagogy of the Bauhaus, and the work of Ernst Neufert, whose '*Bauentwurfslehre*' — translated as 'teachings on building design' — later became referred to as the *Architects' Data Handbook*. The chapter argues that the broader cultural change to rational and optimal design practice propagated through an agreed assemblage of temporal and spatial measurement that afforded architects control over knowledge and communication.

Chapter 4 explores the most significant transformation in data's wider cultural identity, caused by Claude E. Shannon's *Mathematical Theory of Communication)* (Shannon, 1948). The chapter traces the evolution of measurement techniques through the mid-twentieth century to new practices reconciling human and non-human observation into new relational and context-dependent forms. Data shifts from a character of discrete measurement to continuous monitoring, resulting in architectural expectations shifting from static building forms to designing and realising dynamic environments.

The last three chapters examine practice through the lens of digital data. Chapter 5 examines the present-day paradigm of data-driven decision making in architecture and critically analyses the inherent theory and assumptions. A commercial desire for risk reduction through efficient and precise information and coordination places intense pressures on the architect to render architecture as data and remove human error from practice. Rendering architectural objects as comparable and digitally manipulable data sets up a common collaborative language and functions as an unquestionable premise to design outcomes that links stakeholder expectations with architectural deliverables. In the process, the architect's professional focus changes from stages of drawn media to managing and manipulating data into decisive information.

Chapter 6 also interrogates present-day digital practice but focuses on the cultural influence data imparts through advanced fabrication techniques and web technologies. The chapter concentrates on the 'digital turn' of the 90s to argue for an alternative 'data-turn' where digital information becomes a metaphor for organising materials, assembling atoms like bits. A comparative analysis of three case studies, the open-source Wikihouse construction set, parametric form-finding, and Giles Retsin's digital discrete design and construction technique, uncovers a controversy in data understanding. While the Wikihouse and parametric form-finding use quantified input to relationally reconfigure existing material knowledge, Retsin's approach defers human input to the act of material assembly by resisting information translations in automated production. The chapter finds a common use within the case studies and discourse, the architect gains the means for complex collaboration between humans and machines through establishing and maintaining continuous data communication flow.

Chapter 7 detects an alternative understanding through technical urban surveillance increasingly governing city planning and resource management. The chapter picks up on signals that urban decisions driven by technical sensing start to shape material space around human behaviour prediction. The abandoned Sidewalk Labs' Toronto Quayside development provides a speculative scenario for the built environment where material and spatial decisions were to align to maintain a ubiquitous environment of computing data rather than architectural thinking, thus recalibrating the architect's role in urban development. The chapter argues that when urban assets become managed and organised around a technical image of human behaviour, the architect's skills recalibrate from shaping space for the public to maximising adaptation and data capture.

The final chapter collates and compares the identified shifts in character and influence to address the overarching research questions. The research culminates with a speculative look towards how architects may engage data in the future by addressing assumptions, biases and pressures recognised through the research.

Chapter 1: A Data Framework

Data are commonly understood to be the raw material produced by abstracting the world into representational forms that constitute the building blocks from which information and knowledge are created. (Kitchin, 2014, p. 2)

As no in-depth study of data exists in the discipline, the chapter constructs a framework for recognising, detecting, and understanding data's character and influence in architectural practice. First, the framework sets a foundational understanding of data and its origins and provides an interpretive mode used across the proceeding chapters. The above quote by the geographer, Rob Kitchin, provides a foundational interpretation that brings together representation, informational abstraction and acting on the world. As architects generally act on the world through visual information to construct objects, Kitchin's definition offers a relevant departure point. From this departure, it is necessary to explore what 'raw material' architects produce and to understand how, to use another Kitchin quote, data helps architects 'understand, explain, manage, regulate, and predict the world' (Kitchin & Lauriault, 2018, p. 2). Understanding architecture's raw material for information and knowledge and interrogating its influence on practice requires first interrogating disciplinary controversies, such as knowledge ideology and research bias. A cross-disciplinary inquiry into data sets up the thesis that data takes on many representational form, passing through different identities and applications concerning its origin and intentional application. Data is not a uniquely architectural concept, therefore, discourse outside of the discipline helps to glean the architect's possible assumptions and values. The chapter uncovers that data's origin plays a significant role in its practical influence and that the cultural forces that surround its existence pass into its use. Specifically for the architect, the chapter finds data to play a key role in three key areas of practice, in observation, forecasting and instruction.

1.1 Capturing Reality

Daniel Rosenberg, a professor of history, argues the term ‘data’ became part of the English lexicon in the seventeenth century, from the Latin ‘datum’ to mean ‘a given’, or something taken for granted, defining it as ‘principles accepted as a basis of argument or to facts gleaned from scripture that were unavailable to questioning’ (Rosenberg, 2013, p. 15). Rosenberg describes data’s use in the seventeenth century as an ‘unquestionable premise in rhetoric’; he makes a clear separation between ‘fact’, which referred to ‘that which was done, occurred, or exists’, and ‘evidence’, which we are meant to see (Rosenberg, 2013, p. 18). Rosenberg’s etymology tells us that data first existed as a referential foundation for constructing knowledge; he provides an important distinction, that ‘facts are ontological, evidence is epistemological, data is rhetorical’ (Rosenberg, 2013, p. 15). Data’s distinctively rhetorical use, at that time, meant it resided in material-cultural artefacts that held such esteem they were unavailable to questioning, such as scripture (Rosenberg, 2013, p. 15). Because reading and writing belonged to the educated elite in the seventeenth century, only those with the means to materially record unquestionable premises could control data’s semantic function and origin.

Trained human observation

Rosenberg highlights a critical shift in data’s existence in the late seventeenth century, when the natural sciences positioned empirical observation as a route to practical knowledge (Rosenberg, 2013). Rosenberg labels this change as a ‘semantic inversion’ (Rosenberg, 2013, p. 6) when data no longer originated through reference and operated as a rhetorical given. A helpful way of understanding the shift exists in the oath of the Royal Society in London (1660), ‘nullius in verba’, meaning ‘take nobody's word for it’, promoting experiment and discovery over argument and authority (King & Kay, 2020, p. 54). A consequence, identified by the economists John Kay and Mervin King, is that abstract representations through empirical observation provided the basis for new knowledge production practices through collaborative and systematic inquiry (King & Kay, 2020). Notably, the cultural understanding of and control over data’s origin shifted from religious theology to a new elite engaged in natural science, promoting specific techniques and the resulting knowledge.

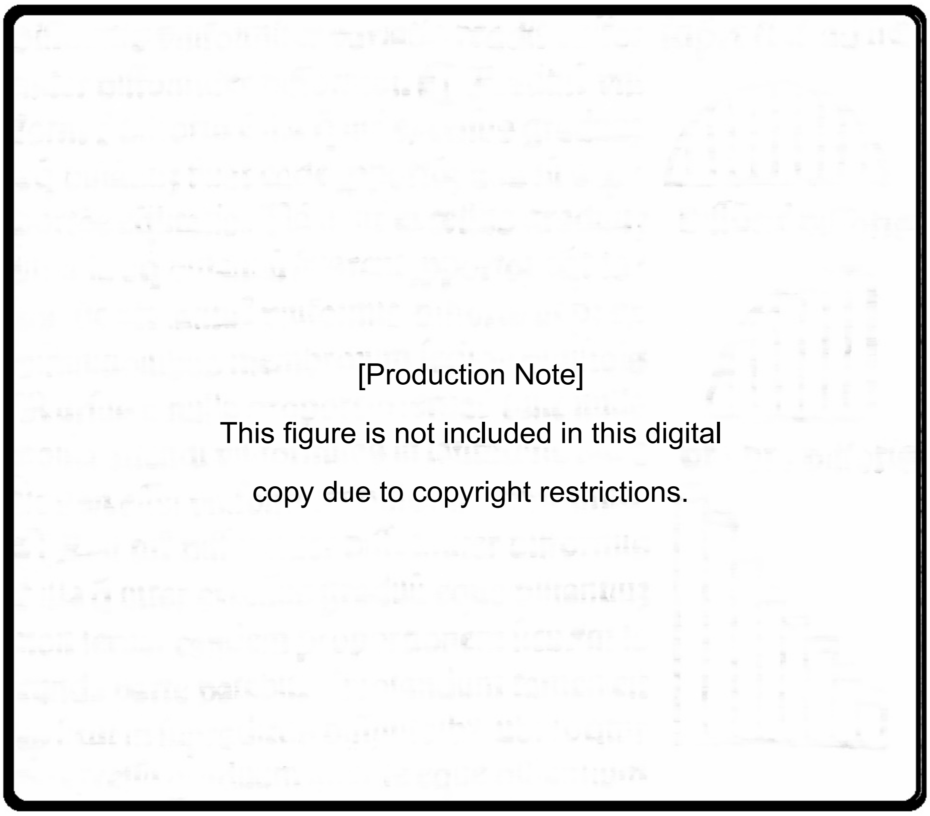
In the late seventeenth and eighteenth century, the new scientific elite trained observation to remove the self, assuming objectivity and recording what was given up by phenomena in a study (Rosenberg, 2013). Lorraine Daston and Peter Galison argue that the natural sciences believed in, endorsed, and maintained objective human observation that aimed to produce knowledge 'unmarked by prejudice, skill, fantasy or judgement, wishing or striving' (Daston & Galison, 2010, p. 17). Those trusting an objective reality independent of human observation existed advocated techniques of emotional detachment and observation that attempted to uncover underlying patterns and forms in nature. Objectivity presumed data's origin as 'given up' by observing nature, thus maintaining its etymology from the Latin 'datum'. Rosenberg points out that objective observation practices tended to vary but still retained an objective status (Rosenberg, 2013), meaning objectivity was not about certainty or truth but about an agreed system of measuring and recording the world.

Early empirical science used human senses to observe reality. Human senses are subjective and limited in what phenomena they detect. For instance, the human senses can detect sound, colour, and taste, but are not able to access magnetic or electrical fields. Consequently, empirical science based on human sensing only partially captures reality. The fact that types of observation never fully capture reality, they only sample, lies at the centre of modern-day critical data studies discourse. Johanna Drucker, alongside Rob Kitchin, argues that rather than being a 'datum' or 'given up', it is more a case of what is 'taken' or 'captured' (Drucker & Eskander, 2010) (Kitchin, 2014), and that the material means of observation limits the extent of reality captured. The limitations of human observation are brought to the fore by Graham Harman, highlighting humanity's unique and limited access to the world through sensory perception and a limited sensory register (Harman, 2011). As pre-scientific and early scientific uses related to human sensory capture, the reality is that despite objective techniques, partiality always existed.

Mechanical trust

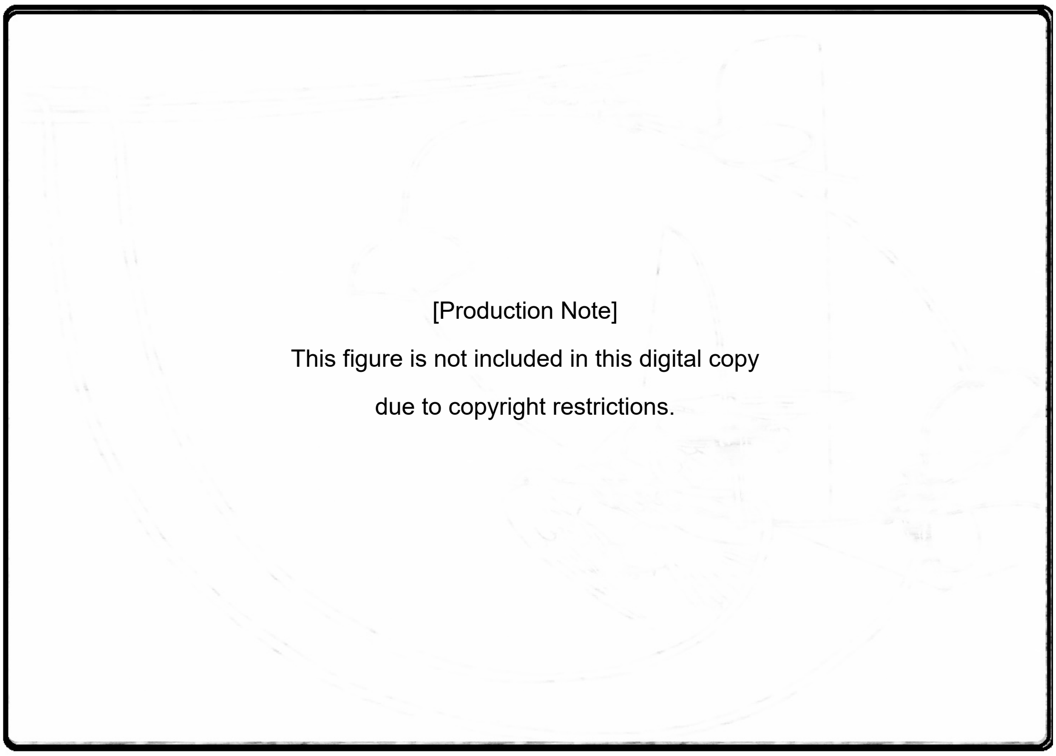
However, not all disciplines agree with Drucker and Kitchin's position; subsets of science operate on the agreement that mechanical observation techniques provide a complete picture of reality, such as in medical science. During the seventeenth century, specifically developed technical apparatuses, such as the microscope, produced a shift in cultural expectation from taught methods of accurate observation to mistrust in human sensory abilities. This mistrust in human observation intensified as machine technology advanced in the early eighteenth century. Luciano Floridi argues this rapid advancement occurred due to a cultural shift favouring machine-based knowledge over human forms, setting up a positive feedback loop where technological measurement catalysed technological innovation (Floridi, 2014). For example, measurement through human observation set the basis for machines invented to improve human precision; this improved precision and subsequently set expectations for technologies that accentuated a beyond-human precision. Siegfried Giedion's writing on motion studies between the fourteenth and nineteenth century, in *Mechanisation Takes Command* (1948), helps locate this shift from trusting human observation to trusting machine observation. Giedion's comparison of Nicolas Oresme's (1325–1382) visual observation and representation of movement (Figure 1-1) with Etienne Jules Marey's (1830–1904) observing machines (Figure 1-2) identifies both a change in attitude to data's origin and a loss of trust in human observation (Giedion, 1948). Giedion argues that Oresme's visually measured movement intensity and Marey's mechanically recorded movement not only differed in origin, but they differed in resulting understanding, with Marey convinced that 'the true form of movement escaped the eye' (Giedion, 1948, p. 24).

Figure 1-1 - Nicholas Oresme's movement observation (Giedion, 1948, p. 17)



1. NICOLAS ORESME: The First Graphic Representation of Movement, c.1350. ***The changing qualities of a body were graphically interpreted for the first time by Nicolas Oresme, bishop of Lisieux. The variation is shown by verticals erected above a horizontal, the later X-axis.*** **(Tractatus de Latitudine Formarum, *Second edition, Padua,* 1486)**

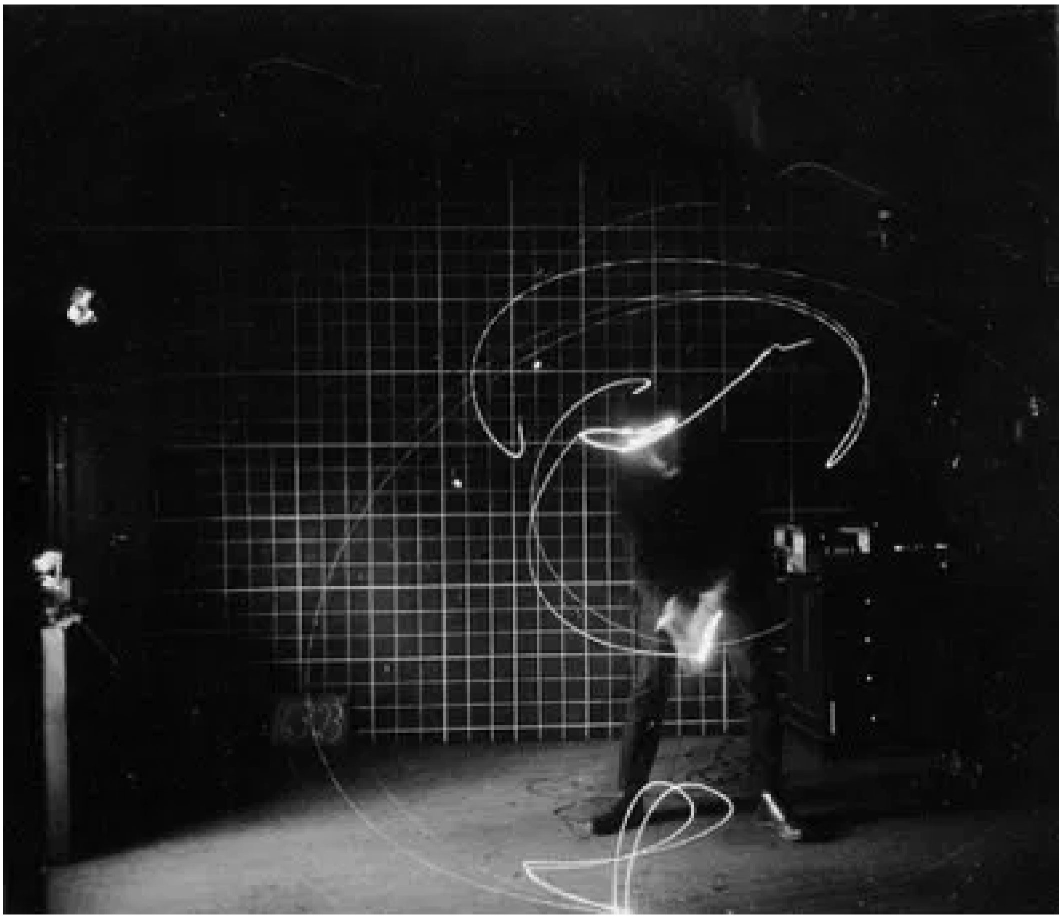
Figure 1-2 - Etienne Jules Marey's observation machine (Giedion, 1948, p. 20)



5. E. J. MAREY: Recording Larger Movements — Flight, 1868. *To trace the more extensive movements of a bird in flight, Marey harnessed a pigeon to the arm of a merry-go-round. The wings, connected to pneumatic drums, record their trajectory on a cylinder.*

While Giedion uses the comparison to highlight a change in graphical systems depicting movement, the examples offer a case where abstraction through machine observation catalysed new ideas and understandings. Frank B Gilbreth's (1868–1924) chronocyclegraph machine (1913) measured and depicted human movement through motion picture camera film, capturing changes in light over time (Figure 1-3). Giedion argues that Gilbreth's light-sensitive film registration and resulting visualisation reinforced an already existing cultural awareness that aspects of reality lay undetectable to the eye (Giedion, 1948, p. 16). This ability to mechanically capture the visually undetectable, emerging in the late 1800s and early 1900s, presents a shift in conceptual understanding from something given to the human senses to a non-human view revealing a reality outside of human experience. Lev Manovich argues that new visual representations and storytelling techniques emerging through nineteenth and twentieth-century mechanical observation conditioned the population culturally 'to accept the manipulation of time and space, the arbitrary coding of the visible, the mechanisation of vision, and the reduction of reality to a moving image as a given.' (Manovich, 1996, p. 4). Manovich uses cinema as an example where mechanical observation represented reality beyond direct human experience, introducing a new understanding of time as a manipulatable entity (Manovich, 1996). This shift from human to mechanical observation provides a critical change in understanding, trusting a different observational origin and the cultural consequences of measurement at a higher resolution than human experience.

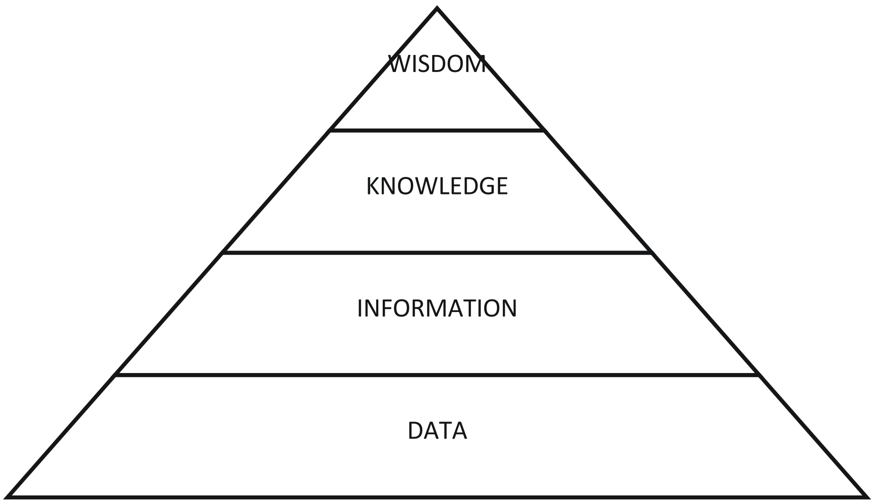
Figure 1-3 - Frank B Gilbreth 'chronocyclegraph' – mechanical observation (Gilbreth, 1915)



Synthetic prediction

Rosenberg argues that contemporary society holds a 'principal notion of data as information in numerical form' (Rosenberg, 2013, p. 33) and points to its emergence through the late eighteenth and early nineteenth-century development of mechanical observation. The prevalent data understanding as numerical information exists through a direct lineage from mechanical observation and its influence on knowledge production. Many disciplines maintain this data identity, none more than the quantified research underpinning information management studies. Data's role holds such an importance to information management that they devised a model to conceptualise the relationship between Data, Information, Knowledge, and Wisdom. The DIKW pyramid (Figure 1-4) provides a helpful diagram to locate data and its relation to abstracting existing information as much as empirical observation. Widely assigned to Russell Ackoff, the 1989 DIKW pyramid argues that wisdom, knowledge, information and data relate to each other in a value hierarchy, with wisdom viewed as most valuable (Ackoff, 1989). Ackoff's original schema defined data as symbols produced through observation, representing properties of objects, events, and their environment. These disparate properties became information once data organised into form, that is, once patterns of relationships occurred between represented properties, resulting in order (Ackoff, 1989). The DIKW schema introduced a possible dual origin for data in relation to information; data capture from reality could transfer up the hierarchy into information as it gained order, while it could also result from abstracting existing information by abstracting down.

Figure 1-4 - DIKW Pyramid (Ackoff, 1989, p. 16)



Ackoff's DIKW schema provided a new definition of data as something originating from existing information, properties abstracted from information sources unconnected to observation. This disconnection from an existing observation meant data did not have to come from a verifiable real, it could also represent properties of anything and therefore be synthetic. The distinction between an observed and synthetic data became a critical aspect of information science, moving away from singular data inputs, to exploring data output. An example of this occurs in contemporary data science, where predictive models based on data, construct new data sets that retain statistical characteristics of the original set (Malde, 2020). This relatively new application, facilitated through computational, algorithmic analysis, introduces a critical issue regarding how the synthetic relates to the captured real; the possibility that partiality transfers over into synthetic forms and provides prediction a false authority. Rosenberg recognises this possible bias from synthetic constructs and states 'it may be that the data we collect and transmit has no relation to truth or reality whatsoever beyond the reality that data helps us to construct' (Rosenberg, 2013, p. 36).

Economists John Kay and Mervin King argue that the assumption that historical data holds evidence for universal laws or axioms is fundamentally flawed (King & Kay, 2020). To illustrate this problem, Kay and King compare two practices. One is the engineer who collects data to discover what works, 'positing a series of small worlds whose behaviour can be understood' (King & Kay, 2020, p. 390). The other is the economist, who relies on generalised models of behaviour, pure reasoning and 'manipulates data to support a priori assertions' (King & Kay, 2020, p. 390). Comparing the two practices, the economist accepts historical sources based on consensus, while the engineer continuously collects and calibrates sources to improve understanding. While architects and engineers have a long historical connection, it does not mean the architect is detached from the economist's pure reason or blindly follows the engineer's empirical approach. Both engineers and economists invite partiality into practice through data's origin, whether through an ideology of universality or a desire to pinpoint behaviour.

From the perspective of understanding the architect's data, capturing reality brings two distinctions to the fore. The first distinction concerns the degree of knowing, that is, whether there is an assumption that data offers a complete picture of a 'given' reality; is it a partial sampled capture, or is it constructed, synthetic and inferred from existing patterns. Understanding the origin of knowledge in architectural practice requires asking if architects invite or manipulate unquestionable facts or engage in observation techniques associated with sampled or synthesised sources. Secondly, a distinction lies in the material register used to capture reality, contrasting most obviously between human and non-human sensory detection. This contrast between human and non-human origins introduces assumptions and ideals regarding availability, veracity, and objectivity concerning knowledge production. A cultural consequence of knowledge produced through non-human processes is an expectation for resolutions or phenomena beyond a human, sensory, lived experience. All observation is partially due to sensory ability, be it human or a designed technical apparatus; both are limited. When applied to architectural practice, any controversy regarding origin encourages a curiosity over the assumptions architects place onto data's use, whether they operate like the engineer or the economist. To do this requires interrogating the unquestionable rhetorical givens architects' reference, establish and propagate in practice. The architect's role centres on designing spaces for and communicating with people. The possible rhetorical givens associate with the first hand empirical and imperfect methods that architect's apply. As modes of data collection and manipulation move away from human action, it is likely these established givens remain intact.

1.2 Sensing Pattern

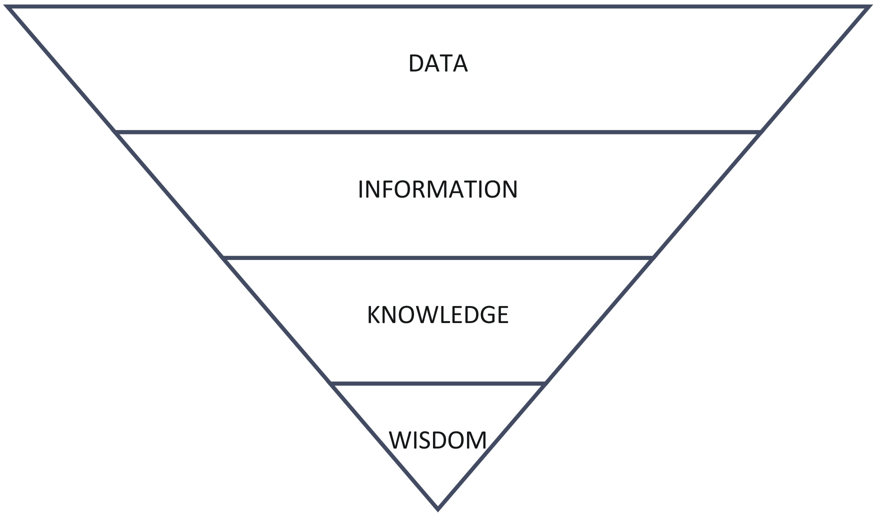
While data's origin relates to material and cultural techniques of observation and abstraction, its identity presents a separate consideration based on application. Origin plays a part in identity, but it is not the only factor; for example, in a scientific study, the origin may be mechanically observed, but the identity is the symbolic form given, which is predominantly quantity.

Assigning meaning

Returning to Russell Ackoff's DIKW pyramid (Figure 1-4) provides a practical start point for understanding identity. Ackoff's schema understands application of data, either becoming information or abstracting from it, arguing that 'the difference between data and information is functional, not structural' (Ackoff, 1989, p. 3). For Ackoff, data and information's 'function' relates to how meaning becomes assigned by detecting patterns in relation to a question or problem. Through Ackoff, data gains an identity of abstract and decontextualised symbols used to encode and decode information.

Although Ackoff's schema introduced a valuable tool to conceptualise and identify data and information, not all were happy with its bias towards communication science and human-centric information systems. In response, Jennifer Rowley adapted the DIKW into an alternative schema that acknowledged data's existence in 'systems or people's minds, or both' (Rowley, 2007, p. 177). Rowley's schema combines human and non-human data and connects origin and application by explaining wisdom, knowledge, and information as a distillation. In contrast to Ackoff's premise that information or knowledge exists through assigning meaning in use, Rowley conceptualises each as a state of ordering and refinement (Figure 1-5) (Rowley, 2007). In Rowley's schema, the head of the pyramid defines data in terms of *what it lacks*; for instance, it lacks meaning, value, organisation, or processing. In a complete inversion of Ackoff's value, Rowley places data at the top of the hierarchy as it holds the potential to distil into different forms of information, knowledge, and wisdom.

Figure 1-5 - Inverted DIKW (Rowley, 2007, p. 177).



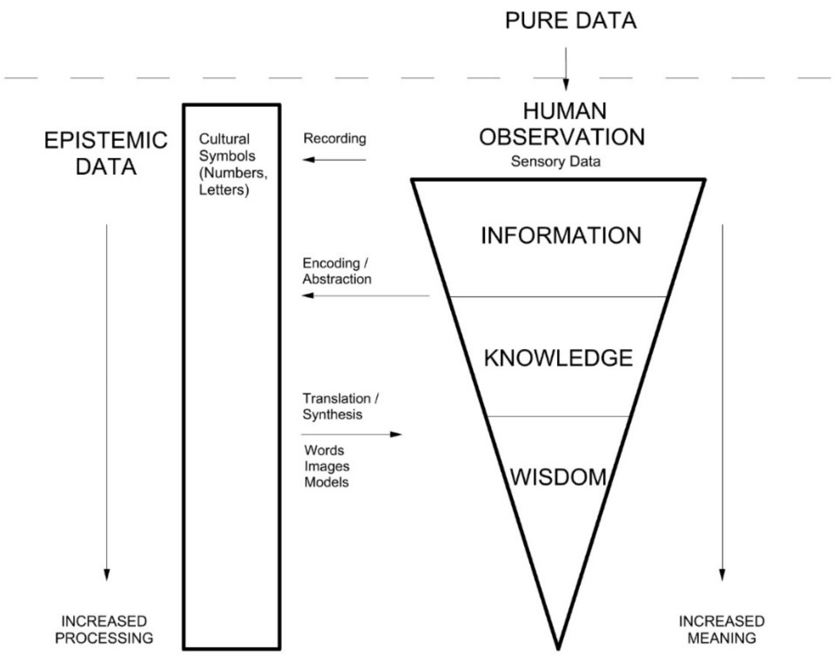
While Ackoff and Rowley's schemas differ in their attitude to data's importance, a similarity exists in identity within a hierarchy of meaning. The distinction in the hierarchy is that while Ackoff identifies data as a pre-existing state to information reliant on the meaning assigned in use, Rowley considers it to always exist in the background; consequently, information, knowledge, or wisdom are not separate *states* but *forms*. Within an architectural practice, this distinction introduces a critical consideration. Is data applied as a foundation for information and knowledge, or is it present throughout with the possibility of resisting or inviting forms of meaning?

While Ackoff and Rowley's schemas propose a possible pre-informational role, they do not recognise the possibility that a stage may exist before data emerges as symbolic representations. Luciano Floridi helps fill this conceptual gap of pre-observational existence through the idea of 'Dedomena', a state of 'pure data or proto-epistemic data, that is, data before they are epistemically interpreted' (Floridi, 2017). Through dedomena, Floridi distinguishes between phenomena always existing but data as a captured observation by considering its existence before any epistemic process constructs meaning unique to an observer. Floridi helps distinguish between data existing all around us awaiting collection – dedomena – and the abstract representations produced through sensory sampling we refer to as 'data'.

Following Drucker and Kitchin's previously discussed notion of data as 'capta', Floridi argues dedomena are 'lacks of (sic) uniformity in the real world' (Floridi, 2010, p. 23) that must exist for information to be possible. Floridi's notion of 'lacks' introduces the idea that data exists where there is a difference, and when a pattern in difference exists, so does information. For Floridi, meaning passes between capturing reality and constructing information and that meaning exists through being 'well-formed', data 'rightly put together according to rules, syntax, that govern the chosen system, code, or language used' (Floridi, 2010). A critical aspect of Floridi's theory is that data comes from capturing dedomena but relies on an existing semantic system that assigns a form, a function, and a basis for meaning. A concrete example of Floridi's theory is how traditional navigation maps construct visual rules that translate differences into visual patterns.

A distinction arises regarding human and machine origins and identities when considering Ackoff's, Rowley's and Floridi's schemas. Two diagrams help visualise this distinction: Figure 1-6 provides a foundational schema to construct a human identity, while Figure 1-7 compares human and non-human registers. Figure 1-6 adapts Rowley's inverted pyramid but places primacy on modes of observing and interpreting, highlighting two stages of pattern recognition, one in producing from Floridi's 'pure data' and the other in filtering and refining symbolic abstractions. The diagram highlights that humans construct identity through observation and cognition and assign meaning through semantic systems.

Figure 1-6 - A schema explaining human data types



Human epistemic recognition

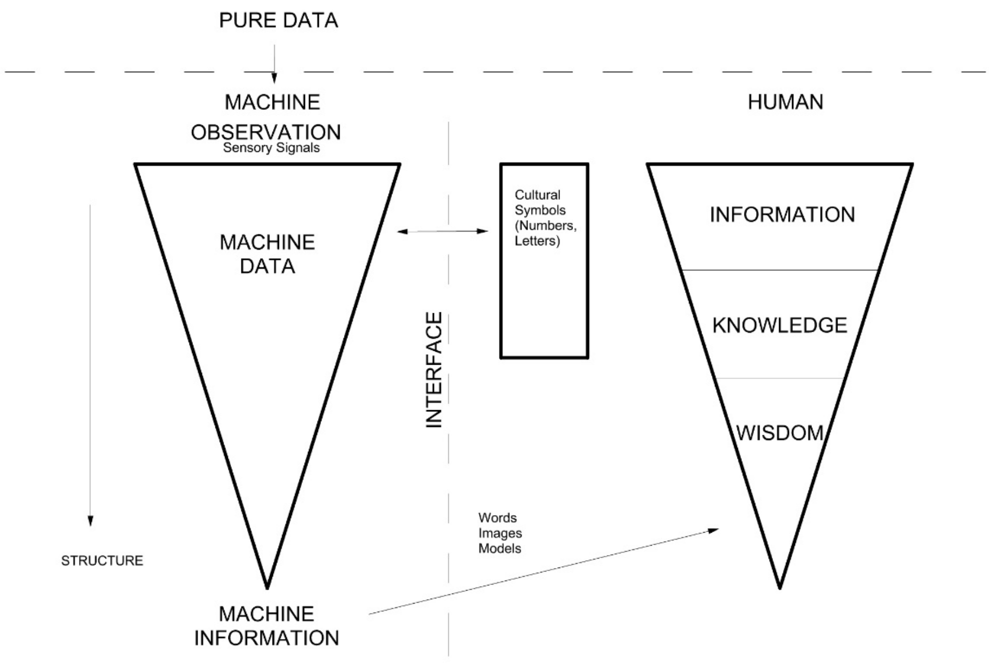
Human semantic systems devise symbolic forms to represent abstractions at the most basic level, this contrasts between the quantitative and qualitative. Although numbers and numerical systems are ancient, James Franklin points to Aristotle (384–322 BC) as the first to popularise quantity to deliver a 'certainty about reality, to the envy of other disciplines, including philosophy' (Franklin, 2014, p. 221). Franklin argues that quantity's 'epistemological clarity' sets the 'paradigm for objective and irrefutable knowledge' (Franklin, 2014, p. 221). Steven Connor points out that quantity provides a seductive ability to identify, define and compare by instilling an equivalence and imposing homogeneity on heterogeneity towards order, or as Connor quips, 'you can reorder the ordered, this is harder than ordering the unordered' (Connor, 2016, p. 36). Connor points out that the radical influence quantitative analysis produced was to reduce phenomena into mathematical relations, giving rise to the field of statistics and the 'taming of chance' (Connor, 2016). Quantity's influence over measuring to control produces what Connor refers to as 'quantitative science' whose 'operation of practical judgement in which all the different forms of calculation cohere, and in which what used to be known so uselessly as interpretation has acquired the new, fair name of engineering' (Connor, 2016, p. 47). As Connor points out through Michael Serres, engineering's success is its procedural concern with knowing *what* exists and *how* it occurred, without dealing with any declarative notion of ‘why’ (Connor, 2016, p. 46). As a result, engineering positively discriminates towards questions and problems of magnitude, scale, dimension, extent, frequency, and duration, that offer easily quantifiable phenomena. Connor highlights that although quantity underpins understanding and controlling physical phenomena, it restricts knowledge to known or knowable quantities producing ‘acts of measurement that influence human adjustment to quantifiable questions’ (Connor, 2016, p. 48). Connor’s quote highlights both the strength and weakness of quantity; quantity accurately records phenomena, allowing comparative accounting, such as natural processes, but disregards questions that do not submit to quantification, comparison, and manipulation, such as cognitive and subjective experience.

While quantity can record and compare phenomena, it cannot record the experience. From an identity perspective, the qualitative exists as verbal (oral or written), experiential (film or notes about people in action) or artefactual (objects, buildings, or urban areas) as a basis for subjective viewpoints (Groat & Wang, 2013). Someone with colour blindness will experience phenomena differently from a typical person; experiential qualities are not generalisable; therefore, qualities are specific to the *observer*. Qualitative abstraction acknowledges subjective interpretation, meaning ambiguity, and the possible plurality of information. Practices that pursue qualitative data seek to understand human experience and engage with personal rather than generalisable shared meanings. What is more, and what potentially adds confusion, is that qualitative approaches treat information as data, that is, meaning existing in information becomes the data. While objectivity requires observation to exclude meaning, qualitative observations require an observer to carefully abstract meaning, aiming for subjective human perspectives to understand individual experiences.

Non-human material detection

In contrast to human representation through symbols, there is an identity of non-human, machinic or systems data. Ackoff's DIKW hierarchy argues that as humans pursue ideals or ultimately valued ends, wisdom provides a uniquely human characteristic that differentiates man from machines, as machines do not generate meaning, learn, or apply knowledge. In contrast, Rowley's inverted schema acknowledges human and machine data mixing, such as humans interacting with information technology, digital sensing, and communication networks. In the example of a digital smart device, data has a dual identity; it describes a sensory product as much as it denotes a substrate for information transfer. Figure 1-7 shows an adapted diagram to compare human and machine data; the critical aspect to note is how data makes up the machine's entirety and how human semantic information results through representation via a visual interface.

Figure 1-7 - A schema for understanding difference in human and machine data



Siegfried Giedion's early to mid-twentieth century writing on mechanical observation occurred in an era of analogue data; observation machines such as cameras recorded light directly onto film material. In contrast, digital photography detects light through a sensor matrix that coordinates pixel values into images. The difference between analogue and digital is that the former *records* directly through material qualities producing an immediate visual representation, while the latter reproduces visual information by *encoding* a pixel mapping logic. Digital representations operate through binary digits (bits), encoding and decoding between observation and representation by assigning a set of instructions for translation. Rather than distinguishing between digital and analogue, Max Tegmark argues it is more beneficial to define by material representation (Tegmark, 2017). It is not the digital that defines data, it is the binary digit symbol that makes the digital possible. Tegmark uses the example of symbols written on paper that rely on ink and paper molecules' behaviour. The degree of organisation of paper relates to the stability of wood fibres and ink as combined materials. If paper molecules behaved more dynamically, the symbols represented could reorganise to produce different information (Tegmark, 2017), meaning data's material substrate directly informs its identity and use.

As non-human machine observation and processing operate at the material level, not the semantic, there is difficulty conceptualising data that is inaccessible to human physical manipulation. Human senses cannot access the molecular scale, and in some cases, cannot interact directly with material forms, such as magnetic databases. Roberto Botazzi, an architect, and researcher, agrees with this notion. Botazzi points out that in modern computers, data lie at the 'deepest editable layer of content in the computer' (Bottazzi, 2018, p. 410), meaning humans never experience or act on digital abstraction; they rely on visual interfaces to organise and structure into meaningful outcomes. At first, this would suggest that including non-human data in this research would be a dead-end; however, Botazzi provides two distinct definitions to deal with human and non-human. On the one hand, designed technical interfaces enable connection to the unseen level of non-human material abstraction. On the other hand, they visually process human 'epistemic data', such as numbers, words, and images (Bottazzi, 2018, p. 410). Both provide a means to represent the world abstractly and construct information, but with differing access to the data level. Despite his dismissal of the digital as a directly manipulable material, Botazzi draws an essential relationship between non-human abilities to store, retrieve, and manipulate human epistemic data. While digital bits are un-editable by direct human action, they become manageable when structured and coded into strings of bits that visualise epistemic symbols. Botazzi's research interests focus on computational architectural practice, but to draw a helpful comparison between human and non-human, he describes both as part of an 'epistemological chain', placing a responsibility on the architect to assign meaning for practical use (Bottazzi, 2018, p. 337).

While electronically represented digital bits are physically inaccessible to humans, the 'bit' requires scrutiny as it conceptually underpins computational paradigms, influencing the types of information made available for human use. Paul Dourish, a computer and social scientist, argues that both non-human and human data require material representations to exist; therefore, the qualities of the material used to store, manipulate, and retrieve shape its practical use (Dourish, 2017). Dourish provides an example of spreadsheets, an interface to interact with both human and non-human data and an organisational tool that imposes granularity through a grid form, which in turn 'provides an organising structure that speaks to what is about to be done' (Dourish, 2017, p. 91). In terms of physically touching and interacting with data, any practice is constrained by its material representation, and the degree of its stability affects its possible manipulation. For instance, a computer interface invites dynamism through electrical flows while a deck of index cards or an encyclopaedia exerts a material stasis. Floridi draws a valuable parallel between data's material qualities and organisational capacity by describing it as both a *resource* and *constraint* to making, allowing or inviting certain information constructs (Floridi, 2017). Therefore, rather than reinforcing the simplistic analogue/digital dichotomy, constructing an identity through how data affords information manipulation turns focus towards material representation modes and practices.

From other disciplines, it is evident how pattern detection complements reality capture towards data's origin and intended use. Once again, a distinction between human and non-human systems arises, which creates a significant difference in determining data's character and use. Human epistemic recognition operates through culturally agreed symbols that assign meaning to data by giving it structure and form through patterns in numbers or words, using mathematics and vocabulary. Human data transfers into different stages of information, knowledge and wisdom as signified order increases and interpretation occurs through an agreed parsing system. In contrast, machines, referred to as non-human in the thesis, work primarily through data configuration, meaning it has a constant presence, becoming increasingly more informing rather than shifting into physical forms of information. Meaning is the difference between human and non-human patterns; where human signs and symbols require an agreed system of significance, the abstract bits of non-human systems work through designed rules of interpretation that are detached and recede away from human access. Once data enters the abstract recesses of the computer, patterns exist through encoded logic, putting the responsibility on the system designer to devise the decoding rules.

1.3 Mapping Meaning

Data's cultural assemblage

While identity relates to material and practical use, it relies on intentions and assumptions based on culturally driven capture. The contemporary field of *critical data studies* addresses the relationship between abstract representations and their cultural production. Rob Kitchin and Tracey Lauriault argue that contemporary scientific research practices produce data within cultural and material frameworks, influenced by knowledge intentions and the apparatus used to abstract observation (Kitchin & Lauriault, 2018). Kitchin and Lauriault portray contemporary big data science research as a socio-technical assemblage where cultural expectations associated with research ambitions influence the degree that humans and non-humans intermingle as observers and audiences in producing knowledge (Kitchin & Lauriault, 2018). Kitchin and Lauriault conclude that it is best to understand data as an artefact born from research practice set within a framework of thinking, ideas and intentions embedded in knowledge production (Kitchin & Lauriault, 2018).

Yanni Alexander Loukissas further validates data′s identity as an artefact when he states, 'whether generated by algorithms, created by instruments, or keyed in by cataloguers, digital data have their own contingencies that are useful to understand' (Loukissas, 2019, p. 16). In the context of Loukissas's research, data represents and makes objects, organisms, texts, and images organisable within museum collections. Loukissas highlights that making data involves multiple material processes to measure, record and capture the world; each has physical constraints, producing cultural artefacts 'at a time, in a place, and with the instruments at hand for audiences that are conditioned to receive them' (Loukissas, 2019, p. 2). Data's identity, therefore, is not just culturally assembled, it is uniquely specific to a location, time, and materially influenced collection. This relationship between data and context holds significance for architectural practices that engage in localised understandings and material propositions.

The cultural and material contexts surrounding collection govern what data exists and set and control modes of practice. Again, Daston and Galison's work on seventeenth-century scientific drawing practices helps understand how those techniques aimed to achieve cultural expectations of 'truth to nature' and objectivity (Daston & Galison, 2010, p. 17). Not only did scientific objectivity train a way of observing, but it also imposed a cultural expectation that humans could objectively observe, given a mode of practice. Making atlases imposed a *way of seeing* that constrained what data made its way into image-making. Also, atlas making required observers to represent ideal specimens by interpolating or averaging all observations into one representation. Daston and Galison describe how the presumed objectivity of atlas making arrived through a set of 'epistemic virtues', providing a set of instructions and standards on 'how to describe, how to depict, how to see' (Daston & Galison, 2010, p. 26). Although the atlas images exist as information, as they are visually understandable as plant specimens, each mark recorded by the eye and hand, filtered by a culturally conditioned lens, exists as data. The atlas images highlight how a cultural expectation regarding observation resulted in a learnt visual abstraction that produces visual information. Daston and Galison refer to the atlas images as being 'at work', mapping observed territories to 'understand and serve' while conversely setting the techniques and agendas for future scientific work (Daston & Galison, 2010, p. 26). While architectural practice involves observation, the primary focus is on built objects, not the production of knowledge. However, it is essential to consider whether the ways architects observe and abstract link to a cultural expectation that has set techniques and agendas within architecture.

Architectural observation

Observation has an acute relationship with understanding and control. Carlos Linnaeus (1707), known as the 'father of modern taxonomy', sought 'order of nature' by depicting life as a singular and definitive data set from empirical observation (Daston & Galison, 2010). The example of Linnaeus's taxonomies introduces a case where observation partiality led to classifications and types used to understand and organise the world. Linnaeus's nature classification could only organise visual differences in form based on human sensory observation, meaning that the categories were not only exclusive to humans but that any future natural study operated on the premise of Linnaeus's categories. As partiality arrives through a material and cultural filter, any pattern emerging from data inherits bias. This partiality has material consequences when patterns enter wider practical use and make partial versions of reality real. For example, Manuel DeLanda argues that taxonomy practices establish and normalise categories based on a partial human sensory register and risk essentialism when classifications become the sole lens for understanding and serving (DeLanda, 2006). DeLanda highlights that the types and categories established through observation pass over into creative practice and potentially constrain thinking. Therefore, in this research, it is vital to examine if the techniques and outcomes of partial observations 'reify' cultural categories established and maintained in practice.

The act of observing and analysing the physical and social conditions of architecture forms an integral part of architectural practice. Architecture has a rich disciplinary and professional knowledge that arrives from and forms the basis of creative practice. While some architects concern themselves with pure research, with knowledge as a product, most use research to shape a creative process resulting in built products embodying architectural knowledge. Data's relationship with information and knowledge means that studying architectural practice must acknowledge how architects see or capture reality. From the perspective of architectural knowledge production, Groat and Wang argue that the question comes into focus when marrying a research question with a mode of systematic inquiry (Groat & Wang, 2013). Many research guides agree with Groat and Wang's opinion that data in research arrives from systematic enquiry -- also referred to as an epistemological framework or school of thought – and shapes decisions regarding research interests, ambitions, strategy, and tactics (Frayling, 1993; Groat & Wang, 2001, 2013; Lucas, 2016). In Groat and Wang's terms, systems of inquiry combined with a school of thought locate the researcher within a set of assumptions 'about the nature of the world and how knowledge is generated' (Groat & Wang, 2013, p. 10). Therefore, epistemological positions or virtues entail an inquiry system in research, i.e., does the question require an objective or subjective viewpoint? Groat and Wang argue that this position establishes a school of thought and an associated way of seeing and studying, such as objective positivism or subjective constructivism. Understanding data's character and influence in architecture requires interrogating the origins of observation and the cultural expectations of knowledge and detecting if paradigms of capture transfer culturally defined strategies and tactics into practice.

When observation occurs within a worldview or knowledge paradigm, a methodological framework dictates what data is. Scholars widely agree that the tactical level of research directs the medium of observation and determines the type collected (Groat & Wang, 2013; Michel et al., 2012; Moloney et al., 2015). To understand influence on architectural practice, we must question what tactics architects employ in observation, and trace these tactical consequences into forecasting the future. Doing so requires interrogating the types of tactics architects apply and the assumptions these tactics bring into creative practice, including the possibility of architects reifying partial realities. From the viewpoint of how architects analyse or employ data, there are always tactical decisions guided by a higher-level set of intentions. Processes of architectural analysis employ sets of assumptions that, at a basic level, divide the world into quantity or quality. This simple distinction brings consequences for practice and requires an examination of architects' tactics.

A connection between tactics and application exists in the units of measurement architects employ. Measurements are cultural, intentional, material, and embed an intended partiality that results from a consensus regarding units, scales, and mapping systems. J J Gibson highlights quantity's reliance on consensus or authority; for example, the cubits, palms, and digit measurements of ancient Egypt (Gibson, 1979). What started in Egypt as an agreement over body parts as a measure evolved into a standardised foot by the twentieth century. Within this logic, any material object used to measure and compare becomes a source that relies on cultural acceptance and cooperation in use.

Just as knowledge production always exists within a cultural framework, so does measurement. Agreed and adopted systems of measurement promote collaboration but become contested cultural artefacts. A relatively new influence on architectural practice, despite its introduction in the 1960s, post-occupancy evaluation offers an example of architects applying measurement to a practical application. Post-occupancy evaluation attempts to provide a 'useful, economical, timely and beneficial evaluation of buildings' (Preiser et al., 1988, p. x) to connect architectural proposals with an observed reality of inhabitation and produce professional accountability. Wolfgang Preiser et al. describe how post-occupancy evaluation's introduction aimed to detect a building's failures and successes and incorporate 'learned lessons' into future buildings (Preiser et al., 1988). However, when interrogated from the perspective of economic power and control, post-occupancy evaluation emerged as a tool co-opted by building owners to explicitly state performance criteria and recast architecture's success based on client objectives. Through Preiser et al.'s description, post-occupancy evaluation offers an example where data collected to expressly analyse building performance came to construct and reify categories of testable criteria. For instance, decisions regarding window placement shifted from aesthetic or historical considerations to an argument over insulative qualities, infiltration rates, cold bridges, weatherability, cleanability and durability (Preiser et al., 1988). Post-occupancy evaluation emerges from a cultural need of accountability; however, the mode of analysis folds back onto practice, setting the expectations for an architect's future success or failure. A consequence of post-occupancy evaluation is that architects' decisions move away from applying experience and education-based knowledge to appeasing performative metrics based on skewed client perceptions of merit. The example of post-occupancy evaluation demonstrates how a cultural identity and partiality can radically reconfigure the architect's responsibility and install an economic and legal accountability.

Architects must have critical insight into what assumptions exist in the intentions, strategies, and tactics they deliberately invite in or are forced to contend with. Additionally, if architects access existing data before or during design, they risk drawing conclusions that absorb a partiality from external influences. The potential of patterns such as taxonomies and categories to consolidate rather than expand thinking, as DeLanda argues, shows how the practice of observing and pattern detection constructs a potential space of conscious or unconscious bias based on data's origin. The seemingly benign act of assuming or expecting impartiality in data has real consequences when it guides decisions that attempt to forecast a building's impact. This research must first account for different origins and identities to uncover influence in architectural practice. Are these origins and identities determined by the architect or imposed on them? A potential consequence is that data imposes a way of thinking onto a creative practice regarding knowledge and sets up expectations regarding the architect's responsibilities and achievements.

From knowing to proposing

Data's origin and identity impart a set of epistemological virtues that initiate a conscious or unconscious partiality in defining architectural requirements expected from practice. Architectural practices that focus on built propositions involve stages of idea generation and exploration that employ imagination. Imagination is a crucial element of the architectural discipline; Michael Hays argues it is a faculty that mediates sensuous experience and conceptual understanding to create immaterial images that convert into material representations when visualised (Hays, 2019). Hays argues that imagination forms through visualisation of architectural sense-data (Hays, 2019); he assumes an objective register and ignores the possibility that visualisation techniques potentially constrain the imagined possibilities of architecture. In contrast to 'imagination', which restricts practice to pure image-making, this thesis views 'forecasting' as a more suitable description of the architect's creative ability. The idea of forecasting reality through a creative process emphasises the predictive claims architects make and the degree of accuracy between representation and reality. In forecasting architecture's future impact, architect's transfer assumptions or biases into their creative space.

Data's scientific status as the building blocks of reality could become the material used to shape architecture. An example of this material use is in map-making practices (cartography). Cartography provides a helpful analogue for understanding data in architectural practice, as it constructs information and accentuates partiality in visual communication. Gregory Bateson describes mapping as recording a field of differences: 'what gets on the map, in fact, is difference, be it a difference in altitude, a difference in vegetation, a difference in population structure, difference in surface, or what-ever' (Bateson, 1987, p. 458), meaning that maps visually organise discrete differences into a coherent and interpretable whole. Mapping visually communicates abstract representations into information and connects an observer with an audience through semantic translation. For instance, early navigation maps visualised landscapes by connecting recorded differences in physical characteristics with representation systems. When plotted, each physical difference provided a data point that produced spatial information. Mapping through a graphic language gives data meaning, thus translating it into semantic information. Additionally, the map produces and expresses relationships between data; in the example of navigational maps, each point links graphically to another to visualise an edge, threshold, or boundary information.

The example of geographical and territorial navigational maps introduces a vital relationship between observation and authority. Just as botanical atlas-making sought to define through recording, geographical mapping depicts or enforces new political realities, such as landmarks, borders, or territories. The authorial and political role of mapping means data takes on a highly curated identity and gains an unquestionable status when selected or fabricated by the cartographer. Cartography introduces how cultural authority conveyed in a map is a mixture of choices regarding what gets onto the map and what relationships emerge from the graphical language employed. James Corner, a landscape architect, highlights how the assumed objective nature of the map as a direct projection of land to paper produces a 'benign neutrality' that ignores the abstractness of the map, that involves ‘selection, omission, orientation, projection, distance and codification’ (Corner, 1999, p. 215).

A double layer of partiality occurs in mapping through data’s origin and the mapper’s visual intentions directed to an audience. Corner refers to mapping’s partiality as its strength, for while it can deal with pure communication and certainty, its creative potential is in generation and possibility, ‘a practice that both reveals and realises hidden potential’ (Corner, 1999, p. 213). Corner argues that intentional partiality enters the map through a series of graphical devices employed by the producer, such as ‘framing, scaling, orientation, projecting, indexing and naming’ (Corner, 1999, p. 215). A map’s cultural use comes from its data, which in turn relies on a cultural framework for collection; for instance, a quantitative, objective, and rational map imparts a technique onto production and assumes truth and neutrality. Corner accentuates that maps are instead ‘highly artificial and fallible constructions, virtual abstractions that possess great force regarding how people see and act’ (Corner, 1999, p. 213). From Corner’s scrutiny, we learn that the practice of mapping invites and relies upon partiality across two interrelated actions — what is extracted and invited onto the map, and the graphical system used to organise and represent. The graphical system connects the existing with a forecasted new. The rules of graphical representation become a system for interpreting data into information as partial as the cartographer.

Mapping provides architecture with an example where data organises into information through a rarely neutral and always cultural practice. By the map’s ability to set up and manipulate information interpretation, mapping practices also provide an assumed means of *forecasting* by first understanding, then controlling through the rules extracted from data. Therefore, a map is never a mirror, it is only a representation, and the mapper chooses what and how based on a map’s intended purpose. In Corner’s words, ‘mapping is not the indiscriminate, blinkered accumulation and endless array of data, but rather an extremely shrewd and tactical enterprise, a practice of relational reasoning that intelligently unfolds new realities out of existing constraints, quantities, facts and conditions’ (Corner, 1999, p. 251). Mapping provides an example of practising through an *epistemological chain*, from observation to graphical manipulation and information production, through a cultural expectation and trust in practical use. The critical aspect for architectural practice is acknowledging where partiality meets with designed systems of meaning generation to create versions of reality unique to the architect.

Applying mapping to architectural practice introduces some concerns for the thesis. The first concern is that even if architects do not directly use abstract representations in observing the existing or forecasting the new, cultural assumptions set a framework for practical action. For example, epistemological virtues encourage specific methods and material techniques that promote and shape thinking, such as positivist desires to extract generalisable rules. The second concern is the false authority gained through application and the conscious or unconscious partiality that tracks extraction, analysis, and categorisation to forecast and propose an architectural scheme. For architectural practice, questioning data's influence must pay attention to its origin and identity and address whether partiality transfers over into patterns and rules architects use under the guise of technique or a method's authority.

From proposing to realising

In addition to exerting influence through origin, identity and application in practice, data potentially influences the translation between how architects forecast new realities and how built outcomes materialise. This zone of translation, between information encapsulated in a 'design' and realising material form, is a space where information meets real-world material performance constraints and human capabilities in building assembly. Bob Sheil defines this space as a *materialisation*, a process of 'translating ideas in matter' that relies on information to guide action (Sheil, 2008). Information in materialisation communicates instruction from the architect to a means and mode of production, making accuracy in interpretation critical as architects construct and transfer information. While this space of translation between practice and materialisation ties closest to modern-day design services, the emerging architect of the Renaissance also had similar concerns.

Architects produce information to describe and enable material assemblies, but rarely physically build. Therefore, for materialisation to occur, architects become responsible for translating forecast propositions into actual material forms through directing physical action. Forecasting the future requires understanding the present through observation. Materialisation connects forecasting back to material reality. Therefore, observation sets the foundation for forecasting and materialisation throughout practice. This observational foundation means questions regarding data's origin and identity come into play when considering materialisation, such as, who is the intended audience of construction communication or who is responsible for translating information into material form? The audience for the materialisation of architecture is often skilled or unskilled human workers who rely on an agreed semantic information system. A critical element of this translation is that communication employs agreed and recognised meanings. However, what happens when the audience is not human; what activities transfer from human to mechanical processes; what consequence does this have on semantic information? In this case, the epistemic chain breaks down, as machines operate through a literal description, not through experience, skills, and meaning-based semantic information. If non-human automated processes do not require human semantic information, does data become a consistent form of communication, and how does this change the architect's practice? Influence comes to the fore where materialisation processes operate through human and non-human interactions requiring different communication forms and different engagements with meaning.

The space between the architect communicating their intentions, and the physical act of building offers an opportunity for control through careful and skilful documentation and specification. At the same time, this space potentially invites indeterminacy through ambiguity in interpretation. Robin Evans highlights the gap between the architects' ambitions and the knowledge and skills required to translate information into material production (Evans & Mostafavi, 1997). In the context of increased automated data communication, Evans' space of translation requires critical attention to interrogate how architects utilise or pass on knowledge and skill towards material fabrications and assemblies. As communication becomes increasingly technical, data partiality potentially passes over into an attitude regarding material production and assembly; for instance, accentuating machine metrics and robotic control could remove any trace of human material reference.

The intentions and expectations that set techniques and agendas within architecture must be understood explicitly for data in practice. Whether recorded, detected, or synthesised, data assemble to address a particular intention, which could be to understand phenomena as much as to decode a communication. When inviting data into practice, architects must be aware of the intentions, strategies, and tactics embedded into data's existence and whether this invitation brings a partiality that risks bias. If the architect does not directly observe and record, abstract representations may result from assumptions or cultural intentions determined by others. As the architect maps meaning onto data, this potential partiality grows in significance, assigning false authority to patterns and rules that absorb and hide partiality under the guise of a technique or a method's veracity. Moving between proposition and material constructions, the cultural partiality embedded in data becomes a reality when mapped meaning instructs material action. It is essential to consider how data moves from this point; does it pass over into human interpretable forms, or does it remain as machine communication? This distinction is most relevant for material production and assembly processes when architects utilise and control information translations.

1.4 Conclusion - Observing, Forecasting, Instructing

Captured data that represent properties of real phenomena or synthetic data that abstract existing information are never natural and simply given up to sensing. When discussing data's existence, it is important to acknowledge that it is always reasoned and, therefore, partial. Often, it operates as a rhetorical tool to justify actions and specific needs; historically scholars would culturally maintain and utilise status of unquestionable premise that would represent a truth or objective reality. As data is always questionable; its future importance in technologically saturated societies means we cannot take it for granted. The prevalent exclusively quantifiable or information management understanding limits data's identity to a simplistic digital or analogue dichotomy. The real difference in this divide is the work of material abstraction caused through representation techniques making it critical to acknowledge and explore representational forms beyond numbers and bits.

Three key findings emerge from interrogating data from other disciplinary perspectives. The first is the split in data's origin, what source of abstraction architects use, and how it occurs. This split sits between human seeing and recording and non-human sensing, the former referred to as organic observation, the latter as technical detection. This distinction sets the basis for the research framework to see if this split exists within architectural practice. Data's character always correlates to a mode of abstraction, its origin, meaning the representations architects use and to what ends become an important factor. Secondly, it is essential to understand data's role in information and knowledge production and its existence as an assembled artefact. Understanding data as assembled through material techniques towards cultural intentions highlights the presence of bias and partiality wherever data exists. The third point is the significance of identifying or constructing meaning through relational pattern, presenting in two very different ways, as human interpretable rules or logically encoded through communication signals.

The research framework anticipates data's influence through three areas of architectural practice.

- Intentions and material techniques invite partiality through *observation.*
- Architects connect the existing to the future by *forecasting* new material and spatial conditions.
- Architects realise these conditions by translating design into material form through *instruction.*

Restricting research *to* these three territories helps detect data's presence in the architect's practice and uncover if they have a distinct use and understanding. Exploring the architect's data anticipates that the typically subjective responses to site, program, and design that they apply become influenced by data's synthetic capability identified in this chapter. The space where analytical observation shifts to synthetic processing becomes an important consideration as it influences how the discipline and profession regulates, controls, and increasingly automates decision making. When architects extract, seek, combine, or assemble abstract representations they do so with cultural intentions.

To recognise data's character and its influence in architectural practice, the research must interrogate the ways architects invite abstract representational forms through empirical observation or non-human detection and how they subsequently apply these to connect material realisations to forecast futures. Just as other disciplines have experienced multiple changes in understanding, the research anticipates architecture to have experienced changes in data understanding that align with significant cultural shifts. The next chapter uses Rosenberg's identification of data's seventeenth-century linguistic emergence as a launching spot and identifies and compares two originating architectural uses.

Chapter 2: Translated Observation

As identified in the introduction, the term ‘data’ predominantly registers across architectural scholarship in conjunction with twentieth century information technology. Knowing that a linguistic concept emerged in correlation with empirical observation and pattern recognition in the scientific enlightenment, suggests that architectural use dates earlier than computation, as far back as the 1400s A.D. Two practices demonstrating abstraction and pattern recognition during this time exist in Leon Battista Alberti (1404–1472 A.D.), an Italian architect and philosopher, and Jean Nicolas Louis Durand (1760–1834 A.D.), a French architect and educator. These architects bookend the intense scientifical discourse of the European Enlightenment and provide a way to understand this period’s influence on architecture in terms of observation, forecasting and instruction. Alberti and Durand’s practices offer two contrasting approaches to how they abstracted observation and consequently controlled information, in the process constructing a practical identity for the architect. Tracing data back to very early understandings of the architect establishes a base reasoning for its consistent presence in practice. The first chapter sections compare and contrast Alberti and Durand’s approaches to construct an initial character. The last section considers each architect’s abstraction techniques to understand data’s influence on their practices and intended purpose. Interrogating these two significant architects uncovers two distinct characters, one as a part of the architect’s control over information, the other as a basis for a disciplinary knowledge establishing rules for architectural composition and interpretation.

2.1 Precise Instruction

In *The Alphabet and the Algorithm*, the architectural historian and critic Mario Carpo argues that Leon Battista Alberti provides the earliest example of ‘digital practice’ (Carpo, 2011). According to Carpo, Alberti’s approach was digital because he ‘digitised’ architecture into numbers to assist graphical translation and reproduction. While Carpo connects this digitisation to the modern-day influence of software on authorship and material reproduction, he spends little time interrogating data as a concept within Alberti's practice. In 1440, Alberti's ‘Descriptio Urbis Romae’ (Furlan et al., 2007) devised a machine for charting and subsequently reproducing a map of Rome. Alberti's ‘horizon’ instrument, described as an 'ex mathematicis instrumentis' (mathematical tool) (Furlan et al., 2007, p. 3), used a 'horizon and radius' to visually represent Rome through polar coordinates and connected lines (Figure 2-1). Alberti provides an early example of architects using apparatuses to assist human observation and production by translating abstract quantities and visual information.

Figure 2-1 - A Reproduction of Alberti's Horizon Instrument. (Nasifoglu, 2012)

Abstracting control

Alberti's tool occupies a historical moment just after linear perspective's invention — attributed to Filippo Brunelleschi (1377–1446) at around 1410–1420 (Hänsli, 2012) — thus, locating his drawing machine as part of broader cultural explorations of reproducing visual reality. A vital difference between Alberti's technique and perspective was that while perspective aimed to represent observation visually, the 'horizon' sought to record and store observation for later use. The horizon instrument associated graphic map information with polar coordinates to translate between abstract numbers and visual information. Alberti's instrument aimed to depict the visual by accurately recording optical experience and representing it as plotted points and lines. The drawing apparatus represented the architect's view through 'quantitatively precise figurative data' (Furlan et al., 2007, p. 22) while also providing a way to translate abstract numbers into visual information. The horizon was used to understand the physical so as to act back on it; therefore, the apparatus reads like an early land survey technique required for an architect's spatial decisions.

Quantity's crucial role in Alberti's mechanical drawing reproduction was to control efficient information distribution. As a prophetic pioneer of distributed production, Alberti proposed drawings and objects be made locally through instructions rather than delivered across Italy, making the architect an author (Carpo, 2011). In the 1400s, new printing technologies enabled architects to disseminate knowledge via increased accessibility to texts and images (Scott, 1914). The weight difference between distributing a printed image and a set of instructions would be nominal, so what was Alberti's reasoning for abstraction? Carpo argues that Alberti's focus was on the mode of reproduction rather than the reproduced, meaning that his technique rivalled the printing press rather than utilised it, and 'Albertian objects' resulted from a 'mechanical reification of an authorial script' (Carpo, 2011, p. 77). Carpo associates Alberti's intention with technological control, but his approach relates to managing error and the loss of precision in communication. Therefore, while the horizon instrument may have tried to provide a mode of production, mapping numbers provided the emerging architect with a way to control an accurate and objective information production process suitable for design.

As Alberti's instrument enabled control over a repeatable process without losing information, data's character is technical and cultural. Despite greater access to knowledge through Renaissance literature, there was still a disparity in wealth and status regarding access to education. Skills of representation belonged to a few privileged artists and architects. Therefore, Alberti's objective information production process reads as an attempt to establish cultural access and distribute information rather than material. Carpo refers to the horizon as a 'cultural mediator' (Carpo, 2011, p. 77), as it enabled faithful reproduction irrespective of human drafting skill or any memory or knowledge of the image's origin. In this mediation, the architect used numbers as a material to offer a translatable set of information and practical knowledge via the apparatus's use. In Alberti's case, data and machine combined to offer an early example of democratic access to understanding the built environment. Alberti's process gained political power over replication; by controlling the map, he exerted control over the territory.

Measured authority

Abstracting the physical Rome into coordinates allowed Alberti to control accuracy in representation and reproduction. In this process, his instrument controlled a translation process assigning meaning to abstract coordinates to produce a visually recognisable map. In Alberti's thinking, quantity permitted an objective representation of Rome unconcerned with human interpretation, reliant only on interaction between media, instrument, and human operator. Numbers provided input to the machine to map into meaningful information, creating a communicative bridge between the human observer and a geographically disparate human audience. In Alberti's case, coordinates were unique to the material instrument and only proved meaningful when deciphered like a code. Alberti's numbered coordinates were only applicable if translated through a tool, making data reliant on a material technique for its origin and use. Alberti provides a case where the tool rather than the visual information acted as the central creative focus. The significance for the architect was the possibility to shape tools that could control an abstract space of operations to order and assign meaning without the need for human experience or knowledge.

Alberti established control by fixing a linear mapping relationship between observation and visual information. This relationship meant accurate reproduction and distribution but relied on fixing coordinates within the mechanical system. An alternative coordinate set or a different mechanism would lose the visual information necessary to represent Rome. Therefore, fixing data meant that Alberti could attest to a universally understood, objective representation of his city and claim authority over the resulting information. A consequence for the emerging architect was that control over information objectivity required close control over measuring observation and translation, which consequently overlayed a static character onto data.

Alberti used numbers to construct and reproduce visual information that benefited from non-human accuracy and precision. Carpo confirms this view when he states, 'in all such instances, Alberti's images were meant to be carriers of precise quantitative information and to record measurable data — data that could be used and acted upon.' (Carpo, 2011, p. 68). Data provided the emerging architect with an authorial claim on reality to know the physical and act upon it. Therefore, the architect gained authority over observation and assigned practical power to measurement, visual production, and reproduction.

From the perspective of this thesis's overarching claim that data has always been a part of architectural practice, Alberti's use holds significance, as he is regarded as the first design architect (Picon, 2004). Alberti provides the research an initial character, as static sets of materially generated quantities used to coordinate and reproduce information. Later, Alberti's data came to influence how architects authored information production by establishing and controlling translation between observation and instruction.

2.2 Disciplinary Knowledge

But the principles of any art, or of any science, are none other than the results of observation. To discover them, one must observe; and to observe with profit requires method. [1795] (Durand et al., 2000, p. 77)

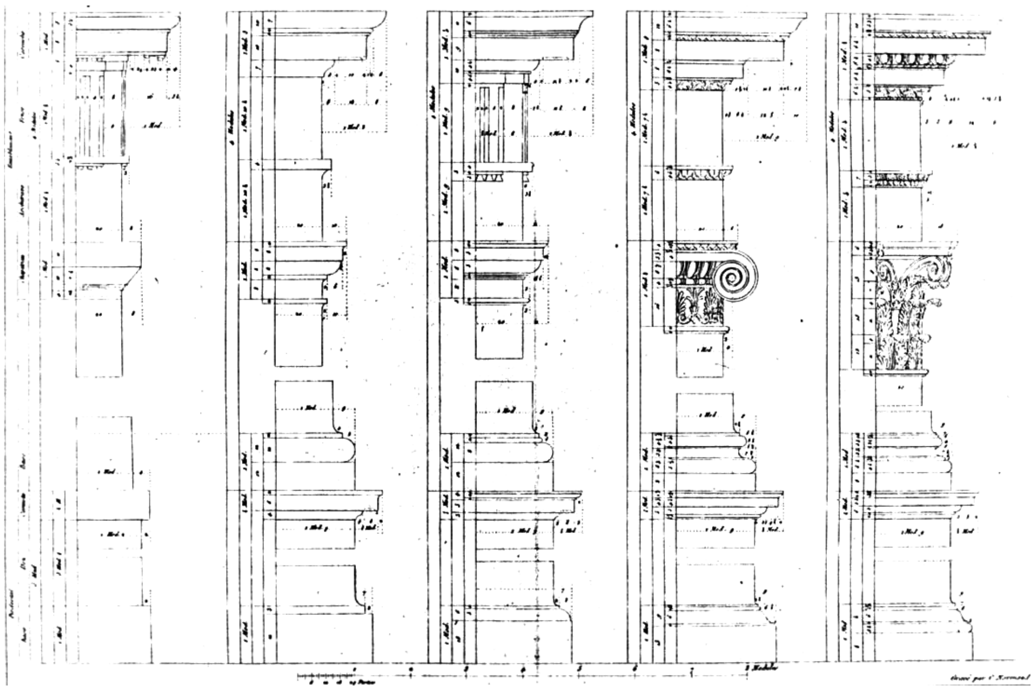
Around 400 years after Alberti (1404–1472), Jean-Nicolas-Louis Durand's (1760–1834) practice provides an architectural use of data that contrasts with Alberti's reproductive mapping ambition. Bernd Evers et al. describe Durand's work as an 'attempt to place the world architecture of former days in an historical context' and to place the 'social appropriateness' of a 'profitability of construction' at the fore of a new socially aligned architecture (Evers et al., 2003, p. 328). Durand's practice responded to the stylistic, traditional, and symbolic approaches of his French peers such as Jacques-Francois Blondel, and associated 'profitability' with a necessary efficiency in design, through a 'technical computation and the logistical execution of building work' (Evers et al., 2003, p. 329). For Durand, a moral duty lay with the architect to serve the people through efficiency and profitability. During the French Revolution, Durand was 29 years old, and this dramatic egalitarian shift registers in his practical methods, social responsibility, and teaching curriculum.

Architectural analysis

Durand viewed the architect as a measured observer, someone who learnt by studying historical buildings in a technical and systematic (Evers et al., 2003). A systematic understanding meant understanding buildings as whole-to-part systems requiring close measurement and pattern recognition. Durand's measurement sketches show how he first broke precedent down into its constitutive elements, then reduced those elements further into quantities to find proportional patterns. Figure 2-2 provides an example of

Durand's analytical drawing studies, analysing architectural precedents and reducing them to quantities in the manner of empirical scientific enquiry.

Figure 2-2 - Durand's analytical drawing (Durand et al., 2000, p. 217).



Quantity provided Durand with a means of comparison that invited classification and comparison in the manner of scientific practice. Like Alberti, Durand used quantities to record and represent architecture; however, while Alberti's quantity abstracted a point in space, Durand described the size and scale of architecture's elements. Alberti's apparatus translated numbers into graphical information through grid coordination; in contrast, Durand's drawings organised architectural parts through rules and orders deduced from measured observation. In Durand's case, quantified measurement and mathematics recast architecture as a technical response to rational problems. Perez-Gomez supports this assertion by arguing that Durand sought to align the architect with the revered engineer and furnish material outcomes with the natural sciences' objective esteem (Pérez-Gómez, 2016). Durand's rational process of reducing architecture to abstract proportions to subsequently organise material elements spoke to the emerging reductive science of the time. Reductive analysis aligned Durand's architecture with scientific thought to define a new professional status for the architect.

Antoine Picon agrees with this assertion and depicts Durand's practice as a response to new scientific thinking introduced through new academies, which promoted a perception that mathematics, mechanics, physics, and chemistry exceeded the disciplinary importance of architecture (Picon, 2000, p. 36). During this time, civil and mechanical and military engineering drove the nineteenth century's technological innovation and became an essential set of institutionalised knowledge (Collins, 1998). Durand's response to architecture's weakened status was to apply scientific techniques to analyse and foreground architecture as an object of study. Alberto Pérez-Gómez highlights the link between Durand's practice and his education and teaching at the scientifically- and military-aligned École Polytechnique in Paris. As an engineer measures to understand, Durand used descriptive geometrical methods to understand and manipulate the physical world (Pérez-Gómez, 2016). Durand's link to geometric measurement meant he was part of the analytical ideal of the Enlightenment, which Picon connects to the scientific-analytical methods defined by John Locke (1632–1704), Étienne Bonnot de Condillac (1714–1780) and Marie Jean Antoine Nicolas de Caritat (1743–1794). When Picon quotes Durand as saying 'order in which generation becomes easy' (Picon, 2000, p. 36), he uncovers an important link between 'order' detected from analysis and a means of 'generation' by combining elements. For Durand, the architect needed to analyse the physical world to find order for creative synthesis.

Quantity resulted from a measured study of built forms and became a part of a taught practice analysing and composing architecture. However, producing a body of knowledge required an epistemology, and maintaining this knowledge required a pedagogy. Christian Gänshirt highlights that Durand's analytical approach thus promoted architecture as a scientific subject, teaching design 'from the perspective of the technical basis of architecture' (Gänshirt, 2012, p. 15). Durand's systematic and technical approach positioned architecture as interpretable via composition rules, requiring an architect to detect patterns from measuring elements and parts (Corona-Martínez et al., 2003). Durand's patterns detected from curated measurement set up a system to understand architecture, which found easy translation into teaching methods. While analysis enabled a human comprehension of architecture through breaking down a complex whole into a system of parts, it conversely provided a method of setting out architecture into a process of sequential recombination (Picon, 2000). When considered in terms of architecture's material output, Durand's analytical decomposition of architecture spoke to the positivist ideology emerging from France during the early nineteenth century, taking in the assumption that patterns within measurement held evidence for universal laws or axioms. In Durand's hands, data's positivist undertones enabled architecture to propose new outcomes instead of stylistic reproductions.

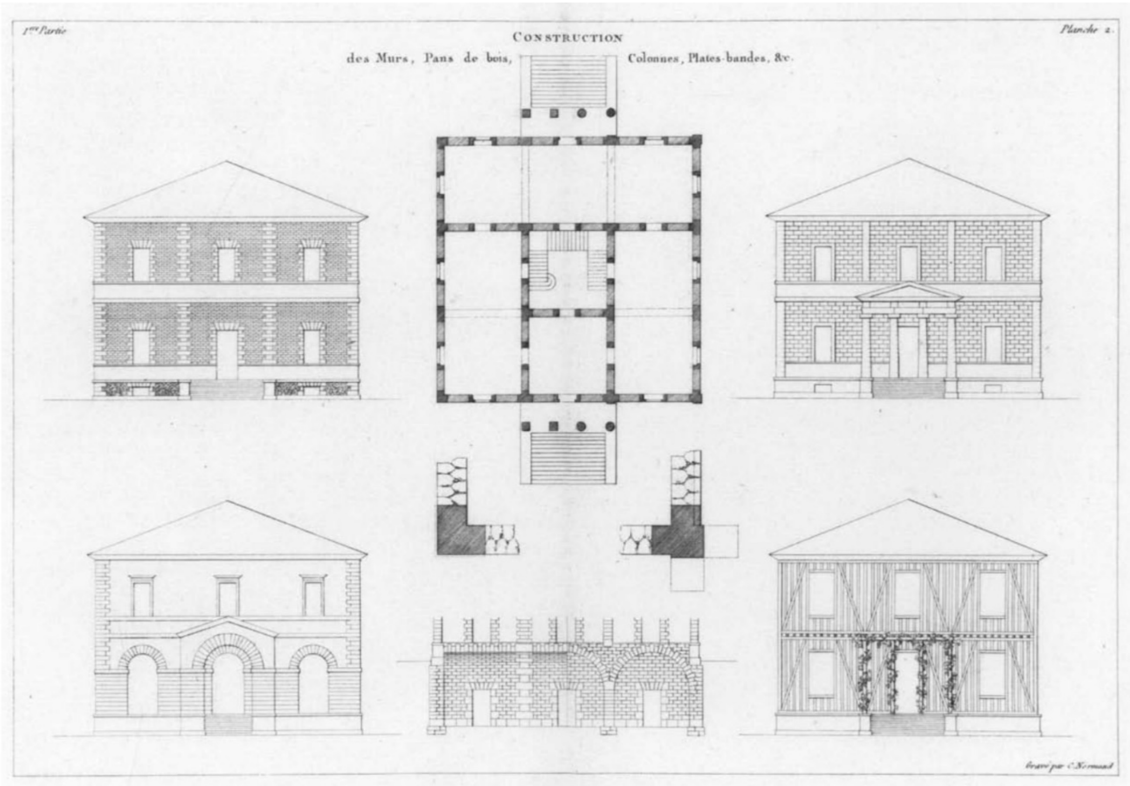
Averaged Composition

Antoine Picon argues that Durand's compositional orders were not enough to create an architectural form; he required a way to connect the spatial with function, which he did through applying architectural types (Picon, 2000). Durand explained, through his lectures at the Ecole Polytechnique (1802–05), that architectural types helped his analytical method, as he found difficulty in applying his orders into new architecture (Durand et al., 2000). Picon points out that the diagrammatical orders born from Durand's analysis required a connection to functional and constructible outcomes; this meant employing type as a 'generic formula, a crystallized usage...the physical correlative of utility' (Picon, 2000, p. 22) that brought Durand's architectural elements into order. As functional categorisations, Durand's type distinguished between public and private function. It then subdivided along the lines of purpose, which Picon likened to the distinction between classes of mammals, birds, and reptiles in life sciences (Picon, 2000, p. 45). Functional types such as forums, basilicas, theatres, colleges, and libraries formed through Durand's historical comparison (Evers et al., 2003), helping to bridge between 'architecture's primary constituents and its products' (Picon, 2000, p. 7). Therefore, while Durand's measured pattern detection method worked directly on architecture through quantity, Durand's classifications into types did not come through quantity; instead, they transposed the cultural idea of scientific classification onto architecture.

Durand's lectures promoted a working process of categorising materials in terms of durability and cost and then arranging these into architectural 'elements', such as walls, piers, and string courses. These elements then became recognisable parts of buildings, such as porticoes, porches, vestibules, staircases, rooms, galleries, and courtyards, to culminate in architecture, described as an 'assemblage' (Durand et al., 2000, p. 188). Durand's 'assemblage' hierarchically composed materials, elements, parts, wholes through diagrammatical orders. Durand composed by combining architectural form as a system of patterns, with type as a classification system to generate an assemblage based on function. Therefore, while Durand's idea of type did not come from quantity, it imagined materials as architecture's data, arranged into recognisable elements and parts, and organised through universal orders and axioms. Figure 2-3 shows one of

Durand's lecture slides, showing how he drew architecture to express his classified parts, materials into elements (walls), into parts (rooms, porticos), into assembled form.

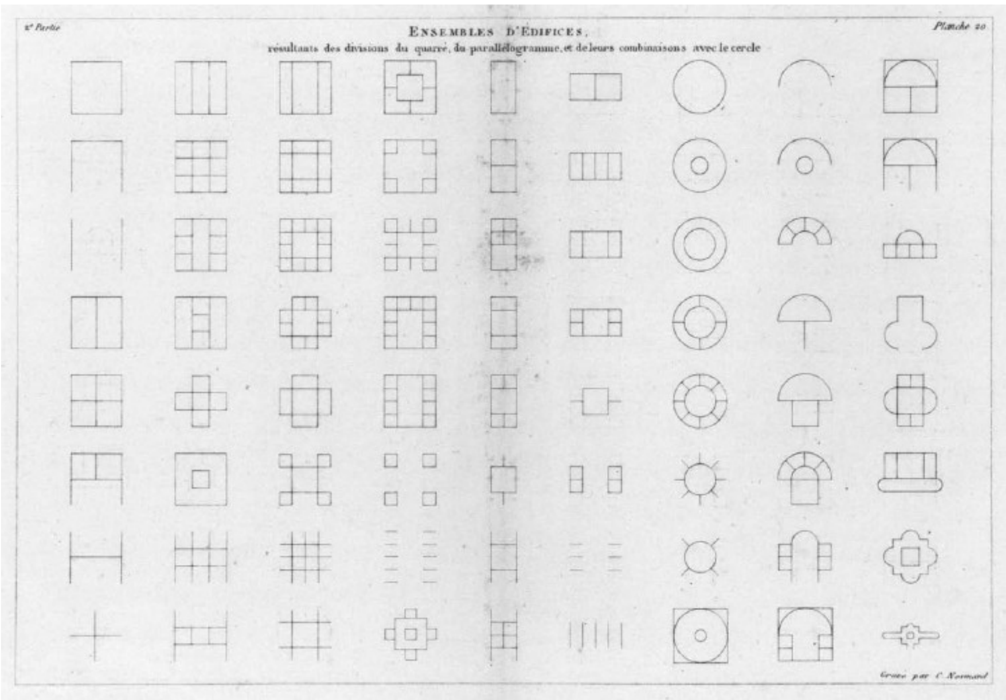
Figure 2-3 - Durand's analytical/compositional process (Durand et al., 2000, p. 213).



This combination of spatial orders and type acts as a mapping process, one Ludger Hovestadt and Vera Buhlmann describe as an 'object of functional mappings and rational calculation' (Hovestadt & Bühlmann, 2013, p. 297). Picon threads the positivist influence of science throughout mapping pattern to functional type to an 'inventory of architectural means and ends; a repertoire of formulas and programs that he would attempt to systematize' (Picon, 2000, p. 6). Through proportion and typology, Durand's composition portrayed architecture as functional but based on an unseen order arrived at through analysis. This analysis represented a beyond-human view of architecture as the patterns and orders detected arrived through a material technique of comparison external to the brain. Architecture, based on visual patterns of material elements whose proportions relied on historical precedents, aimed to elevate the human condition by engaging with unseen patterns. Therefore, data lent Durand's architecture a gravitas by aligning with science and taking on a cultural association of the universal and unquestionable.

The study of Durand's technique reveals that his systematic analysis and reduction into dimensions and proportions imposes an averaging force onto architecture. Mathematically, an average distributes within a range of values by smoothing out rather than extracting an optimal. When applied to an understanding of architecture as a distribution of measurements and ratios, Durand's column would smooth into the average of his measurements, producing a diagrammatical system for a column rather than a repeated set of traditions. This diagrammatical approach to orders appears in Durand's formal types (Figure 2-4) based on historical examples and measured observation. In Durand's systematic approach, his diagrammatic orders as averages did not provide the optimal as a moment of maximum efficiency or utility; instead, the average offered a foundation for safely and confidently progressing in design decision making.

Figure 2-4 – Durand's diagrammatical orders (Durand et al., 2000, p. 242)



Comparing Alberti's and Durand's practices uncovers different pioneering attitudes towards how architects abstractly represent reality through quantity. While Alberti used numbers to control communication, Durand used quantity to analyse architecture and set up architectural production systems. The common ground between both approaches is that instrumentation is used to translate between the physical and visual representations. However, while Alberti applied numbers to system control, Durand's use offered control over architecture's practical knowledge.

2.3 Material Mediation

Abstract measurement provides different practical intentions. For Alberti, it provided a precise connection between observation and instruction. For Durand, it helped generate rules to map observation onto forecasting. Common ground exists in how both Alberti and Durand developed abstracting techniques to represent material reality. This similarity reinforces the importance of material abstraction in the thesis and the relationship between data's origin and its role in the material means of its existence. The question arises of how each architect consciously set up and utilised a material interface to mediate between understanding the world and acting back on it.

Machined meanings

As highlighted earlier, Alberti's mapping apparatus produced and operated through a set of polar coordinates. Alberti's horizon's superimposed grid plotted abstract numbers into visual information, enabling information reproduction through a two-way process. Alberti's apparatus encapsulated a set of relationships that enabled the architect to capture reality and subsequently control a process of distributed production. Alberti's practice reads like an early claim for architectural responsibility, tasked with surveying and sharing information about the built environment. Through visually surveying Rome, Alberti produced a political territory for the architect and provided a precursor to their engagement with do-it-yourself production. Alberti's emerging architect required data to function as a communication mode, requiring a technological translation to produce information and form. Therefore, practice with the horizon would open new territory for generating meaning independent of an audience's knowledge or skill. This independent meaning would suggest that while his cultural and humanistic outlook placed the architect at the centre of observation, data originated more from the material qualities of recording through the instrument. As the horizon existed as a physical embodiment of Alberti's ideas, a cultural artefact, Alberti's data is equally understood as shaped by his material and cultural context.

In contrast to Alberti's figurative Rome mapping, Durand's measurement formed the basis of two practices: analysing architecture and composing and proposing architecture through spatial and functional mapping. The critical move in Durand's analytical and compositional approach was to treat architecture as an object with no regard for context. Durand's diagrams demonstrate the grid's importance in plotting and analysing the existing and composing new arrangements. To reconcile analysis with synthesis required establishing a standard and repeatable measurement embedded into material elements. In Durand's case, data did not enter practice through a translation; instead, a detected pattern found in a measured average set up a coordinating grid for practice. In Durand's hands, numbers set a basis for composition but did not provide a composition material; instead, they remained fixed within universal axioms established through analysis. Durand's quantified analysis technique lost connection to cultural meaning within this process when reduced purely to geometric forms and patterns deemed rearrangeable through classified types.

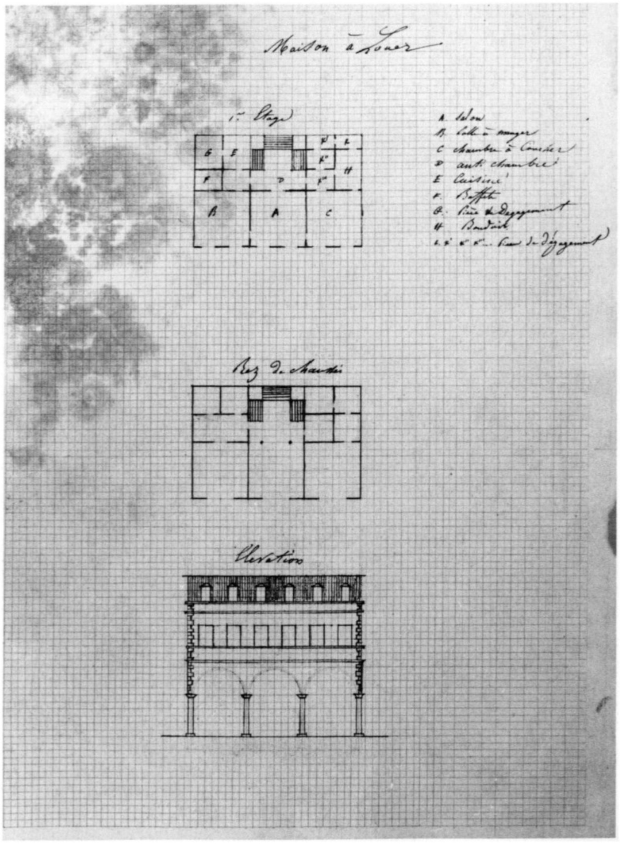
Unlike Alberti's understanding of the architect as a technically augmented observer, Durand's system of analysis and composition aimed for architects to elevate architecture's status through orders associated with scientific study but grounded to practical human use through type. In Durand's hands, data disconnected architecture from any cultural reading and instead required architecture's audience to interpret patterns in composition, thus removing the architect's ability to engage with symbolism or metaphor. Manfredo Tafuri calls Durand's approach a 'geometric silence' by reducing architecture to purely geometric and non-symbolic and codifying architecture through patterns (Tafuri & La Penta, 1976, p. 13). Alberto Perez-Gomez agrees with Tafuri but further critiques Durand's assumption that architecture could reduce into its elements and then recombine through a set of universal rules in the image of scientific data. Perez-Gomez highlights how Durand sought an 'objective space of descriptive geometry' that avoided any 'messiness of translation' when brought into a process of materialisation (Pérez-Gómez, 2016, p. 127). While measurement enabled Durand to rationalise architecture, its abstracting quality tended to break existing structures of meaning when used to forecast new forms. This abstraction gave Durand the freedom to explore universal meaning beyond aesthetics through pure mathematical forms.

Durand's loss of referential potential due to architecture's abstraction also applies to Alberti. Both architects sought to establish and manage a zone of human interpretation between data and information, which in both cases relied on the architect's observation partiality, with both claiming responsibility for selecting and filtering data. Through comparing Alberti and Durand, we see that each employed a mode of observation that replaced symbolic reference, and both number extraction and material translation became spaces of creative exploration. This filtering highlights how both aimed for authority over what observations did and did not become part of architectural practice. For example, Alberti's mapping considered material edges necessary to represent Rome, to the detriment of surface texture or colour. At the same time, Durand filtered to the extreme of only describing through an exclusionary system of dimensioning.

A quantised influence

Figure 2-5 presents one of Durand's working drawings, what Perez Gomez refers to as a 'technological instrument' (Pérez-Gómez, 2016, p. 101) that did not directly work with numbers but communicated a set of patterns extracted through analysis. Durand's compositional drawings presented material arrangements in an accurate, technical, and deliberate way, coordinated using graph paper, based on a 'module' gleaned from Durand's averaged elements (Durand et al., 2000, p. 56). Durand's module found practical action through the matrix quality of graph paper, providing a quick technique for generating form and what Picon describes as an 'instructional tool' for Durand's students (Picon, 2000, p. 41). Peter Collins links Durand's use of graph paper with a need to teach architecture quickly within a heavily weighted scientific syllabus and produce architecture that could compete with the speed of the machine (Collins, 1998). Collins's emphasis on Durand's economic ambitions in practice and construction shows how Durand's approach foresaw the cultural changes brought by increased mechanised production. The graph paper matrix originated from and maintained a set of data in practice and locked architecture into a palette of repeatable material forms.

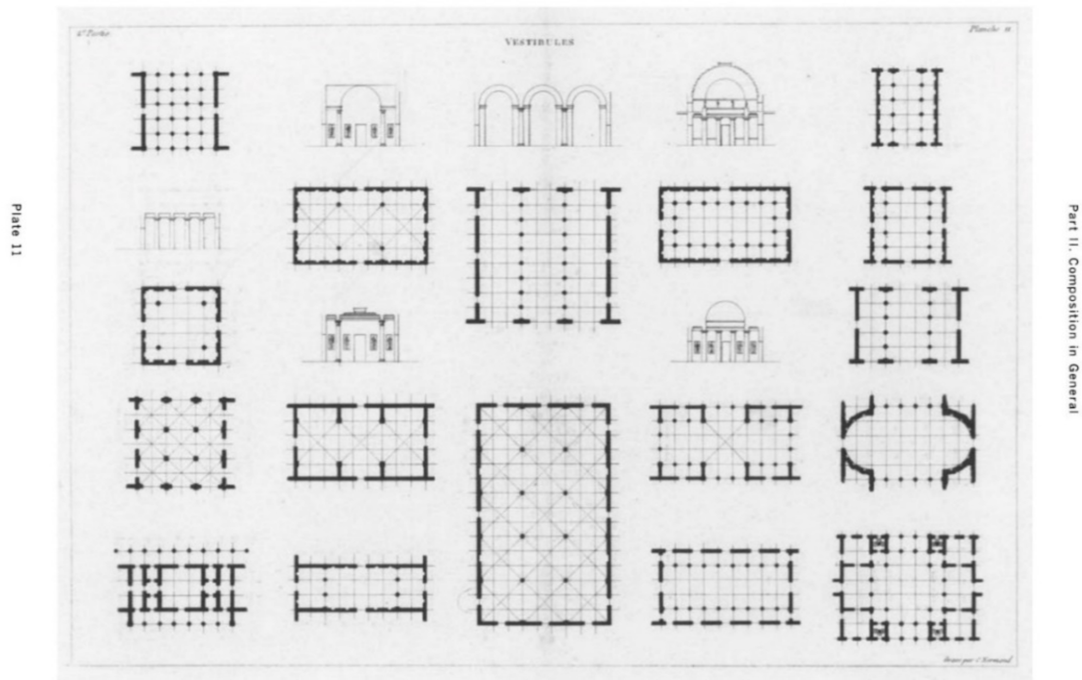
Figure 2-5 - Durand's competition entry for an apartment building (Durand et al., 2000, p. 30)



For Durand, the matrix served to apply his operational proportional patterns quickly. The cellular matrix governed a material arrangement space, guiding form towards square or rectangular proportions. The grid acted as a substrate for his measured and filtered data, offering an analogue precursor to how binary code logically organises within digital computation's pixelated interfaces. The discrete quality of Durand's gridded matrix defined the material resolution of his architecture and snapped compositional decisions into position. Durand's approach holds comparison with the gridded quantisation of digital music composition, a snapping of notes to a grid to eliminate imprecision in expressive performance. This non-human influence in precision compensates for musical skill but removes any potential 'swing' in the expert musical expression. Durand's matrix reads like a similar non-human quantising influence, but rather than compensating for skill, the module reduces a space of choice and directs a design decision-making process.

Alberti's horizon and Durand's matrix offer systems of precise coordination; however, a difference in application points to Durand's technique as a generative rather than replicating process. Durand's compositional matrix resulting from filtered and partial measurement calcified into rules made available to other receptive architects to forecast new designs. In contrast, Alberti's drawing instrument sought to replicate rather than forecast, and his material interface determined the origin and use of data. The implication for Durand's technique was to set up authority over a mode of architectural composition that resisted manipulation and adjustment due to the rigid nature of representation. Figure 2-6 shows how the grid technique, when used to forecast new architecture, restricted the geometric possibilities to a rectilinear arrangement of spatial and material proportions, correlating to a pre-conceived set of universal rules. The use of a quantified comparative matrix in design placed primacy on data regarding the material and structural, to the detriment of understanding human experience.

Figure 2-6 - Durand's use of the grid for analysis and composition (Durand et al., 2000, p. 223)



2.4 Conclusion – A Dual Identity

Leon Battista Alberti and Nicolas Louis Durand provide two pioneering approaches that assigned a contrasting character and influence on data. In both cases, recording and mapping numbers connected the architect to architectural production through measurement and pattern. Each considered measure a vital part of the architect's role but had differing ends.

The first key finding concerns Alberti placing primacy on the mapping of human observation into accurate and reproducible information. Through Alberti's surveying method, architects could control visual representation, gaining the ability to minimise information loss between observation and production. The architect gained precision and authority over translation and reproduction through a surveying apparatus acting as an interface between observation and information. For Alberti, this interface would restrict choice in mapping between data and information, giving the architect power over instructional ambiguity and material production. While Durand also recorded and represented architecture through quantity, he searched for proportional patterns to establish and justify architectural compositional rules rather than encoding translation. Durand's comparative quantities contributed to an emerging rationalist basis of architecture, where every design move arrived through a connection to an empirically measured origin. Durand's example of an early measuring and analysing practice provided a foundation for disciplinary knowledge that located the architect within the larger scientific project of this time. The common factor between Alberti and Durand's abstracting practices is the necessary existence of a material interface between the human observer and abstract representation. In both cases, material mediate between observation and number to remove error in composition; for Alberti, this involved plotting coordinates into visual information, while for Durand, his composing matrix resisted any hand-drawn expression.

Two initial characters and influences tie to Alberti and Durand's quantified abstraction. Alberti understood data as a means to remove meaning and transport information, to accurately translate between the physical real and visual representation. Data's influence on Alberti's practice sat in controlling a translative process between observation and representation, with no deviation in mapping allowed between the two. In short, data helped reproduce information through precise instruction. For Durand, data took on a different role in enabling the architect to forecast and propose buildings. For Durand, numbers uncovered architecture's proportions and these patterns, coupled with a compositional matrix technique, aimed to remove human error in composition and assist the architect in decision making.

Alberti and Durand's data practices introduce two trajectories that demonstrate data's historical presence in architecture: one of encoding and manipulating geometric information, the other guiding decision making through pattern-extracted rules. This important distinction caries across the thesis and registers in how architects use abstract measurement to control communication to instruct or establish disciplinary forecasting of knowledge. Both abstractions for communication and knowledge introduce assumptions and bias into practice. Within early science, the observer took on the responsibility to see objectively, sometimes unaware of their sensory limitations. Both Alberti and Durand required the architect to observe and abstract, critically deciding what and how to record. In both cases, the architect's trained eye and subjective sampling decisions meant that partiality existed as an architectural trait from the beginning.

The next chapter explores data's character and influence into the early twentieth century and uses the communication and knowledge distinction recognised in this chapter as a point of comparison.

Chapter 3: Optimal Metrics

Beyond the nineteenth century, more architects began to explore, celebrate, and exploit material interfaces for measurement and communication. The prevailing narrative concerning the architectural shift from the 1800 to 1900s portrays this period as an explosion of new material forms, radical theories and architectural roles emerging through an exploitation of industrialised production. Despite the wealth of attention this period has received, there is little understanding of data's role or influence during this time. Examining early twentieth century practices that engaged with abstract measurement uncovers a distinct character and influence from Alberti and Durand's example. Reinterpreting modernism through measurement identifies a shift from the communication/knowledge duality to architects controlling both through material-cultural systems, metrics, and standards. The chapter finds a connection between a more rationally led architect and the engineer's precise material measurement critical to the success of scientific knowledge. In contrast to Durand's historical study, this period places value on close measurement and abstraction of the body as a guiding scheme for analysing and composing architecture. From understanding Le Corbusier's 'metrics' in the portrayal of his 'new architecture', the chapter moves to consider data's role in design education, helping shape cultural expectations of optimisation and rationality in material use. The final section looks at the material influence of data's practical and cultural role through two case studies. The cases explore the role of scientific management in the 1926 Weißenhofsiedlung exhibition and Ernst Neufert's collation of repeatable measurements in the 1936 *Bauentwurfslehre* (Architects' Data Handbook) and discuss how architects began to bridge observation, forecasting and instruction through optimised metrics. Much work on this period portrays practice as an intense dialogue with production of new machines and the social consequences. An alternative depiction of this era is of architects began to exert and promote disciplinary control over observation to align forecasting and instruction with new functional predictability.

3.1 New Rules

From the early 1800s, the industrial revolution's disruptive division of human labour through machines produced new social and cultural contexts that stimulated new architectural responses. Modernism positioned architecture as a critical social project but establishing political status for it required a set of disciplinary knowledge and arguments that recognised the act of building as a social enterprise. With the backdrop of mechanised production, the engineer's cultural status as a skilled technician increased with the responsibility to devise and maintain machines. The engineer's role of understanding and manipulating the physical world required increasingly accurate observation techniques and measurement, setting up a relationship between technical accuracy, mathematical calculations, and technological progression. A progression of 'second-order technologies' emerged from industry — new machines invented through new accuracy of mechanical measurement (Floridi, 2014).

Le Corbusier's [Charles-Édouard Jeanneret's] book *Vers Une Architecture* (Towards an Architecture) (1927) directly refers to the engineer's preoccupation with measurement and calculation as an inspiration for a new architectural theory. A practice capable of providing 'truth' (Corbusier, 1927) linked the engineer's measurement to calculating optimal solutions to design problems. Le Corbusier's book set out an argument for architecture to engage with the materials and techniques associated with industrial production, just as the engineer did. Architects engaging with industry required greater control over material form and produced superior precision and utility. This praise for the engineer arose from a perception of practice, where 'forced to work in accordance with the strict needs of exactly determined conditions, engineers make use of form generating and form defining elements. They create limpid and moving plastic facts' (Corbusier, 1927, p. 2). Le Corbusier continues with his praise for engineering when he proclaims, 'today it is the engineer who knows, who knows the best way to construct, to heat, to ventilate, to light' (Corbusier, 1927, p. 5). Appropriating the engineer in Le Corbusier's rhetoric shifted positivist thinking into practices that could claim to know the *best* design solution based on measurement as material facts. Le Corbusier's argument likened architecture to understanding an engineering machine as 'true' material form. In *Vers Une Architecture*, Le Corbusier states, 'Architecture deals with quantities' *(Corbusier, 1927, p. 5)* to persuade the reader that architects must align themselves with the engineer's precision. Le Corbusier suggests that quantities brought objective reality into practice, equipping the architect with a palette of facts to argue design validity and portray architecture as an unquestionable truth.

Quantifying a 'New' Architecture

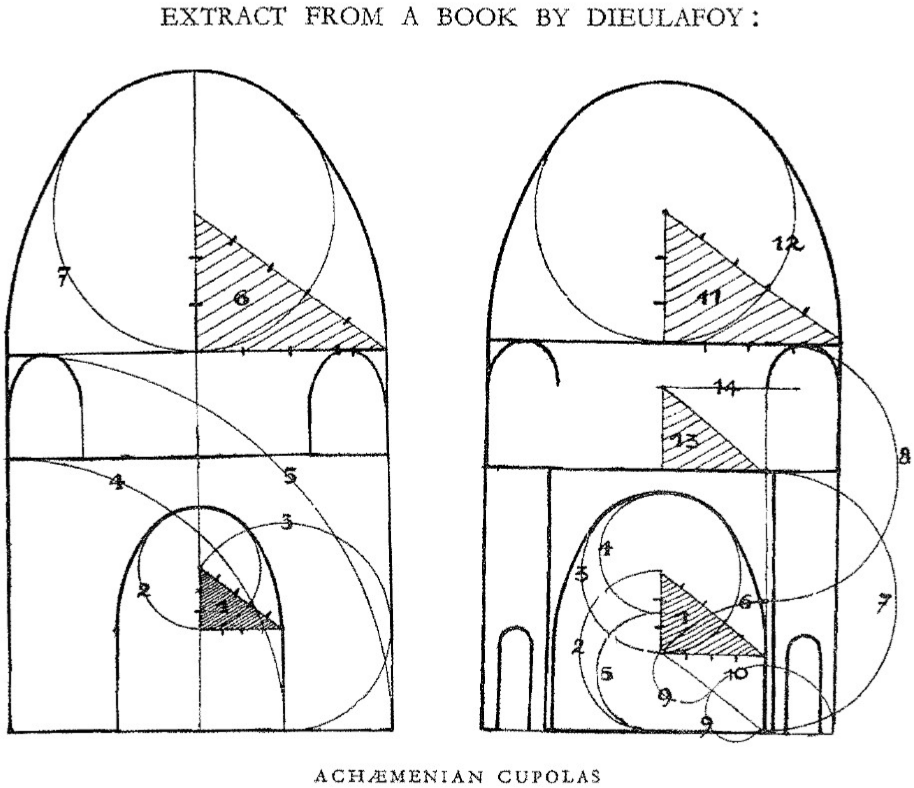
Unlike Durand, who used empirical measurement to evoke a natural 'truth' in architecture through precedents, Le Corbusier turned to other disciplines, patterns, and formulae for inspiration. Peter Collins points out that Le Corbusier's architecture did not refer to historical precedent as it sought to break free from the symbolism of past architecture. Instead, Le Corbusier referenced material objects created by the engineer's mathematical practice, leading to a fetishisation of objects such as boats, cars, or factory silos (Collins, 1998). The lack of precedent indicates that Le Corbusier did not seek architectural data; instead, he promoted engineering analysis and calculation as a new, culturally acceptable source of measurement and knowledge.

Le Corbusier only uses the term data once in *Vers Une Architecture*, stating:

"Once the conception of the cupola was established in accordance with the poetical needs of this race and of this epoch, and in accordance with the *static data* of the constructive principles applied to it, the regulating lines come in to rectify, correct, give point to and pull together all the parts on the same unifying principle, that of the triangle which develops its effects from the portico right up to the summit of the vault." (Corbusier, 1927, p. 77)

The reference to the 'static data of the constructive principles applied to it' indicates that Le Corbusier sought an argument for combining geometry with proportion, and found a suitable solution in the formulaic descriptions of nature. Such descriptions of nature resulted from scientific enquiry rather than architectural research, which brought science's objective ideology to design. What is more, the 'static data' suggests that Le Corbusier understood nature as fixed and universal, bound to 'constructive principles' of form. Le Corbusier continually uses the idea of 'governing lines' to argue that architecture should follow nature's rules. This idea of architecture as nature contrasts with Durand's argument that architecture had higher orders than nature (Figure 3-1). While Durand argued for beauty by studying architecture, Le Corbusier argued for beauty through the proportions and ratios extracted from a scientific study of nature, which promoted a positivist understanding linking mathematics and natural morphology.

Figure 3-1 - Le Corbusier's diagram describing regulated line and proportion (Corbusier, 1927, p. 76)



Maurice Basset reports that Le Corbusier rejected all measurements and instead relied upon 'rules of thumb' (Besset, 1987, p. 194), drawing a parallel with engineering practice. However, Basset offers a misleading account as Le Corbusier's practice sought to understand materials' and structures' behaviour, through the engineers precise measurement. While Le Corbusier did not consider measurement a necessary task for the architect, he referenced those he considered more capable of constructing scientific and mathematical representations of nature. Le Corbusier recognised that the engineers measure provided a much-needed functional argument for inventing material objects, considering engineered products as 'tools' forged out of a 'necessity', which (Corbusier, 1927, p. 14). Positioning architecture as a functionally engineered object associated design reasoning with natural laws that were beyond question. Le Corbusier's New Architecture provides an understanding away from architects having a data production responsibility, to inviting data in from other disciplines whose skills were far more potent for controlling and organising the material world

From orders to standards

In *Vers Une Architecture,* Le Corbusier announces, 'rhythm is a state of equilibrium which proceeds either from symmetries, simple or complex, or from delicate balancings ... rhythm is an equation' (Corbusier, 1927, p. 50). Le Corbusier's use of the word 'equation' signals an understanding of data's influence in this period. An equation, equating one thing with another in mathematics, provides a way of inference through comparison. At the time of *Vers Une Architecture* (first published 1927), statistics and mathematical tables provided a popular means of equating and reducing time and cognitive effort in a calculation, which altered data's cultural importance (Akera, 2007). A reference to 'equation' reasonably ties Le Corbusier's arguments to a desire to reduce the architect's required time and cognitive effort.

Additionally, calculation provided architecture with an engineering argument that material technologies could equate to specific social solutions. Central to this idea of equations were standards. Le Corbusier extolled the virtues of standardisation when he argued, 'architecture operates in accordance with standards. Standards are a matter of logic, analysis, and minute study; they are based on a problem which has been well stated' (Corbusier, 1927, p. 5). Le Corbusier's reference to minute study, analysis and experiment evokes scientific observation and hints at a relationship between measurement and standardisation that further problematises Maurice Basset earlier statement of rejecting measurement. Standardisation already existed within industrial production as early as 1800, from standard screw thread size for bolts and nuts to interchangeable parts for rifle manufacture (Ping, 2011). In the early twentieth century, standardisation began to creep into professions to achieve replicability and quality consistency (Carpo, 2011). Durand's lectures highlight how orders of ancient architecture read as early proportion standards; for example, Greek king Dorus standardised the Doric column sizes based on a man's foot as one-sixth of his overall height (Durand et al., 2000). Dorus's standards used the human body as a common language between craftsmen, helping them work collaboratively. Industrialised standards helped facilitate construction in the twentieth century and set a template for materialising products without difference. In this regard, standardisation operated in a way similar to Alberti's coordinate- and apparatus-controlled map reproduction but applied to architectural production.

Setting and controlling standards meant defining what logic, analysis, and minute study occurred in architecture. This restriction and control over what measurement entered practice benefited the architect on two fronts; it enabled more significant control over construction outcome and quality (Carpo, 2011), and provided material means to engage in scientific discourses of efficiency and optimisation. However, restricting measurement constrained the possibilities for architectural design. Nader Vossoughian highlights how setting standards constrained industrial production systems and regulated architectural decision-making by centralising and homogenising architectural knowledge, causing a routinisation of design and almost inviting plagiarism (Vossoughian, 2014, p. 49). Fixing measurement within standard material parts inadvertently transposed a cultural mode of repetition onto practice, which encouraged repeated processes and techniques that invited the formal homogenisation we now recognise in this era.

It is evident from *Vers Une Architecture* that Le Corbusier was aware of standardisation, placing a collective responsibility of standards-setting with the architect (Corbusier, 1927). Setting standards requires consensus or authority over the quality of a final product and the process required to achieve it. They afforded architects control over mass collaboration in production but risked promoting linear and pre-determined practices that set up causal expectations between practice and outcome. Through this repetitive influence, standardisation became a means for states to maintain control by normalising spatial relationships of social and political power (Vossoughian, 2014). Vossoughian argues that standardisation, or Normierung – institutionalised norms – was a project of information and knowledge coordination and control through material means (Vossoughian, 2014). An example of this control exists in the 'octometric brick', which Vossoughian points out, set to both build and regulate buildings based on a 24cm module, which in return altered the dimensions of the 'well proportioned' person (Vossoughian, 2014, p. 44). If standards sought to control information and knowledge through material objects, then the measures governing objects acted as a new architectural data which folded back onto the image of the human inhabitant. Vossoughian helps us understand this relationship between data's normalising influence when he points out that standardisation was a process that 'transforms the subject and not just the object' (Vossoughian, 2014, p. 49) as it shapes things as well as thought.

Standardisation fixed information and knowledge through material measures that influenced how buildings were built and experienced. Standardisation both helped and hindered architecture and society in the early twentieth century. It also meant the data bound within experiments and logic-defining dimensions and material proportions became fixed. Standards produced a fixed data memory and constrained tangible outcomes through defining material dimensions, possible configurations, and modes of construction during this time. In contrast to the flexibility inherent in Durand's proportional orders employed through the material matrix, standards imposed an increasingly quantified and homogenising influence on practice.

A body of data

Like the Doric columns shaped around the Greek man's body, early twentieth-century architecture reverted to the body to gain tighter control over standardisation. Historically, measurement through the body dominated architectural thinking. Most significant is Leonardo Davinci's ideal Vitruvian man, whose patriarchal construct presented a symmetrical, rightly proportioned, balanced human male at the centre of knowledge (Oranges et al., 2016). In Marcus Vitruvius Pollio's theory, the ideal man provided a basis for expressing proportional harmony and a reference point for describing and understanding architecture (Pollio et al., 1914). In Da Vinci's and Alberti's hands, accurate measurement of the human body produced relational systems to map, recreate and sculpt the ideal body, thus resisting the notion of individuality and promoting the idea of an optimal geometrical form based on unquestionable rules (Lester, 2012).

Durand's lectures highlight how Greek craftsmen did not produce consistently sized columns, for the Doric proportion system never stipulated *which* man set the scale (Durand et al., 2000). Subsequently, craftsmen formed architecture through various values relating to their social group. This way of working through a range of data changed after industrialisation, when machines relied on and required exact measurements for reproduction. Architecture, assembled from standardised material elements around the guiding principle of an 'ideal man' as an architectural subject, meant the human body once again became a means to connect architecture with the unquestionable rules of 'natural' proportion. Between 1930 and 1946, Ernst Neufert and Le Corbusier established separate dimensional descriptions of the body, leading to architectural rules. Twenty years after *Vers Une Architecture,* Le Corbusier's 'Le Modulor' proposed a proportional system for architecture based on the body, his Modulor Man (Figure 3-2). Le Modulor bolstered the argument that architecture should follow nature's patterns by arguing that the proportions also existed in the human body. Le Corbusier's Modulor man diagrammatically represented the body through the same logic of governing lines displayed in *Vers Une Architecture,* suggesting that the body and architecture commonly follow the same 'natural laws' and architecture is constructed around the body, which follows the constructive principles of nature. Much like Durand's averaged proportion, the Modulor Man initially obeyed an average European man's height (1.75m). However, the body's dimensions changed in Le Corbusier's attempt to calibrate imperial and metric measurements and establish control over European and American architecture, changing to 1.829m (6 feet) in 1946. Frank Zollner offers an alternative explanation to imperial and metric calibration, one that connects the height change to the ideal of six-foot detectives found in novels (Zollner, 2014). Whether the change arrived through unit translation or cultural construct, the standardised body assisted architectural construction by setting dimensions or conforming to an existing measurement system.

Figure 3-2 - Le Corbusier's Modulor Man (Corbusier, 1968, p. 49)

[Production Note]

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Le Corbusier's intention for Le Modulor was to create an architectural unit, a 'quantum', a unit of measurement that could 'regulate the whole work and this work is on its scale to his own proportion' (Corbusier, 1927, p. 64). The quantum gave Le Corbusier control over practical measurement, which adjusted to conform to proportions borrowed from the mathematical golden section rule based on the number Phi. Richard Padovan describes Le Corbusier's system as an 'imposition of a rational mathematical schema upon a generalised image of the body' (Padovan, 2002, p. 331). In Padovan's description, he considers the Modulor Man as an interface between two data sets, a mathematical understanding of nature, and Le Corbusier's understanding of the European male body. Padovan refers directly to data within this interface when he refers to the Modulor as 'a fitting together of two mutually complementary but not identical sets of data: the experience of nature's endless variation, and our human, intellectual desire for order and unity' (Padovan, 2002, p. 332). Le Corbusier's control over abstracting and representing the European male body provided a way to control architectural production and align practice with the increasing certainty born from mathematical and statistical modelling.

In contrast to Durand's scientific proportional systems for re-composition, Le Corbusier used nature through the body as a guiding set of constructive principles. The data existing in the Modulor Man set up a new system to interpret and generate architecture. Additionally, the Modulor system afforded Le Corbusier power over architecture by instigating control over a construction system. Le Corbusier's Modulor Man has common ground with Alberti's control over material reproduction and devised a practical organisational method similar to Durand. On the one hand, Le Modulor attempted to improve translation between the architect's graphical representations and accurate material production through the body as a cultural mediator. At the same time, it provided a proportional system to analyse and compose architecture. The difference lay in changing data's origin, previously extracted from architecture; in Le Corbusier's case, it now entered from a single resource or from outside the discipline.

In addition to the 'Modulor Man' schema, Le Corbusier also produced a set of material objects, a measuring strip, a numerical reference table, and books that explained the system and the combinations possible from it (Cohen, 2014). Le Corbusier went as far as to patent the Modulor system in 1945, which, Cohen argues, confirmed his megalomaniac tendencies, as Le Modulor provided an instrument whereby Le Corbusier could maintain hegemony over post-war production (Cohen, 2014, p. 9). Controlling data and its translation through material cultural objects provided a political advantage within the architectural discipline and influence over competing ideas.

In summary, Le Corbusier's theory and practice did not work directly with data, which remained in the background through his alignment of engineering and architecture. As Le Corbusier's system of proportional calculation entered into architectural culture it was far more influential than the architect's personal measurement and analysis. Through the engineer's influence, architects gained precise understanding of structural forces, material performance and mathematical proportions. However, in Le Modulor, Le Corbusier inadvertently calcified a set of measurements and proportions through an imagined architectural subject oblivious of its European male bias. The data fixed into Le Modulor and the Modulor Man translated into expectations of the body's spatial performance, which imposed a spatially homogenising influence on the inhabitant. Through Le Corbusier, data does not register as something directly manipulated in practice; however, he did align architecture with new engineered precision, mathematical universality and assumed natural truth of human proportion. Architecture's admiration of engineering's efficiency and economy influenced architects to look for new sets of rules to design through, taken from use rather than historical progression. Efforts to collect and establish architectural measures, proportions and standards from materials and the body meant that a new set of rules entered the discipline, a potential territory of political influence for the architect, one which Le Corbusier was quick to exploit.

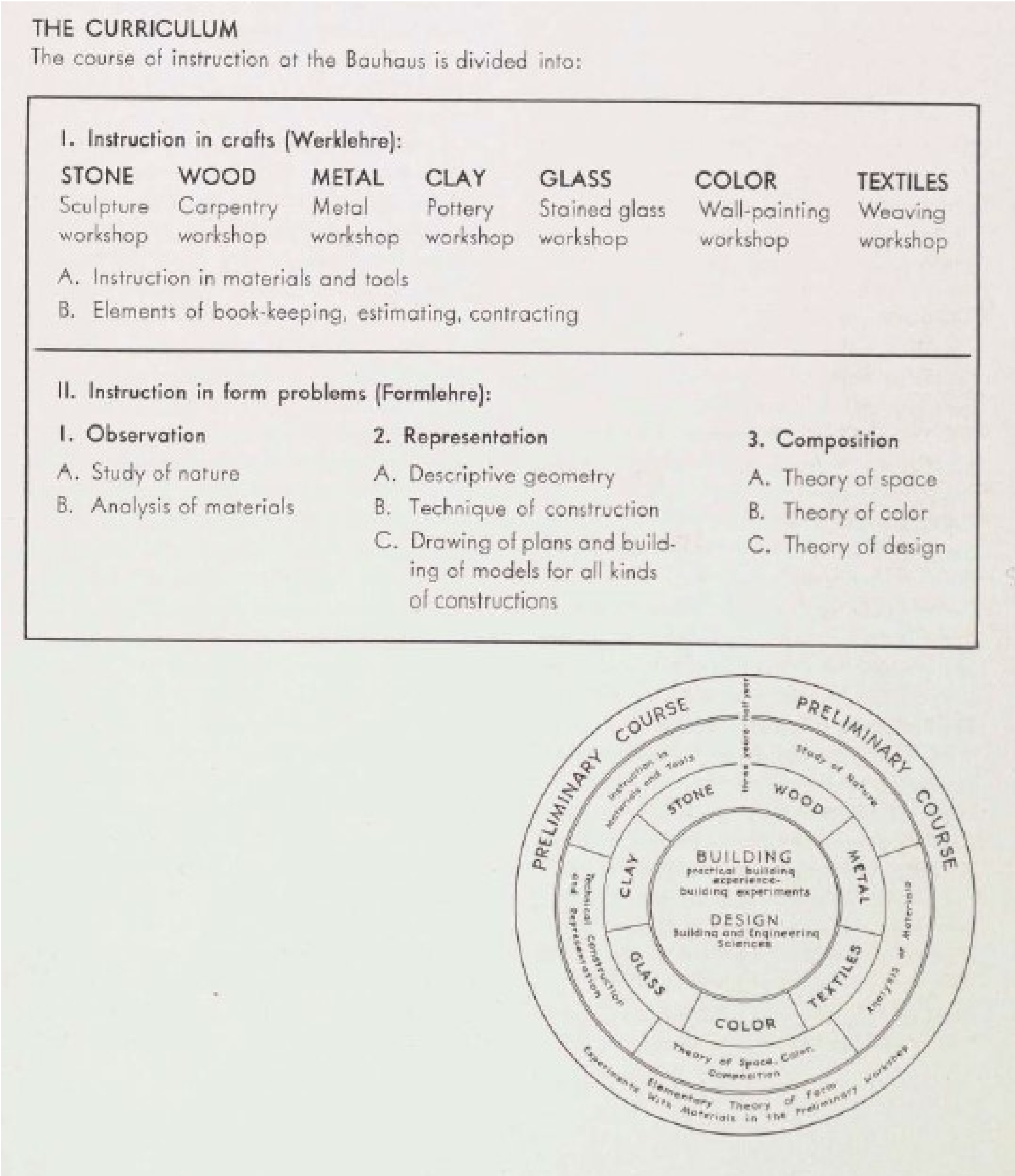
3.2 Predictable Process

Le Corbusier was not the only architect in the early twentieth century to explore the link between engineering and industrial production. While Le Corbusier used measurement and mathematical proportions to justify architecture as a system presented as 'universal' and 'true', in Walter Gropius's hands at the Bauhaus, the architectural concept of data shifted slightly through a return to processes of observation, analysis and design conceptualised as trained synthesis.

Architecture in a world of synthesis

The original Bauhaus curriculum split teaching into two domains, *Werklehre* (handicrafts), leading to a *Formlehre* (form theory) (Figure 3-3). The diagram shows an 'observation' stage for Formlehre, where empirical observation and abstraction begin to emerge. Studying nature and analysing materials through observation aligned to Gropius's stance — that architectural experience occurred at both a visual and material sensory level. This multi-sensory understanding is evident when Herbert Bayer quotes Gropius 'conception of space demands realisation in the material world, a realisation accomplished by the brain and hands. The brain conceives of mathematical space in terms of numbers and dimensions...The hand masters matter through crafts' (Bayer & Gropius, 1938, p. 24). At the Bauhaus, Johannes Itten's teaching combined both subjective and objective observation positioned design as a bridge between art and science. Itten instilled a means of understanding the world through the artist's register, interpreting subjective sensory experience and close, 'objective' technical measurements through abstract drawing and proportion (Siedenbrodt & Schöbe, 2009). This practice required an exact observation of nature, coupled with visualising and representing material accurately. In contrast to Le Corbusier, Itten reinstated the architect as the observer rather than referencing the engineer, and architects began to be tasked with absorbing new avenues of mechanical data into practice.

Figure 3-3 - Bauhaus Curriculum (Bayer & Gropius, 1938, p. 25)



THE CURRICULUM

The course of instruction at the Bauhaus is divided into:

I. Instruction in crafts (Werklehre):

STONE	WOOD	METAL	CLAY	GLASS	COLOR	TEXTILES
Sculpture workshop	Carpentry workshop	Metal workshop	Pottery workshop	Stained glass workshop	Wall-painting workshop	Weaving workshop

A. Instruction in materials and tools

B. Elements of book-keeping, estimating, contracting

II. Instruction in form problems (Formlehre):

1. Observation

A. Study of nature

B. Analysis of materials

2. Representation

A. Descriptive geometry

B. Technique of construction

C. Drawing of plans and building of models for all kinds of constructions

3. Composition

A. Theory of space

B. Theory of color

C. Theory of design

The Bauhaus's pedagogical mission of a 'new art of building' responded to a loss of handicraft caused by mechanisation and its perceived dehumanising and homogenising effect on society (Siedenbrodt & Schöbe, 2009). Driven by Walter Gropius, the 'new art' required students to understand space and form through analysis and produce designed products through manual trades and craft skills. By the mid-1920s, this predominantly tactile craft practice gave way to an engagement with industrial production. In a politically fractured country, culture offered the clearest territory for action towards the new German Republic, and the early Bauhaus of Gropius set about trying to unify cultural influences, impulses, and trends, to ‘develop an image of the world in synthesis’ (Siedenbrodt & Schöbe, 2009, p. 17).

However, producing a coherent synthesis schema required a method of analysis that architects could use to render the world knowable. Their response was ‘nature research’, where Itten and Gropius demanded a ‘systematic training of all the senses to know and understand one’s environment’ (Siedenbrodt & Schöbe, 2009, p. 72). Gropius’s and Itten’s interest in nature expanded on Le Corbusier’s visual and proportional use of the processes found in nature that produced optimal forms fit for purpose (Siedenbrodt & Schöbe, 2009, p. 130). The Bauhaus curriculum used nature as a constructional model for teaching design. Nature provided a ‘true’ functionalism appliable to human environmental well-being (Anker, 2010). Nature research holds similarity to Durand’s functional typology analysis; however, Gropius’s ambition was for architects to produce their own visual data sets through precise measurement. Data collection became part of a practice and considered measurement a foundation for understanding within design.

The Bauhaus pedagogically imparted a responsibility on the designer to systematically generate empirical data. This systematic approach extended Durand’s idea of establishing and transporting architectural knowledge through practice, with the distinction that nature now set the focus of analysis, not architecture’s formal cannon.

Calculated prediction

Taking nature and its biological processes as a driver for form continued to align design with science while initiating new explorations into design as a scientific method. Alexander Klein (1878-1960), a German architectural contemporary of Walter Gropius, provides an example of such an architect engaging data through a mathematically rigorous design methodology translating quantified analysis into rational design decisions (Bevilacqua, 2011). In Klein’s work on German housing quantified analysis drove decisions regarding types and combinations of lodgings. Klein sought an ‘existenzminimum’, an idea shared with Walter Gropius that called for an architectural morality based on minimum provisions of space, air, light, and heat to achieve building function. Klein’s solution was to treat apartment units as a problem of optimal and efficient spatial arrangement, requiring precise understanding and comparison.

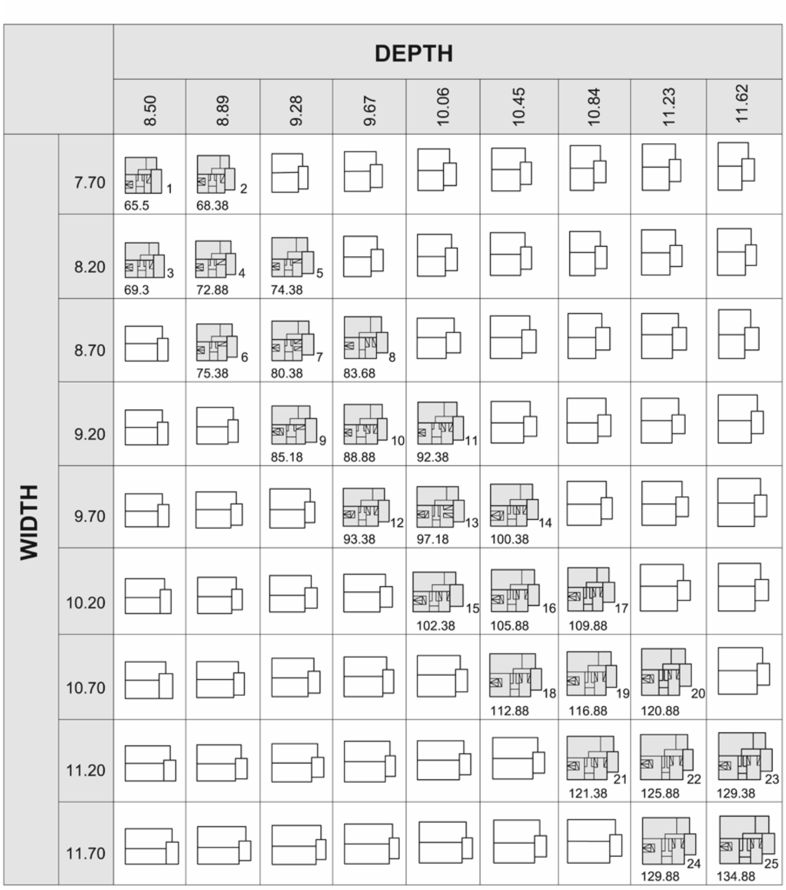
Marco Giorgio Bevilacqua describes Klein’s process as quantified measurement of both the construction problem -- building materials, geographic and cultural context -- and the lodging requirements of the inhabitants — such as hygiene and psychology (Bevilacqua, 2011). Klein created scales and scores to establish a 'scoring' system for evaluating unit types as a solution (Figure 3-4). Klein's practice used quantity to correlate between material form and space to evaluate and aid design decision-making.

Figure 3-4 - Alexander Klein's quantified questionnaire design analysis (Bevilacqua, 2011, p. 302)

11	10	9	8	7	6	5	4	3	PROJECT NR.			
65.76	75.46	73.14	89.40	90.00	80.94	88.00	66.82	74.18	1	BUILT AREA	MAIN CHARACTERS OF THE HOUSE	ECONOMIC ASPECTS
274	324	314	393	387	360	392	283	319	2	BUILT VOLUME		
51.47	53.18	64.45	63.02	65.45	61.33	65.90	51.10	58.35	3	USED AREA		
2	1.5	2.5	2.5	2.5	2.5	2.5	2	2	4	AMOUNT OF ROOMS		
2	3	3	4	3	3	2.5	2	2	5	AMOUNT OF BEDS		
32.90	25.15	29.76	22.26	30.00	26.98	29.33	33.41	37.09	6	BETTEFFEKT: 1/5		
137	108	128	98	129	120	131	141	159	7	BUILT VOLUME PER BED 2/5		
16.40		20.60	20.00	17.30	20.00	21.00	20.25	24.10	8	LIVING ROOM'S AREA	MAIN ROOMS	
13.50	32.60	22.60	26.45	28.95	22.75	24.40	14.00	13.90	9	BEDROOM'S AREA		
29.90	32.60	43.20	46.45	46.25	42.75	45.40	34.25	38.00	10	RESULTING AREA 8+9		
15.30	11.40	11.30	8.70	10.60	10.80	11.20	9.80	9.75	11	KITCHEN'S AREA	SECONDARY ROOMS	
3.85	4.32	4.75	3.92	4.30	4.00	5.00	3.65	4.20	12	BATHROOM'S AREA		
2.42	4.86	5.20	3.95	4.30	3.78	4.30	3.40	6.40	13	SERVICE AREA		
21.57	20.58	21.25	16.57	19.20	18.58	20.50	16.85	20.35	14	RESULTING SERVICE AREA 11+12+13		
0.783	0.705	0.722	0.705	0.727	0.758	0.749	0.765	0.787	15	NUTZEFFEKT: 3/1	COEFF.	
0.455	0.432	0.483	0.520	0.514	0.528	0.516	0.512	0.512	16	WOHNEFFEKT: (8+9)/1		
+	+	-	+	-	-	-	+	+	17	Is the orientation homogeneous both in the living and in the bedrooms?	HYGIENIC ASPECTS	
-	-	-	+	-	+	-	-	+	18	shadows avoided in living and bedrooms ?		
-	-	-	+	-	+	-	-	+	19	Is the light sufficient ?		
+	-	+	+	+	+	+	+	+	20	not-served rooms avoided?	CHARACTERISTICS REGARDING THE HABITABILITY	
-	-	-	-	-	-	-	-	-	21	may children be divided in base of the their sex ?		
-	-	-	-	-	-	-	-	-	22	Is the rooms' dislocation good for the habitibility?		
-	-	-	-	-	-	-	+	-	23	Is the bathroom separated from the toilette?		
-	+	+	+	+	+	-	-	+	24	Is the access to the loggia indipendent from bedrooms?		
+	+	-	-	-	+	-	-	-	25	Is the position of doors and windows good for the furniture's disposition?		
-	-	-	-	-	-	-	-	-	26	Are bathroom and w.c. adjacent to bedrooms and indipendent of them?		
-	-	-	-	-	-	-	-	-	27	Are there spaces for wardrobes?		
+	-	-	-	-	+	-	-	+	28	Are movement areas concentrated?		
-	-	+	+	+	+	-	+	-	29	Are rooms differentiated in base of use and dimensions?	SPATIAL AND DISTRIBUTIVE CHARACTERISTICS	
+	-	-	+	-	+	+	+	-	30	Disadvantageous connections between rooms avoided?		
-	-	-	-	-	-	-	-	-	31	Are rooms well connected?		
-	-	-	-	-	+	-	-	+	32	Is the light aesthetically good?		
-	-	-	-	-	-	-	-	-	33	Are encumbrances reduced using wall-wardrobes?		
+5	+3	+3	+7	+3	+9	+2	+5	+7	SCORE			

Klein applied quantity to score each configuration and sought correlations between spatial ratios to objectively compare plans between a total built area and the number of beds (Bevilacqua, 2011). Klein then applied his evaluation system to planning spatial layouts via a matrix, as shown in Figure 3-5. The matrix's axis became a range used for managing incremental differences in plan and evaluation towards a 'best' in terms of profitability and habitability (Bevilacqua, 2011). Klein's data existed as an input in a system of comparison and evaluation, which presumed design could argue for a 'best' solution based on quantity. This idea of the 'best' emerging from calculation was contrary to the previous justification of architecture as a ‘truth’ through a trusted set of proportional rules. Klein’s approach offers a moment where statistical prediction seeped into the architectural consciousness and a possibility for practice to lay claim to a predictive capacity of evaluation; therefore, aligning spatial planning with the burgeoning predictive sciences.

Figure 3-5 - Alexander Klein’s evaluative method (Bevilacqua, 2011, p. 305)



Klein’s approach and assumptions regarding quantifying architecture set his practice apart from other architects at the time. Bevilacqua describes how quantity aimed to remove the irrational, emotional, or personal interpretations from planning, thus connecting objective quantity with a non-human aid in decision making (Bevilacqua, 2011). Klein’s practice provides a case where quantity provided a rational basis for understanding architecture, which formed a basis for evaluating and predicting a design outcome's success. Therefore, Klein’s quantified spatial correlation comparison provided planning with a link between present and future. However, in doing so, he locked spatial planning into an ideology of optimisation and efficiency with disregard for architecture’s communicative capacity. Due to the rigid correlation of decision making to quantity, Klein's approach reads like an early data-driven approach, offering a prelude to the modern-day data-driven design paradigm discussed in future chapters.

As architecture established and mobilised new rules of design and construction for practice, a new use of data arose that conceptualised architecture as an optimal calculation. Understanding architectural planning as a calculation extracted rules from architectural function and programming by reversing the logic of abstract measurement. Data representing material and spatial measurements afforded the architect a process of forecasting that could calibrate spatial correlations and predict material outcomes through an alternative evaluative framework of optimisation.

3.3 Controlling Communication

Two case studies, the *Weißenhofsiedlung* and Neufert's *Bauentwurfslehre,* help understand influence through quantified measurement, analysis, calculation, and standardisation propagated into the architectural culture. Both cases connect to how data's cultural significance, through scientific analysis and technical representation, formed a design reference to validate decisions and transmit ideas. The previous examples of Le Corbusier, The Bauhaus and Alexander Klein highlighted how the precision and speed of machine observation became embedded into rational and efficient practices. Data's cultural influence in precise measurement began to play a significant role in scientific methods used to understand and manage productivity. Frederick Winslow Taylor's scientific management, emerging in 1911, sought to transfer the idea of industrial material standardisation to production processes. Taylor applied machines to measure motion in time. While his technique (Taylorism) aimed for human benefit through efficiency, it perversely led to exploiting human labour to gain a competitive advantage (Lohr, 2015). Mauro Guillén recognises that the United Kingdom and Germany offered very different cultural interpretations of Taylor's methods, with the former suspicious of its 'inhuman' nature and the latter celebrating the emancipation potential of time efficiency (Guillén, 2008). That these contrasting views arrived from the same technique alludes to how assumptions about cultural knowledge production shaped application.

Uncritical replications

Taylor's quantified task efficiency technique, through tape measure and stopwatch, treated the body's movement as an optimisable system, while ignoring psychological or physiological consequences. Larry Hirschhorn argues that Taylor's quantified work efficiency introduced a cultural norm in which unquantifiable aspects of context such as emotion became unnecessary to produce an idea of the 'best' outcome (Hirschhorn, 1986). In business terms, increasingly available scientific knowledge propagated the idea that a task could have an optimally efficient method that increased its prospect of becoming a repeatable action. When measurements of movement and energy in space uncovered potential efficiency patterns, an idea of the 'optimal' data became a favoured and repeatable set from which to work. Durand's idea that architects employ existing sets of favoured and repeated spatial axioms connects to this cultural shift. However, for Taylor, quantity explicitly measured space and time, leading to the scientific management of human movement.

Scientific management met with architecture through Christine Frederick's household study (Frederick, 1919). Fredrick, an American home economist, applied Taylorism to the idea of efficiency in domestic work to save female householders time and energy. Karin Kirsch describes how Fredrick's ideas arrived in the architectural consciousness through kitchen design. German architect Erna Meyer and Austrian architect Margarete Schutte-Lihotzky (1897-2000) applied Frederick's ambitions and Taylor's principles to spatial planning, producing the 'Stuttgart Small Kitchen' (Figure 3-7) and the 'Frankfurt Kitchen' (Figure 3-6) (Kirsch, 2013). Both schemes organised the kitchen around scientifically observed functional requirements of a female housekeeper. They presented the kitchen as a rationalised and optimal material arrangement to save time in domestic activities.

Figure 3-6 - Margarete Schutte-Lihotzky's Frankfurt Kitchen planning drawings (Kirsch, 2013, p. 25)

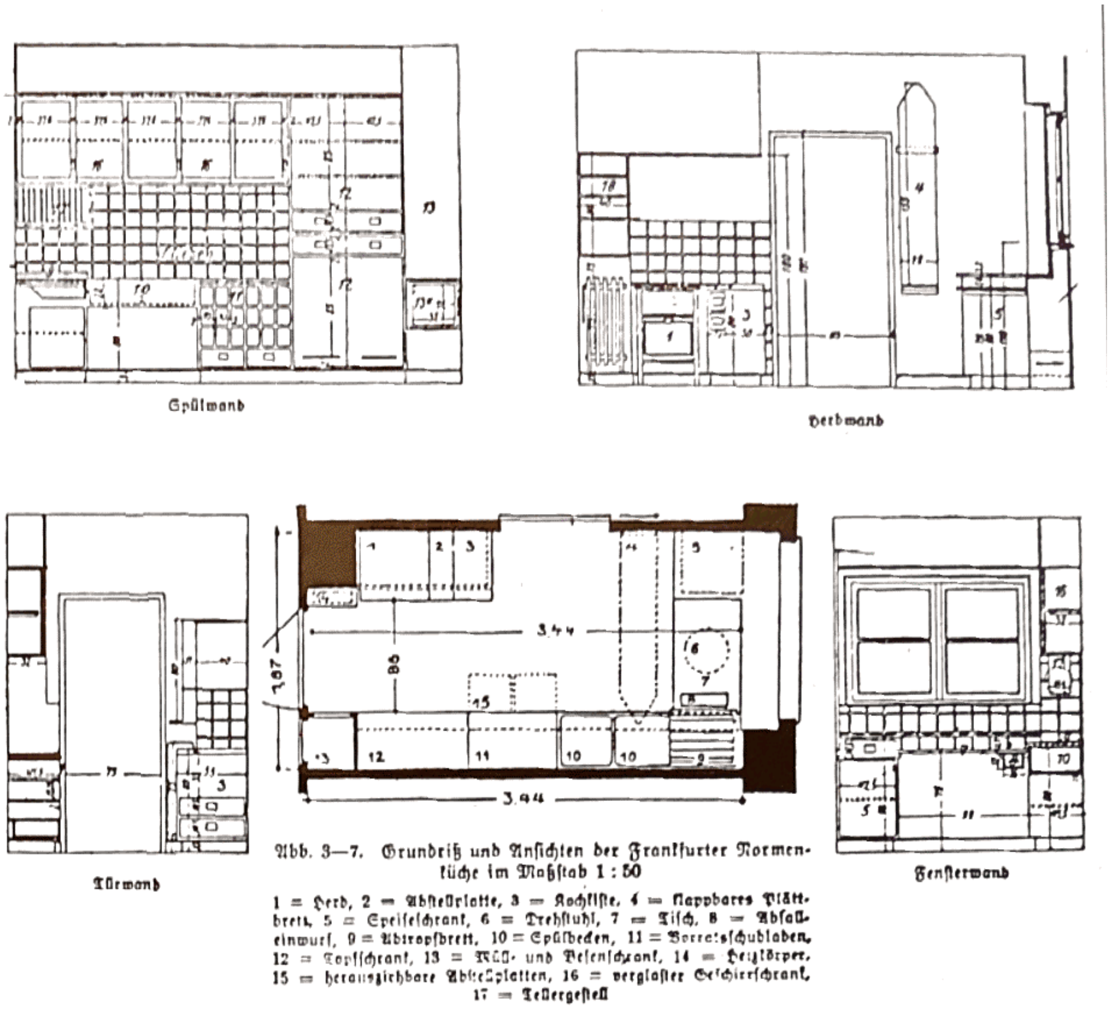
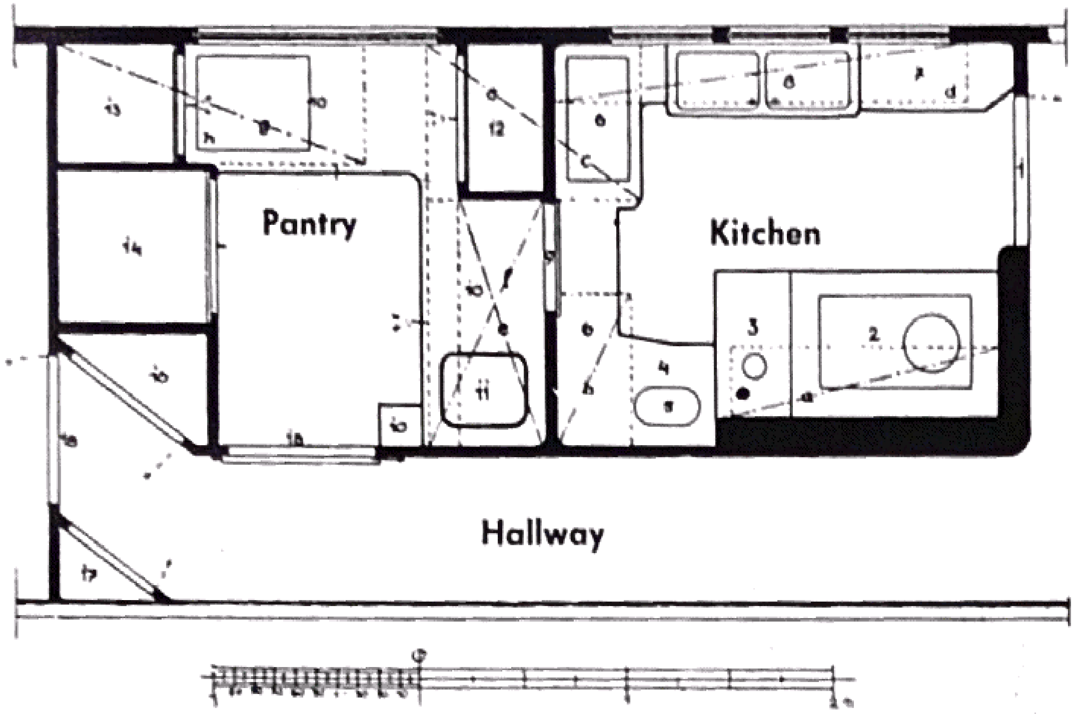


Figure 3-7 - Erna Meyer's planning drawings for the Stuttgart Kitchen (Kirsch, 2013, p. 26)

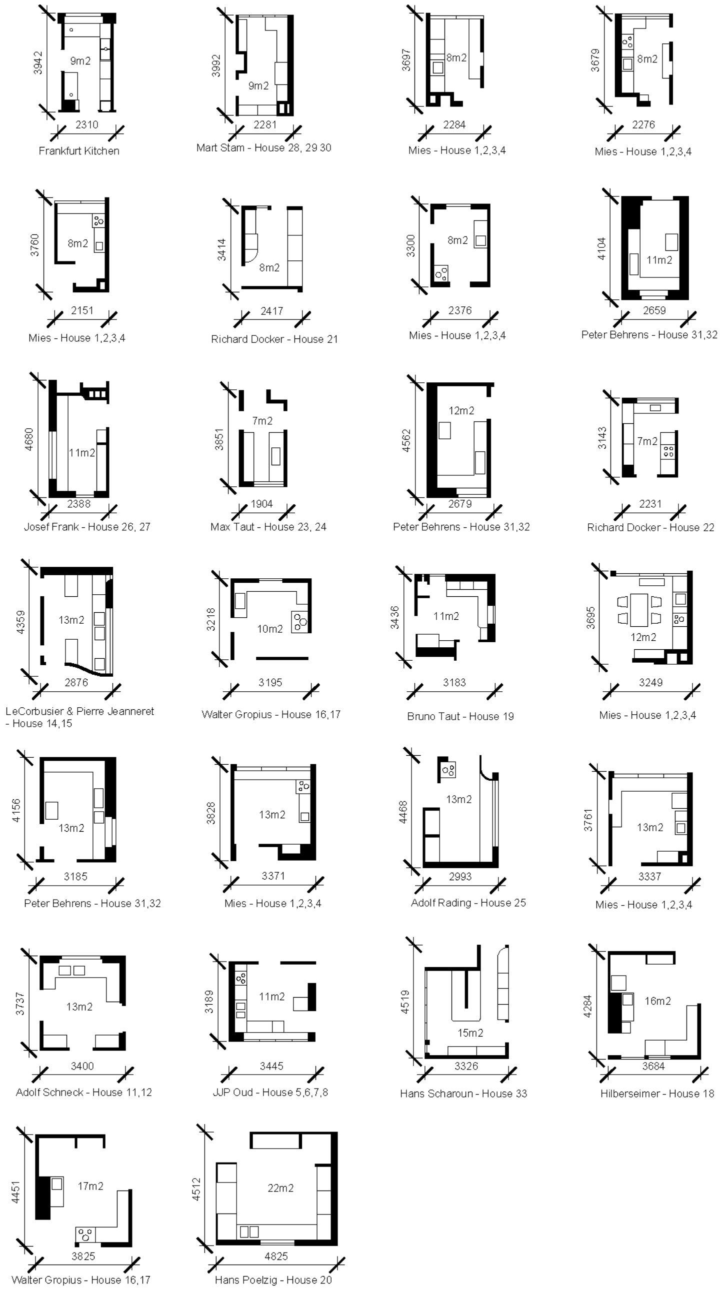


In both cases, data entered architectural planning through Fredrick's time-motion studies, resulting in a set of spatial and material dimensions aimed at minimum movement in a kitchen. The two kitchen designs and associated plan drawings presented kitchens justified through scientific measurement, portrayed as objectively optimal solutions. Understood as a continuation of Gropius's Existenzminimum thinking, the kitchen designs promoted by Meyer and Schutte-Lihotzky shaped around the minimum space required to achieve a task, a time and space for ironing or cooking, became a fixed location, distance and direction or intended movement. Each design's claims for optimal efficiency were immersed easily and quickly into German architectural thinking that equated material and spatial waste with economic and social failure (Barnstone, 2016). Additionally, Taylorism's reputation for rationally and objectively improving industrial productivity and economic benefits transferred over to kitchen designs that masked the adverse effects of efficiency and the banality of repetitive movements.

In 1926, the Deutsche Werkbund organised an exhibition to promote German design and architecture to solve a lack of housing experienced in Germany after WW1. The Weißenhofsiedlung, a planned estate of built housing prototypes, offers a moment where the concepts encapsulated within modernism find material form towards a 'new architecture' to reshape Germany's social and cultural identities (Kirsch, 2013). However, the *Weißenhofsiedlung* also reads as an instance where a scientific understanding of space transfers into the built products of an emerging modern architecture. Although it is not possible to detect the term 'data' in the literature concerning the project, it registers in Margarete Schutte-Lihotzky and Erna Meyer's Taylorist approach to optimised planning that propagated across the project.

In several houses completed at the Weißenhofsiedlung, it is possible to trace a vector of influence from Taylorist analysis to a new representation mode that directly registered measurement. While the economic management analysis applied to space did not refer to data, the presence of time and distance recommendations introduced an authority and meaning promoting its use. There is evidence that Mies van der Rohe distributed Margarete Schutte-Lihotzky's Frankfurt kitchen planning guidelines within the project (Kirsch, 2013), suggesting the drawing circulated as a cultural object. The kitchen plan and elevation contained millimetre dimensions (Figure 3-6). However, this is not unusual for construction using a drawing to plan; arguably, the image transferred the kitchen from the status of an idea to a proposal. Measurements presented as data in kitchen drawings likely increased its absorption into practice and many of the exhibition's schemes. Figure 3-8 compares the Weißenhofsiedlung kitchens and indicates that the Frankfurt Kitchen dimensions found their way into many schemes. While the comparison shows that not all kitchen designs adhered to the Frankfurt guidelines, more than half of the schemes are within a metre in the original kitchen's dimensions or floor area.

Figure 3-8 - Author's comparison of kitchen schemes at Weissenhof Seidlung.



It is impossible to state with certainty that the Frankfurt Kitchen had a deterministic effect on the schemes because of the complex social and cultural interactions within the Seidlung project. However, it logically follows that as science produced economic benefit and economics aligned so closely with household management, applying a proposal backed with scientific measurement could occur with little critical response. The similarity in areas and dimensions across the Weissenhof may have been as much a consequence of Erna Meyer's status as a consultant at the behest of Mies van der Rohe (Kirsch, 2013). However, there is no archival evidence to suggest that Meyer stipulated kitchen planning had to adhere to either the Frankfurt or Stuttgart kitchen. It is more likely that the presence of specific measurements under the cultural backdrop of scientific management rendered the kitchen a quick and readily justifiable addition to the overall spatial arrangement.

The scientifically justified Frankfurt and Stuttgart kitchens presented optimal design solutions to the problem of energy efficient domestic space. Arranged through a rigorous rationale of distance and time minimisation, each kitchen presents an early example of data driving the architect's decision making. Similar to Alberti's coordinated communication, the kitchens materially translate domestic labour data sets. The quantified measurements embedded in the kitchens arrangement set a logic for its existence and provided an argument for spatial planning. In contrast to the architect taking control of measurement and translation as Alberti intended, the data embedded into the optimal kitchen imbued design with a cultural significance and a reason for mass replication.

An architect's data

In 1936, 10 years after the *Weißenhofsiedlung* exhibition, Ernst Neufert, a professor of architecture at the State University of Applied Sciences in Weimar, produced a book based on his lectures. This textbook, entitled *Bauentwurfslehre*, from the German '*bauen*' (building) and '*entwerfen*' (design), sought to record Neufert's knowledge, gained through architectural education, practice, and experience (Delmes, 2015), systematically and objectively. In 1970, Rudolf Herz translated *Bauentwurfslehre* into English, and the book title changed to *Architects' Data,* evidencing a conscious relationship between architects and data, at least in English speaking countries. The book provided the first systematic collection and communication of experience gained in practice. Neufert's book aimed to provide a framework for assessing buildings' dimensions and their constituent parts via a 'theory of planning' (Neufert, 1936, p. 13) based on the human being. The book collated and presented material, spatial, and ergonomic situations through drawings and quantities organised into categories of building elements and architectural types. This initial description makes it possible to read the Bauhaus's influence, particularly the systematic analysis taught by Johannes Itten, who tutored the year Neufert attended in 1919. As discussed earlier, Itten taught design through the creative exploration of materials and form and analysed precedents through mathematical abstraction of measurements and proportions as the basis for a re-composition through abstract drawing. The book's content and layout presented measurement like a scientific data reference (Figure 3-10).

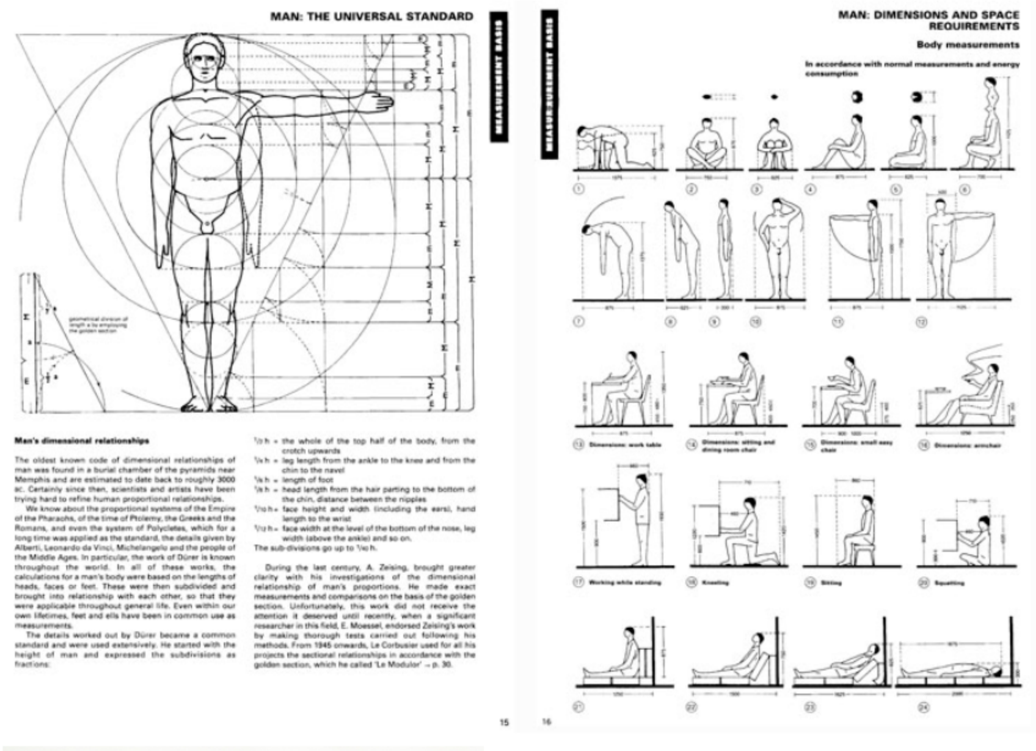
Nadir Vossoughian highlights that both the Bauhaus and the State University of Applied Sciences, where Neufert taught, attempted to reconcile education with the profession through a more efficient type of architectural production and means of communication (Vossoughian, 2014). Through this lens of education and profession, Neufert's *Bauentwurfslehre* reads as an attempt to improve production efficiency through a set of standard spatial scenarios, each tied to a physical outcome through measurement. The book provides accurate and repeatable spatial patterns that could achieve rapid material action for the masses and continues a line of thinking present in Durand's practice and pedagogy through scientific management ideology. In this sense, Neufert connected data directly to a mode of production.

While Le Corbusier's and Gropius's thinking linked architectural standards to nature's rationality, Vossoughian describes how standards also became instruments for statecraft (Vossoughian, 2014). In architectural practice, standards enable collaboration and provide a way to calibrate broader expectations in quality. Defining a standard required an in-depth understanding, which scientific analysis could provide. A new standard required a base of evidence justifying its use. However, the broader project of quantified knowledge experienced during and after WW2 found socialisation through architecture as a cultural channel (Vossoughian, 2014). Therefore, defining and controlling data within the standardisation project became important, meaning whoever set the standard set the data.

Neufert's book provides an example of the architect constructing a cultural perception through research authority and a design method that set data, standards, and proportions. In the 1970 translation of *Bauentwurfslehre*, Rudolf Herz states, 'time-consuming research into user requirements wasting so many assistants' hours has largely been eliminated, and information and experiences for many different building types have been gathered, analysed and developed' (Herz, 1970, p. 5). According to Herz, Neufert's book was to free architects from time-consuming 'research' and increase their creative activity. By externalising the architect's data into a book, Herz viewed the architect unburdened from storing and filing, in turn reducing their 'mental load' (Herz, 1970, p. 13). Neufert expected each designer to take the measurements and standards embodied in parts of building arrangements to 'perforce arrangement [sic] all the essential components of the project himself to form a unified and imaginative construction' (Neufert, 1936, p. 13). In Neufert's terms, a set of architectural data took away the need for architects to research, leaving more time to monetise design services. Additionally, the handbook realigned thinking back to positivist science by promoting architecture as an applied collection of universal rules and axioms based on quantitative measurement.

The process of using the book, described in the first section of the *Data Handbook,* describes an approach to building design through typology, with data entering design once the spatial arrangements became clear (Figure 3-9). Neufert created types by incorporating previous 'building problems', models, and experiments from Neufert's experience, introduced through personal analysis and categorisation. This research act became a zone for efficiency and standardisation to help the architect save time and money in practice. However, Neufert did not anticipate that architects would, in practice, design by simply copying his work. Rudolf Herz's admission in the introduction to Neufert's English translation that the book's spatial scenarios risked appearing 'peremptory and doctrinaire' (Herz, 1970, p. 2) to the reader confirms this lack of anticipation. Herz's association between data, saving valuable time, and possible dogmatic application highlights how it played a critical role in how the now professional architect managed their economic pressures.

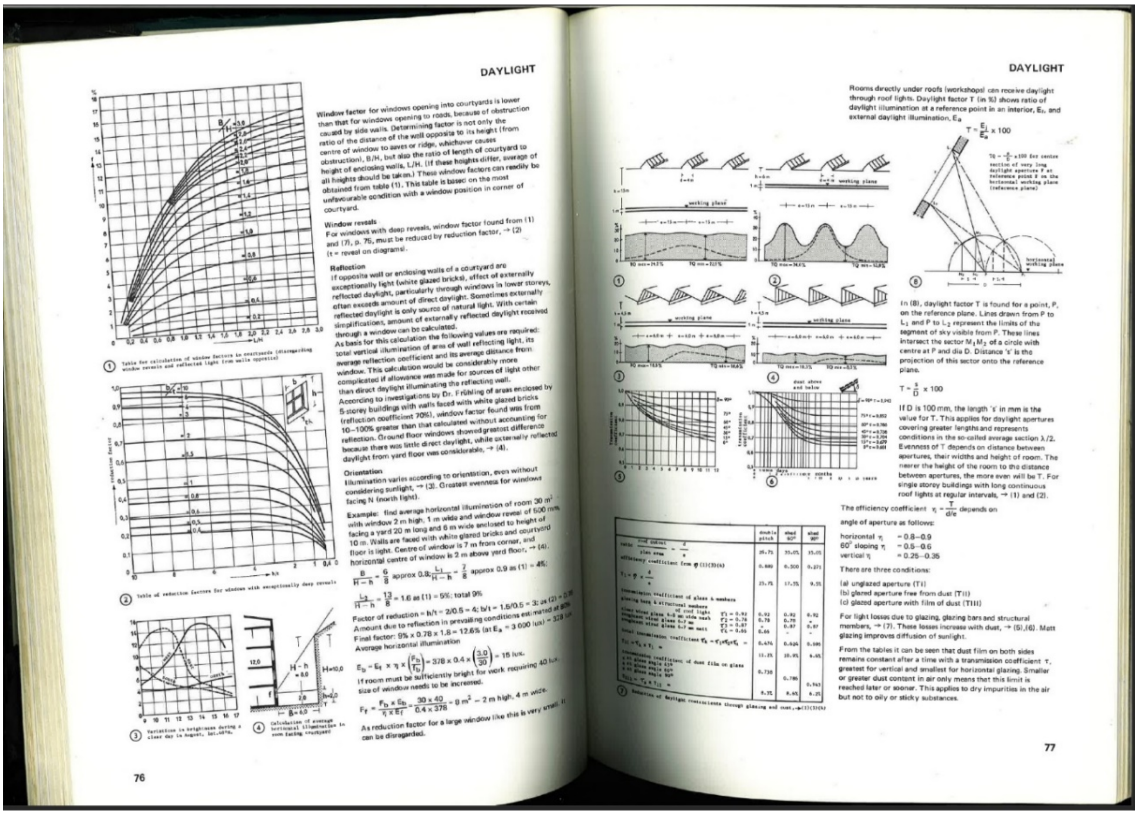
Figure 3-9 - Neufert's Functional Body Data (Neufert, 1970, p. 15)



Neufert's book of curated standards and metric measurements act like abstract parts of architecture waiting for combination. Each spatial abstraction presented in the book holds no meaning for architecture when considered individually but becomes significant when organised into a coherent scheme. As discussed in Chapter 1, structured and organised data produces information, and information influences how we think and act in the world. Using this reasoning, how architects organise their data could attain control over thinking and innovation. Neufert's *Bauentwurfslehre* organises standards and measurements in two ways: spatial situation and grouping into architectural types. This control over the organisation would conceivably influence the designer to think of architecture in terms of functionally driven internal requirements, with a risk of ignoring or unintentionally assuming external cultural or environmental contexts.

In Neufert's terms, architect's data are abstractions that offer quick and efficient answers to architectural problems. Neufert's data read as a set of quantified functional standards assumed to produce an ideal solution to a functional architectural problem. Also, in later editions, Neufert included quantities describing environmental phenomena, such as daylight and sound, promoting a more technical understanding of requirements. This inclusion of technical imagery indicates a trend for the architect to obtain interpretive skills more familiar to engineers (Figure 3-10). In this sense, the book's content and organising structure started to shape how the architect approached a design and interpreted design problems.

Figure 3-10 - Neufert's daylight measurements and calculations (Neufert, 1970, p. 76).



Considering the material form of the *Bauentwurfslehre*, data's influence manifests in two ways. Firstly, standards and measurements aligned architecture with reductive positivist science. Secondly, the book's paper and ink representations overlayed a framework onto its use. The material stability of the book meant it served as a reference that resisted manipulation and restricted the designer from alternative orderings. Neufert's book presented abstract parts for solutions while also influencing their possible combinations through how pages, sections, and chapters sat in the book. The handbook organised data into different functional requirements to impose seriality and linearly ordered procedures. Therefore, while the book provided a time-saving resource for the architect, it limited the overall information available due to its static nature.

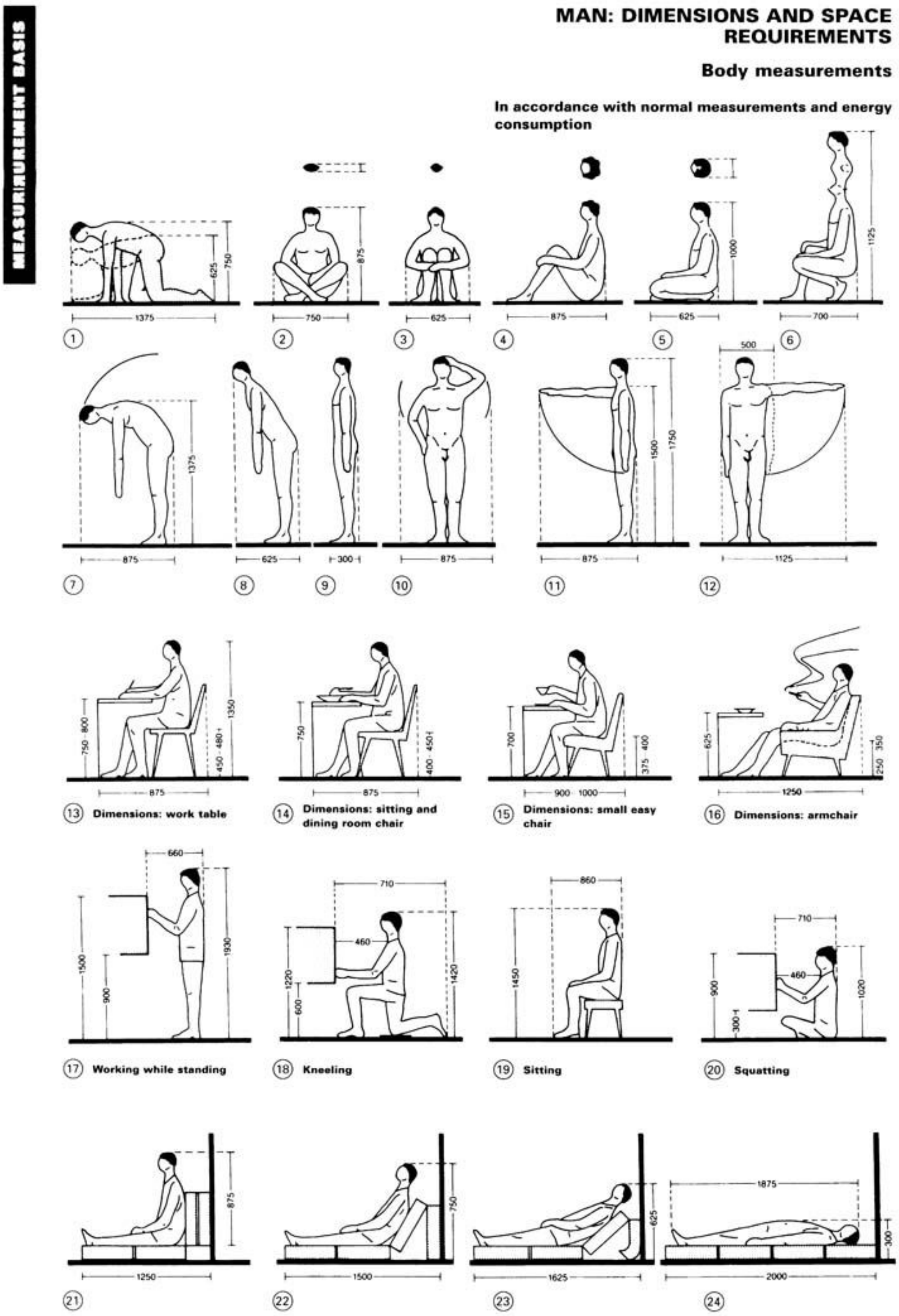
This idea of the book as information technology ties to Neufert’s theory of *‘Schnellentwerfen’* (rapid design); this aimed to reconcile education and professional practice and align them both towards the economic realities of the marketplace (Vossoughian, 2014). Vossoughian argues that Neufert’s experience in collaboration between industry and design meant that he viewed the economic conditions in which architecture had to operate as a machination, absorbing the creative energy of architecture (Vossoughian, 2014). A cultural image born from data required a new architectural economy of time and energy, associating the architect’s money-saving with machine-like efficiencies. Neufert’s rapid design routinised design tasks through easily accessible measurements, which Vossoughian argues favoured the empirical over the psychological (Vossoughian, 2014), providing a method of design that could compete with the speed and efficiency of the machine. Neufert’s idea of rapid design, which translated into ‘design method’ in English, promoted streamlining design decisions through data (Neufert, 1970). Therefore, Neufert’s book helped maintain the cultural position that architects did not need to observe nature in order to design; instead, they required new skills to sample and recombine from existing sources.

Before 1900, data offered architecture a common ground for engaging with positivist rules and axioms, aligning with scientific knowledge's authority, and encoding construction information. Neufert’s book's status as a cultural object changed this relationship, as the book now provided authority through evidence. Additionally, as a book’s medium holds meaning independent of the data content, the book provides authority over standards and measurements. In contrast, the communicative role of the book offers a procedure and source of validation. When considered a repeatable and mass-produced object, the book also centralises control over what architects consider and how they think about architecture.

Reinier de Graaf’s examination of Neufert uncovers a modest number of buildings associated with his architectural practice, the earliest built in 1930, moving between housing, commercial offices, and factories until 1960 (de Graaf, 2017). This limited oeuvre suggests Neufert did not have first-hand experience of all the standard building types presented in his Bauentwurfslehre. Instead, Neufert relied on understanding data as something defined and unchanging, requiring just one measurement rather than a progressive comparison of measurements. The observation here is that the design process, set up through the book as a static set of data, tended to homogenous outcomes when applied and ordered through the book’s imposed structure.

This power over definition and control introduces a concern with bias and partiality. Partiality appears in the standards and measures Neufert chose to include and how the book coaxes design activity towards specific outcomes. Neufert's presentation of repeatable spatial scenarios mobilised objective thought to present an architecture perfect for accommodating the human body. The fact that the body in question was the average German male inserted a cultural and gender bias into his curation. Measurement and proportion based on an averaged European male aligned architecture with an industrialised and standardised population. However, the human body's smoothing into a rational 'ideal' male human would produce inequality in use, mobility, and cultural interpretation around a normative body (Lambert, 2010). Neufert confirms this bias in the section 'The Human Scale: man himself', where 'man' relates to the presumed gender status of an architect (Figure 3-11). Categories such as man in space, man and his transport, man and inhabitation, bachelor hostels, and the graphic description of women in domestic situations indicate a professional assumption that patriarchy was a conventional system that architecture would help maintain.

Figure 3-11 - 'Man Himself' – Ernst Neufert's Architects Data Handbook (Neufert, 1970, p. 14)



Collecting and communicating data representing and defining the ideal human body, architecturally interpreting the body through scientifically efficient spatial arrangements, and locating this all within a centrally controlled repository creates a severe political imbalance for architects. An uncritical deployment of the book in design, repeating 'ideal' ergonomic schema, presumed that architecture's primary role was to cater functionally for adult males, placing an invisible scaffold onto the built environment. The data handbook attempted to define and transfer data unique to the architect by setting spatial standards and organising measurements around materials (elements) and use (the body). Three problematic shifts for architectural culture are associated with this move: firstly, the book controlled architectural knowledge by functionally evaluating space; secondly, Neufert introduced his partiality into what architects addressed through design; thirdly, the handbook promoted specific spatial and design thinking. The culmination of thinking regarding efficiency, logic, precision, and standardisation materialised into the handbook, providing a data use that brought knowledge and communication into nexus, guiding the professionalised architect on conceptualising, and realising architecture.

In summary, the architect gained unprecedented control over communication in practice through the effects of time abstraction on space and movement and a newly centralised definition and collection of architectural data. An architectural data set could now link observation, forecasting and instruction through an agreed understanding of how the architect should synthesise and evaluate buildings. However, this unprecedented control did not occur without consequence. This period is best understood as one where control of architecture's rules concentrated into so few hands that a distinct partiality entered into the discipline and exercised control over what data migrated from observation into the newly bridged practice. In the case of Neufert's data, this benign collation of time-saving metrics established and propagated bias in the built environment.

3.4 Conclusion – A Disciplinary Truth

The Western European architect of the early twentieth century faced intense pressure to achieve the efficiencies and time-saving outcomes associated with mechanised industry. Consequently, abstracting architecture into numbers and justifying material outcomes through general positivist terms allowed the architect to gain cultural equivalence with the scientist and engineer.

Just as Durand's practice responded to the empirical science of the sixteenth century, the early twentieth-century architect encountered new scientific measurement and analysis methods and responded to this cultural influence. The architect retained a need to observe, measure and analyse. However, additional measurements and rules arrived from external expert references to offer specialist input into increasingly specialised design process. Inviting scientifically backed sources into architecture provided a means to appease and justify cultural notions of the ideal. Architecture increasingly absorbed the positivist idea of data as a static representation of reality, a 'truth' portraying the natural world in an ideal state of ordered equilibrium made legible through universal rules. Architecture sought its own rules, which informed new decision-making tools, such as Neufert's *Data Handbook* and Le Corbusier's standardised human proportions. To practice architecture meant directly engaging in architecture's protected rules that were constructed from and communicated through data.

The early twentieth-century period presents a cultural shift for the professionalising architect that merged the communication and knowledge duality recognised in Alberti and Durand, with an architect under pressure to control and optimise commercial practice and material products. Alberti's controlled realisation and Durand's controlled forecasting combined into an evolved set of rules, standards and measurements for design and material production. However, this shift did not emerge from studying architecture, the architect responded instead to the changing cultural context of efficiency and precision by using spatial metrics to link observation and forecasting with functional prediction. Additionally, abstracting function and the human body in the image of scientific management allowed a select few to control knowledge within a globalising architectural culture.

A unique set of architectural data found roots when architecture held significant social responsibility. Centrally collating data enabled widespread collaboration and rapid construction to meet post-war urban blight, but fixed architecture into a repertoire of space function patterns that normalised notions of the ideal human through material forms. A key influence comes from how architects' used time to measure occupation, enabling design to consider energy in use and position the architect within discourses of efficiency, rationality, and optimisation. Unfortunately, evaluating material space through time and energy efficiency metrics transferred ideological expectations of optimisation and efficiency into social lifestyles and ultimately limited architectural access and experience.

This reconciliation of knowledge and communication via time and spatial measurement imparts the early twentieth century period a distinct character and influence. Architects increasingly collated and centralised specific spatial data within books and measuring apparatus. This centralised control enabled the architect to integrate observation, forecasting and instruction within more expansive industrial production. At this time, data were standard numbers extracted from documents, charts and graphs that were replicated across projects. For architects in this period, measurement acted as a universal, fixed and culturally uncontested input into design which provided authority and a scientific alignment with the ideal, optimal and truth.

The key trend identified is the desire to replace individual observation and measurement, as detected with Alberti and Durand, with an agreed architectural set intended to speed up professional design services and the architect's economic productivity. Moving into the later twentieth century, the architect's control over knowledge and communication through an agreed set of data and evaluative metrics receded as data took on a new informatic identity. The next chapter will consider this shift as measurement conceptually shifted from fixed and agreed values drawn from historical or empirical observation to an engagement in real time technical sensing, providing the architect feedback.

Chapter 4: Statistical Feedback

While many architects continued to employ standard measurements and proportion systems into the mid- and late-twentieth century, others rejected universal positivist rules and embraced systems thinking and subjective perspectives. A critical juncture in understanding data as primarily digital occurred after Claude Shannon invented the binary digit, or 'bit', defined as the irreducible base unit for encoding information patterns through 1's and 0's (Gershenfeld, 2008). The period between Shannon's invention (1937) and the introduction of computing into practice in the 1980s and 90s presents a progressive shift from optimal measurement and rational proportion to architects exploring relational systems, statistical prediction, and material adaptation. This period is often portrayed as a succession of styles and theories that reflect radical social, cultural, technological, and political change. Much work explores architecture's relationship to military-industrial funding, popular culture, and environmental technology; however, little work interrogates the impact of data's statistical transformation on the architect and their practice.

Three detected turns in data's character and influence organise the chapter. Firstly, objective thinking associated with information reconceived as a statistical probability transfer into practice, requiring new pattern recognition and application skills to negotiate design decisions. In response, some architects countered quantitative objectivity and took on broader social and cultural engagement to celebrate subjective senses and architecture's psychological and environmental capacity. The third shift considers late-twentieth century attempts to reconcile the lingering objective/subjective dichotomy by conceptualising architecture as sensory and technical data environments.

Across the three changes in character, a general arc emerges in data shift from static measurement to a dynamic monitoring giving the architect new relational and plural contextual feedback for design. The newfound data dynamism translates into architects changing focus from composing static objects to establishing design processes that could realise adaptive forms as responses to increasingly complex problems.

4.1 Plural Pattern

Neil Gershenfeld, a professor at MIT's Centre for Bits and Atoms, provides a history of digital fabrication that begins with Claude Shannon's 1937 master's thesis. Gershenfeld credits Shannon, an American mathematician, electrical engineer, and cryptographer, with naming the 'bit', or binary digit, used to describe the irreducible base unit for encoding information patterns through 1's and 0's (Gershenfeld, 2008). While Gershenfeld acknowledges Shannon with naming the 'bit' and the introduction of digital binary digits, he and others associate digital data with the earlier cog calculating machines of Blaise Pascal (1645), Gottfried Wilhelm von Leibniz (1671), and punch card applications by Joseph Marie Jacquard (1804) and Charles Babbage (1837) (Gleick, 2011) (Bottazzi, 2018) (Carpo, 2011) (Leach, 2019). What set Shannon's master's thesis apart from previous machines was the digital bit's new electrical representation and its association with information technology innovation. Shannon's research gained notoriety through its use of algebraic logic to organise 'bits' into information-rich messages. Shannon redefined information as a quantity by ignoring any semantic communication content to focus on the *amount* of information contained within a message. In 1948, Shannon developed the thesis into the *Mathematical Theory of Communication* (Shannon, 1948) and exposed his newly quantified definition of information to a wider audience. Shannon's *Mathematical Theory of Communication* provides a transitional moment during the modernist nexus where data took on a new cultural identity within a larger engagement with emerging digital information technology.

Norbert Wiener, a contemporary of Shannon, entertained similar thinking and highlighted the benefit gained from representing information as a quantity by positioning information as a new scientific topic and rendering it comparable with physical phenomena such as matter and energy (Wiener, 1962, p. 132). Roberto Bottazzi describes how Shannon and Wiener helped reconceptualise information as a 'statistical probability of communication signal reproduction', which, he argues, paved the way for future digital computing that could 'relate formal logic, electrical circuitry, and information transmission under the unifying language of binary numbers' (Bottazzi, 2018, p. 318). Shannon's critical innovation was not the binary unit per se; instead, it combined Boolean logic and on/off electrical states used to arrange patterns of bits and visually represent human-readable abstract symbols. Shannon's research provided an electrical and logical means of manipulating bits, significantly altering its practical use. Through information technology and computational networking advancements, digital data attained a new cultural understanding as something increasingly abundant, attainable and manipulable (Halpern, 2015).

From the past to a presence

Omar Kahn maintains that architecture tends to discuss data diametrically as either analogue or digital, resulting in discourse favouring how architects process information rather than how they invite it into practice (Kahn, 2013). While the analogue/digital dichotomy risks oversimplifying influence, the distinction introduces two critical points regarding its identity in the mid-twentieth century. Firstly, the analogue and digital differ in their relationship to reality; the analogue directly records how humans experience reality, while the digital abstracts continuity through algebraic and logical rules. Bottazzi highlights this digital–analogue diametric when he states that the digital tends to 'reduce continuity to the binary logic of 0s and 1s creating a problematic conceptual and, at times, practical gap between the natural and the artificial' (Bottazzi, 2018, p. 269). As analogue machines record continuously, using materials, reproduction of the recording requires reversing the process, such as forming and reading a vinyl record's undulations (Floridi, 2010). Digital processes, however, break recordings into discrete chunks, meaning encoding always requires a set of instructions to decode and recombine. The critical point is that digital bits always add a translation layer between observation and human forms of information. The digital non-human bit never directly represents and requires an interpretive intermediary to achieve human understanding. The distinction is that digital data is never 'raw', i.e., unfiltered, or partial, as it results from a second-order process via a non-human sensory interface.

The equivalence between human and non-human sensory interfaces lays the basis for Norbert Wiener's cybernetics (Wiener, 1950). Russell Ackoff, the author of the DIKW schema, argues that cybernetics ushered in a new age of thinking that favours knowing over understanding as a response to the analytical and causal rational reductivism associated with the mechanical industrial world (Ackoff, 1993). Rather than analysis, cybernetics introduced synthesis as a way to understand wholes rather than just their parts. This expansive rather than reductive thinking would suggest a disengagement with abstract representation. However, Michael Goodman points out that data's scientific identity consequently changed from 'identifying patterns of behaviour over time, to surfacing the underlying structures that drive those events and patterns' (Goodman, 2018). Cybernetic thinking consequently ascribed data two characters; an observational input from the world and a basis for pattern extraction and application.

For cybernetics, a pattern held as much significance for human behaviour as it did for understanding non-humans. Shannon and Wiener portrayed information as a statistical probability of pattern recognition, referring to information as a state of minimal 'entropy', i.e., optimising order. By ignoring the semantic content and focussing on detected patterns, cybernetics emphasised bits to predict the future rather than understanding the past. Orit Halpern describes Shannon's theory as 'redefining information not as an index of a past or present event but as the potential for future actions (not what you say but what you could say)' (Halpern, 2015, p. 103). Halpern helps us understand that communication became about anticipating pattern within a limited choice of possibilities bound within data's order (Halpern, 2015, p. 103). For Shannon and Wiener, this meant that for maximal information transfer efficiency to occur, there needs to be minimal ambiguity in interpretation between sender and receiver. In Wiener's hands, the idea of information as an anticipated potential meant it was predictable and consequently controllable. Wiener's cybernetics posited that the material world existed as a technically measurable system of 'information' flows — i.e., quantifiable signals — rendering reality measurable and predictable through statistical probability (Wiener, 1950). Molly Wright-Steenson argues that cybernetics allowed Wiener to measure and describe feedback and control within all systems, making biological, computational, anthropological, or even political systems equivalent and comparable through patterns (Wright-Steenson, 2014). Essential to Wiener's desire to predict information and understand behavioural control was a need to observe, measure and then detect patterns, the order in information, making the bit a crucial part of comparing and understanding organic and non-organic systems.

Cybernetics conceptually shifted data's origin by advocating systems thinking, opposing scientific reduction, and redefining information as a statistical pattern. From a practical perspective, scientific methods changed from reducing objects into parts to synthesising time and context-specific relationships. Halpern points out that cybernetic concern with pattern altered science's understanding that nature forms from a 'Darwinian notion of diachronic descent', a linear series, to it being a process of 'synchronic structure of information' (Halpern, 2015, p. 47). The difference between the Darwinian and the synchronic is that the former sought patterns through time-based series across different contexts; the latter detects a pattern based on a time and location. Halpern's distinction introduces how systems thinking ignored historical accounts to portray data, and consequently, information, as a sensory and cognitive process born from presence rather than singular measurement. Consequently, a cybernetic data presence placed cultural importance on non-human abstraction, not working with human-readable numbers and symbols, but making human and non-human information equivalent through the binary unit — the bit.

Whilst a cybernetic equivalence between the human and non-human helped understand natural and physical systems, it ignored human meaning and treated human behaviour as a cognitive process separate from the body. Katherine Hayles criticises Wiener's approach for presuming 'patterns analogically related to events in the world', portraying information as exclusively relational and cognitive and disconnected from bodily experience (Hayles, 1999). Shannon, Wiener, and systems thinking produced a critical shift that normalised data's identity as digital, thus shifting understanding from defining the past to organising and ordering the future.

From objects to processes

Despite Hayles's argument that cybernetics took an unfortunate and unintentional dehumanising approach (Hayles, 1999), some defend Wiener's 'science of form' (Halpern, 2015, p. 47) for providing a shift in thinking from forms to understanding processes of formation. Consequently, biological life sciences theorised through cybernetics began to understand material forms as outcomes of embedded information, molecular and cellular level assembly instructions (Tierney, 2007). Consequently, information producing creative practices exposed to cybernetic thinking, such as architecture, focused on finished objects to formation processes (Pangaro, 1990).

Alongside digital data's new importance in making information anticipatable and predictable came a recognition of its possible variance *within* systems. This variability within systems becomes apparent when considered through the lens of psychology. James Gleick points out that until the innovation of Shannon's Information Theory, psychology relied on generalised notions of the soul and essence, until measuring the brain through sensory channels of bits made the 'ineffable' mind describable and comparable, thus rethinking the brain as a constantly reshaping entity (Gleick, 2011). Lorraine Daston and Peter Galison point out that the cybernetic measuring of the ineffable increased the desire and need for objectivity, requiring observation to exist outside the systems in question, placing primacy on mechanical observation, and casting further suspicion on the individual as a basis of knowing (Daston & Galison, 2010).

In general, cybernetic thinking and quantifiable systems held a mutual attraction with architecture, a discipline contending with the physical as much as the complex ineffable world, such as behaviour, delight, and emotion. In parallel, cybernetic thinking passed into architecture through scientific research and the post-war military-industrial complex, which produced, normalised, and popularised Shannon and Wiener's thinking in endeavours ranging from economics, space missions and urban planning. Through cybernetics, the bit's relational, abstracting, and objective quality found application across various system logics thought to be potentially controllable. In architecture, this control expressed itself most acutely through authorship and the perceived importance of the architect in producing the built environment. The wider resulting arc of this authorship moved from the centralised and patriarchal control associated with objective optimal metrics to an attempted removal of the architect in material forming processes.

The implication for the architect was a new a priori knowledge condition for the architect. Where the architect previously relied on data collected through observation or experience, they now came to rely on rules sourced from technical system representations and translations. As the architects skills in abstracting and translating observation gave way to interpretations and representations detached from its spatial and material concerns their authority over architecture's material context eroded.

Contextual presence

As a related but alternative position to Shannon and Wiener, Marshall McLuhan's media theory critiqued cybernetics' assumed detachment between a message and the material medium as a communication channel. Media theory posited that information resided in both the message and the material medium used to translate bits and information, i.e., the media interface. A difference between Wiener's and McLuhan's understanding of information systems lay in their assumptions regarding data's relationship to nature and culture. While Wiener regarded nature as a universal system to be described by data flows, McLuhan recognised the cultural forces involved in communication, emphasising the importance of context in interpreting information. McLuhan's proclamation, 'the medium is the message' (McLuhan, 2001 (1964), p. 7) countered Wiener's semantic information ignorance by arguing that a behaviour-influencing communication channel could not ignore the information inherent in technology's culturally driven material forms.

Media theory's interest in how message and medium influence human behaviour registers how architects began reconceptualising practice and architectural experience as information environments (Busbea, 2020). Cybernetics thought complex behavioural systems adhered to patterns detected from human and non-human observations. However, Hayles argues that McLuhan's conceptualisation of information as an environment, rather than a singular channel or signal, changed the concept of observation from being historically collected and stored later to being an embodied sensory detection of pattern through a 'presence' (Hayles, 1999). Associating presence with non-human information anticipation and human pattern recognition inspired new thinking in architecture and design. Halpern gives an example of this inspiration through Ray and Charles Eames, who reconceived design as catering to a new type of audience, one culturally conditioned to recognising and constructing patterns from visual information treated as cybernetic data (Halpern, 2015). Larry Busbea similarly identifies how architects absorbed media theory to reconceive space and material form as plural, contextual and information-rich environments that rejected objective assumptions of universal experience (Busbea, 2015).

In summary, the change in understanding information abstraction from observed human signs to statistical signals affected how architects approached design practice and architecture. Firstly, thinking altered from positivist rule-based predictions that presumed ideal information to embracing an idea of potential, where information could take on many versions, but with the same input. For the architect, the notion of practice designing static and ideal objects gave way to devising form-making processes that decentred the architect as an author and celebrated data's relational quality. Rather than basing architecture on rules extracted from the past, architects began to design environments that required inhabitants to interpret information-rich and contextual patterns. Patterns remained central to the architect's practice, but now, rather than existing as repeatable and standardised spatial relationships, information-rich environments gave primacy to contextual pattern recognition through an image of data as relational, plural, and reconfigurable.

Over the latter part of the twentieth century, cybernetics and information technology normalised a character associated with digital bits resulting in new forms of design practice and informational environments. Consequently, some architects began exploring design environments that combined human and non-human observation to celebrate architecture's contextual, relational, and plural experience.

4.2 Objective Process

Architects engaging in the earlier truth of optimal but static metrics were slow to shake off the positivist legacy established by Taylor's scientific management and Neufert's handbook. However, some architects began engaging with Shannon and Wiener's new take on information by reconceiving design practice as a predictable pattern, first as a method akin to scientific research, then designing through spatial and material patterns.

Design as science

Despite Shannon's newly defined digital information, architects of the 1950s did not have access to digital computing or technical sensing, relying instead on existing analogue manipulation methods, such as Alexander Klein's matrixes and comparative tables. While architects were not directly interacting with computing and electrical bits, the idea of quantifiable and objectively measured information filtered into design practices. Peter Rowe, a Professor of Architecture and Urban Design, identifies a shift during the mid-twentieth century when architects began to adopt an 'information processing' approach in design by introducing information management strategies into practice (Rowe, 1987). Rowe argues that architects began patterning information with an ambition of 'finding' solutions within extensive collections by breaking down and structuring search (Rowe, 1987). Rowe points out that architects engaged in processing their information did so through a rigid scientific, interpretive framework providing a 'logical-empirical interpretation of man and his world' that presumed ideal artefacts existed by manipulating patterns through defined parameters (Rowe, 1987, p. 199). Using parameters to evaluate design solutions connects to the instrumentalising means-end analysis Reinhold Martin recognises in the corporate and military-industrial complex occurring in the mid-twentieth century (Martin, 2005). Martin portrays how the corporate cultures of information management in the 1960s took on cybernetic thinking to prioritise pattern recognition in new cultures of knowledge production, transposing a scientific systems worldview onto all aspects of government, from economy to social welfare (Martin, 2005). Architects, conscious of being professionally left behind by the dominant scientific research and cybernetic information systems, and always aware of the technologies of authority available to them, took in new models for predictive decision-making based on pattern detection and application.

Central to data's influence in design solution searching and decision making was a general and continued scientific mistrust in human observation and economic pressure on architecture to match science's technological innovation. This pressure to engage non-human technical sensing bridged observation with managing, producing, and processing information to justify decisions as statistical predictions. Architects and designers looked towards the example of science and its mode of systematic inquiry to argue for a design method, a set of actions thought to produce architecture as objective, accurate and predictable, as science demonstrated. From an architectural pedagogy perspective, Rowe recognises this pressure in the objectivity teaching at the Ulm School (founded 1953), Germany, where the ideal and universally interpretable artefact emerged through technical collection (Rowe, 1987). The Ulm school taught architecture through a 'universal' approach of 'environmental design' by architects involved in the design methods movement (Dubberly & Pangaro, 2016). The architects teaching at the Ulm school, Max Bill, Thomas Molando, Horst Rittel and Christopher Alexander, developed a 'radical instrumentation' pedagogy that transferred scientific thinking directly onto an approach of universal architectural interpretation (Dubberly & Pangaro, 2016). Observing and predicting the world through instrumentation provided architecture with a non-human perspective to provide objectivity in design and eventual outcomes.

In parallel to the Ulm school's teaching, the design methods movement attempted to utilise non-human objective thinking to all design aspects, not just architecture. Nigel Cross traces the design methods paradigm through architecture and argues that both positivist and systematic sciences provided seductive paradigms for design (Cross, 1993). Cross argues that design practice mimicked science, 'not just the utilisation of scientific knowledge of artefacts, but design in some sense as a scientific activity itself' (Cross, 1993, p. 21). Through publications and conference proceedings, Cross dates the design methods movement as starting in 1962 before ending in 1971, when many establishing members rejected its deterministic tendencies (Cross, 1993). Design methods popularised the idea of architectural practice as a set system of linear steps that could remove informational ambiguity in human decision making, aiming to establish material form through linear problem-solving steps. These steps did not refer to specific object forms; instead, they calculated solutions by connecting observation with relational patterns.

This causal thinking at the heart of the design methods movement became formalised into a building analysis method to connect the built reality of architecture with future design decision making. Post-occupancy analysis quantifiably represented architecture in use, giving architecture a set of metrics for comparison and evaluation, aligning practice with management studies and economic discourse. This design feedback through systematic observation provided a framework for interpreting architecture and placed new professional expectations onto practice. This abstract representation linked design solutions to predicted outcomes and reconfigured the language of architecture's expected performance. Previous expectations of architecture as an artistic experience met an approach to practice that ideologically indexed buildings to economic metrics of anticipated success. Roger Ferris argues that while the design methods paradigm in architecture was short-lived, it presents a moment where art and science separated. To make professional claims to exclusive and expert knowledge meant rejecting the artistic that subverted 'institutional claims to authority based on rational/technical ideologies' (Ferris, 1996, p. 9).

Hierarchy and pattern

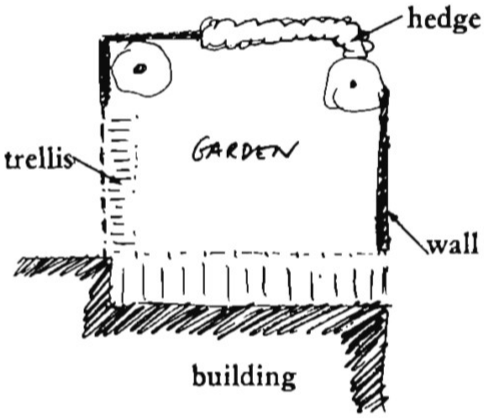
As science adopted cybernetic thinking, architectural practices invested in scientific and mathematical thinking followed suit. Christopher Alexander, a mathematician and architect at the forefront of the design methods movement, provides a case where the digital bit's cultural influence registers in both the mode and means of practice in the mid-twentieth century. Alexander developed a theory and method of architectural practice that portrayed buildings as solutions to complex social and physical problems. Along with Sara Ishikawa and Murray Silverstein, Alexander advocated a method that systematically married knowledge embedded in empirically observed and validated patterns with an architect's site observations and 'designers' instincts' (Alexander et al., 1977). Cybernetical thinking appears in how Alexander et al. considered architecture to organise. Their book presents 253 combinable patterns that respond to discrete spatial scenarios and help make up larger patterns of interacting relationships within a given context. Alexander et al. do not directly refer to data in *A Pattern Language*, but the cultural importance of pattern recognition and the new relational character of the bit registers in their approach.

Practice depicted as constructing and applying ‘a pattern language’ sought to promote historically evolved vernacular responses to physical, social, and contextual responses as solutions to stated design problems. Each pattern is considered an entity and a component in an architectural system, combined with a set of rules, a written statement and a diagram relating it within a larger design. Each pattern represented a ‘best guess as to what arrangement of the physical environment will work to solve the problem presented’, acting as a scientific hypothesis to a research question but applied to a design problem (Alexander et al., 1977, p. 15). While the ‘language’ within the pattern language aimed to generate infinite combinations, it applied a reductive analytical lens to buildings based on the author's observations and experiences. This part-to-whole abstracting approach mirrored science’s efforts to uncover causal relationships to argue solutions to problems, using the logic of answers to questions. Heavily influenced by cybernetic thinking and mathematics,

Alexander assumed objective design solutions existed through recognising repeatable patterns through experience. Patterns extracted from what Alexander deemed ‘good’ architecture became combinable ingredients in design. In Alexander’s approach, patterns could justify a design solution as a possible ‘true invariant’, an ideal and unchanging proposition thought to summarise ‘a property common to all common ways of solving the stated problem’ (Alexander et al., 1977, p. 15).

Rather than providing objectivity, Alexander et al.’s patterns imposed a pre-conceived expectation based on the author’s experience, introducing a partiality to the patterns used to synthesise into form. An example of this partiality shows when considering one of the pattern sequences. In Alexander’s approach, each pattern connected to specific larger patterns, which remained incomplete if not included at all scales. The example used in the book is the pattern for ‘laying out a green’, which required combining the patterns for ‘identifiable neighbourhood’, ‘subculture boundary’, ‘work community’, ‘quiet backs’, ‘accessible green’, ‘positive outdoor space’, ‘tree places’ and ‘garden wall’ (Alexander et al., 1977, p. 7). When studying pattern 173, ‘Garden wall’, it is evident that the wall as an architectural device offers a solution to noise relief and privacy to the detriment of any other approach based on subjective experience, without acknowledgement of such. Alternative approaches, such as landscape contouring, were unavailable if not part of an observed historical and conventional vernacular. In other words, if Alexander had not experienced a pattern, it did not exist for application. The consequence of this partiality is that each applied pattern was authored, not objective, and certainly not universal.

Figure 4-1 - Example of Pattern 173, Garden Wall (Alexander et al., 1977, p. 808)



Alexander et al.'s pattern language fully embraced the cybernetic ambition of complex behavioural prediction by describing discrete architectural moments in terms of physical, social, and contextual forces. By abstracting architecture into a logical pattern system, this time represented as rules for environmental solutions, Alexander took in cybernetic thinking to construct a design argument for ideal architectural suitability based on environmental meaning. By constructing a system of meaning between practice and architecture, Alexander could logically argue for ideal architectural form through rule-based logic (Alexander, 1964), which evolved into defining architectural production as a relational system of functional and environmentally characterised rules (Alexander et al., 1977). Both of Alexander's concerns equated cybernetics' information anticipation through objective pattern recognition to a new design ability to anticipate form by presupposing architecture to operate like data's new relationship with information.

Alexander proposed pattern as an objective design solution, believing that spatial problems always had a correct outcome. His pattern 'language' relied on grammatical rules, extracted from personal observation, thus translating subjective experience into an arguable architectural truth. In spoken language, such as English, information assembles and transfers through agreed grammatical rules connecting letters – data – to meaningful words – information. An individual alphabetical letter does not have meaning, they rely on semantic associations and syntax to combine into words and then sentences to pass on communication. As Alexander's pattern language operates through patterns which have meaning, for instance the Garden Wall', each pattern embeds design information. The material and spatial components that make up each pattern exist as the data in Alexander's language, relying on associations to construct and utilise information. Although Alexander's pattern language does not refer to data, it presence is critical for his argument that each pattern embeds meaning, therefore as pattern emerges, so does information. We conceptually understand that data must exist for information to emerge, therefore, within Alexander's information rich pattern technique his data are the very elements of architecture, such as surfaces, textures, and objects. In Alexander's case, data took on a radically different identity and use. Rather than a measured quantity or observation, architecture's formal elements became data within a pattern producing, information building, meaning imbuing design system. Just as Russel Ackoff's DIKW hierarchy understood information as refined and ordered data, Alexander's pattern making architect was expected to produce form through selecting and ordering elements brought together in predefined combinations.

Although computers were absent in Alexander's practice, his PhD thesis, *Notes on the Synthesis of Form*, introduced the idea of material form behaving in the manner of nature. Through the lens of cybernetics, nature acted as a self-organisable system of embedded information (Alexander, 1964). Alexander refers to data several times in *Notes on the Synthesis of Form*, each providing an analogy between scientific method and architectural practice. Two practical uses relate to the scientific concept of hypothesis and observation detecting regularities. In 'hypothesis', Alexander compares scientific reasoning to justifying architectural form, as in his opinion, both require clear principles for organisation. In 'regularities', Alexander argues for architectural patterns that operate as 'structural facts…from thoughtful interpretation of observations' (Alexander, 1964, p. 109), indicating the importance of how architects impose meaning onto abstract representations through inference and interpretation. *Notes on the Synthesis of Form* provides a clear link between architecture and data when considered through a scientific and mathematical analytical lens. However, in Alexander's case, he considered data a constructional allegory for generating form rather than a measure, ratio, or proportion; thus, architecture produced through an ideal logic rather than an ideal dimension. Unlike Neufert's spatial and material dimensions, Alexander's relational pattern composition attempted to connect environmental observation with an anticipated architectural experience.

Alexander's approach holds similarity with Durand, as both tied observation and pattern to devising architectural rules. However, while Durand's approach looked to the architect to expertly apply rules, Alexander was more interested in automating decision making and embedding practical and professional knowledge into a design system. Within Alexander's design system, patterns offered an interface to coordinate and manage increasingly large input sources into the design process. The order and logic of self-organising cybernetic systems transferred into spatial and material patterns, comparing architecture with information. Durand and Alexander's rule-based patterns show efforts to manage complexity. While Durand offered a simple guiding proportion system tied to function, Alexander et al. sought to interface architectural knowledge and decision-making.

However, Durand and Alexander differ in how they applied rules to compose form. For Durand, rules emerged through conscious determinacy of form based on simple averages. In contrast, Alexander et al. introduced interacting problem/solution rules into indeterminate formal outcomes, organised under the assumption of behavioural prediction. Theresa Tierney argues that this idea of a simple process leading to complex outcomes sat as part of a broader cultural move towards 'complexity built on simplicity' (Tierney, 2007, p. 78), arriving through cybernetics at the time. Scott Marble traces how Alexander's simplicity, unfortunately, tended towards similar outcomes due to its restricted pallet of forms, materials, and spatial requirements (Marble, 2012), with some architects even naively reproducing 'rote patterns' (Alexander et al., 1977).

Technical trust

Since an architectural practice based on a defined method or process of spatial composition required quantified evaluation of existing architecture, this period accentuated spatial conditions and material forms that favoured easily quantifiable design parameters. Just as Shannon's information ignored meaning, so did material responses that concentrated on social and physical environments, to the detriment of cultural interpretation. Quantity continued its primacy as an external and assumed objective observation combined with architecture as an objective pattern to portray design as a self-organising process. As a result, the architect emphasised accuracy of observation and prediction through positivist causal systems. The pressure to connect architecture with quantified and scientifically measured social and behavioural outcomes, now characterised as environment, gained architects a professional status but began to erode the authorial role and relevance of those who did not link design to behavioural research.

A cultural understanding of non-human observation and quantified measurement lay at the centre of behavioural research. An example of architecture meeting such research is William Whyte's *The Social Life of Small Urban Spaces* (Whyte, 1980). Whyte's quantified urban observation research argued for a much-needed scientific inquiry into public spaces to uncover unseen patterns. Although published in 1980, Whyte's Street Life project occurred in the early 1970s; it studied the behaviour and everyday rituals of 'ordinary' people using time-lapse photography to capture spatial use over time (Figure 4-2). Whyte's data originated from the evaluation of photographs to deconstruct the scene of fixed landmarks and people, converted in maps of typical movement (Figure 4-3) and visualised into charts (Figure 4-4). Whyte's observation technique required the researcher to detect patterns within and across many photographs, seen through the objective camera's viewpoint. As Whyte's Street Life project temporally observed the city, the photographs and charts showed change over time, monitoring the city rather than singularly measuring. To its detriment, however, the research reduced people to quantities that uncovered spatial patterns but could not explain why the patterns occurred, as the mode of abstraction could not deal with cultural relationships.

Figure 4-2 - William Whyte, Time Lapse Observation (Whyte, 1980, p. 102)

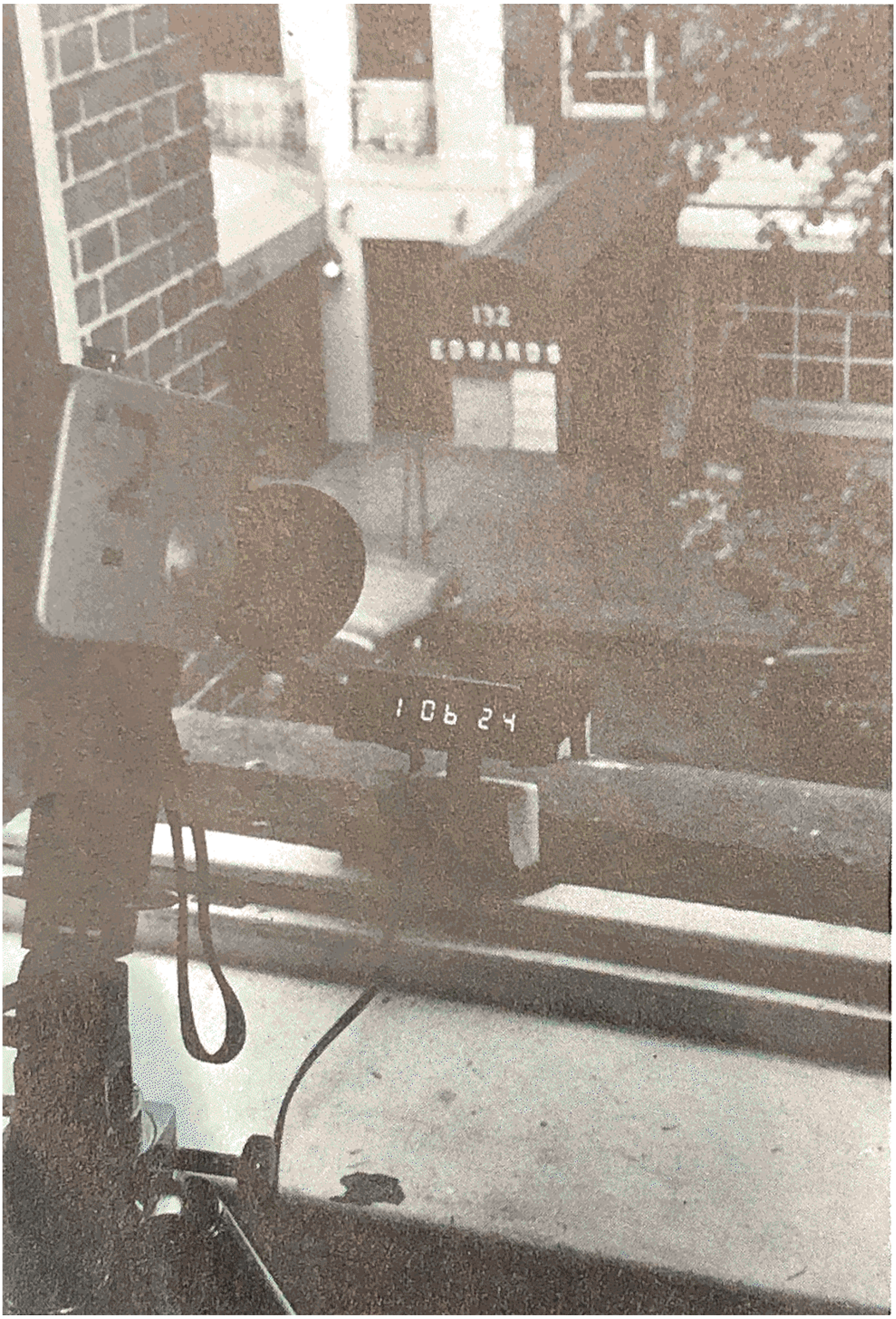


Figure 4-3 - William Whyte, Typical Sighting Map (Whyte, 1980, p. 23)

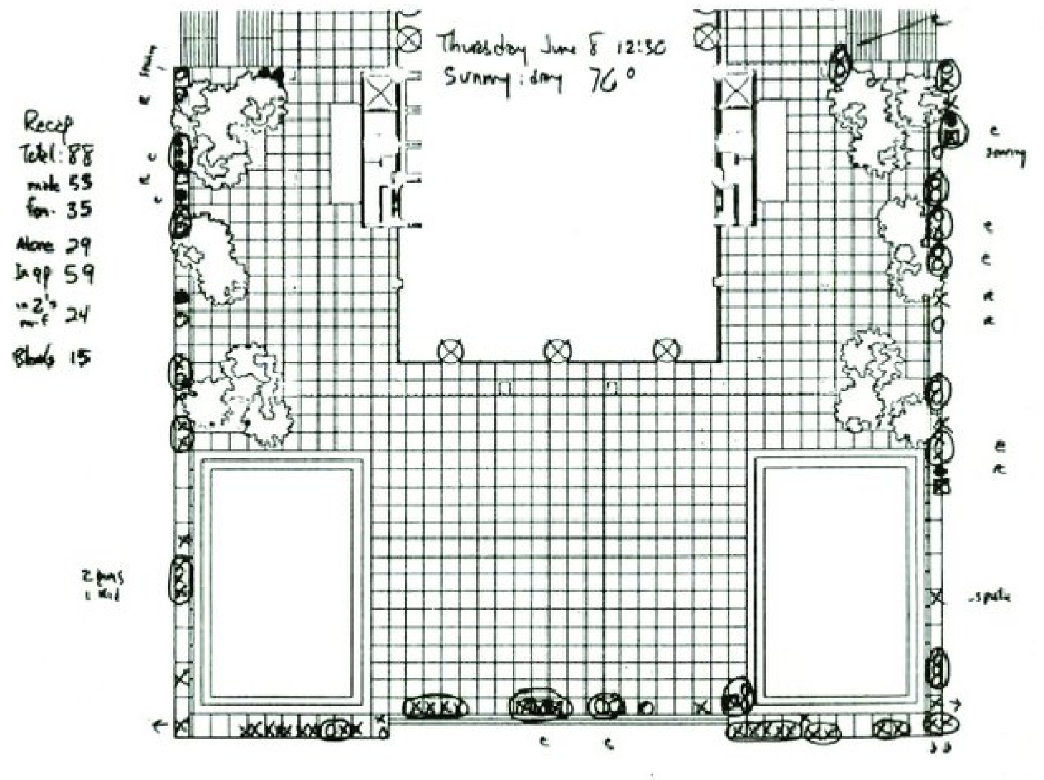
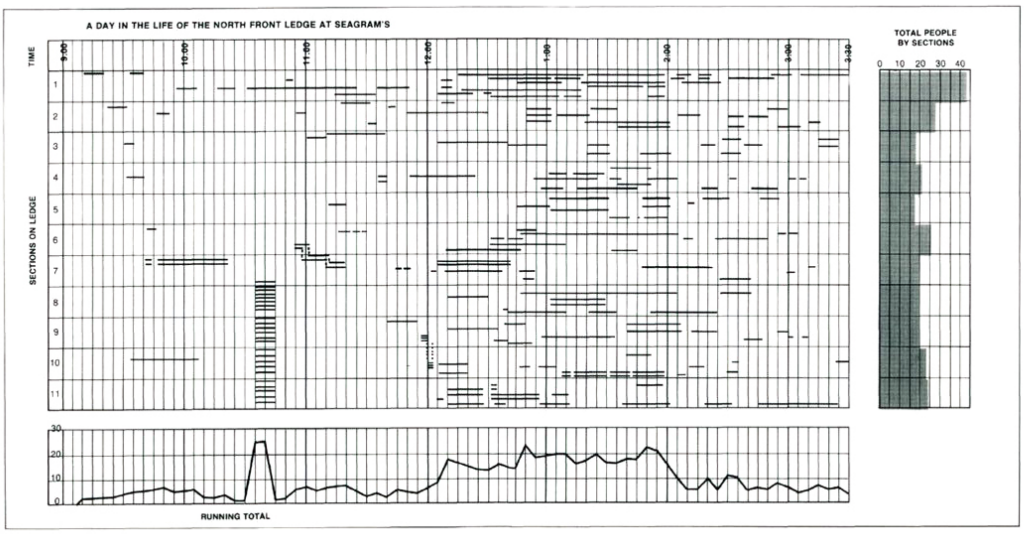


Figure 4-4 - William Whyte, Day in the life at the Seagram Building (Whyte, 1980, p. 70)



Whyte's research applied a mid-century understanding of mechanical objectivity to predicting behaviour, finding patterns of behaviour to predict future action and 'gain a sense of power by anticipating' (Whyte, 1980, p. 110). However, in the same sentence, Whyte comments that 'by anticipating what they will do, you are yourself causing them to do it' (Whyte, 1980, p. 110), which begins to speak to the unravelling of assumed determinism in scientific culture and architectural practice. Whyte's research points to a moment where the assumption of objectivity and a rational, Taylorist, time-space based understanding of the city received scrutiny concerning the lived subjective experience of the city and architecture. Aside from the obvious questions regarding research ethics and unconsented surveillance, Whyte's research showed how data in urban behavioural studies culturally assumed an uncontested argument that it could uncover solutions and answers from quantified observation and analysis.

William Whyte's urban studies draws close comparisons with Taylor as it exploited technical instrumentation to uncover previously unseen patterns. However, in contrast to Taylor, Whyte's 'measurement' relied on time and pictorial evidence that sought to uncover spatial behaviour within the built environment. Where Taylorist motion studies sought to detect in order to influence optimal energy use in service of function, Whyte's understood spatial movement as an informational process. Whyte's successful observational vantage points celebrated both human and technical sensing to detect what was imperceptible at ground level. The small urban spaces project reconceived urban and architectural space as environmental influenced decisions rather than task-based habits.

For the architects, specialised urban studies carried out by other disciplinary researchers offered a scientific spatial understanding that provided authority. Whyte's urban data established new rules for public space which filtered into urban and architectural discourse. Just as cybernetic systems thinking introduced an a priori knowledge for the architect, Whyte's approach provided a practical knowledge base that reduced the architect's personal observation commitments. Removing observation requirements from practice benefited time to concentrate on design services. However, Whyte's data resulted from single observation points in space, making it problematic in two regards; one that subjectively interpreting pictorial evidence can invite bias, the other that any detectable equipment from the street would become part of the system, making the observer an influence on spatial behaviour. Despite its scientific grounding and new urban insights, Whyte's studies did not acknowledge the bias inherent in data sampling.

To summarise, the period initiated by Shannon and Wiener's innovations brought a shift in architectural practice focus from objects to process, driven by an image of data as relational, plural, and reconfigurable. As part of an architecturally driven logic, objectivity connected observation with the environment through relational and statistical pattern recognition. These ideas hold together through the notion of technical trust, where pure statistical data could uncover and see what lay outside of human senses. One response was to portray design as objective science, capable of achieving solutions that behaved as an optimal information signal. This overtly objective ideology placed the non-human central to achieving better human environments and justified its axioms and rules through a higher order born through an objective process. The reality, that such approaches based architecture's patterns on personal experience and subjective observation, contradicted their continuing notions of architecture as an objective design solution. The realisation that the architect's subjectivity was an inevitable part of practice initiated a shift to engaging with qualitative data to escape the trappings of determinism and predictability.

4.3 Contextual Response

By the 1960s, several architects critical of reductive scientific causality looked towards more humanist and subjective approaches to reengage with meaning. Many scholars point to the 1968 student-led protests as an explosive expression of resistance to mechanistic mass-social management and a desire for greater individual freedom and community (Burke & Tierney, 2007) (Hays, 2019; Rowe, 1987). Across the western developed world and particularly in America, a late 1960s counter-culture witnessed efforts towards more anti-hierarchal democracy through ideas of individualism and collectivism. Ratti et al. associate the 1968 protests and resulting utopian ideas to a cultural shift regarding individual sensory experience and information (Ratti & Claudel, 2015). Data took on a new cultural identity through media theory and new electronic media communication technologies. Measuring the individual became part of a broader desire to tackle increasingly complex social systems such as urban planning.

From mass function to personal interpretation

In contrast to the early twentieth-century industrial-mechanical society, organised through measures, standards, and ideal propositions, the more cybernetically- and information-influenced 1960s began to associate information measurement with mobilising and organising humans into new service-based labour divisions. Yuval Noah Harari points out that at this time, today's dominant western mode of production, capitalism, began to evolve to place greater importance on the individual's participation in markets, positioning the individual and family unit as the ideal scale for organising society (Harari, 2015). The objective and predictive practices of solution-providing pattern application changed to embrace personal concerns and individuals' behaviour through a qualitative lens that acknowledged and embraced meaning. Nicholas de Monchaux, an architectural professor, traces how governments in the twentieth century increasingly emphasised census data collection and mapping in the hope of making more fine-grained decisions (de Monchaux, 2016). For state governance, collected information provided the raw material to uncover relational patterns and provide insight into a population. In this case, 'data' relates to governments' desires to produce new, specific information used to organise or influence society.

Under the cultural shift towards a more individualised western society, architects more interested in human interpretation than objective solutions took personal information as a design material. Those who tried hardest to influence the built environment outside of the positivist causality of science came from the architectural periphery. The French situationists critiqued the city through mapped 'dérives' — 'a drift or meander that tends to undermine the order of the planned city' (Nichols, 2004, p. 33), highlighting the way architecture shaped the possibilities of movement in the city and maintained conventional political and legislative controls over the city (Nichols, 2004). Guy Debord, a member of the situationists, directly blamed scientifically driven mechanical automation for increased pressure on expected labour times, resulting from a combined Taylorist and cybernetic thinking (Debord & Knabb, 2016 (1967)). Rather than architecture offering a solution or attempting to causally connect means with ends, as design methods and Alexander espoused, Debord saw the urban environment as a site of resistance through self-actualisation and play. Greenfield recognises Debord's and the situationists' part in a broader cultural shift at the time from imposing order to imagining the spatial dimensions of individual human interpretation (Greenfield, 2017).

Two urban design practices during the 1960s provide examples of an identifiable change in data's identity and influence. On the one hand, the American computer engineer and systems scientist, Jay Forrester (1918-2016), modelled the city as a cybernetic regulatory system of urban dynamics (1969). In doing so, Forrester treated physical systems, natural systems, and human systems as information, only differing in their degree of complexity (Jarzombek, 2016, p. 130). On the other hand, Kevin Lynch (1918-1984), an American planner, began mapping and imaging the city (1960) through personal accounts and interviews, which introduced new techniques of psychogeography and cognitive mapping to interpret the urban environment (Nichols, 2004). Although neither Forrester nor Lynch called themselves architects, their attitudes to the built environment strongly influenced the architect's professional role.

Forrester's and Lynch's approaches seem at odds on the surface, but both were inspired by cybernetic systems thinking interested in city order. Forrester equated the city to a biological information system, using systems dynamics and control systems engineering to predict social organisations (Akera, 2007) and modelling urban systems based on complex economic interactions (Figure 4-5) (Psyllidis, 2017). Urban dynamics greatly influenced government cartography projects, which did not map through a spatial register but diagrammed signal flow, visualising an 'if this then that' computer programming logic (de Monchaux, 2016). The causal basis of information programming seeped into urban management and invited comparisons between the city and the computer. Together with other systems thinkers, Wiener described urban contexts as information processing systems, conflating urban forms with circuit boards (Mattern, 2017).

Forrester's urban management approach has since come under criticism from two opposing camps; those who view urban dynamic's treatment of the city as a computer, ignoring subjectivity and applying a solution-engineering problem of optimisation and control (Burke, 2010) (Mattern, 2017), and fellow systems engineers whose objective outlook lament urban dynamic's 'scarcity of frequently updated data' (Psyllidis, 2017, p. 45). The 'ideal' city, when viewed through a technical solution lens of information processing, became understood as maximising data collection, providing a new cultural understanding of data abundance. This abundance remains the foundation of contemporary data-driven smart-city discourse and a key part of its anticipated success. However, at the time of Forrester's work, the cultural image of abundance and the technical reality of availability were at odds. The condition of abundant and high-speed data underpinning cybernetic theory proved unattainable using 1960s sensing technologies such as William Whyte's photography. As Claude Shannon popularised, Forrester imagined the city as a physical system applicable to any urban condition by ignoring meaning. Forrester's abstract urban management systems mapped independently from location, and while they could reasonably predict capital flows, they could not reflect the specificity of place and time (Vanky, 2015). By ignoring the cultural systems in the city that produce meaning, Forrester missed seeing that the built environment was an equally important data source. Shannon Mattern highlights that humans do much more than make urban information by systematically filtering data in the cybernetic imagination; they engage both body and mind, resulting in multiple material sensory experiences unique to specific contexts (Mattern, 2017).

Figure 4-5 - Forrester's model of an urban area (Forrester, 1969, p. 16)

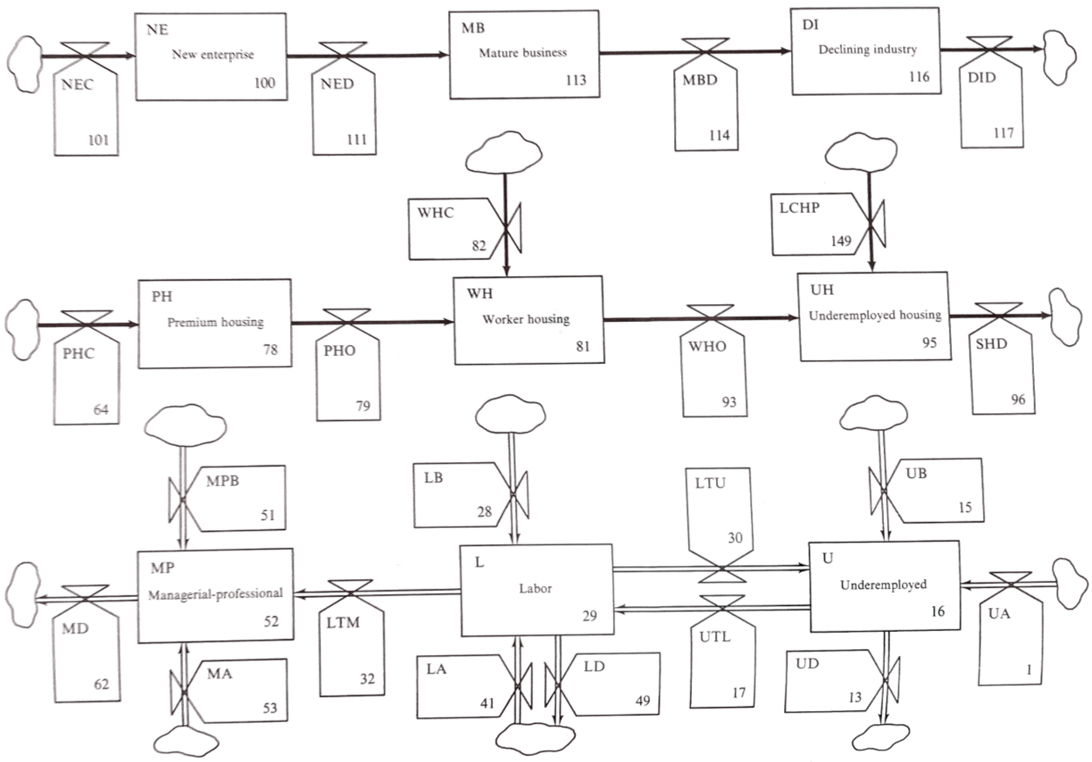
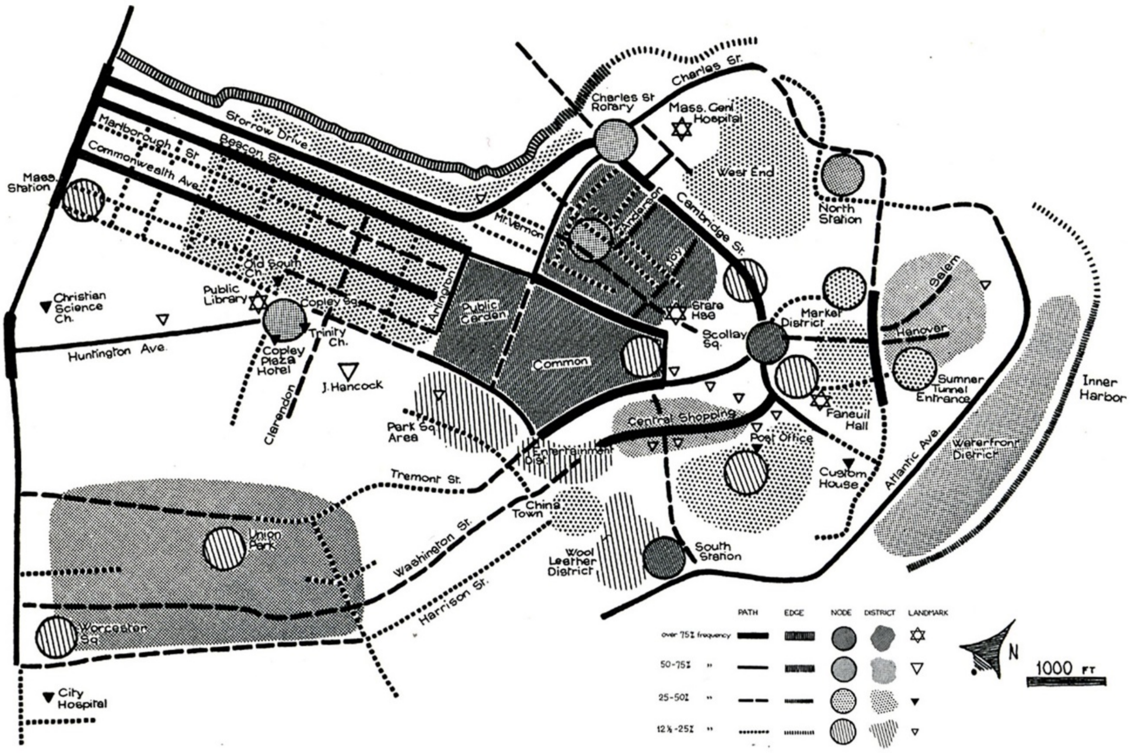


Figure 2-4 The major levels (rectangles) and rates (valve symbols) for the model of an urban area.

In contrast to Forrester's approach, Lynch sought to understand city-making in terms of human meaning (Lynch, 1960). While Orit Halpern recognises a cybernetic influence in Lynch's work, arguing that Forrester and Lynch studied the city's organisation rather than its built forms (Halpern, 2015), their systematic approaches differ. For Forrester, cities should manage around quantifiable human behaviour measures (Jarzombek, 2017), while Lynch understood the city as a composition of visual symbols with ambiguous and subjective interpretations (Figure 4-6). Lynch's approach opened a new understanding of the city and architecture's visual role through individual cognitive maps. Individual observations and human experience rather than mass behaviour uncovered the qualitative aspects of architecture that helped define the built environment.

Consequently, the city concept changed from a quantifiable pattern of information processing to a collage of qualitative and personal images of spatial perception. Rather than treating architecture as objectively and universally understood, qualitative information informing personal cognitive maps introduced the possibility of many different readings and meanings, providing an opportunity for the architect to construct open-ended and less deterministic systems. As Jane Jacobs pointed out in her New York street life study, local low-level observations detected bottom-up decision making. This bottom-up perspective provided a better understanding of lived experience than the centrally planned top-down government (Jacobs, 1961).

Figure 4-6 - The visual form of Boston as seen in the field (Lynch, 1960, p. 19)



Indeterminant and relational pattern

In addition to subjective resistance against objective and abstract systems, critique also targeted the reductive logic of scientific analysis. Nicholas de Monchaux argues that a consequence of Lynch's urban approach was a cultural realisation that wholes existed as more than the sum of their parts, promoting an attitude that patterns from analysis bore no connection to the outcome of applying them in synthesis (de Monchaux, 2016). This realisation problematised Alexander's design patterns as discrete spatial solutions;

as Adam Marcus points out, Alexander worked on a premise of architectural 'facts' but assumed all contexts were socially and culturally equivalent (Marble, 2012).

Architecture's invitation of subjectivity into practice did not merely shift identity from quantity to quality; it also emphasised the abundance and variety of cultural qualities. Media theory introduced the idea that architecture acted as part of a wider communication environment, meaning that ordering and relating bits of data as the basis of information became part of a readable and culturally interpretable environment. Larry Busbea connects media theory's concern with understanding both information transmission and meaning in communication, to a view of architecture as 'content' for a new environmentally aware pattern recognising subject (Busbea, 2015). As discussed earlier, Orit Halpern echoes Busbea's recognition of a new pattern recognising the audience for architecture and design through Ray and Charles Eames's design and pedagogy practice (Halpern, 2015, p. 95). Halpern's argument is significant for architectural practice; the Eames's design and pedagogy required themselves and their students to become consumers of data and the designers of visual systems that were 'data-driven, non-structural, and relational' (Halpern, 2015, p. 71).

Consequently, a process of patterning became both a material and method in design towards intended relational systems. Orit Halpern provides a material example of the Eames's approach in the IBM pavilion, designed with Eero Saarinen, and the accompanying video projection attraction, 'Think', for the 1964 New York World Fair. The architecture user became the curator of individual experience by constructing personal information through multiple channels (Figure 4-7). Halpern explains that this multi-channel interior experience came through a desire to maximise choice and a potential for endless interpretations from the audience (Halpern, 2015). Rather than interpreting an environment based on preconceived classifications, Halpern argues that the Eames's expected the audience to 'apprehend' the information by combining and relating media sources rather than interpreting an environment based on preconceived classifications. The interior formed around audience viewpoints and curated a theatrical entry experience. Halpern refers to the Eames's approach as 'data-driven', aiming for 'communicative objectivity', a practice of detecting patterns that were 'non-structural and relational' (Halpern, 2015, p. 95), meaning multiple experiences occurred from designing an environment rather than a static form. The Eames's 'data-driven' approach did not utilise measurements within a practice, such as Durand's or Lynch's; instead, the Eames's redefined architecture's context as a sensory environment, reconceptualising interior experience as a sensory curation. In the case of the IBM pavilion, while moments of personal interpretation and pattern recognition appear in the pavilion skin and the tree-like lattice structure (Figure 4-8), the interior provides an architecture expressing their pattern-recognising practice using multiple media sources, portrayed, and understood as data.

Figure 4-7 - Ray & Charles Eames with Eero Saarinen, IBM 'Think' Pavilion interior (Ostroff, 2020)

[Production Note]

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Figure 4-8 - IBM Pavilion 1964-65, New York Times advert for the World's Fair (Ostroff, 2020, p. 296)

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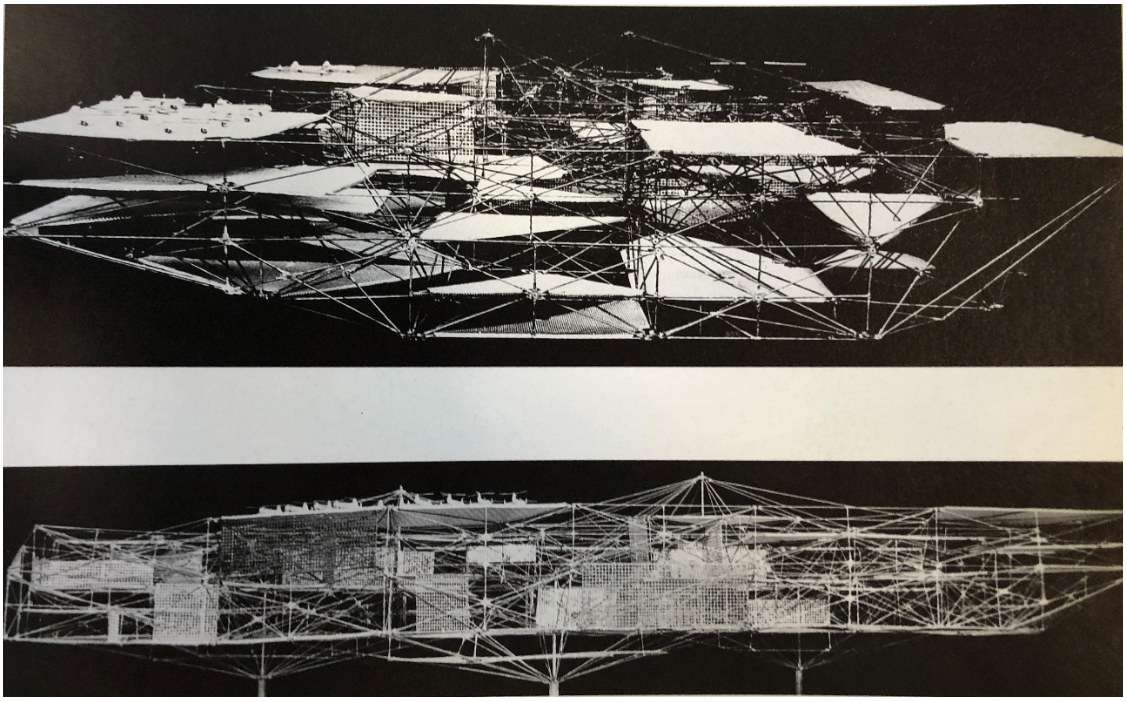
An architectural example of the Eames's data-driven approach exists in Constant Nieuwenhuys's (known as Constant) city concept, 'New Babylon' (1959-74). New Babylon only existed as a proposal, but its models and drawings provided a material-cultural alternative to capitalism, consumerism, and a mechanically automated society. Constant theorised a city to form around its inhabitant's nomadic exertion of personalisation rather than an imposed material form. Configuring architecture around personal lifestyle choices required architecture to act as digital data, taking the Eames's information systems idea and applying it to materials. Constant's city proposal reconceived architects' practice from designing complete buildings to developing material systems that afforded personal and transient lifestyles (Figure 4-9). Constant's project of adaptable infill to a larger structural grid, providing living space that responded to its occupants' individual needs and desires, understood data in two ways. Firstly, as part of personal and subjective sensory experience, and secondly, as part of a spatial reconfiguration system. Mark Wigley interprets New Babylon as a new conception of 'social space', from previously deriving cohabitation through ecological statistics to understanding it as an interaction between psychology and environment (Wigley, 1998). Wigley points to Constant's resulting 'assembly project' of micro and macro structures, which opposed the notion of assembly line standardisation and gave inhabitants control (Wigley, 1998). The static form of data associated with the positivist nexus that drove mass production gave way to understanding individualised psychological environments. New Babylon provides a case where data was associated with understanding inhabitation as a sensory environment, not just space, requiring architecture to design in material instability that could adapt to unpredictable and individual human behaviour. As a reconfigurable material system, architecture provided an environment for human action in dialogue with sensory experience.

Figure 4-9 - New Babylon Sector Construction Model (Wigley, 1998, p. 109)



Disciplinary rules to contextual adaptation.

New Babylon did not offer finished housing; instead, it supported life through a structural framework providing a personally reconfigurable and artificially conditioned interior. The introduction of personal behaviour into a structural system aimed to produce material assemblies that expressed digital computing's reconfigurable instability. Julie Nichols argues that New Babylon's main aim was to reconcile the material organising role of architecture with a rising cultural shift towards ideas of virtuality and immaterial psychological environments (Nichols, 2004). Nichols highlights New Babylon's similarity to M. Christine Boyer's proposed 'Cyber Cities', as 'metaphorical entities in virtual space where the computer matrix of data management comes together with the notion of city' (Nichols, 2004, p. 43). Nichols highlights how both ideas equate information dematerialisation with the material basis of the city. In Constant's case, New Babylon's self-reconfiguring material supporting structure imagined human movement in the manner of virtual immaterial flows working within what Nichols calls the ‘network metaphor of globalised digital communication’ (Nichols, 2004, p. 45). In Constant’s project, data is a metaphor drawn from information technology. Opposed to architects arranging materials through agreed measurements and proportions, New Babylon imagined materials assembling and structuring like digital bits. A significant realisation from New Babylon was that the shift from shaping objects to designing self-organising systems and processes could potentially engage with monitoring, leaving the architect’s dated modes of measurement and standardisation surplus to requirements. At this point, data was no longer objective technical sensing or drawn from information systems, it becomes a spatial concept for the built environment. Opposed to data establishing architectural rules for material combination, Constant used data’s role in information processing as a metaphor for material components. Imagining architecture’s material parts as data introduced the idea that decisions driving architectural form arrived during construction and evolved well past its initial construction.

In addition to highlighting the architect's reduced influence and providing a seductive idea of architecture organising through interacting relationships, New Babylon also highlighted the limitations of functionalist ideology. Bratton argues that while New Babylon's material assembly grid inadvertently produced an authoritarian layer of governance unable to adapt at the speed of behaviour, it did acknowledge that use dynamically changed and evolved (Bratton, 2015). Just as Yanni Alexander Loukissas argues that all data are local (Loukissas, 2019), Bratton highlights how observation is always contextual and unique to a time and location. Unlike Forrester’s urban dynamics, New Babylon accentuated the reality that humans experience differently based on sensory capacity, location, and time. New Babylon provides a distinct shift in data’s cultural image from something universal and hierarchal to being personal, local, and most importantly, relative to a time and place. An alternative model for the architect was to take in the cybernetic notion of environmental monitoring to theorise architecture as forming through a constantly changing individual contextual adaptation.

The architect’s understanding and response to data between the mid- to late-twentieth century reads as a shift from the objective quantified prediction based on universal rules to individual contextual adaptation. A new cultural awareness, conceptualised through information technology as the raw material of media and psychological environments, assigned importance to the user in architecture as an audience for design and as part of self-forming material systems. A realisation during the 1960s and 1970s that environmental context meant that reality is not a consistent register implied that architects could no longer assume universal interpretations or uses of architecture. Consequently, previous understandings of architecture as a historical progression of disciplinary rules became reconfigured as a designed or emergent response to local observations, making architecture relative to context. In practice, individual observation, and sensory experience prioritised cultural constructs such as standards and pattern languages.

Although New Babylon only existed as an extreme thought experiment, it introduced the possibility of material forms detaching from an architect and becoming driven by time and location-specific, subjective, sensory response. Data, culturally understood as part of a subjective and individualistic environment, left the architect's traditional practice of describing pre-determined forms unable to engage with the dynamism of everyday life. As skills and thinking to respond to this dynamism came from other disciplines, data's influence migrated to the edges of material and informational techniques, and architects struggled to follow.

Inviting subjectivity into the design process as a generator of difference is a response to the objective ideology of design science. Through subjective input, architecture's idealised rules and axioms gave way to indeterminism and personal interpretation, with the potential for architecture to adapt to context. The radical material destabilisation imagined by Constant took on the cultural expectations of individualised society, one increasingly understood and organised through data collection. During this subjective response, data did not manifest as a number or pattern; it conceptually existed in architecture's audience and inhabitants, who could provide difference in contextually responsive systems. Architecture, configuring like data under the input of the individual inhabitant, continued the architect's focus on process over material objects, with the latter now conceived of as a responsive sensory environment. Engagements and explorations of subjectivity and human sensory environments under the cultural influence of technical information systems meant data became a concept to engage human audiences. At the same time, data became a cultural artefact and a potential material for the architect to engage in practice. Through new experiences and material concepts, data became a cultural signifier that aligned architecture with futuristic innovative computation.

4.4 Second-order Form

In contrast to methods and patterns acting as interfaces between knowledge and design, architects in the late twentieth century began to directly design digital interfaces. Designing digital interfaces as tools for architectural design recast data as a system input thought to reconcile objective cybernetic thinking with contextual adaptation. Consequently, the architect's reduced role alluded to in New Babylon became a reality via automated computer systems of data management. Digital computing experiments by architects in the 1970s and 1980s offer examples where practice became conceptualised as a combination of understandings. These understandings divide between human subjective sensory interpretations and non-human logical communication, assigning an unquestionable and rhetorical character to both. As architectural academies and research groups gained access to computing machines in the late 1960s, architects began experimenting directly with digital data as an input and codified design pattern under the influence of evolved cybernetic thinking. New practices utilising computing intelligence continued the cultural understanding of data as part of an environment wherein practice is intensely scrutinised and reconfigured. Eventually, new human-machine collaboration systems extended the notion of the environment from design practice into production and the built architecture.

Adaptive material relations

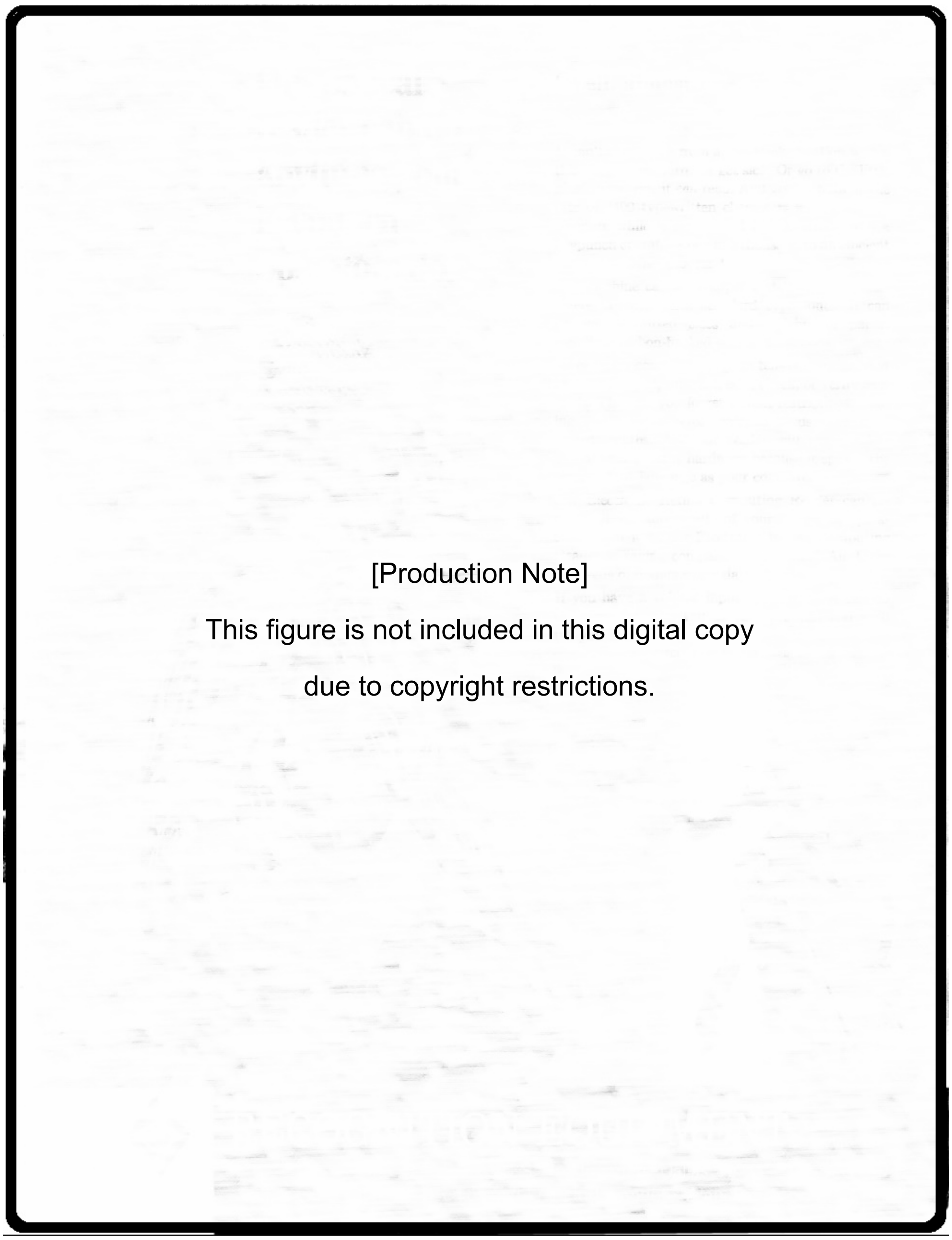
In the mid-twentieth century, the cybernetic thinking underpinning quantified and positivist architecture reassessed its conceptual foundation and realised the objective observational limitations recognised in William Whyte's research. Second-order cybernetics emerged with the realisation that any observer of a system inadvertently influenced the system observed (Glanville, 2004). Control and prediction remained central to the cybernetic paradigm, but it now considered observation to be as crucial as the information system, both part of a mutual relationship. Second-order cybernetics reconceptualised communication as a multi-directional conversation between humans and non-humans, breaking from the unidirectional media of the early and mid-twentieth century.

Gordon Pask introduced his cybernetic 'conversation' theory into architecture through his Architectural Association teaching and collaborations with Nicholas Negroponte, Cedric Price, and John and Julia Frazer (Kolarevic & Parlac, 2015). Architectural practice provided Pask with a concrete example for his conversation theory, which criticised the United Kingdom's built environment based on 'material stability and style…driven by conventions of society and individual practitioner' (Pask, 1969). Pask's conversation theory proposed an 'architectural mutualism' that philosophically and practically accepted contextual relativity as a concept for self-organising and evolutionary outcomes. Rather than the architect imposing form on material, Pask's mutualism conceptualised material assemblages as interactions, arguing that architecture existed firstly as information, with material a secondary consequence (Pask, 1969). Usman Haque links Pask's conversation theory to the uptake by architects keen to avoid architectural products that were too prescriptive, restrictive, or autocratic (Haque, 2007). As a response, Pask's writings inspired many architects to explore New Babylon's self-organisation, surprise, and indeterminacy while retaining an influence over the system.

Environments of data-mation

Nicholas Negroponte, an architect influenced by Pask and with access to experimental computing technology, explored machine sensing and processing and proposed a data-use radically different to the paper-based storage of Neufert's Handbook. In his book, *The Architectural Machine*, Negroponte refers to an American magazine, *Datamation*, published in the late 1960s, which proclaimed a possible 'data-mation' of the world by deferring tasks and decisions to machines (Negroponte, 1970). Negroponte's reference to 'datamation' indicates a cultural link to a specific business and communication way of thinking, associated exclusively with information technology. The articles and advertising messages in the magazine consistently associate computer-managed data with time and cost (Figure 4-10), alongside problematically sexist depictions of labour replacement (Forest, 1966). The magazine's title and Negroponte's use of 'data-mation' indicate alignment with corporate thinking. The Architecture Machine Group's links to defence research contracts, National Science Foundation and private business funding (Wright-Steenson, 2013) provide further evidence for Negroponte's underlying labour optimisation research agenda.

Figure 4-10 - Advert in Datamation magazine (Forest, 1966, p. 2)



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Negroponte's research focused on optimising decision making efficiency with a secondary concern with the building outcomes of practice, which, he felt, could not anticipate unknown needs for human inhabitation (Negroponte, 1970). In Negroponte's mind, data-mation provided the architect with an opportunity and problem. Firstly, there was an opportunity to absorb myriad data sources available to design into the computer to reduce the 'lost information' in human perception. However, a problem lay in managing and interpreting the new complex combinations of human and machine interactions (summary of types in Table 4-1) (Negroponte, 1970). Environmental sampling provided

Negroponte with an argument for machine involvement in practice capable of multiple inputs. Human behaviour measured and detected through 'direct observation channels' (Negroponte, 1970, p. 27) would avoid the 'mutations of transfer from the real world to designer's sensors to designer's brain to designer's effectors' (Negroponte, 1970, p. 9). The data types listed in Table 4-1 show how the data nexus of Alberti's communication and Durand's knowing came together through information technology to detect and measure the world while constructing and transferring information.

Table 4-1 - Negroponte's data types (Negroponte, 1970)

Type	Description	Role
Human sensory	Analogue range of values Environmental phenomena (sounds, light, tactile, temperature)	Knowing/communicating
Human measured	Quantities, words	Knowing
Machine sensory	Analogue (range of quantities) Digital (either 1/0)	Knowing
Machine interaction	As a material of dialogue - transferring human information into machine useable information	Communicating
Machine communication	Combinations of 1/0 (bits of information) that describe larger collections of numbers used to translate information	Processing/communicating
Machine memory	Bits of information Informational structure stored and described as bit combinations	Communicating
Machine software	Translation instructions manipulation, described through machine	Communicating

The Architecture Machine Group took data's new cultural and technologically derived qualities of detecting, storing, and communicating and applied them to architectural design. Pask's conversation theory registers in Negroponte's design description as a mutual human-machine dialogue through a 'common language' (Negroponte, 1970, p. 9). Data formed this common language, emphasising machine capabilities to map meaning onto input based on previous experience. Consequently, design through the machine became a simulation process connecting the past with an anticipated future.

The computer provided an apparatus to automate positivist architectural simulation and promoted a future where technology would move from problem-solving to ‘problem worrying’, thus anticipating design problems and solutions outside available human knowledge (Negroponte, 1970, p. 119). Design as problem-solving and solution-searching relates closely to Alexander’s pattern language. However, Negroponte’s design process of technical problem worrying shifted thinking from human pattern application to automated pattern production.

Negroponte’s common data language imparted a cybernetic equivalence between the architect and the technical system. To make this equivalence, Negroponte introduced the metaphor of ‘environment’ to conceptualise and redirect practice from designing objects to initiating and maintaining transfer from human needs to machine stored solutions (Negroponte, 1975). The Architecture Machine Group built ‘intelligent’ machines and interactive interfaces to provide an early version of computer-aided design. The group developed machines that would conceivably prompt the designer to ask questions, pose problems and subsequently provide architectural solutions by applying architectural ‘truisms’ — rules embedded within models — to user-defined problems. The computer was to assist by bringing the ‘unique and exceptional’ to the user’s attention through knowing a design problem's precise particulars (Negroponte, 1970). In turn, the computer would ‘simulate’ a process through the theory that if the computer knew enough rules of a process, it could take on the character of the event ‘and undergo a make-believe happening of that process’ (Negroponte, 1970, p. 47). As a result, Negroponte aimed to design a technical environment where data communication facilitated an intelligent machine and human collaboration.

Figure 4-11 - The Architecture Machine graphical user interface (Negroponte, 1970, p. 80).

Negroponte's take on a new architectural practice collaborating and communicating with machines through a technical environment utilised the non-human capability to store and retrieve architecture's 'vast knowledge' (Negroponte, 1975, p. 109). Negroponte thought the architect and non-architect were better off utilising stored knowledge 'through a window of his needs and the medium of some sophisticated man-machine interface' (Negroponte, 1975, p. 109). The Architecture Machine Group concerned themselves with how the personal needs and situations of the technical interface's 'user' could reconfigure architectural knowledge (Figure 4-11). This user, however, did not have to be an architect; Negroponte, alongside Yona Freidman, took the position that the machine should take on all design responsibility. Larry Busbea recognises this transition from human to machine responsibility by comparing Negroponte's Architectural Machine and Yona Freidman's 'YONA' and 'Flatwriter' projects. Both projects attempted to bring architectural knowledge into a design conversation between non-architects and computers by using data in software to encode architectural axioms and heuristics, driven by a belief that architecture consisted of uncontested rules (Busbea, 2007).

For both the Architecture Machine Group and Freidman, a human-technology environment allowed the architect and non-architect to apprehend and apply a store of knowledge. This readily available store changed design to a process of filtering and curating data suitable for a design problem. In this context, as New Babylon theorised, it mapped user input onto a reduced choice based on a simulation rather than data maximising choices. In Negroponte and Freidman's case, the technical user interface became the means of restricting decision options by only presenting information deemed suitable for a design solution. Shaping a design solution space through mapping continued the objective thinking of Alexander; however, it reconceptualised user input as a source of variation regarding human desires and goals, making design accessible to those without requisite knowledge. In Negroponte's theory, an environment of user input and machine feedback replaced the architect; users defined architecture's needs, and the machine logically proposed a solution. Negroponte indicates this position when he argues for an architecture of 'Do-it-yourself-ism', a process that recast the consumer as a producer and the dweller as a designer (Negroponte, 1970). Facilitating the 'Do-it-yourself-ism' meant imparting enough data to machines to encode, store and retrieve architectural knowledge and wisdom.

Through Negroponte and his Architecture Machine Group we encounter a new dual role for data, as the basis for technical design assistance and as the conceptual foundation for dynamic, feedback loop, architectural environments. The Architecture Machine relied on data, making it indispensable not only to the computer-based process but also as a promotional tool, a cultural meme that signified logic, prediction, and certainty.

Although Negroponte viewed the architect as unnecessary, the implication from his human-machine experiments was for a new role as a curator, filterer and inputter of quantities and language deemed useful in design. The computer would then construct or fill in 'gaps' missed by human sensing (Negroponte, 1970). Negroponte anticipated and expected observational errors from architects. The human-machine environment became a medium and architectural message, causing a shift away from traditional architectural drawing modes to visualising the informational 'image' bound within a user's data. For Negroponte, finding this 'image' shifted architectural focus from objects to information and understood buildings as second-order outcomes from interfacial translations between data and information.

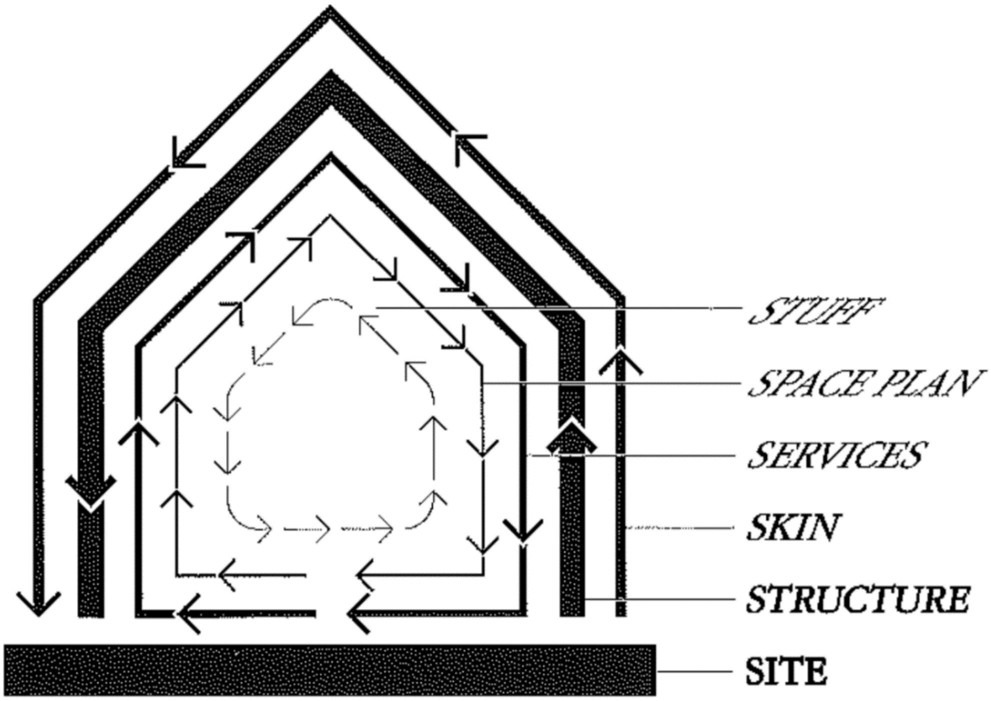
The drawback of Machine Architecture's approach was that they only explored aspects described through user input intelligible to the interface, meaning this space of interaction shaped the problem arriving at the computer and the solution feeding back. The radical notion that architectural practice could reconfigure and involve human and machine collaboration across a designed technical interface recast architecture's products as responses to user-defined material-spatial problems, all within a lingering positivist worldview. Design as a mapping between user input and encoded knowledge imagined the architect would take on a new responsibility for shaping and maintaining the knowledge-communication environment. However, when it came to the reality of technical research, the architect's role diminished to one of simple input, as they were unable to participate in the complexity of technical development. Negroponte's research provides a logical progression of ideas in New Babylon and *A Pattern Language* but explored through an exclusively technical understanding. Research and experiments with automation and assisted design were no longer happening at the architectural fringes; they attempted to escape the discipline.

Material data adaptation

Negroponte and the Architecture Machine Group's idea of a design process shaped by a human and non-human knowledge-communication environment offered an alternative architectural focus, from organising material assemblies to reconceiving architectural experience as a sensory conversation. In addition to Negroponte's technical design environment research, he envisaged human and non-human interaction migrating into architecture's built products to feed self-organisation and adaptation. Such thinking took on ideas of earlier post-occupation research and brought the human-machine interface concept into the building. In *Soft Architecture Machines,* Negroponte wrote of the built environment becoming an 'intelligent environment' by investing 'man-made intelligence' into the built environment (Negroponte, 1975, p. 125). A building as an 'intelligent environment' introduced the possibility of immediate feedback between use and design, introducing evolutionary thinking to vary and control building use within its lifecycle. The concept underpinning Negroponte's building intelligence research was a building capable of technically sensing and mapping a 'functional image of itself' to allocate space and manage energy use, again indicating a broader subtext of technologically replacing the architect (Negroponte, 1975). This closing of the non-human data loop between building solution and occupation, as conceptualised in the 1970s, still exists in the contemporary intelligent building discourse.

The idea that buildings could sense and intelligently adapt over time fundamentally challenged the architectural expectation that design practice evolved buildings between projects; it could now occur during a building's lifecycle. This new understanding of evolution moved from information as a time-based lineage to a cybernetic argument for information apprehended as pattern through sensory recognition. During the 1960s and 70s, a cultural critique from technology and software innovators aimed at the architectural discipline recognised an inability to incorporate or realise adaptation in their built products. Technically driven innovations of real-time building automation and evolutionary thinking introduced notions of systems, adaptation and evolution, catering for users' needs, to design discourse. Some authors even attempted to portray architecture as information technology or design. In particular, Stewart Brand, a prominent technology reporter and entrepreneur, advocated for a new architecture without architects, a collection of material systems left in the hands of building users (Brand, 1994). In the manner of New Babylon, Brand depicted architecture as an adaptable material framework, but one existing as multiple overlapping systems offering different rates of change. Using Frank Duffy's diagram of shearing layers (Figure 4-12), Brand encouraged buildings to provide material adaptation and relinquish form to unpredictable and pragmatic user behaviour. Architecture, conceived as a system of interacting sub-systems, attempted to remove the traditional architectural practice of designing and documenting 'finished' buildings understood as individual objects with a single lifecycle. In this model, the architect needed to become a systems designer, creating soft systems that could re-organise materials like digital data.

Figure 4-12 - Frank Duffy's Shearing Layers diagram used by Stewart Brand (Brand, 1994, p. 13)



SHEARING LAYERS OF CHANGE. Because of the different rates of change of its components, a building is always tearing itself apart.

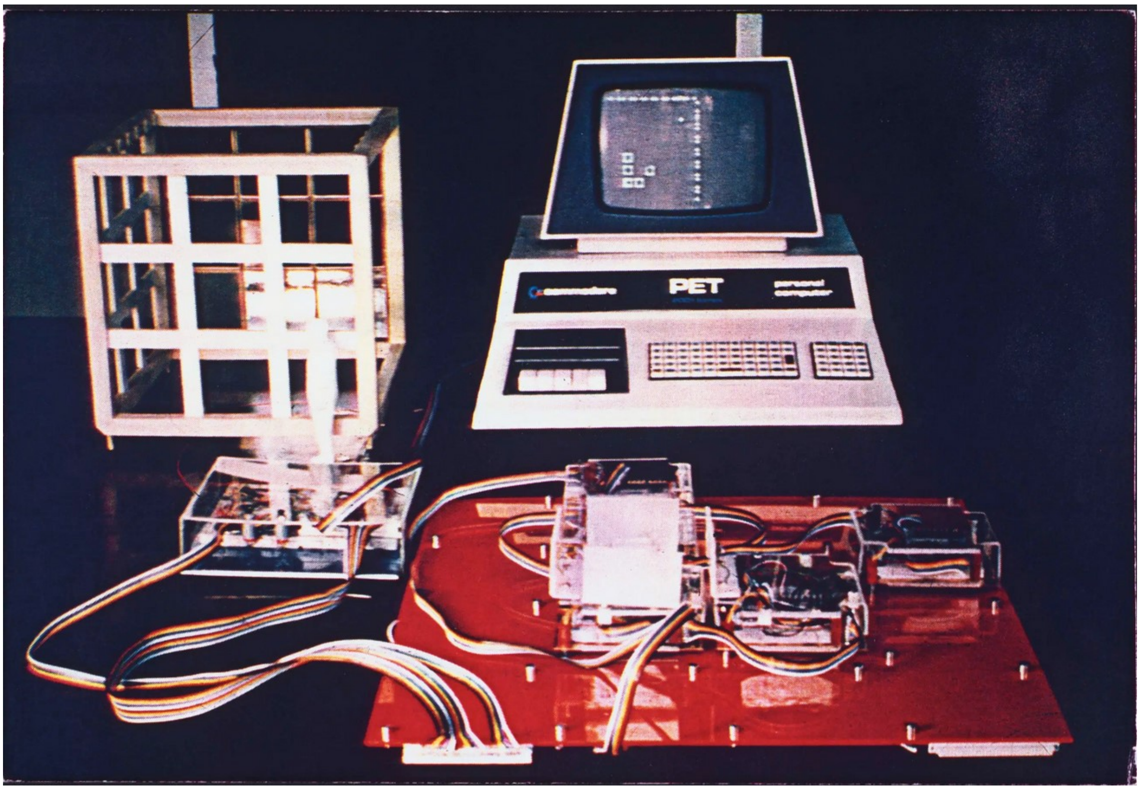
The overtly technological understanding of architecture as a collection of designed systems for user choice challenged the fundamental practice of architecture and its notion of material assembly. Architects interested in Pask's notion of material form as secondary information consequences experimented with designing feedback systems between users and material frameworks. One theory Pask explored with architects was that humans have multiple competing desires, resulting in many transient user requirements. Rather than a user physically manipulating a building, as Brand advocated, input and feedback would drive adaptation through 'co-designing' architecture (Pask, 1969). Through Pask's theory, architecture produced through co-design emphasised understanding user requirements over time rather than an initial design input. Cedric Price's Generator project (1976-79) is an example of this approach: a proposed office for the Gilman Paper Company that adjusted space based on user feedback describing an employee's lifestyle and leisure. Cedric Price's practice, which invested heavily in architecture's social role, worked alongside Pask to explore architecture as a flexible system of material interfaces linking the user's desires with patterned assembly. Although never built, the Generator used 150 mobile combinable cubes as a kit of parts for visitors to design and create temporary structures for personally desired end-effects; with no specific program, all cranes were movable as desired (

Figure 4-13) (Cline & di Carlo, 2002). Molly Wright-Steenson's analysis of the Generator project highlights the importance of Price's experiment in using feedback between material form, human use, and emotional response to help continually construct and demolish material structures (Wright-Steenson, 2010)(

Figure 4-13). A central computer acted as a programmatic research tool and a co-designer of arrangement based on activities and requirements (Figure 4-14). With the help of Julia and John Frazer, two unique computer programming architects, Price produced a drawing programme, an inventory program and an 'an interface for 'interactive interrogation to act as a 'perpetual architect' that enabled 'users' model and prototype Generator's layout before committing the design' (Wright-Steenson, 2010, p. 5). The user input and computer logic of Negroponte's design environment transferred to building architecture through the user's changing needs. The generator has similarities with New Babylon's ambition to provide personalised space for lifestyle and leisure, with the significant exception, that while Babylon imagined architecture reconfigures like digital information, Generator used feedback to calibrate human and building behaviour. Price's idea of the computer acting as a 'perpetual architect' and injecting an intelligence into the building further indicates data's influence in embedding architectural knowledge in a system and removing architects' involvement. Architectural practice radically reconfigured to designing and realising construction and decision-making systems, with data taking on a role as a material to construct and shape information.

Figure 4-13 - Cedric Price's Generator Project (Cline & di Carlo, 2002, p. 156)

Figure 4-14 - Cedric Price, Julia and John Frazer, Interactive Model (Cline & di Carlo, 2002, p. 156)



The profound change for architects was not just the threat to their role and profession, but a realisation that the basis of their design thinking regarding a building's program was obsolete in a new age of monitoring able to describe and track personal behavioural desires. Material forms generated through user input and information feedback offered an unquestionable outcome based on human needs, increasingly accepted without modification from the technical system. A new type of architecture reconfigured through rapid communication was incompatible with construction techniques reliant on skilled labour. Negroponte highlights this incompatibility in 'soft architecture machines' when he describes the difference between 'soft' and 'cyclic' materials (Negroponte, 1975). For Negroponte, a soft approach employed light and manoeuvrable materials, such as inflatable plastics, to respond to the speed of change uncovered by technical feedback. The soft approach would enable low tech solutions achievable by unskilled users but could not provide the internal conditions required for human survival. The alternative cyclic approach imagined a process of continuous construction and destruction, governed by a building's sensed needs and user feedback expressed as 'informational and operational features' (Negroponte, 1975, p. 150). While the soft approach treated material in the traditional manner of the architect documenting and representing assemblies, the cyclic acted to dematerialise through feedback between construction, use and adaptation, with images influencing movement and possible arrangement of materials (Negroponte, 1975). The main distinction between the soft and cyclic concerns architectural instruction; while the soft relies on the architect to describe and coordinate, the cyclic self-organises through information. For architects to achieve the cyclic meant incorporating material systems that could reconfigure at speeds equivalent to changing user needs and system feedback.

The idea of architecture organising and adapting through a combination of human and technical information processing systems found an impasse with the realisation that data and architectural parts were irreconcilably at odds concerning scale and time. The vision of producing evolutionary architectural objects of adaptable moving parts resulted in disappointing static and fixed forms, lacking the human ability or desire for reconfiguration. An example of this disappointment exists in The Centre Georges Pompidou, completed in 1977 by Richard Rogers, Renzo Piano, and Gianfranco Franchini for Paris's Beaubourg district. The Pompidou Centre proposed a reconfigurable museum to adapt to different social situations and cultural themes. Architecturally, the centre combined a highly engineered steel structural framework with moveable interior partitions, providing a lightness for the interior. The Pompidou Centre's adaptation ambitions did not eventuate, in part due to the architectural system's resistance to change and political pressures on the museum's operation (Postle, 1980). The Pompidou Centre offers an example where a cultural speed of information arriving through digital communication proved incompatible with the large-scale and heavy material reality. This material reality of stasis rather than adaptation appears in two images of the Pompidou library 35 years apart; Figure 4-15 and Figure 4-16 show little difference in their spatial configuration between these periods.

Figure 4-15 - Centre Georges Pompidou Main Library from Denis Postle's 'Beauborg' (Postle, 1980)

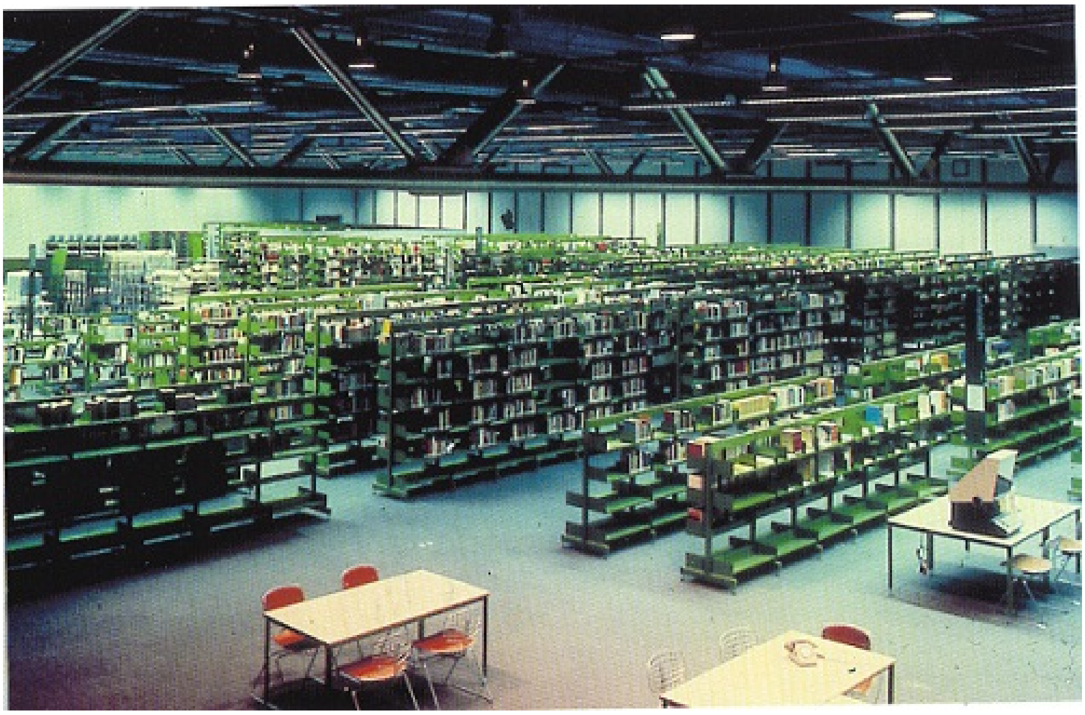


Figure 4-16 - Centre Georges Pompidou Main Library 2015 (Flickr)

During this period of intensive experiments with design environments, the general arc of architectural practice, automation, and adaptation through user input and technical monitoring shows a movement away from mainstream culture to a position beyond the fringes of the discipline. Beyond the 1970s and 80s, the realisation that the speed of change detected by monitoring proved irreconcilable with architecture's material basis correlates to a shift by many involved, who applied their thinking to other new design disciplines. Molly Wright-Steenson argues that because Negroponte explored information management more than material processes, his ideas influenced 'information architecture' more than architecture (Wright-Steenson, 2014). The first reason is that Negroponte's research focused on technology and artificial intelligence, not architecture. Defining problems and searching for solutions in architectural design provided a well-defined process to innovate machine intelligence, which was the genuine research interest of the Architecture Machine Group (Wright-Steenson, 2014). As researchers embedded within the lucrative American Military-Industrial Complex (Kwinter & Davidson, 2008), the Architecture Machine Group and Negroponte never sought to produce architecture. No physical buildings ever emerged from the research. Instead, their ideas and theories became fertile ground for developing technology and investigating new human-computer relationships. Negroponte continued the Architectural Machine project but concentrated on designing interfaces that could translate between 'atoms and bits' (Negroponte, 1995) for application in multiple fields.

The presumed objectivity provided by non-human observation and processing and entering into architecture from systems and cybernetic thinking had more influence on the design of human-machine interfaces than the built environment. However, when architects conceptualised data as part of collaborative and interactive design and building environments, this period laid the foundation for more present-day attitudes. The biggest criticism of this period, and the Architecture Machine Group in particular, is that they portrayed architecture as a technical, rational, and predictable discipline, fully replicable within the encoded logic of computers. Theodora Vardouli echoes this recognition, arguing that this period continued the deterministic and paternal thinking associated with scientific positivism by promoting calculation over mistrusted human intuition (Vardouli, 2012).

In summary, in an attempt to reinstate an authority over architecture, some architects moved to calibrate the objective/subjective polemic by combining human and technical data within a design environment. As cybernetics adjusted to acknowledge the subjectivity of system observation, some architects entertained design and architecture ideas as adaptive material relations made legible through technically encoded knowledge interfaces. This period of intense experimentation with sensory environments that combined human input with computerised data processing and logic profoundly influenced later digital simulation and information architecture practices. For some architects, information management took on greater importance than direct material decisions within an understanding of buildings as constantly adapting to user needs. Consequently, some moved to discuss material form as second-order information processes, requiring a new need for architects to construct, manage and curate data within designed environments. The consequences for the architect was profound, where the sensory skill of pencil of paper tacitly engaged skill and knowledge, the screen and keyboard imposed a technical mediation which removed sensation and means of literally drawing architecture. A consequence of portraying complex design problems as only possible by engaging objective data systems was that the architects primary mode of expression and representation, the drawing, became an information visualisation, an image, interfacing the architect's input and the technical systems underlying data.

4.5 Conclusion – Context and Complexity

The mid to late twentieth century experienced an abrupt change in data understanding due to information's conceptual redefinition as a statistical probability. Claude Shannon's information theory sits as a threshold in architectural thinking between the analogue and digital, from recording observation into abstract material representations to data sources escaping human experience through technical detection and further abstraction into on/off signal states. The first significant change was for technical data to gain relational significance in the broader cultural consciousness. What was previously static and fixed began to be considered flexible, adjustable, and manipulable, enabling radical information storage and organisation. Architecture began to absorb information theory, cybernetics, and rule-based systems thinking despite having little access to computing machinery. Christopher Alexander's design pattern language experiments of the 1960s transposed data's relational identity onto explain architectural design as searching for the optimal solution, imbuing material form with the statistical certainty of communication. Architects experimented with dynamic patterns under the expectation that design decisions and material elements could organise with the same correctness as digital data.

As technology migrated into research facilities, the possibility of recording and monitoring the present, rather than accessing fixed historical measures, encouraged theories associated with calculating and modelling predictable outcomes. Quantified measurement altered its association with verifying design decisions to become part of searching and predicting solutions from stored digitised information. Instead of culturally signifying objective evidence, it now represented an encoded communication-knowledge environment with possibilities for replacing the human architect. Under a cultural mistrust of the architect and their inability to embrace and manage material change at the speed of monitoring and technical feedback change, questions arose regarding their relevance. In response, some architects explored data-encoded communication–knowledge environments that technically connected observing, forecasting and instruction. This shift began to conceptualise architecture as an information system, with material form considered a secondary consequence to data and information feedback. As a second-order data process, architecture changed design focus from finished objects based on established rules and axioms to material assemblies configuring around technically assisted decision systems. The possibility of collecting and accessing occupancy and behavioural information meant the architect's role extended into the building's life and altered the expectations of the architecture to it adapting contextually during use.

During the mid- to late -twentieth century, data differs in three ways in the architect's hands. Firstly, its influence continued through static measures and patterns used to direct design decisions under the auspices of objectivity. This was before shifting in identity to a relational, non-linear, and dynamic catalyst for adaptation and difference. Then, in the mid- to late-twentieth century, the understanding altered again, data became a mappable material in practice, part of a human/machine collaborative environment. A trend identified across all three characters is an architectural desire to improve the architect's cognitive ability by using data to guide choice or automate decisions. Consequently, for some architects, the space in practice between observation and instruction which previously relied on analogue sketching became one of curating and maintaining data logic mappings within technical systems.

The most radical change was for data's character shifting from measurement sets to a potentially constant technical monitoring. Architects took on cultural expectations associated with this scientific shift, meaning data was not a one-time input but now understood as a dynamic background to practice. Data as a static measure previously mapped observation in a linear way to link forecasting with instruction. Data as a dynamic environment to practice meant that the architect became more responsible for what became monitored or what degree of monitoring became an input for design. Rather than inviting fully formed information into the design process, the architect was now tasked with constructing information through data collection, processing, and feedback. In effect, during the later twentieth century, data's role changed from a practical *measurement* to a constant *monitoring* achievable through non-human observation. Subsequently, during the late twentieth century, architects took on cultural expectations associated with this scientific shift, meaning data was not a one-time input but understood as constantly changing.

The change from one off observation measurement to a technical mediated monitoring significantly altered the architect's role and perceived responsibilities. The architect's ongoing interest in optimisation moved from relying on established rules and axioms to an engagement with contextually adaptive feedback. This shift in contextual dependency indicates a growing awareness of the digital's influence on information, making it plural and relational, requiring the architect to embed or resist their partiality. The cultural expectations for architecture and the architect change from producing singular functional use and static objects to managing and predicting interplays of multiple and temporal programs. At the centre of data's influence is a newfound engagement with managing complexity. New sources of design input and an ability to manage these through statistical pattern meant that architects began to consider design problems with many more variables and scalar consequences.

Across the period in question data relates to an overarching change in the architect's efforts to link architectural objects with increasingly complex and interrelated economic and cultural contexts. The next chapter compares the findings from the previous chapters to critically examine present-day data use in commercial design practice.

Chapter 5: Design Currency

Data as monitored dynamic contextual feedback associated with information technology gained wider acceptance as computers migrated into architectural practice due to the popularity of personal computing in the 1980s and 1990s. Today, the majority of commercial architectural practices rely on digital tools to manage operations and offer design services. In some cases, architects have come to prioritise data to the extent that design becomes described and increasingly promoted as a 'data-driven' process. Architects increasingly emphasise data collection and analysis as part of their service offering. However, despite a great deal of critical attention given to data-driven business and science, limited research explores the assumptions and biases architects attract when taking on this approach. Predominantly, discourse on commercial data-driven projects explore efficiency, time, and cost benefits with little critical reflection on what data is and how it influences the architect's thinking.

The move to 'data-driven' decision making represents a shift in responsibility from collecting and managing to constructing information. Commercial value increasingly concentrates around applicable information, requiring the architect to detect and visualise patterns in data. Consequently, data justifies and validates design outcomes, presenting unquestionable evidence in service of a design solution. In this approach, data takes on a cultural status of being 'given up' by technical processes when in reality it is sampled and assembled. Under this assumption, the conceptual shift identified in the chapter is that data becomes so valuable that architects change focus from manually arranging materials to processing and manipulating data. In short, data becomes a new material for design practice.

5.1 Unquestionable Evidence

When contemporary architects talk of the 'data-driven', they refer to a design practice that verifies and justifies design through evidence rather than their learned knowledge and intuition. From an American architecture, engineering and construction industry perspective, Randy Deutsch, an architectural professor of design, professional practice and technology, categorises data-driven architectural practice as follows (Deutsch, 2015, p. 50).

1. Geometrical - describing virtual 3d form, such as point coordinates and directional vectors – used within a software package
2. External - describing measured phenomena to interact with and calibrate geometry, such as sunlight – used to modify or generate new geometry.
3. Coordination - introduced as part of a project's information repository, such as material performance, positions, dimensions, or manufacture.

From the above descriptions, two identities link to the history described in the thesis:

1. Input into a design process (knowledge)
2. To transfer information (communication)

All three types above relate to producing digital architectural representations, establishing data as an essential aspect of operating in the virtual realm. The data-driven paradigm is generally associated with large-scale commercial projects that utilise digital software environments such as algorithmic modelling and building information modelling (BIM). While the data-driven is not exclusive to large scale building projects and commercial practices, Deutsch argues the approach best suits architects who must navigate the myriad economic pressures and industry requirements found in commercial building briefs (Deutsch, 2015).

Valuable prediction

At its core, the base for design outcomes is accurate description of geometry, external phenomena, and coordination information. The above types take on the character of data because they all become input into a material-cultural apparatus, in this case, the computer. Further abstraction into the computer is the process that converts this disparate information into data for comparison and analysis. Pattern recognition and visualisation coax the data into useful information when transferred over to the computer. The desire to produce design information via computational comparison and analysis emphasises quantity as an objective and precise abstract representation.

However, besides providing valuable information, these types also provide a communication link between project collaborators and clients, forming a common ground to discuss and represent buildings. Randy Deutsch refers to this link as a shared language that provides a translation between design decisions and investment (Deutsch, 2015). Architects responding to complex building briefs must operate in highly competitive commercial markets governing design services and building construction. As a result, architects must submit themselves to the market's self-organising logic, what Jeremy Rifkin describes as seeking to place every aspect of human life into an economic arena, suitable for open comparison and exchange in the marketplace (Rifkin, 2014). Data's role as a 'shared language' relates to providing equivalence between building objects, commercially regarded as comparable objects.

This ability to compare is a foundation of commercial success, which, as Steve Lohr points out, depends on predicting trends and reacting accordingly by managing risk (Lohr, 2015). Risk binds the economy and the market to the physical world via an ability to predict future outcomes, as Carpo states, through an analytic and predictive positivist world view that 'what happened before, if retrievable, will simply happen again' (Carpo, 2013, p. 50). Therefore, we begin to understand the role in data-driven design that affords comparability and risk management, translating architects' acts and creative output into financially comparable and predictable representations.

Many regard data-driven design as a necessary response to the commercial demands of real estate development. Under pressure to compare and manage risk, architects must foreground efficiency and optimisation in human and material performance to the detriment of form (Briscoe & Marble, 2016). Architects engaged in large construction projects in commercial markets must participate in resource allocation systems based on price-based competition. An architect's engagement in the market is through design skills and project delivery capabilities. Additional pressures on practice come from industrial-economic growth requirements, which architecture responds to through increased speed and cost-effectiveness in production and construction. To keep pace, Randy Deutsch advocates that architectural services market themselves in terms of production efficiency and focus on optimising time, quality and price (Deutsch, 2017). Therefore, those that utilise the data-driven approach see it as a way for architectural services to connect design with efficient production and predictable results (Deutsch, 2015). Data-driven design treats data as an objective representation, made comparable and organisable through digital abstraction to provide value through efficiency and predictability.

Deferring responsibility

Contemporary data-driven design operates by mapping data into information to coordinate architectural form. Both uses rely on technical sensing and computing to produce and manage information, introducing a non-human influence into design practice. Considering information production first, technical innovations associated with accessing, storing, and algorithmically analysing text and numbers provide a capacity to interrogate more sources than previously available to human analogue techniques. A consequence of this technical layer is that a big data attitude becomes seductive, one where huge volumes and diverse varieties of fine grained and comparable datasets invite and encourage statistical analysis and predictive decision-making (Kitchin & McArdle, 2016, p. 3). This big data paradigm reduces the world into discrete points based on micro question-answer points compiled into organisable and comparable sets. For example, a set of question-answer pairs related to a photograph posted on a social platform could be:

Name: Eiffel Tower

Location: [48.8584, 2.2945]

Photo: b8735265

Liked: true

Time: 12:00:00

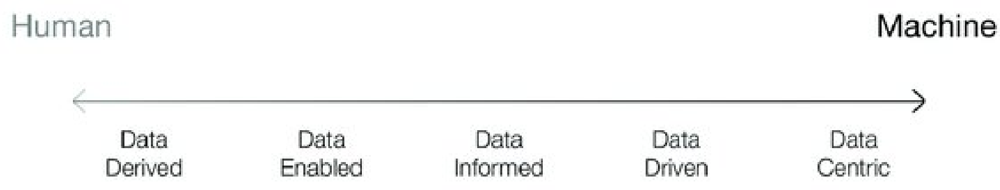
These pairs describe object qualities and place them into precise analytical comparison with other objects. When volume and variety exist, it is called big data and assumes that technical analysis will uncover patterns outside of human capabilities. Big data assume that given enough points, a complete picture of reality exists as a technologically augmented extension of causal and positivist thinking (Lohr, 2015). Today, a cultural assumption that all relevant data can exist replaces previous scientific approaches to a lack of availability that relied on statistical inference (Cukier & Mayer-Schoenberger, 2013). The impossibility of ever obtaining all data introduces a paradox for big data proponents between the prospect of causality and correlation. Economists Kenneth Neil Cukier and Viktor Mayer-Schoenberger argue that big data practices can only uncover correlations, therefore can only detect general patterns (Cukier & Mayer-Schoenberger, 2013). Significantly for architects engaged in data-driven design, big data's positivist causal thinking arrives from and exacerbates a cultural mistrust in human brain capacity and intuition (Madsbjerg, 2017). The available design inputs may be individual and subjective, but the algorithmic techniques central to big data assume objective analysis and empirically verified causal explanation, extending the historical mistrust of human observation onto human analysis. Therefore, at the heart of the data-driven design approach is a tension between an economically desirable non-human objectivity alongside an equal economic mistrust in human subjectivity.

The idea that with more data points comes more accurate predictions butts against the understanding that data points arrive from cultural intentions and by their epistemological basis are destined to always be partial. This tension between data evangelism and conceit of human bias places greater importance on interpretation as essential to understanding. For the architect, this tension manifests in either a complete relinquish to a data deity or inserting themselves and working with data to support traditional architectural techniques.

Much of the digital innovation occurring in architecture adheres to deity as rise of digital platforms and database infrastructures introduced a greater awareness and access to big data techniques. In his study of digital design in practice, Mario Carpo refers to the rise and impact of big data as a 'new science of data' involving a 'non-human post-scientific method' created by autonomous machine processes (Carpo, 2017, p. 7). Carpo highlights the radical change this method brings when describing how machine processes rapidly search and compare 3d model data to recognise patterns of material behaviour (Carpo, 2017, p. 67). As sophisticated algorithms of data searching lead to more predictable material outcomes, Carpo alludes to a future preferencing of machine search over human measurement and experience based intuition.

However, an issue lies in completely preferencing machine prediction when these non-human processes do not understand a data's context and are unable to engage with meaning beyond finding correlations. Randy Deutsch identifies this distinction between human understanding and digital calculation in his schema of data involvement in practice (Figure 5-1) (Deutsch, 2015). This human/machine data spectrum diagram characterises data's involvement in design as a calibration between subjective inputs of learnt knowledge and expertise and objective sources based on scientific measurement and analysis. Data-driven design sets up a negotiation between the economic benefits of human intuition compared to non-human statistical probability. The critical aspect of involvement across the spectrum relates to the degree of non-human influence. The data-derived portrays a predominant human subjectivity, while the data-centric describes a fully automated non-human algorithm. The data-centric removes human involvement, aiming for a speed and accuracy that surpasses human abilities. Therefore, the data-driven reads as part of a technical automation trajectory in architecture, which increasingly favours removing humans in decision-making to generate efficiencies and speak the evidence-based language of commercial development.

Figure 5-1 - Randy Deutsch's data-driven design human/machine spectrum (Deutsch, 2015)



The cultural expectations coming from big data knowledge practices generate a seductive opportunity for commercial operations to generate information beyond the scale of direct human observation. Concurrently, the scale and resolution of non-human observation produces new expectations of efficiency and risk minimisation for the professional architect. In these conditions, data acts to provide a level of detail beyond the brain's capacity, making data a material not only for managing complexity in architectural practice but for simulating and predicting reality. The data-driven process positions digital abstraction as a non-human participant in design, aligning the architect with commercial expectations and competitive requirements. The commercial reality of operating in a market is that architects must compete by promising the fastest, cheapest, and highest quality building outcomes by managing complexity and encapsulating professional knowledge into collaborative models (Deutsch, 2015).

In a data-driven and data-centric mode, architectural decisions become based more on algorithmic pattern recognition than on utilising the architect's knowledge and intuition. The non-human influence overlays a forced dichotomy onto the design, between the rational, objective, hard, quantitative machine and the intuitive, emotional, subjective, soft, qualitative human (Deutsch, 2017). Deutsch admits that focusing design through computer analysis and pattern recognition attracts this dichotomy but continues to espouse the approach for its economic benefits. For the architect practising under intense financial pressures and required to align their design forecasts with outcomes, non-human observation and analysis provide a competitive advantage. Associating data with non-human objectivity provides architects with unquestionable evidence for decision making. Deferring decisions to information constructed through computational analysis provides a convincing design justification based on a non-human capability. Rather than designing through learnt knowledge, the architect defers design responsibility to the information inherent in digitally derived patterns. Digital analysis gives the architect a capacity to uncover previously undetectable information at a scale and resolution beyond the individual.

Within the architect's new commercial responsibilities, data provides a means to defer responsibility in the design process, but it also registers as a new type of architectural service. Today, architects involved in complex commercial projects take on data tasks and responsibilities that do not fit within their traditional remit. Michael Kahn, an architect and PhD researcher, goes so far as to describe them as 'non-architectural in nature' (Kahn, 2021, p. 218). Kahn's research highlights architects' increasing responsibility for sourcing and applying quantity in large scale infrastructural projects, such as metro stations. Kahn observes, 'architects deal in data, and architectural knowledge is about how to both extrapolate data into a documentable design and extract data from the design process to provide clarity about what the design is' (Kahn, 2021, p. 217). From his participation in such design projects, Kahn identifies data's primary role in architectural knowledge, indexing spatial and material decisions with the architect's professional contractual design service commitments. To index action with the product, data relationally integrates between defining the brief, producing designs, documenting, and then delivering tangible or informational outputs (Kahn, 2021). These stages defined by Kahn speak directly to the earlier identified stages of the architect's practice, observation (brief), forecasting (design) and realisation (documentation). The distinction that emerges from Kahn's research is the critical role data has as evidence proving that a design meets 'the requirements as outlined by the stakeholders or established by specialists' (Kahn, 2021, p. 215). Data becomes an architectural deliverable in its own right. Spreadsheets, matrices, schedules, and data sheets become part of the architect's representational media that feed forward into a building and back onto future design responses. As Kahn confirms, 'the data came full circle, manifesting at each stage of the design development process, first as a guide to what must be provided, then as a means of providing, and finally as proof that the design accommodated those requirements' (Kahn, 2021, p. 210).

Non-human performance

This observational and pattern-recognising disconnection from humans erodes architectural authorship when driven through an objective data ideology. In addition to architects deferring decisions and optimising design services, data also serves to index architectural objects to commercial market forces. A building's operation abstractly represented as quantity places a performance evaluation framework onto architecture and sets up a rhetorical logic for connecting claims with outcomes. In contrast to understanding architecture's performative capacity through visual communication such as theatrical scenography (Brejzek et al., 2017), scientific building performance evaluates through energy, material, spatial or human resource management logics (Sinopoli, 2010). A widely held view in the construction industry, and articulated by David Barista, the editor of *Building Design and Construction* magazine, is that metrics describing performance provide a necessary framework to optimise building designs and operations (Barista, 2014). Yehuda E. Kalay, a professor at UC Berkley, extends Barista's position, claiming that performance provides the best measure of architecture, as it ties together form, function and use, which he views as a way of discussing architecture as a commercial product (Kalay, 2013). These two statements offer a clear understanding of what performance means: architecture must optimally operate to maximise building asset value.

Commercially monitoring and optimising a building requires a degree of prediction from patterns, recalling the work of Christopher Alexander. Although Kalay argues that building performance avoids the causal design methods approach explored in the mid-twentieth century, he discusses Alexander's 'puzzle-making' approach as an early data-driven practice that justified through 'forward reasoning' according to pre-set rules (Kalay, 1999, p. 398). This forward reasoning provides a way to connect observation with future prediction, and while Kalay acknowledges this is futile for function, he misses that there is technical determinism in predicting behaviour and use. Architects wary of technical determinism criticise the favouring of performance over form, as it situates architecture in the mandate of economic sustainability, running the risk of fetishising optimisation at the expense of broader design goals (Marble, 2012). Architecture, represented in performative terms, links quantified metrics to efficiency across all aspects of building use — the spatial, material, structural facilities and operations (Marble, 2012).

Evaluating buildings through quantified performance metrics and deferring responsibility to non-human pattern recognition brings consequences for the built environment. Rather than shaping architecture through an economy of the standardised body, the data-driven performance paradigm shapes architecture around standardised control and optimisation of all resources. The consequence, Marble points out, is for an architecture of 'detached formalism', producing form devoid of any referential input, or one of 'hyper-functionalism', designed purely through performance analysis (Marble, 2012, p. 46). Prioritising metrics that in turn prioritise economic productivity and construction efficiency to the detriment of harder-to-define aspects such as spatial experience risks homogenising outcomes. In this regard, the consequences of linking design to economic performance speaks to the automation experiments of the 1960s and further back to Neufert's handbook. The distinction for contemporary data-driven practice is that it submits both the architect's design process and products to an economic performance logic. The characterisation of architectural data as a common commercial language across process and products occurs through an overtly economic rather than a spatial or experiential lens. The indexical relationship between building performance and market forces requires architecture to always *do* something rather than express qualities that might *say* something.

The intense economic pressure on architecture to represent buildings as commodities and manage professional risk liability relates closely to why architects increasingly defer to data to justify design decisions. This deferment is partly due to the commodity requirements placed on architecture and the degree of non-human objectivity required in practice. Representing and designing architecture as a speculative commodity places the architect in a necessary framework of standardised performance targets that measure, distribute, and optimise all available resource value. Consequently, the architect constructs an identity of objective and unquestionable design evidence that satisfies investors. The architect must develop new capacities for selecting and presenting the data to reconcile creative intentions with a capital surplus. As Jean-Louis Cohen points out, where architects once operated through the artistic atelier model where stylistic replication relied on key orthographic representations, today the design studio of the specialist and globally reaching architect participating in large and complex projects is a common scenario (Cohen, 2016). The value gained from predicting and managing risk, alongside the benefit of deferring decisions to information within an ideology of objective and standardised performance, elevates data's status to being a primary material in practice. A source of unquestionable evidence provides the architect with a protective layer to professional decision making, because a consensus spans across all consultants and stakeholders, meaning data sets a framework enabling design and construction services to operate and collaborate.

5.2 Framework for Certainty

Any assumption that data offer objective facts about reality suggests a lack of criticality regarding its origin and use. An objective understanding of architecture coincides with the positivist notion that an empirically observed phenomenon will repeat given the same conditions. Scientific positivism provides a seductive school of thought, as it provides a comfortable link between observation and prediction, linking action with a degree of commercial certainty. However, commercial certainty risks submitting architecture to a repertoire of economically predictable forms under a logic of replicating solutions to architectural problems.

Intentional partiality

Rather than using existing information sources, the data-driven architect produces it from 'raw' data (Deutsch, 2015). The architect becomes a producer rather than a consumer, and new information sources provide client value. Architects engaged in producing information visualise the patterns found in an analysis by filtering and analysing presumed objective observation.

Deutsch's reference to raw data indicates an alignment with scientific positivism, which places the whole design paradigm under the same problematic ideological assumptions. Scientific positivism and statistical prediction underly the data-driven attitude that design decisions deferred to digital pattern recognition offer 'right' rather than merely 'good' solutions. Peter Rowe argues that this difference between good and right comes directly from a legacy of scientific causality linking architectural means with predictable ends (Rowe, 1987). Rowe argues the contrast exists in the division between discipline and professions; architects seeking 'good' outcomes judge based on knowledge and intuition, while the 'right' attempts to position architecture as the best solution to a problem. A problem occurs when qualitative inputs find similar treatment, leading to positivist thought transferring onto a project. What is more, the overuse of purely quantified descriptions of reality creates a tendency for design rhetoric argued through the language of ‘best’, ‘fact’, or ‘truth’, which shapes architecture around only that which can be quantified. Digital tools compound this trend and further reinforce the character of quantity as an objective reading of reality and architecture.

The web-based Design Explorer tool created by research company CORE Studio provides an example of architecture evaluated through visualising data patterns (Figure 5-2). CORE studio provides a sample data set describing volumetric dimensions and simulated environmental performance (Figure 5-3). The metrics that Core studio provide describe architecture through depth, height, orientation, window to wall ratio and the number of shading devices, alongside calculated metrics for Cooling (kWh), Heating (kWh), Lighting (kWh), Light Depth (m), Daylight Autonomy DA (%), Useful Daylight Illuminance UDI (%), Continuous Daylight Autonomy CDA (%) and Spatial Daylight Autonomy SDA (Area%) (Figure 5-2). The resulting visualisation plots parameters across a comparative matrix, allowing a designer to search through design iterations and find versions that achieve the desired target metric combinations.

Figure 5-2 - CORE Studio - Design Explorer online evaluation tool (Peng, 2019)

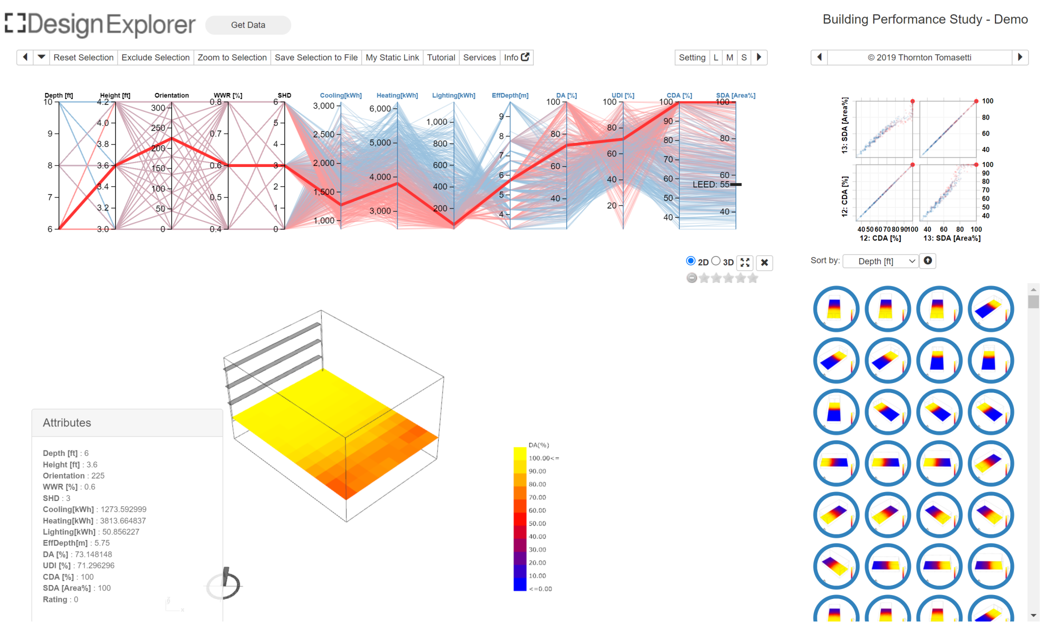


Figure 5-3 - Design Explorer sample data set excel spreadsheet (Peng, 2019)

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Depth [ft]	Height [ft]	Orientation	WWR [%]	SHD	Cooling[kWh]	Heating[kWh]	Lighting[kWh]	EffDepth[m]	DA [%]	UDI [%]	CDA [%]	SDA [Area%]
2	10	3	0	0.4	0	1775.336166	4019.071531	694.957328	4.75	40	46.111111	54.444444	50
3	10	3.6	0	0.4	0	1913.459768	4279.592955	627.582736	5.25	43.888889	51.111111	57.222222	55
4	10	4.2	0	0.4	0	2044.072567	4561.665896	452.009184	5.75	46.666667	56.666667	61.111111	58.89
5	10	3	135	0.4	0	1636.365174	4613.369826	901.327576	3.75	29.444444	43.333333	40	37.78
6	10	3.6	135	0.4	0	1679.93789	5064.550758	739.431426	3.75	32.777778	48.333333	44.444444	40
7	10	4.2	135	0.4	0	1809.852796	5486.842676	632.340733	4.25	35	48.888889	47.777778	45
8	10	3	180	0.4	0	1539.029747	4690.948475	985.065021	3.25	27.777778	48.888889	40	35
9	10	3.6	180	0.4	0	1600.892071	5138.017664	866.67329	3.75	30	49.444444	43.888889	39.44
10	10	4.2	180	0.4	0	1727.329948	5553.301973	831.336929	4.25	35	50.555556	45	43.33
11	10	3	225	0.4	0	1693.788327	4617.726414	1036.311189	3.75	29.444444	45	40	35.56
12	10	3.6	225	0.4	0	1769.769984	5057.033168	904.24208	3.75	31.666667	46.666667	44.444444	40
13	10	4.2	225	0.4	0	1879.986521	5496.575857	822.939682	4.25	35	50.555556	45	45
14	10	3	270	0.4	0	1807.10452	4381.451273	976.481354	4.25	31.111111	43.333333	43.333333	41.11
15	10	3.6	270	0.4	0	1926.974325	4776.972418	797.258013	4.25	35	43.888889	48.333333	45
16	10	4.2	270	0.4	0	2062.064852	5182.027602	673.895108	4.75	38.333333	46.111111	50.555556	48.89
17	10	3	315	0.4	0	1865.443658	4186.402421	798.259644	4.75	35	38.333333	48.888889	48.89
18	10	3.6	315	0.4	0	2015.246221	4520.767016	658.44339	5.25	38.333333	38.888889	50.555556	52.22
19	10	4.2	315	0.4	0	2181.150756	4791.706179	638.468117	5.25	40.555556	42.777778	55	55.56
20	10	3	45	0.4	0	1785.0415	4161.353533	592.432813	4.75	35	37.777778	48.333333	48.33
21	10	3.6	45	0.4	0	1969.739098	4465.294646	475.415757	5.25	40	38.333333	52.777778	51.67
22	10	4.2	45	0.4	0	2096.003234	4772.866069	366.636037	5.25	42.222222	40.555556	55.555556	54.44
23	10	3	90	0.4	0	1792.34298	4361.452891	770.057753	3.75	31.666667	39.444444	44.444444	40.56
24	10	3.6	90	0.4	0	1855.072586	4745.051515	592.464828	4.25	35	40.555556	48.333333	44.44
25	10	4.2	90	0.4	0	2031.594016	5101.081038	495.236552	4.75	38.888889	43.333333	50	49.44

The tool relies on collated data for comparison, meaning the designer is responsible for deciding what data inputs are relevant. In the case of CORE studio's sample set, a designer decided the relationship between volume, position and energy use needed comparison. In the data-driven paradigm, these metrics satisfy the demands for optimal environmental performance. The brief defines this performance, meaning the client speaks for the metrics, favouring what data inputs make it into comparison, aligned with their intentions.

Comparative metrics expect the optimised outcome to speak for itself as the logical calibration of quantified intentions. However, it is essential to realise that deciding on a metric constrains possible architectural outcomes. For instance, Useful Daylight Illuminance (UDI) gives an average of light levels across the year but provides no clues regarding light quality (Callender, 1982). UDI measures useful light within the 100 lux and 2,000 lux range; it treats light as a target for optimal comfort, not as something that defines space. This performance intention means that architecture shapes around how it operates rather than being spatially experienced. As John Hancock Callender's architectural design data highlight, calculations provide valuable time-saving estimations that the building designer must combine and connect into a meaningful composition (Callender, 1982). The limitation of calculated estimations is that it aims for the general rather than the specific, for instance, in the case of light, the tool favours functional illumination rather than an experiential interplay of light and shadow.

The data introduced into the Design Explorer constructs an evaluative framework, potentially constraining formal possibilities (every space becomes rectilinear) and embedding ideology into decision making. In the tool's sample data set, 'environmental performance' imposes a need to consider metrics that describe typical mechanical ventilation systems. Measures such as Cooling (kWh) and Heating (kWh) presume a building will default to electrical energy and mechanical systems to the detriment of considering passive alternatives. Consequently, the data introduced risks normalising mechanical systems that depend on cheap and abundant energy, a cultural attitude persisting since Reyner Banham's mid-twentieth century 'well-tempered environments' (Banham, 1969).

The Design Explorer tool provides an example where the architect must be aware of introducing partiality by choosing what metrics to use to describe and evaluate architecture. This unintentional partiality continues the twentieth-century trend for presuming data to be given, requiring the architect to construct meaning. What is different in the digital version is that the tools result from data partiality, filtered into knowledge and applied through technology. For example, the Design Explorer sets the framework for designing and evaluating architecture. However, it also culturally normalises assumptions of resource use, such as embedding assumptions of mechanical ventilation over passive alternatives.

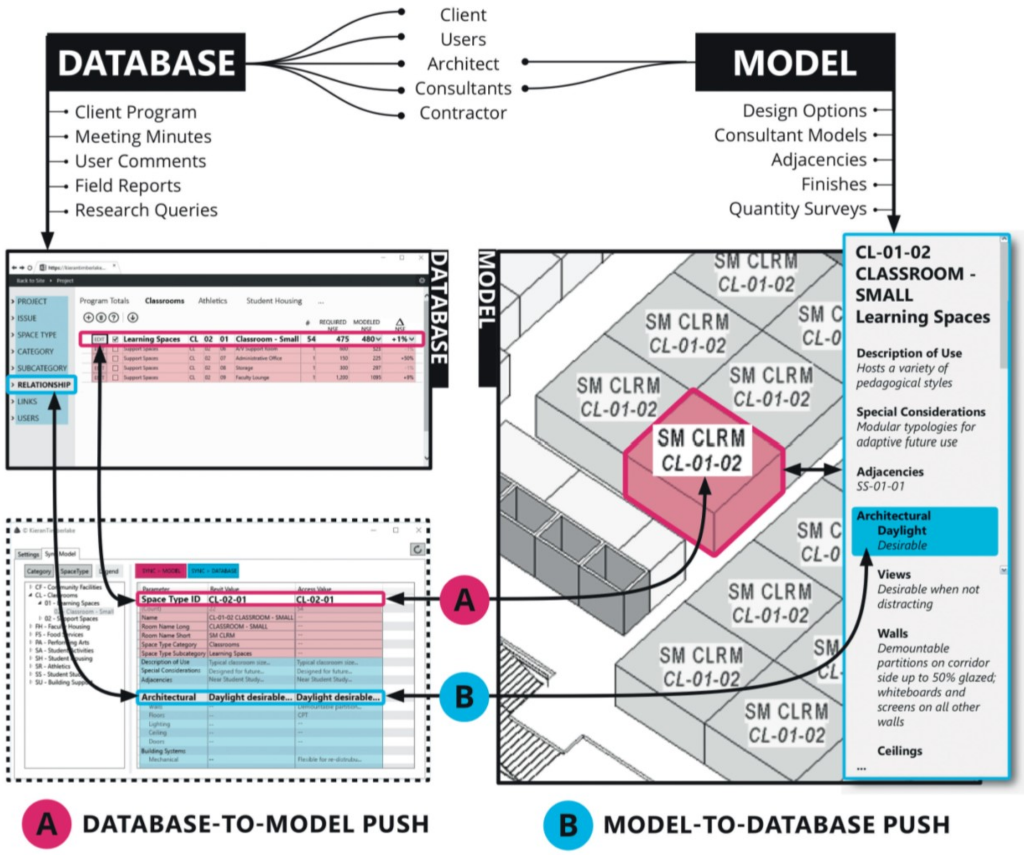
Many data systems politically or professionally imposed onto architects receive critical attention based on their capacity and true intentions. One example in Australia is the quantified BASIX sustainability tool used to measure and prove building energy efficiency. The tool launched in 2004 to establish indoor thermal comfort, water and energy efficiency targets, and sustainability levels, but as built environment academics Grace K C Ding and Goran Runeson point out, the tool misses the lifecycle of a building's energy use and the impact of social and economic factors in sustainable development (Ding & Runeson, 2007). A disjunction arises between political benefit of providing a data tool that tackles sustainably, and the reality of a method that acts as a blunt tool with a limited set of discrete criteria. The example of BASIX indicates how data can necessarily formalise a concerted approach, while in the process limiting benefits. Data acts as a way of measuring action against others within a commercial market, once again aligning decision making with economics. At the same time, data helps the building industry justify limited action when critical understanding and ethical responsibility would benefit all.

Materialising the data(base)

The client and their brief document set the initial aims for a project and provide a statement of intent for an architectural project. The brief becomes where human information and data fixes into a client's requirements, such as quantified area requirements or thermal performance. The brief migrates to or arrives in a collaborative and shareable digital database format in the data-driven. Deutsch argues that the database places a set of initial expectations onto the design process, one where decisions become driven by true/false conditional checks or a scheme's ability to achieve acceptable percentage targets (Deutsch, 2019). Additionally, the client's gradual shift from inhabitant to business corporation means commercial briefs extract statistics and metrics from consultancies rather than first-hand observation (Cuff, 1992). As a response, Deutsch calls to architects and architectural educators to stop teaching 'buildings as buildings' or 'buildings as documents' and instead treat 'buildings as data' (Deutsch, 2015).

When architecture's requirements and judgment become represented as metrics and architectural practice shifts focus to managing and analysing inputs, the architectural skillset moves from drawing and imagining to accessing, manipulating, and correlating databases. The digital model, coordinated via relationships between data, becomes the concentrated site for design and becomes a prediction tool akin to a scientific model. The outcome is to build images and information portrayed as predictive and performative design solutions straight from the database. Steven Kieran and James Timberlake's practice provides an example of this model database visualisation in Figure 5-4. KieranTimberlake's workflow responds to an identified problem of information loss between the brief and design model and uses the database to place all necessary considerations into a relational system. KieranTimberlake uses the language 'live flow' to describe data's role in linking the architectural brief and developing model (KieranTimberlake, 2019). As a result, the live flow between building requirements and virtual models becomes a way of testing and optimising, presuming a 'best' solution exists.

Figure 5-4 - Kieran Timberlake's Data Workflow (Deutsch, 2017, p. 95)



In his foreword to Randy Deutsch's book *Data-Driven Design and Construction* (Deutsch, 2015), James Timberlake has no problem describing architecture as 'fact-based performative form', repeatedly referring to non-human observation and analysis in the context of design automation (Timberlake, 2015). In Timberlake's rhetoric, data 'give form meaning, extend form, and make form performative' (Timberlake, 2015, p. xiii) by scientifically connecting empirical evidenced outcomes with architectural means. Paradoxically, Timberlake argues for assigning greater meaning to architecture while attempting to remove any trace of the human which may prove detrimental to efficiency and optimisation. At one point, Timberlake directly refers to Le Corbusier's Modulor as 'simple data in the form of a rule-set, or principles, which helped to engender form' (Timberlake, 2015, p. xiii). This statement helps reinforce the thesis's claim that data has long existed in architecture. However, Timberlake sidesteps the positivist and functionalist worldview we now know the Modulor Man promoted.

Le Corbusier and the other examples in this research show that architectural use is not uniquely digital. However, the digital does provide something unique to the use of data and construction of information — its unstable material substrate. The difference is not analogue/digital; it is from static to dynamic representation. The same distinction applies to the data-driven. Its objective assumptions do not rely on the digital, but an ability to manipulate and organise data provides valuable information.

This relationship between data manipulation and information is central to Building Information Modelling (BIM). Today BIM is the default software tool for large scale architectural production, with some business markets using industrial directives and standards to guarantee its widespread adoption (Lorek, 2018). BIM is not an isolated tool; it operates as a software network connecting many different databases. Therefore, BIM's appeal centres around the benefit of organising and sharing through abstraction, enabling collaboration and integration of information within and across projects. The database offers a consistent and central set of information, accessible and editable by multiple stakeholders, such as architects, engineers, building contractors and developers. Subsequently, the database exists as an information organising technology that describes objects and rules for organisation into form.

Although much discourse surrounds the materiality of the database, such as Dourish's argument that databases restrict some information visualisations over others (Dourish, 2017), there exists a controversy regarding BIM's influence on material form. On the one hand, Mario Carpo depicts BIM as a source of design indeterminacy through 'collaborative leadership' and multiple authorship (Carpo, 2013). In collaborative leadership, Carpo depicts BIM as a seamless connection between authors of a project within a communication framework akin to Alberti's description of Rome. However, Danelle Briscoe, an architectural professor, disagrees with Carpo, highlighting that data-driven models do not provide a flat sharing hierarchy; they are often contested sites of management and control, encouraging work systems that favour time and material optimisation (Briscoe & Marble, 2016). Briscoe engages discourse on database materiality when arguing BIM overlays a normalising force onto architecture through a rigid control over procedural clarity (Briscoe & Marble, 2016). While Carpo considers BIM a source of authorship, Briscoe highlights the political advantage of controlling evidence and analysis and protecting produced information.

The process of visualising analytical insight to produce information is a central aspect of BIM; as a result, control over information becomes a space of political and financial manipulation to extract value. All digital modelling software uses geometric systems for translating data into a virtual form that links to a degree of reality via a modelling paradigm. Bottazzi points out that software develops via a connection to reality and intended use; for example, boat building software deals with material translation, while animation software does not (Bottazzi, 2018). In digital modelling paradigms, representation of geometry exists through a consistent cartesian index between the real and the virtual through point coordinates, distances, and vectors. Concurrently, the programmed abilities in modelling software that make up an environment diverge in their choice of mathematical relationship to form, producing visual differences between NURBS, mesh or voxel-based modelling (Carpo, 2014). In a digital modelling environment, coordination takes on an objective characteristic; it is consistent across all visual registers of human viewers and most software packages, given the correct instructions in translating into a form. Therefore, while software provides different mathematical techniques to manipulate point coordinates, distances, and vectors, the database remains a universal truth, an objective communication across different interfaces, providing confidence in information accuracy within a practice. Consequently, modelling software imposes translation and representation logics that introduce a partiality in observation and representation.

Partiality embedded into software design feeds forward into material products, which become part of a maintained feedback cycle. Briscoe recognises this in BIM’s functionality, which relies on storing, recalling, and hierarchically organising data into multiple information visualisations producing and controlling informational transfer based on commercial gain (Briscoe & Marble, 2016). As information control reduces financial risk, BIM’s design and management become driven by those with the most financial investment, typically the project developers. Consequently, this financial imbalance and market-based development logic promote material and spatial requirements that utilise standard building elements and link directly into existing and lucrative production and supply chains.

The data-driven attraction lies in efficiencies provided by automating interface-based translations into multiple forms of information. For instance, representations of a building via the screen interface range from visualising geometric representation within the model to organising and presenting material, technical or project management requirements. Through the digital's ability to abstract and relationally organise, the architect becomes more valuable to architectural projects through visualising information for decision making rather than primarily operating through materials and form. The outcome is an architect whose practice focuses on managing and manipulating a database. The architect as 'database manipulator' requires their skills to become attentive to collating, curating, processing, and analysing the numerous sources available whilst being mindful of the constraints of metric selection within digital tools, skills that sit well outside of traditional architectural education. Beyond the technical affordances provided by data visualising tools, architects must be mindful that what gets invited into the tool constrains the space of design exploration.

Calibration over composition

Returning to Deutsch's three types, discussed earlier — geometry, external and coordination — each act as a separate vector of possible information. As a result, the data-driven architect requires skills in creating and managing information across the entire design process from brief to a digital model. The importance of human information in the building process repositions the architect as a designer of information rather than material form, organisation results from the logic and evidence inherent in digital analysis. This new architectural focus of designing through constructed information provides a technique for 'organising and taming' the flows of information possible from data (Marcus, 2012, p. 47). Marcus's metaphor of flow connects to KeirenTimberlake's design flow and depicts information as a moving entity; the difference for Marcus is that information only exists as an instance of the data at that point in time. From Marcus, two characters emerge, one as an input into design requiring analysis to construct information, the other as a substrate of information transfer for communication. In both cases, the data remains the same, but use contrasts between recognising relational structure (analysis) and removing structure (communication). In KeirenTimberlake's example we can recognise the two characters recognised in chapter two in one design process. As an input into design, the architect must detect or assign relationships to construct information, like Durand's knowledge; but as a design output any relationships must rigidly fix to transfer and accurately decode information, just as Alberti controlled translation.

In contrast to Marcus's interest in constructing information, Deutsch's description of information transfer as a 'dataflow' places a different efficiency and accuracy expectation onto architectural production (Deutsch, 2017). Deutsch's characterisation characterises 'dataflow' as controlling and restricting the possible information so that architects gain control over material outcomes. The extreme version of Deutsch's ‘dataflow’ is the ‘digital twin’, a virtual replica of an existing or proposed physical building. The virtual computer-based model becomes the primary site of design and occupation simulation through the lens of measured building performance, conceptually linking building design with visualising and predicting future building operations (Bier & Knight, 2014). With increased value placed on building simulation over physical post-occupation analysis, form calibrates around measured phenomena found to be consistent and predictable. The consequence for Perez-Gomez is that the ‘digital twin’ promotes precision in planning, fabricating and assembling material elements that require architecture to reach a formation limit within the digital space, avoiding any human translation ambiguity (Pérez-Gómez, 2016).

While digitally abstracting data provides a capacity to radically open information across an architectural project, its typical application is to restrict and control information under commercial pressures. The data-driven approach benefits communication but risks reducing formal possibilities due to the types of information involved. For the architect Alejandro Zaera-Polo, this restriction of information means the site of architectural expression potentially shrinks to the building envelope as the interior forms around ‘architecture’s facts’ of ‘inexorable laws of physics, economics, buildability, climatology and ergonomics’ (Zaera-Polo, 2008, p. 76). Realigning the architect’s practice to collating and managing evidence provides radical connectivity between performance, design and building production. However, the architect's practice becomes increasingly internalised, driven by the assumption that detected and constructed information can link observation, forecasting and building use through simulation.

The outcome is that the architect and architectural formation operate within a strict commercial representation of unquestionable evidence, insulated from architecture’s cultural critique or disciplinary conversation. The dominant mode placed onto the architect is to optimally calibrate material parts using unquestionable performance ‘facts’ rather than composing through traditional visual techniques such as the plan and section. The influence over the architect's practice is that form calibrates around performance feedback rather than being composed through spatial or material proportions. Within an imposed market logic, the architect becomes responsible for establishing and maintaining a data-flow, a seamless transfer of data across a project that gives liquidity to the metrics seen as necessary to evaluate and calibrate architectural commodities. This liquidity mirrors the logic of markets, where financial flows maximise engagement and return on investment. Calibration over composition treats the building as a constantly manipulable entity across design, construction, and operation. Data becomes the language of development where materials and established architectural types previously operated.

Architects impose a framework onto practice when they invite data partiality through narrow representations and continue limited evaluation into databases that constrain relationships across design. This framework changes design to calibrating evaluative metrics that portray and discuss buildings as performative objects. This framework also assigns partiality a status of unquestionable evidence. Both constraining frameworks relate directly to the choice of metrics, placing a responsibility on the architect to be aware of what data enters into an evaluation and what partiality they impose. Designed interfaces that assist or automate decision-making invite partiality, from the inputs selected worthy of analysis to the data that establish the technology's intentions in the first place.

5.3 Conclusion – Extending Control

Data-driven decision making in architecture is the modern-day outcome of data's dual knowledge and communication identities. Today, data operates as a source of design intelligence, employed in practice like a material to construct information. This application as design intelligence continues the thinking first established in the 1960s when architects started to curate, digitally input, and algorithmically relate technical abstractions to establish predictable and risk-free design decisions. What sets present-day data-driven processes apart is that it places humans and buildings into a new evaluative framework of economic performance, linking quantitative abstraction with statistical prediction and economically compared outcomes.

The key findings regarding data's character and influence relate to augmenting or replacing human decision-making. In such practices, architects favour non-human observation to make and justify design decisions at a speed and precision beyond the capacities of human cognition, due to mistrust over human intuition and assuming objectivity. The data-driven approach equips practice to respond to the commercial demands imposed on large architectural practice, requiring efficiency, optimisation, and risk management to financially survive. While data undoubtedly afford time and energy efficiencies, its application promotes and maintains an ideological superiority of statistical certainty over human intuition. Promoting measure, control, and optimisation of all resources through a non-human technical register places a requirement onto architecture — that it must be productive and enable extracted value.

Central to this ideology is a maintained scientific worldview that seeks to organise and commodify the physical based on measurement. This shift back to measurement from the monitoring experiments of the 1980s is significant as it places the architect at an essential point of choice over what observation enters design and becomes fixed. Consequently, measurement calcifies data at the project's initiation, leaving the architect to construct information and shape decisions within the design process from a static and partial source. Therefore, through data-driven thinking, architecture evaluates and shapes around time-specific snapshots that are far from objective.

Controlling time and location-specific measurement enable architects to submit all parts of architecture, from practice to building operation, into comparison and performative analysis. The relational affordance of the database exists as a new site for architects to construct information and calibrate human intuition with non-human pattern recognition. Algorithmic recognition and predictive simulation lies at the centre of linking and coordinating virtual 3d form with material constructions, assigning a new importance to data, relinquishing responsibility, and deferring outcomes to the evidence at hand. In doing so, the architect develops new skills of information construction and communication as a way to reconcile stakeholder requirements with visual evidence. Building metrics and associated visual evidence establish a shared language between client and architect that connect the design process with the architectural object as a material construction and operational building.

The data-driven intensifies the architect's control over knowledge and communication by assigning designed information a status of certainty and objectivity. In reality, the architect maintains partiality in what metrics and measurements become part of design evidence. Metrics extracted from resources management and building physics increasingly lock architecture into an evaluative framework of performance, maintained by architects producing information that justify such design response. Today's data-driven architects contribute to global commercial building markets by submitting architecture and environment to an economy of predictable performance. Rather than data operating in discrete moments such as observing, forecasting, and instructing, it reconceives practice as a scientific process of problem description, solution exploration and building evaluation. The architect's role changes from directly modelling and drawing architecture to mapping causal relationships into form. Consequently, in the commercial data-driven architect's hands, information production receives as much focus as material form, requiring the architect to evolve from a twentieth-century manager to a twentieth-century information constructor.

While the data-driven paradigm offers a means for architecture to satisfy demands of economic efficiency, optimisation, and risk management, not all architects willingly participate in maintaining the market-based ideological status quo. Some architects resist capitalism's quantitative comparative expectations by using data to disrupt established hierarchies such as labour relations (Deamer, 2015) or community participation (Sanchez, 2014). The next chapter explores such disruptive practices associated with the shift to producing and sharing data.

Chapter 6: Bits and Atoms

Parametric, algorithmic design and digital fabrication processes are often called 'data-driven' but offer a case distinct from the commercial market-driven application discussed in the previous chapter. This distinction exists in both application and outcome. Many books promote the material and formal opportunities afforded by digital design tools without ever critically considering data's role and influence. Mario Carpo's book The Digital Turn in Architecture 1992–2012 (Carpo, 2013) offers one of the first attempts to trace how digital tool uptake caused practical shifts for architects. In Carpo's first digital turn, information provides the main character during an era of radical networked connectivity with little attention paid to data's role. Carpo's subsequent book, The Second Digital Turn (Carpo, 2017) recognises this omission and emphasises data new significance exploring how today scientific observation techniques introduce a wealth of new influences for architecture. Despite Carpo's recent acknowledgement of data's rising influence, there is still a gap in understanding how architects characterise data in relation to digital tools, particularly in response to the internet's subtle change in communication paradigm that caused radical sharing capabilities. Three case studies help explore this gap and interrogate alternative takes on data's role and influence in the present-day digital era, what Neil Leach refers to as the 'post-digital', an era he argues where computers simply replicate analogue methods rather than provide objective autonomous operations (Leach, 2018). The case studies provide examples of where a shift in data's cultural image provides new ideas and metaphors that reconcile the architect's previous observation and instruction responsibilities into a new focus, setting and maintaining a seamless transfer of communication, a data-flow. The chapter detects how architects increasingly conflate data with matter and defer design decision making to algorithmic processes than maintain data's seamless transfer. In contrast to Leach's claims of the digital simply replicating the analogue, the chapter argues that through data, digital design has become both an ideal and a process to integrate all parts of the architects practice.

6.1 From Object to Instruction

The internet's emergence and ubiquitous growth in the 1980s and 90s radically changed data's cultural status. A paradigm shift in how the internet operated in the late 1990s distinctly changed architectural use as data became as much produced as consumed, and open networked sharing stimulated new theories and applications. The Wikihouse project exemplifies an architectural response to this broad cultural shift of data sharing, resulting in a shift in practice from siloed and controlled knowledge to openly available information and design. Studying Wikihouse reveals similarities and differences in data understanding that connect to earlier automated design environment practices.

An interface product

The internet and web would not exist without data. In the 1980s both the internet emerged from the United States Advanced Research Projects Agency (ARPA), and the Organization for Nuclear Research (CERN) invented the World Wide Web. The internet and web combined to produce one-way data transfers between screen terminals. In the late 1990s/early 2000s, graphical web interfaces that previously translated unidirectional data packets into information began to invite input from the user via simple elements such as buttons, text inputs or images. This two-way transfer, heralding the arrival of Web 2.0 (DiNucci, 1999), introduced the possibility of data originating from anyone, not just being the exclusive domain of professional media producers. This transfer across the computer interface catalysed a cultural realisation that 'every consumer of data can be a data producer, and every user a maker —as well as an editor, self-appointed curator, and referee for any existing body of data' (Carpo, 2013, p. 49). While the computer screen acted as the site of information transfer, the new bi-directional transfer of Web 2.0 elevated it as a new site and mediator of cultural production, open to those with access to the expanding information network.

Consequently, the combination of new tools to design bi-directional transfer interfaces alongside a shift in focus from serving media to interacting through data meant that data altered its identity from being a carrier of information to becoming a way for humans to abstract information into digital form. The shift to users becoming producers and not simply consumers meant that as information met with the computer interface, it took on a new cultural identity of data, even if information remained unchanged. New online platform economies coalesced around this bi-directional transfer, such as Google and Facebook, whose business models formed around maximising interfacial interaction by gaining and holding attention.

Designing design

Web 2.0 turned the passive media viewer into a potentially active and valuable producer and consumer. Jeremy Rifkin refers to the resulting economic subject as the 'prosumer', defined as 'consumers who have become their own producer' (Rifkin, 2014, p. 9). Rifkin argues for an end to capitalist modes of production and distribution as data takes over from materials as the dominant consumer product. Rather than materials moving around, prosumers share data for digital translation into fabricated forms or information representations.

Rifkin shares the 'prosumer' term with Alvin Toffler, who used it forty years earlier to describe an emerging economic sector of home-based material production (Toffler, 1980, p. 81). In contrast to Rifkin's producing and consuming subject, Axel Bruns highlights that Toffler's prosumer described a new professional consumer keen to involve themselves in commercial product development by providing consumer data (Bruns, 2008). Brun's interpretation contrasts with Phillip Kotler's view that Toffler foresaw a subject who moved from 'production for exchange' — specialist industrial making — 'to production for use' — localised and personal production (Kotler, 1986, p. 510). While the late twentieth-century understanding and present-day prosumer concept are similar, the data version alters drastically. For Toffler, consumer data brought products and services closer to an individual's needs through distributed observation, leaving design responsibility to an expert. For Rifkin, data acts to distribute observation and instruction through shared interfaces. Therefore, for the present-day prosumer, the user becomes the author and generates instruction rather than buying products. Previously, one set of centralised instruction was mass-produced through the prosumer; today, multiple versions of instruction are output through prosumer data interaction.

Rifkin's theory presents an alternative design mode for architecture based on pooling and accessing data. An architectural equivalent exists in Jose Sanchez's game-based design practice that produce shared 'collaborative commons' of user feedback that decentralise decision making 'from mass production to production by the masses' (Sanchez, 2014, p. 116). Sanchez's collaborative commons provide a source of design differentiation from the lone practising architect to engaging an 'interplay of resources and social innovation' (Sanchez, 2014, p. 116). Sanchez's example encourages alternative production methods detached from commercial pressures and interested more in social self-organisation. Rather than the architect acting as a sole and ‘promethean’ author, they potentially become part of a ’choral’ practice that acknowledges multiple participants and shared authorship (Ratti & Claudel, 2015). The architect designs the interface of interplay, just as Alberti’s apparatus distributed map production. Today’s critical data distinction is that the user gains influence to affect change. Where data was mapped onto a singular observed version of Rome, today’s observational and instructional quality maps onto different translations, resulting in input-dependent outcomes.

As a constituent and outcome of an interfacial interaction, data transfers authorship over to an input that generates instruction. This transfer offers a profound shift in thinking for the architect, ceding authorship to the prosumer and treating instruction as an outcome rather than form. Through data and the bi-directional interface, the architect can transfer a mode of design, which establishes a new relationship between the architect and a building’s user. Thinking in terms of instructional data interfaces requires the architect to design ways to encourage users to make design decisions; the architect’s practice changes from delivering representations to designing interactive systems.

Observation in, instruction out

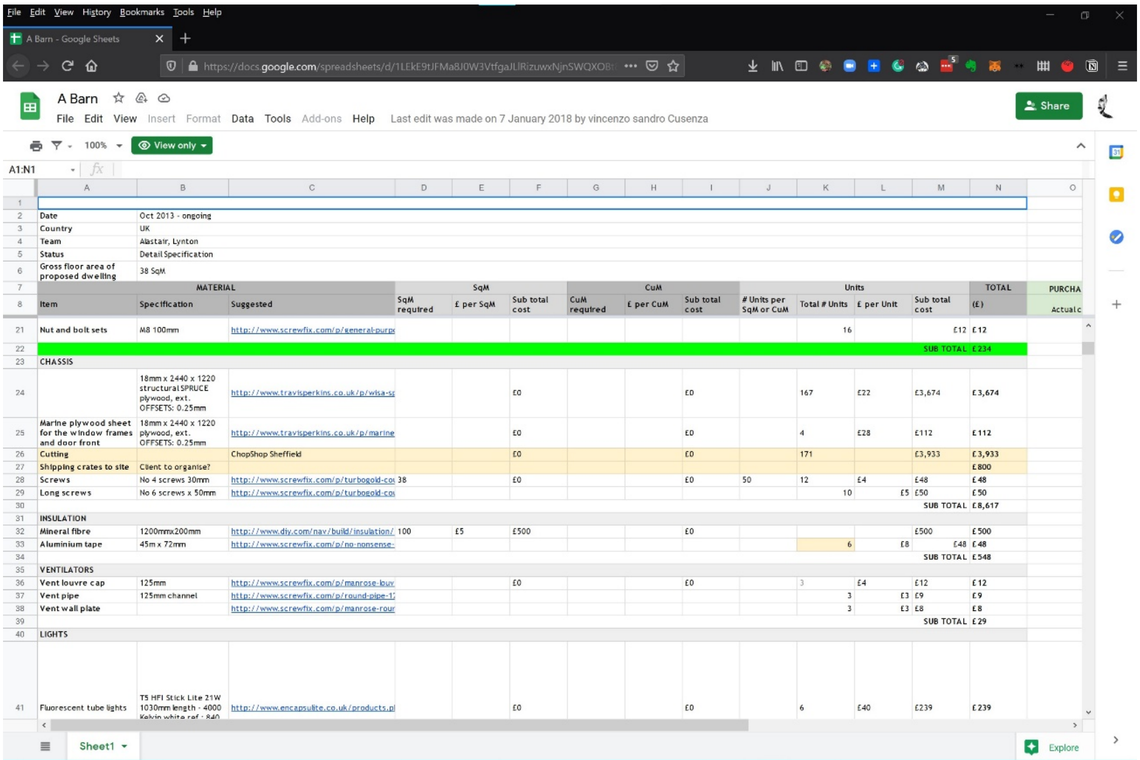
The major shift in authorship caused by data is in the relationship between humans and material production. In Toffler’s case, humans would rediscover a pre-industrial handcraft culture, while Rifkin points to widespread digital tool uptake designed for amateur use. The modern-day production we experience today has not switched to ‘production for use’, as Toffler predicted. However, pockets of makers with newfound access to technology has meant an information prosumer prevails over the material version. Neil Gershenfeld provides a reason for this in his 2012 article ‘How to make almost anything’; he argues that digital fabrication provides a new ability to ‘turn data into things and things into data’ (Gershenfeld, 2008, p. 2). This two-way translation between things and digital descriptions produces two materially significant consequences. One lowers the skill and knowledge required to produce complex forms; the other provides a metaphor for material assembly in the image of digital bits (Gershenfeld, 2008). Gershenfeld assigns data responsibility for managing complexity and reducing the skill and knowledge required to make things through software and hardware from a social perspective. The logic of data’s bi-directional interfacial translation between the user and information introduced by Web 2.0 becomes appropriate to making instruction fabricate, organise, and assemble materials into form.

Often the architect's role involves managing stakeholder decisions through skilful communication, sometimes providing the illusion of choice in order to secure a favourable decision. To facilitate participation procedures are encoded into software to constrain decision choice for the unskilled user. A high-profile example of this thinking exists in the Wikihouse project, a DIY house production system that opens design, fabrication, and assembly to everyone (Wikihouse, 2019).

The Wikihouse construction kit proposes a 'digitally derived architecture based on digital fabrication and unskilled human assembly involvement that can scale through data production, modularity, interoperability and data agnosticism across software packages to maximise use' (Wikihouse, 2019). The kit exists as software files that provide associative rules of geometry and combination to construct a virtual model and production instruction.

Initially, the Wikihouse project managed data participation via a shared google document offering digital files of the parts required to make a basic house form (Figure 6-1). This early incarnation provided anyone with access to modelling software a chance to participate in the project. In 2020, the Wikihouse project moved to a software-sharing platform and focused application through the commercially available modelling software, Rhino 3D. Today, the Wikihouse utilises algorithmic modelling to manipulate pre-defined relationships.

Figure 6-1 - The Wikihouse Specification Spreadsheet



The construction system defines a kit of parts and assembly rules. Using the largest structural system, 'Wren', as an example, a graphical algorithm represents a complex associative system linking pragmatic design intentions, such as length, width, height, with a digital model and fabrication/construction information (

Figure 6-2). The visual algorithm encodes the rules for material connection and the limits of material structural integrity. As a result, parameters and relationships restrict variation in building size (width, length, wall height, roof height, floor height, column position), form (roof points, number of storeys and mezzanine), and critical parameters (bays, beam width, connector grip length, connector slot floor, connector slot wall, fin depth, frame grip length, gauge, ply thickness, sheet length, sheet width, slot spacing, tolerance, tool size). The system takes in quantified requirements regarding building size, form, and fabrication equipment and maps these through five stages: establishing building section profiles, setting out material connections, coordinating 2D profiles, assembling in 3D and then exporting data in files for fabrication and specification (Figure 6-3). As the design system requires a user to adjust virtual form by mapping personally defined inputs onto the system, one of the data's roles is to align the construction kit with a particular need and use, making the outcome a customised object. The designed algorithm interfaces a user and a possible architecture by bridging personal needs with virtual geometrical instruction. Data connects procedural patterns to the real world, making architecture relevant for a particular location or use case.

Figure 6-2 - Wikihouse 'Wren', overview of the visual algorithm (Prest & Parvin, 2016)

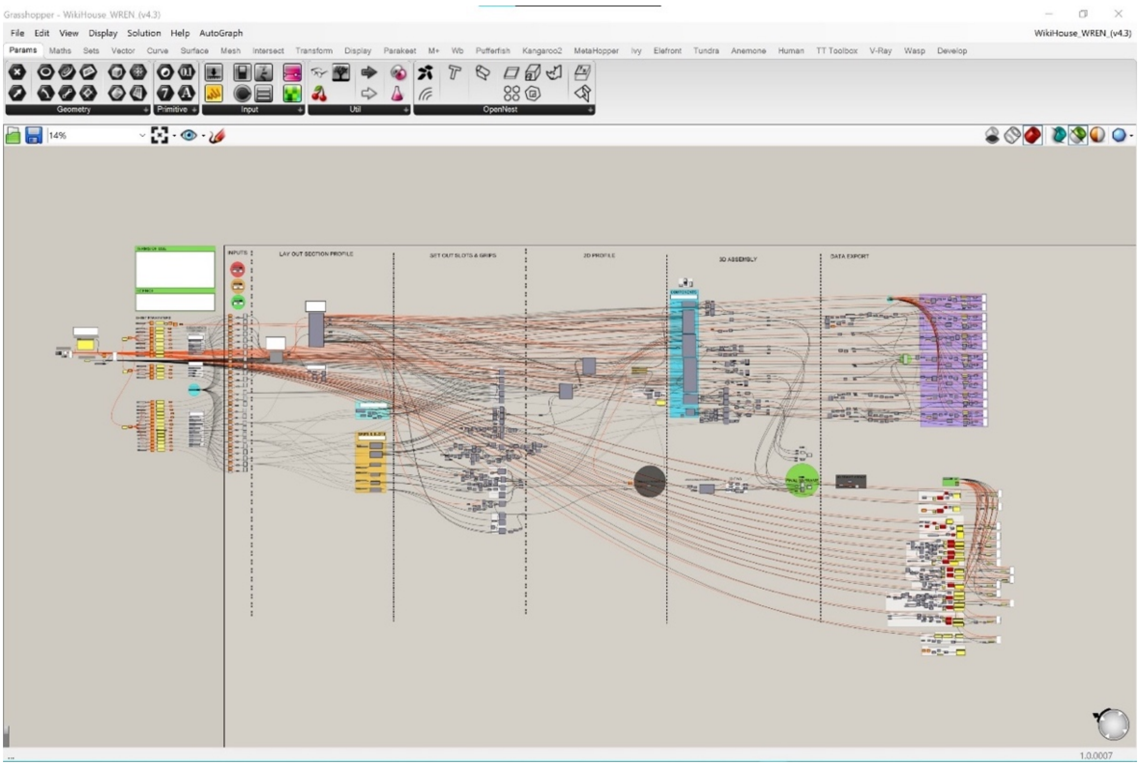
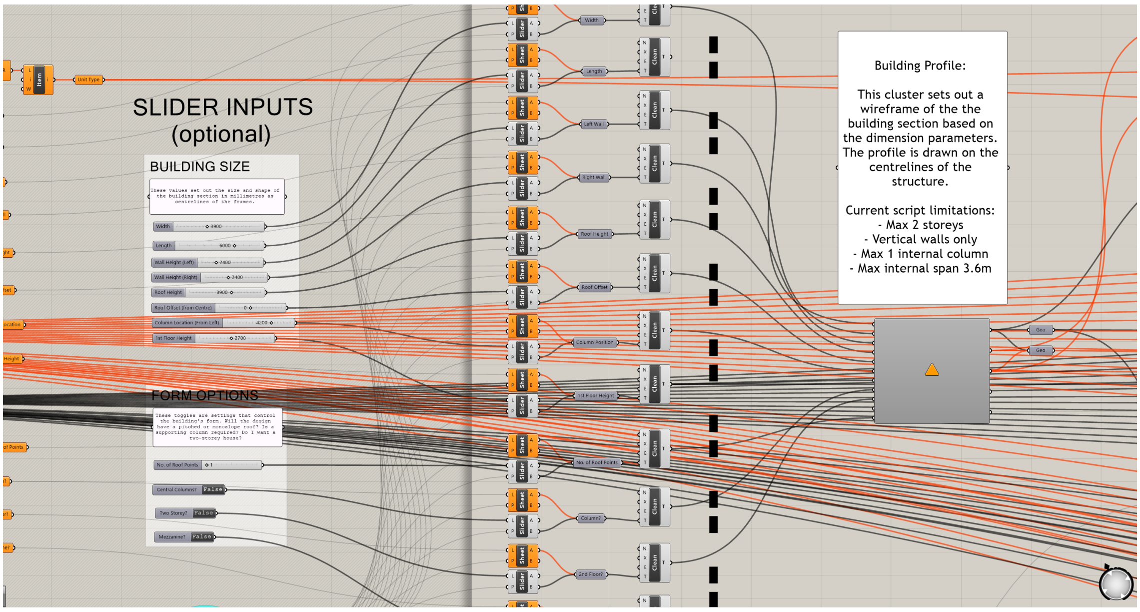


Figure 6-3 - Wikihouse 'Wren' Construction Kit, closeup of the data inputs (Prest & Parvin, 2016)

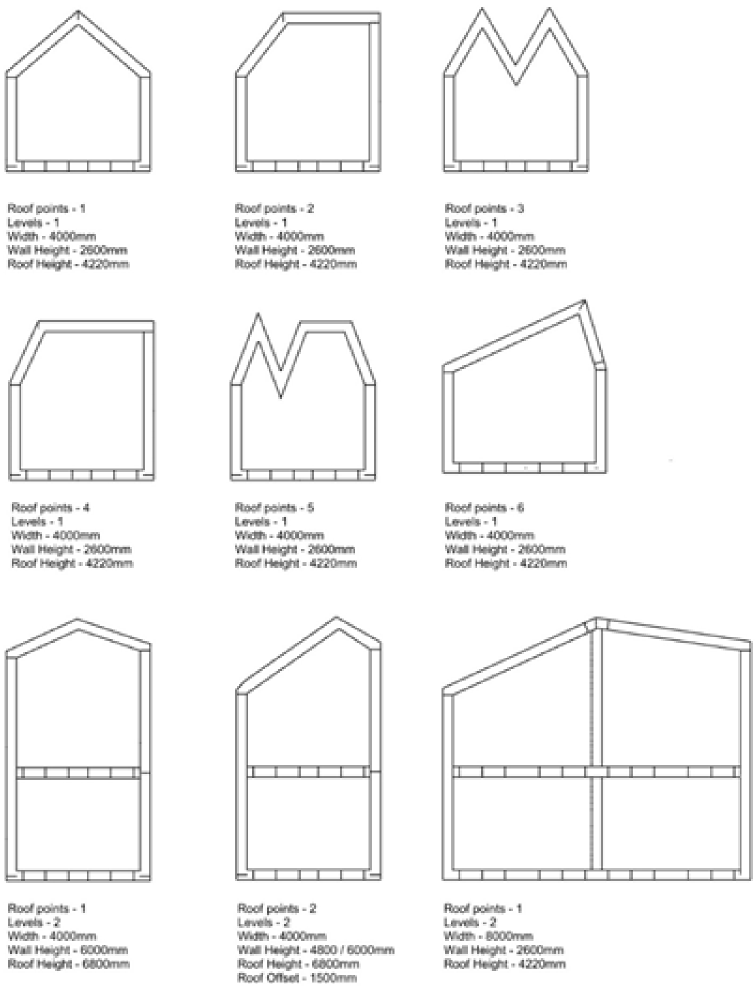


The user inputs represent real-world requirements and provide a source of differentiation in the system. The algorithm maps form through a procedural logic of material parts, connections, structure, and assembly. After data enters as user input, it joins a chain of algorithmic rules whose success relies on establishing seamless movement, linking discrete operations and visually translating data into virtual geometry. For the system to operate correctly, the user must vary input strategically and map these inputs onto a virtual form; if this input is not within a defined range, the system breaks. The input holds a critical role in the system; if it is not within a correct range or type, the whole algorithm and system cease to function. To use the construction kit, the user is responsible for selecting inputs that initiate a data movement and then maintain a flow until achieving visual representation.

To translate the virtual into physical, data takes on an additional character within this flow as it feeds into fabrication and assembly processes. Abstract machine data feed forward through digital files to coordinate numerical control for fabrication, while an information specification becomes a vital reference for human assembly. As an algorithmic output, data bifurcates into abstract digital files and human-readable specifications that initiate a collaborative human/machine process for assembly and construction. For this process to succeed requires data to seamlessly transfer between the separate flows to establish one continuous communication flow from geometry to material to process. Flow in design acts as a formal catalyst before connecting associative logics of construction, creating one continuous communication channel for architectural practice.

The data input and associative rules define a limited design space for design comprehension. Designing a design system predefines a mapping structure to reduce the necessary material skills and architectural knowledge threshold. When using the algorithm, the 'designer' explores a finite space of input combinations and a limited range of possible forms. The Wikihouse operates by curating and managing project information through a construction kit of parts that allow some variability but produce a range of determinable material outcomes. The system embeds knowledge by setting relationships, made adjustable through a quantified user problem definition (Figure 6-4).

Figure 6-4 - Wikihouse 'Wren' Construction Kit experiment outcomes



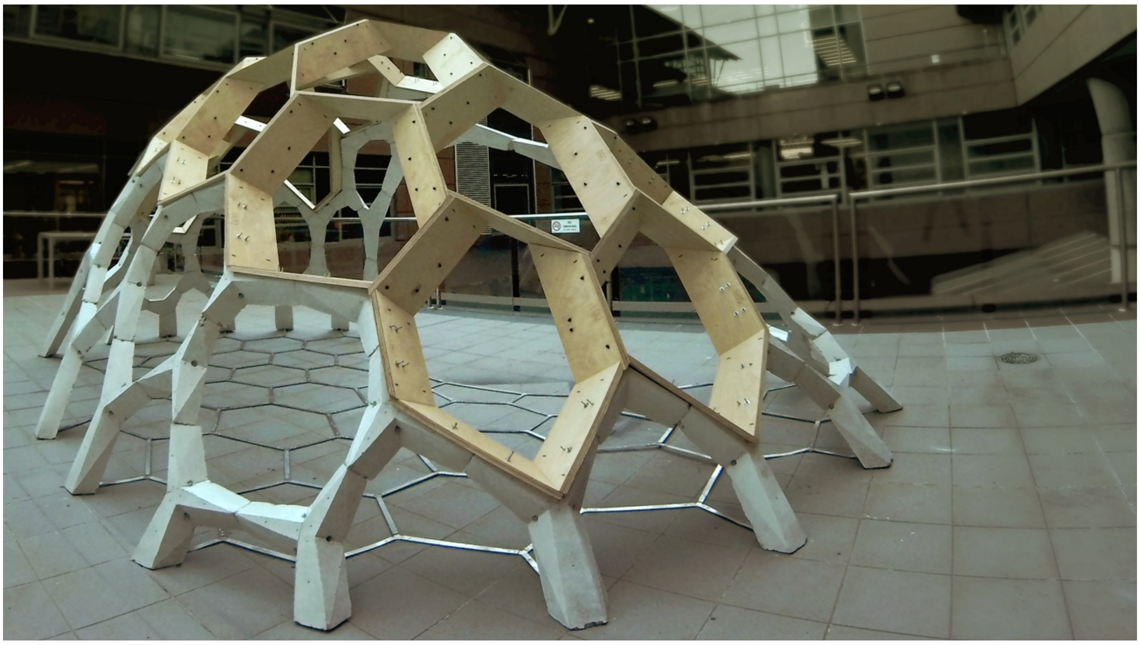
The Wikihouse construction kit offers an alternative to accessing professional architectural services that design static objects to explore a design option space through an associative data system. In designing a design system, the architect's role changes from proposing a one-off form to encoding a procedural logic into a material assembly pattern connected to a digital design environment. Within the Wikihouse system, data holds three characters. It connects predetermined material decisions to the real world, making architecture relevant to a particular time and location-specific context. Secondly, it limits a possible search space to make design manageable for non-architects, providing the user with a practicable sense of agency within the construction system. Finally, data provides a substrate for information flow that feeds into fabrication and construction. Overall, the data has a dual origin and use; it starts as a human observation input based on spatial and material requirements but ends up as two streams of communication, one human, the other machine.

Anything abstracted or translated into the computer gains a data identity through the digital interface. The change in bi-directional transfer of data, caused by Web 2.0, introduced a new data source as an interfacial product, thus splitting data's identity between human input and machine communication. Data's connection to observation and instruction offers an opportunity for the architect to transfer design focus from singular objects to designing algorithmic systems that put design into the user's hands. A consequence of this paradigm is a reduction in design exploration space, limiting the range of architectural outcomes to encourage unskilled participation. This change in data's origin and character in tandem with a cultural shift in data mode to producing means the architect outsources the stage between forecasting and instruction, using data as a source of difference. Instruction outputs result from mapped individualised input producing a range of outputs within a constrained type. Data acts as a source of difference in a universally applied system. To manage this difference requires constraining and managing choice, limiting what data enters and flows through the relational system. Central to this is a continuation of thinking first found with Negroponte's Architecture Machine Group, where the user added input to interact with the design environment. Today's difference is data's radical communicative capacity, allowing files to pass between different design environments and feed forward as digital machine instruction.

6.2 Calculating Stasis

While the Wikihouse maps user parameters into stages of data translations, it treats data as a geometry description, presuming material forces are resolved within the encoded construction system. The Wikihouse treats the material as homogenous by restricting the system to a single sheet timber material and handling structure as a hierarchy. Rather than abstracting a hierarchal logic as seen in the Wikihouse, some architects and designers increasingly incorporate physics to shape architecture around calculating and simulating forces. For instance, Dave Pigram and Iain Maxwell's practice, Supermanoeuvre, explores form finding through simulated network spring systems as seen in their Reticulated Timber project (Figure 6-5). This type of design practice algorithmically incorporates material behaviour into form. Data abstracts analogue material behaviour and in doing so elevates matter as the driving architectural consideration.

Figure 6-5 - Supermanoeuvre Reticulated Timber 2014



Animating flow

Setting up and studying a form-finding workflow presents a different understanding from the procedural instructional logic imposed by designed design interface. The act of finding form in architectural design treats architecture as the outcome of physical forces acting on a building. Although spatial inputs adjust floor areas and heights, the paradigm places the architect into a process of observing and manipulating an animated structural optimisation. The example of a simple dynamic relaxation seen in Figure 6-6 shows a simulation of hanging fabric. The simulation treats the fabric as a tectonic network, calculating form through mathematical formulas that predict material behaviour, in this case, Hooks Law. Form finding is not a new digital paradigm; Antonio Gaudi and Frei Otto's physical model-making practices existed in the early twentieth century. Gaudi and Otto simulated optimal structural forms through physical hanging chain models that became part of their unique architectural expression. Patrick Schumacher refers to early physical form-finding processes as 'material computation' (Schumacher, 2009) as these architects used materials to 'compute' ideal form based on physical influence. In Gaudi's case, material could provide a 'physical recomputation' (Dragicevic & Jansen, 2012) of optimal arch geometry every time an adjustment occurred, giving him a flexibility in design exploration and control over forms that drawings could not achieve.

Figure 6-6 – Screen shot of authors Dynamic Relaxation Form Finding tests

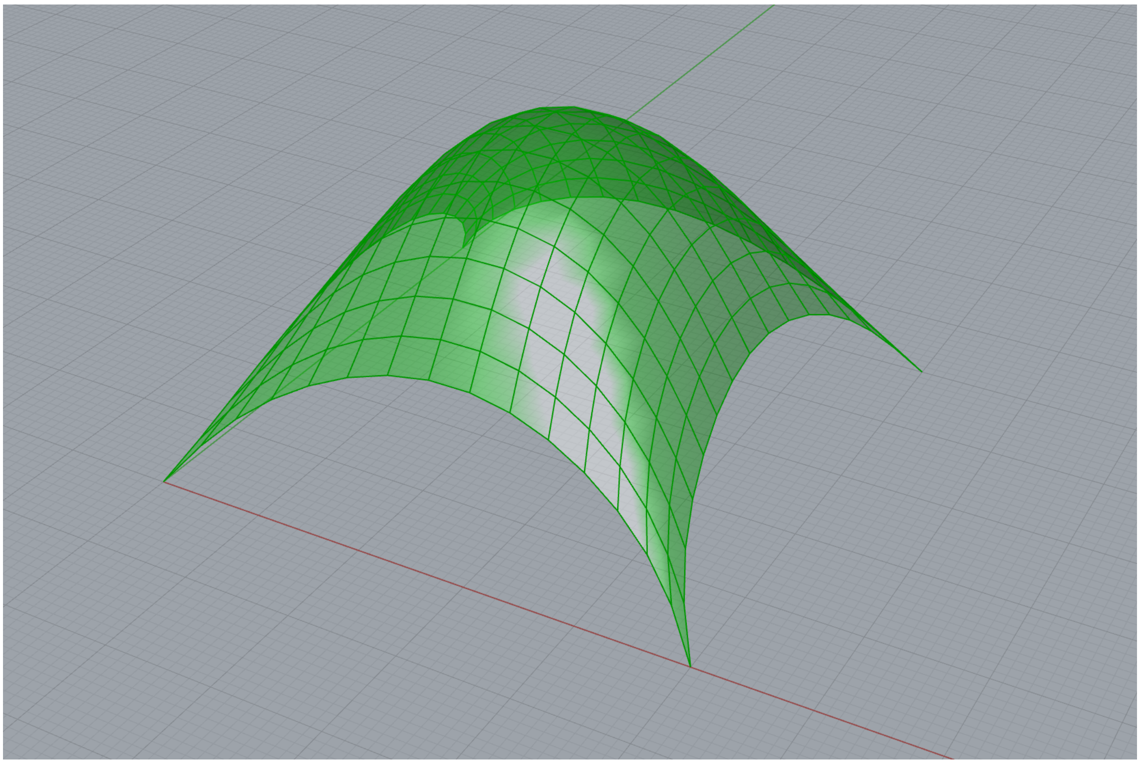
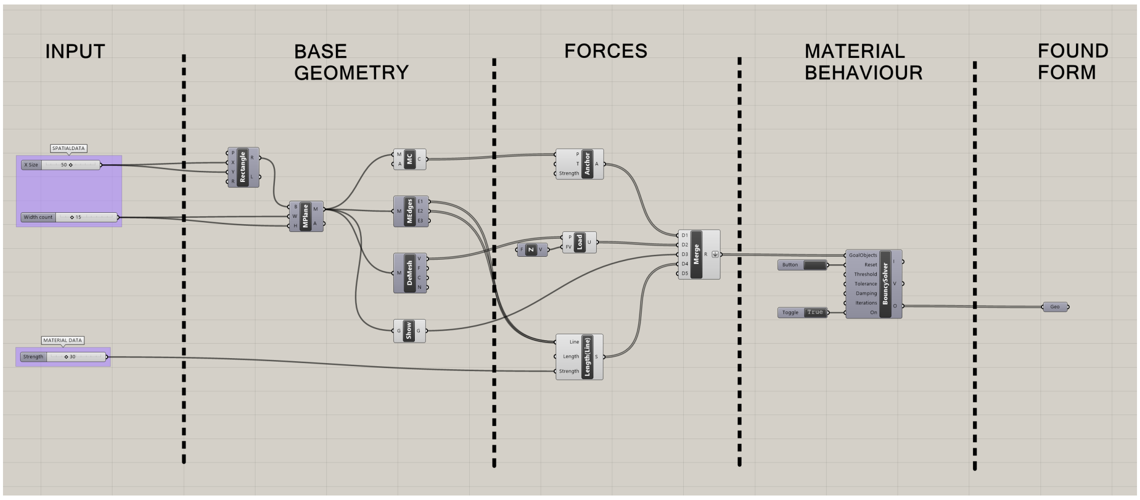


Figure 6-7 - Gaudi's Hanging Chains (Dragicevic & Jansen, 2012)

From a practical perspective, the material of Gaudi's hanging models 'compute' ideal compressional form by equalising gravity loads with material tensile strength. From a data perspective, the gravity load and material tension strength act as inputs into a structural equilibrium system. Comparing 'material computation' with the present-day algorithmic version presents two similar input characters, with a critical difference that the digital versions afford greater speed, giving more design flexibility through base geometry and material behaviours. The algorithm example shown in Figure 6-8 indicates an additional data role. In the digital version, a simulated material behaviour continues to compute an optimal compressional form. However, two identities split across the system, one as an input into the system to define spatial and material requirements, the other as an animating force that links up stages of geometrical calculation.

Figure 6-8 – Screen shot of authors algorithmic dynamic relaxation test



Data’s necessary flow is essential in form-finding and instructional design system approaches. When applied to material behaviour and structural simulation, the flow becomes data’s critical character. It enables inputs to interact over time, thereby animating form and giving the designer a visual sense of movement. Within the parametric form-finding approach, structural equilibrium requires the flow to stop, meaning the architect tries to find the optimal data flow that, over time, will achieve stasis.

Material equivalence

Finding data flow equilibrium is a beneficial design practice for a discipline so closely concerned with structure and material efficiency. Encapsulating material into a calculation allows the architect to defer and justify decisions by skilfully setting up and managing a data organisation. In this process, data replaces material and the architect’s design focus transfers to imbuing data the behavioural certainty of physical materials. Francesca Hughes recognises this and draws a parallel between virtual form-finding and Le Corbusier’s practice of concrete casting (Hughes, 2014). Hughes describes Le Corbusier’s technique as providing an ‘automated assembly’ towards a vision of architecture as formed through material flow ‘making itself, pouring itself; matter responding directly to the command of the architect’ (Hughes, 2014, p. 32). Through Hughes’s comparison, finding form aligns with unquestionable choices in design, transferring from the formwork casting of settled material to the present-day data flow force calculations. Hughes highlights how the language of parametric model form-finding evokes the same unquestionable self-forming tendencies of poured concrete when she states, ‘the optimised configurations of a parametricized system or models are described as ‘resulting’ from their calculatory (rather than physical) constraint’ (Hughes, 2014, p. 128). Form-finding substitutes materials for data, using it to ‘flow’ through a ‘calculatory formwork’ (Hughes, 2014, p. 128), in turn transferring cast materials’ self-forming tendencies onto virtual forms. The architect's skill in shaping flow directs the formwork for calculation, which also sets a framework for evaluation, making form purely a concern of material behaviour. While the benefit of material computation for practice clear gives the architect greater control over translating between design and building, it is important to recognise what is sacrificed. When form results from an unquestionable premise of material behaviour it loses a possible connection to material culture when any trace of human error becomes eradicated. Hughes points out that alongside this eradication, architects also adopt an instrumental rationalism ‘whose indeterminacy we conveniently fail to declare’ (Hughes, 2014, p. 11), thus overstating data’s role and falsifying its precision.

There is a controversy arising from the architect’s assumption that calculating material is analogous to material computation. Form-finding algorithms employ homogenised material behaviour descriptions through scientific formulas and aim for universal predictability. In contrast, material calculation operates directly through understanding a material’s heterogeneous quality and unpredictability. Achim Menges (Menges, 2012) recognises this and argues how measuring the localised behaviour of material elements leads to forms that do not assume generic equilibrium but use different material strengths across a structure to produce differentiation. The difference between the two relates to a cultural image provided by data. The ‘flow’ alludes to data and material having equivalence, but data cannot achieve matter’s unquestionable status; it only presumes through calculation. This calculation is enough to accurately simulate material behaviour. The response is to collect more data in the expectation that it provides a better understanding predictability. In the case of material calculation, data’s flow extends beyond the algorithm to become a source of observation input, arriving as precise and fine grained measurement from material study to produce more accurate and controlled material manipulations.

Data practices that simulate and predict form by calculating equilibrium between physical forces and material behaviour rethink data’s flow from a series of instruction translations, as recognised in the Wikihouse, to image data as an animating force. Assigning an animating role to data within a virtual simulation equates with matter's role in material form. It expects the architect to achieve equilibrium, thus aiming to slow down data flow until it finds stasis. The architect treats data as a material, setting an algorithmic formwork for self-organisation and using equilibrium as an unquestionable end product. A problem exists when equilibrium occurs without considering if its calculatory connection to the real world comes from a limited observation set. This unquestionable status of finding optimal form stems from two influences, one connecting the virtual to the physical through scientific observation, the other occurring through a desire for stasis. Equating data with materials and curating an animated flow means that any architectural outcome takes on the character of a justifiably optimal and efficient stasis once data's movement is arrested.

6.3 Hermetic Flow

Although algorithmic form-finding uses data to connect geometry to material behaviour, its process stems from a scientific understanding that relies on an attitude to data. Science produces new explanations beyond general understanding to detect microscopic variation as measurement resolution increases through technical apparatus. As argued in the thesis, scientific inquiry and discovery and the architect's practice are closely related. Scientific innovations and new material understandings inspire practical techniques that equate digital data with physical matter through the digitally introduced notion of data as observation and instruction. Exploring the working methods of Gilles Retsin's 'digital material' approach uncovers a progression in data thinking that applies abstract digital data as a metaphor for architectural assembly. This section argues that data imposes a new influence on the architect and their material outcomes through a beyond-human process that evaluates form as a degree of order, visualising and materialising the logic of information theory through present-day automated workflows.

New resolutions

Chapter 4 highlighted how the cybernetic and systems theory science of the twentieth century explored the potential of data abundance but did not have the technical means to realise the aims. As desktop computing and electronic sensors migrated and networked into architectural practice in the 1980s and 90s, the new cultural condition of collection and storage meant widespread availability and accessibility. New theoretical engagements with science emerged, offering architecture metaphors related to non-human observation.

One example of architecture's metaphorical use for data is from Charles Jenks, who attempted to make sense of architects' digital experiments in the 1990s. Jencks introduced the term 'non-linear' into architectural discourse, referring to a shift in thinking from 'assumptions of modern, predictive science' to 'post-modern science' (Jencks, 1997, p. 80). Jenks argued that non-linear post-modern science systems proved that universal positivist causality could not predict real-world consequences, as inputs had no relation to the output. The suggestion that data-in did not equate to data-out marked a shift in thinking from simulating statistical models to exploring indeterminacy and chance. Jenck's argument characterised the architectural design process as a non-linear information flow, joining a broader engagement with information at this time and intentions to invite unpredictability into a design.

Jenck's information flow metaphor lingers where architects use observation/instruction systems to create design systems, or simulated form-finding intends calculated stasis. For example, in form finding processes, architects assign trust to data equivalent to material; data's role in an algorithmic calculatory flow both provides the computer with simulation information and takes on the unquestionable cultural status of material agency. Despite the intense focus on information and network logics at the turn of the twenty first century, it is only recently that data has become a point of focus within digital architectural discourse, the most high profile example being Mario Carpo's *Second Digital Turn* (Carpo, 2017, p. 71). Carpo argues that science increasingly understands material formation through images of nature that depict 'distinct chunks of matter, all the way down to molecules, atoms, electrons, etc. ..... with all of the apparent randomness and irregularity that will inevitably show at each scale of resolution' (Carpo, 2017, p. 71). The resolution and volume of data increase through technical sensing innovation, which stimulates new hypotheses and findings outside of the human sensory register, beyond empirical experience. A higher resolution provides a more granular understanding of the physical world. When Carpo discusses 'chunks of matter', he supplants a science that now understands the physical world at the molecular rather than a human empirical level.

New scientific data resolutions correlate to images of matter that transfer into the architectural consciousness. Architects increasingly simulate matter through mathematical formulas in parametric form-finding, using data flow as an unquestionable premise in design decision making. A higher resolution eliminates the need for general models and formulas, as the data uniquely describes material behaviour.

Assemblage logic

In contrast to the prevalent logic of algorithmic material simulation, some architects explores logics of material resolution. An architect and academic, Mollie Claypool, associates this resolution turn with a recent shift in architectural thinking from construction systems to a logic of discrete and reconfigurable parts (Claypool, 2019). The recent discourse surrounding architecture designed and assembled as discrete material parts offers a case where parametric material simulating data flow changes into interests with material resolutions that mimic the digitally derived image of the digital natural world.

A consequence of new scientific data and its images of matter is that architects conceptually associate structure and form with a beyond human resolution. Giles Retsin, an architect and designer teaching at the Bartlett School, provides an example where data's resolution seeps into a mode of material practice. Three projects show consideration of resolution used as a cue for scale. The first project explores the scale of a material, the second a furniture object, while the last consolidates resolution at the scale of inhabitable architecture.

Retsin's practice explores object making at the nanoscale of materials. His 'Blok' research investigates form through a granular robotic control over three-dimensional material deposition (Retsin, 2020) by connecting knowledge of microscopic material constraints with an algorithmic procedural logic. Figure 6-9 shows an image of the internal structure of a 3d printed material dictated by virtual agent pathways. The image draws comparisons to the molecular resolution of timber (Figure 6-10), suggesting Retsin's digital material draws inspiration from nature's nanoscale microstructures.

Figure 6-9 - Blok 42 Object (Retsin, 2020)

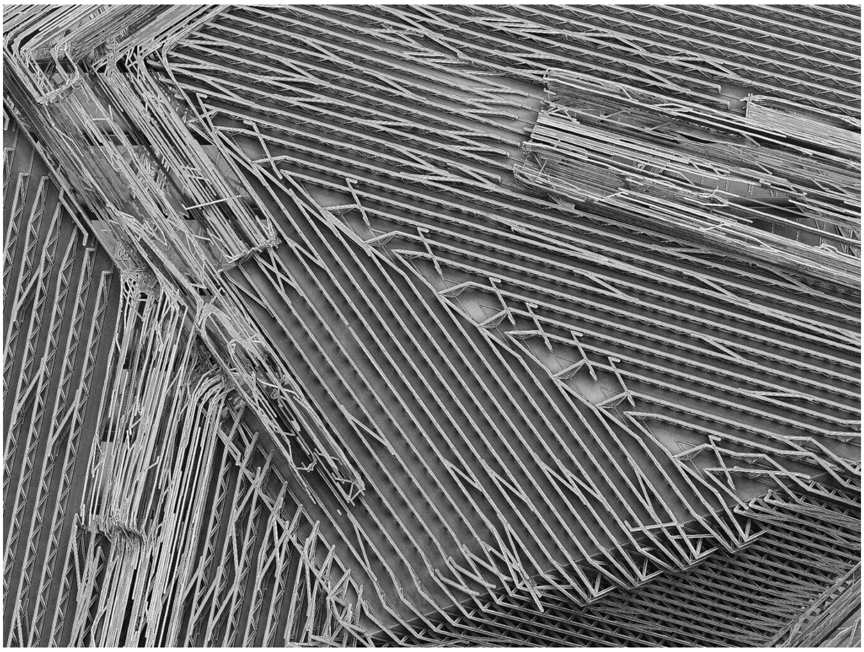
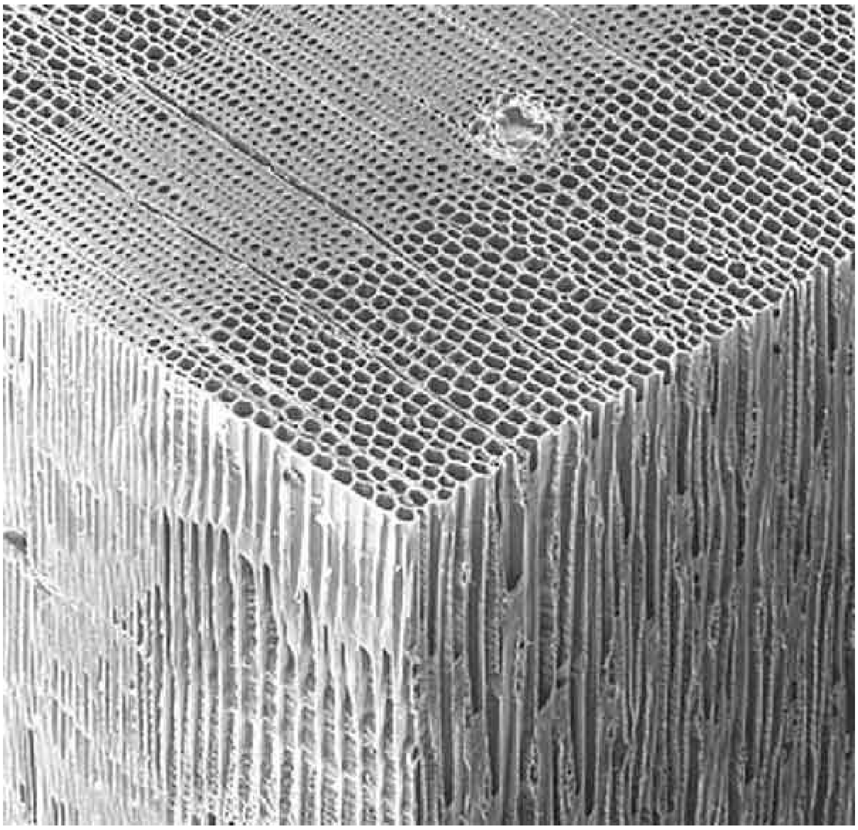


Figure 6-10 - A microscopic image of timber (Huang et al., 2003, p. 323)



Retsin's digitally generated form references an assembly logic in nature, one based on a positional constraint. In 'Blokhut' (2015), Retsin applies the material constraint logic of Blok at the scale of the body and material elements, using a timber post as a repeatable element to generate furniture. Like the Blok objects, the elements in both computer-generated image (Figure 6-11) and finished object (Figure 6-12) assemble and arrange through constrained angles. However, in Blokhut, the constraint comes from the base unit geometry rather than a simulated agent's path. In Blokhut, the possibilities of material formation occur through a logic of combination determined by the connection interface of each material element, governing its ability to combine with other pieces. While the elements in Blokhut appear to combine through organisation patterns, producing a significant degree of variation through generative rules, the material element itself, the single unit of construction, determines where interfaces can and cannot exist. Consequently, Retsin postpones any formal outcome or determination to the assembly by designing a base unit geometry with connecting logic.

Figure 6-11 - Virtual 3D model study for Blokhut (2015) (Retsin, 2020)

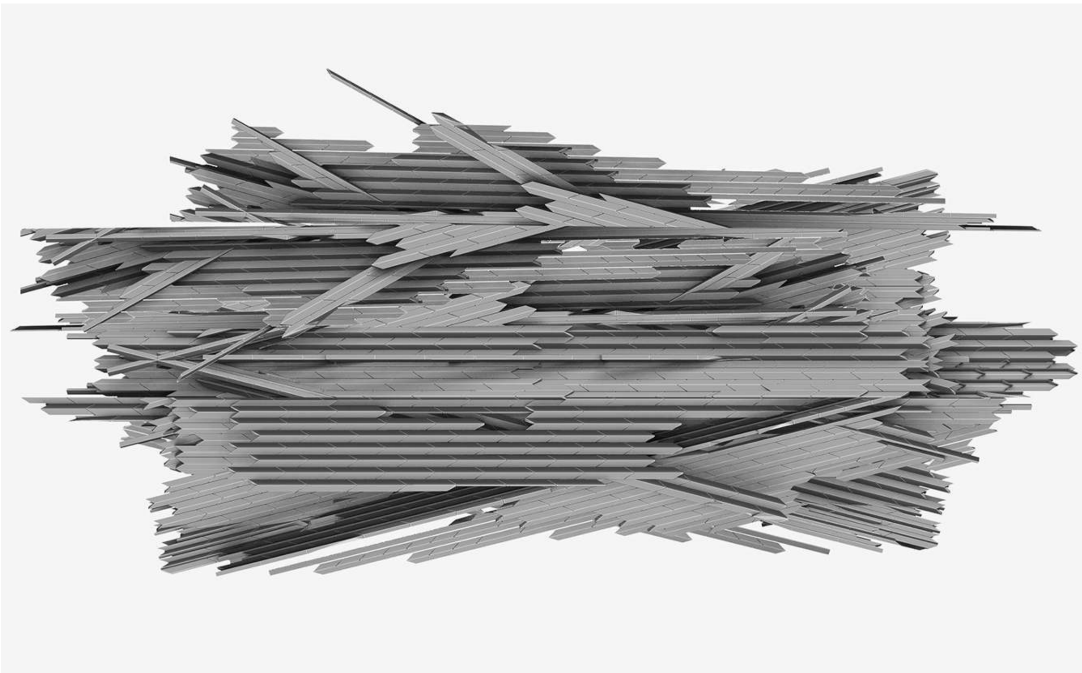
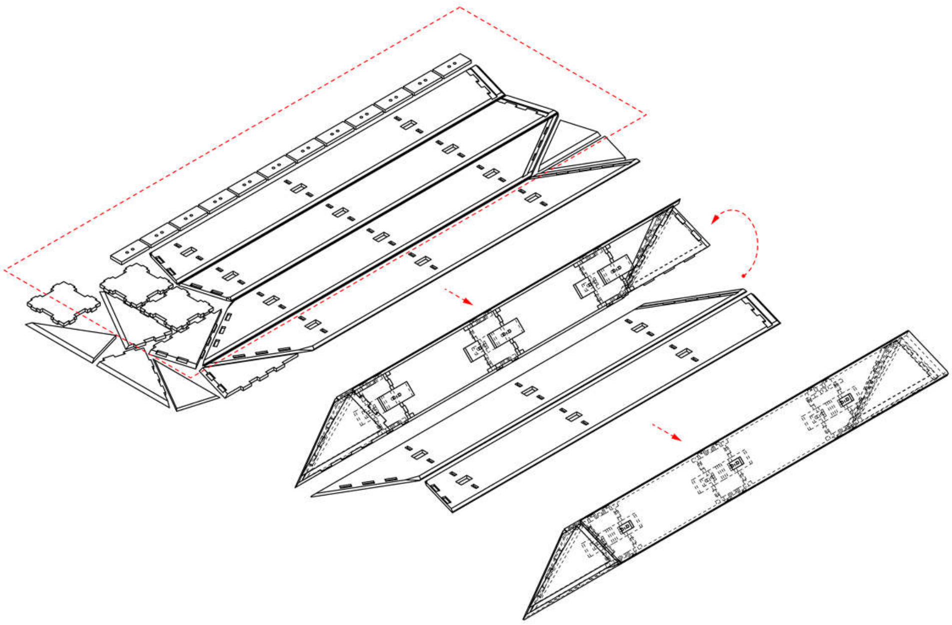


Figure 6-12 - Finished Blok Table (Retsin, 2020)

At the scale of furniture, the resolution of microscopically constrained matter becomes a logic of material connection applied to furniture. Retsin's Tallinn Architecture Biennale pavilion (2017) exemplifies the next scalar jump in resolution (Figure 6-13). In contrast to Blokhut's solid materials, the pavilion consists of sheet materials and metal structural reinforcement (Figure 6-14). When scaled up to architecture, Retsin assigns a social and cultural benefit to the assembly logic, arguing the pavilion offers a system of construction suitable for non-skilled humans, claiming to offer a system able to 'democratise and decentralise production' (Gilles. Retsin, 2019, p. 13). Like the Wikihouse project, Retsin offers a means to self-build through a kit of parts; however, what sets Retsin's approach apart from the Wikihouse is how design concentrates on the repeatable material unit rather than a design interface.

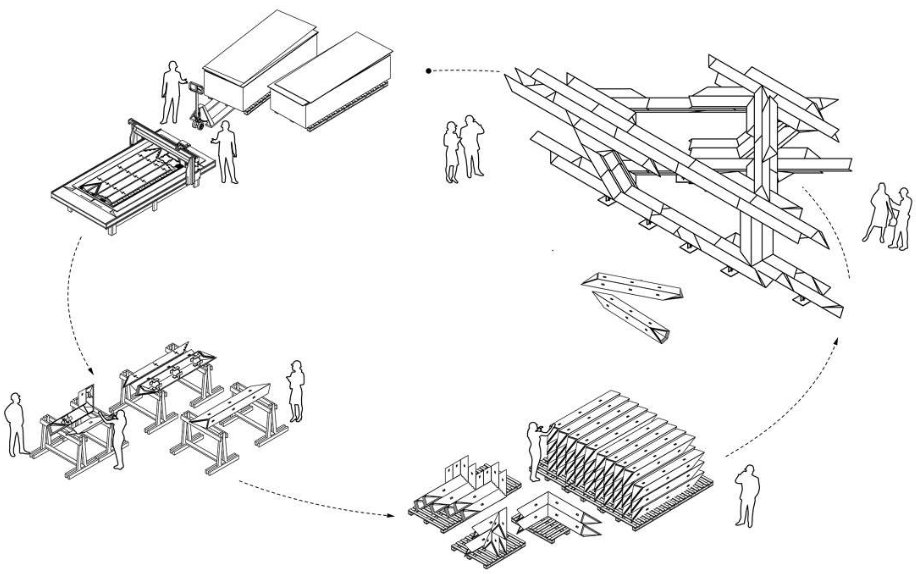
Figure 6-13 - Tallinn Architecture Biennale Pavilion (2017) (Retsin, 2020)

Figure 6-14 - Tallinn Architecture Biennale Pavilion (2017), Material Unit Assembly (Retsin, 2020)



Rather than designing a hierarchy of structural elements with the intent of producing a specific form, Retsin's approach invites form to emerge through setting rules of combination and engagement. This difference in design focus migrates decisions regarding form to the digital model to possibly improvise arrangements on-site through generative assembly (Figure 6-15). Design and assembly practice becomes based on a common substrate, a seamless data flow that the architect uses as a design material and instruction. What sets Retsin's generative assembly apart from the Wikihouse is the embedded control over formal choice in assembly through the material element rather than a data variation of parametric relationships. Both approaches operate through an algorithmic flow from digital model to digital fabrication, but in Retsin's case, his designed geometrical unit results from imposing combinatorial rules. Geometry and rules combine to restrict choice and spatially position elements to set up a mutable relationship between the parts and the overall whole. The unit operates across virtual and physical space; the rules encoded into the algorithmic description portray an assembly logic for production.

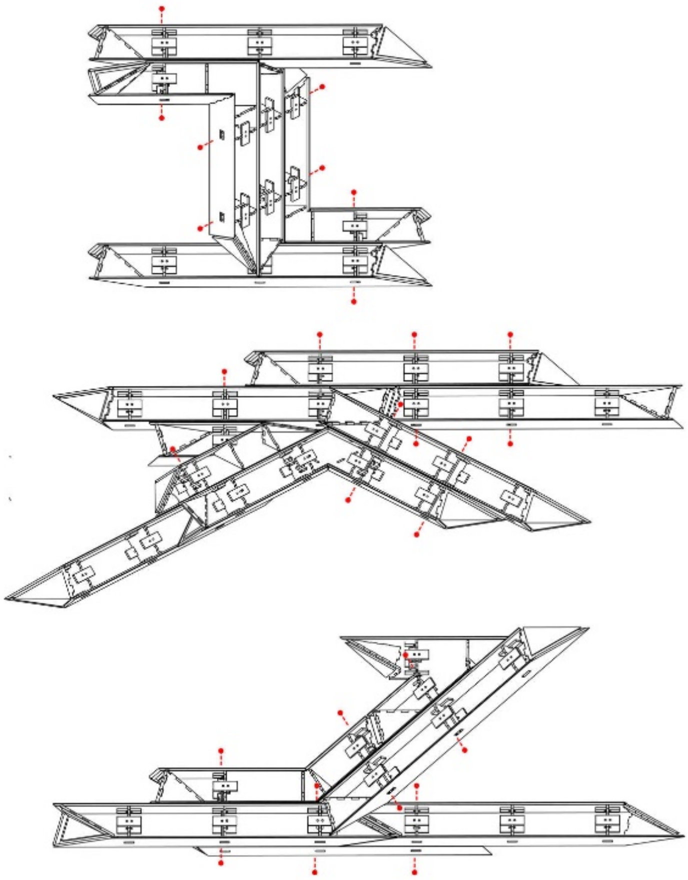
Figure 6-15 - Tallinn Architecture Biennale Pavilion, Production and Assembly Process (Retsin, 2020)



From a coordination perspective, the Wikihouse realises architecture by combining geometrical and positional coordinates, arranging, and locking parts into space and producing a jigsaw-like assemblage. In Retsin's case, the building elements materialises through a description of itself, with no reference to position or combination. In physical assembly, Retsin's elements allow only certain forms and junctions through its geometry but can move freely, detached from a specific point in space (Figure 6-16).

In both self-build construction kit approaches, data describing geometry and material parts provide input into rule-based assembly. A difference in use exists in how they utilise this input as a source of differentiation. While the Wikihouse invites data from multiple user inputs to produce difference in design, but which then sets a fixed form for material instruction, Retsin's discrete approach fixes the input, providing difference in physical assembly. In both cases, data takes on a critical role in practice to virtually describe and mathematically coordinate geometry. However, for Retsin, data takes on an extended significance, providing a metaphor for material assembly in the scientific image of information forming bits.

Figure 6-16 - Tallinn Architecture Biennale Pavilion, Unit Combination Rules (Retsin, 2020)



While The Wikihouse produces form by inviting the user to map personal needs onto adjustable parametric relationships, Retsin's approach postpones user input to the point of material assembly. Both approaches utilise numerically controlled computer fabrication and similarly arrange flat surfaces into volumetric structural elements. However, while Wikihouse assembles through a jigsaw logic, the discrete proposes an automated assembly through a restricted choice of material connections and possible combinations. As the formal repertoires of Retsin's repeatable material component system exist beyond the elements of digital fabrication, assembly acts as the moment where data transfers into human information. The data flow resists translation into information, forming a continuous digital communication until that point. Retsin draws a contrast between his 'discrete' and parametric approaches, arguing that he avoids the post-design rationalisation, material optimisation, variability, and mass customisation baked into the parametric (Gilles Retsin, 2019). For Retsin, this contrast is ideological. From a data perspective, his material formation process occurs beyond any algorithmic communication flow, requiring the human user to follow assembly rules or devise their own. In this argument, Retsin shows his understanding of data to break from an observational input or material simulation to operate as a pure communication flow of a digital assembly logic.

In the case of Wikihouse, part labelling sets up information for reconciling the real with the virtual model; in contrast, Retsin's approach encourages formal difference by not consolidating specific information states. The central idea of Retsin's practice is the rejection of user input difference leading to 'mass customisation' by using standardised building blocks, which Retsin himself refers to as 'like Lego' (Retsin, 2020). Retsin's assembly through interfacial constraints and disconnection from defined spatial position enables a bottom-up response through a human contextual adaptation. At the same time, the Wikihouse places a top-down restriction that can only respond through position and not to a context. The outcome is that, for Retsin, the interface between the human and data migrates from the virtual into the physical, but the data no longer has an architectural significance; it takes on the metaphor of bits just as his parts take on the role of atoms. Data's role in constructing information becomes a logic for assembling parts into wholes.

Quantised material

As the abstract computational character of digital data has escaped exclusively scientific use and entered the architectural consciousness, data as an idea has created the possibility for form to be conceptualised as a digital assemblage. As architects conflate materials directly with digital bits, form becomes a possible self-assembly rather than a traditionally coordinated and documented construction. This shift in understanding data from a process of establishing design evidence and decision making to data as a material and formal idea provides a distinct change in the architects practice. This data as idea approach finds a precedent within engineering, where 'digital materials' shape and assemble through two scenarios; one using computer abstraction to control digital technology and fabricate objects, the other designing material elements that behave like bits (Gershenfeld, 2008). Treating atoms like bits seeks a 'digital materiality' that equates digital information processes with the material scale of architecture. Emmanuelle Chiappone-Piriou points out that the radical configuration of bits realised through digital information manipulation becomes a strategy for assembling structure (Chiappone-Piriou, 2019). In contrast to the traditional architect's consideration of whole from a catalogue of parts, digital materiality concentrates on the part's consequences for the whole.

Concentrating on the part and assembling through automated processes requires designing an assembly logic that mimics procedural algorithmic steps. Retsin's focus on standardised and repeatable material parts engages with architecture's material-cultural history concerning automation. In a nod to Giedeon's 'Mechanisation takes Command', Retsin proclaims 'Automation takes Command' (Gilles Retsin, 2019); in doing so, he swaps mass-produced efficiency and speed for digitally precise non-human fabrication. In Retsin's digital discrete approach, automation exists through a seamless data transfer, a data-flow, spanning architectural practice and providing rapid and accurate communication between machines. This flow exists out of reach to humans, staying within a material production process and resisting any transfer into meaningful human information. Retsin's data flow links design directly to material production, to remove the error-prone human from production. Retsin's automated process of 'highly repetitive operations' (Gilles Retsin, 2019) removes the human from the production process and disrupts established construction techniques by saving time, materials, and labour. While Retsin states that the discrete technique would have a greater social awareness than the parametric (Gilles Retsin, 2019), there is a lack of awareness of a twentieth century Taylorist logic applied to putting humans in highly repetitive operations.

This comparison with Taylorism and previous notions of the mechanised and automated body continues in Retsin's argument for using standardised parts, justified as increasing production speed (Gilles Retsin, 2019). In comparison, Retsin argues that in contrast to the modernist idea that each standardised part had a separate function within the whole, a standardised building block functions autonomously and invites formal and visual heterogeneity across buildings (Gilles Retsin, 2019). However, on closer inspection, the main difference between the digital discrete and early twentieth-century approaches is a difference in data's cultural character. The optimal metrics of the early twentieth century considered and rationalised architecture through available industrialised production techniques and standardised parts, bringing knowledge and communication together into controlled reference sets defining functional spatial use. In Retsin's case, data flows concentrate design at the part and material production level, thus conceptually operating opposite to the traditional architect, considering the part before the whole.

In furthering the rapid and accurate affordances of an automated non-human data-flow, Retsin's digital discrete risks ideologically casting humans as part of the automated material assembly process and missing architecture's primary goal of providing for them. A problem exists in the lack of connection between Retsin's 'autonomous' and generative building parts and any spatial intention aimed for in the resulting building form. When comparing the digital discrete to Christopher Alexander's pattern language, the former avoids functional determinism but detaches from any spatial condition propositions. The counterargument could be that Retsin's discrete aligns with a broader contemporary discussion of spatial heterogeneity and performance as a critique of the strict modernist connection between form and function (Hensel et al., 2009). However, Retsin's architecture engages no connection between material qualities and human experience; therefore, it does not achieve what the heterogenous space discourse explores. Instead, pattern resides purely in material part assembly, governed by restricted joint connections and structural considerations.

Retsin's use of data-flow in digital design practice produces the aesthetic and scalar consequences identified in the case study by reducing human interaction with an architectural process. Just as a non-human scientific resolution inspires digital assembly logic, coordination and production through non-human manipulation, and communication produces beyond human precision, eradicating possible fabrication or assembly errors. Just as Durand's gridded composition practice snapped architectural elements to a material grid, Retsin's digital discrete sets up a material grid through the base unit building block that snaps into position when assembled. This snapping into position parallels digital music production, when automated error correction moves miss-timed notes to a timed grid, increasing precision but losing the music's 'swing' that sonically indicates human involvement. This 'quantisation' is also used in digital signal processing to reduce information loss, which refers directly to Shannon's information theory. This quantisation appears in Retsin's material outcomes that achieve precision in assembly and form but reduces any indication of human tactile skill as parts snap to a three-dimensional grid dictated by the material part. Like musical notes and rhythms snapped to an almost impossible precise timing, Retsin's quantised architecture orchestrates and controls material organisation at a sophistication beyond human capability. Consequently, any material outcome risks presenting something detached from human involvement or cultural meaning, potentially alienating the human observer through a lack of familiarity.

This final example of an algorithmic process in architectural practice uncovers an evolved character of data that escapes the algorithm and becomes a metaphor for architectural assembly. Just as knowledge and information production procedures occur through assembled data, architects such as Giles Retsin move past the material calculation of form-finding to treat the material in the image of digital data. While this metaphor brings practical benefits regarding generating, fabricating, and assembling form, it produces a communication flow that resists any transfer into human interpretable translations. The viewer must evaluate built forms realised through this rule-based aggregation through detecting order and pattern and understanding form as optimal organisation and structure, not through reference or meaning. In this regard, Retsin uses data's digital quality to achieve a hermetic communication flow and a metaphor for material construction. In the end, the material part in Retsin's 'digital material' becomes architecture's new data. It embeds the architect's measurements into a geometrical unit that invites configuration and spatial arrangements. In contrast to locking the architect's measure into operational standards or body-scaled patterns, the material unit becomes the possible site for variation, possibly bringing different proportions or scaler relationships into each building outcome.

6.4 Conclusion – Integrated Communication

Today, sophisticated digital design systems give data multiple characters. It can refer to text and number inputs used to define a problem, numbers to adjust parametric relationships, bits to encode and manage relationships in software, and a communication stream connecting described geometry with material production and assembly. The critical change in nomenclature relates to the term data sitting in for digital instruction, used to pass geometry between software and machines. More significantly is data's influence on digital design practice. Through data's communicative control and assembling logic, architects position the digital as an ideal in design outcome by conflating material prediction with associative geometry descriptions. In parallel, data's scientific cultural image imparts design with an assembly process taken directly from the logic of bits, meaning the quantising and error removing nature of digital data becomes a model for understanding, speculating, and realising material forms. Within this image, process has come to embrace input from architecture's intended user through 'data optioneering' enabling unskilled design and construction, while also becoming so tightly integrated that it imagines materials to assemble like digital information.

Rather than the architects traditional role of documenting instruction through agreed drawing conventions linked to skill-based craft, through data architects aim to set up and manage a hermetic data flow with carefully planned intervention moments. Consequently, a data flow from digital model to a material part via machine fabrication replaces the traditional stages of communication engaged by the architect. Just as market-based data-driven decision-making gives data an unquestionable status, practices that assign data and material an equivalence assign an additional character of precision used to reconcile design with increased resolution. The critical difference from the design currency character identified in the previous chapter is that the abstract hermetic data flow operates purely as synthetic data, meaning it does not necessarily refer to observation or experience, it is a purely communicative process. Such an approach achieves radical affordances in information transfer, but it does not refer to a recognisable observation origin and suffers a lack of potential meaning gained from experience or reference. In this design as ideal and process, the architect confines mapping within the data-flow meaning the architectural data-out may have no meaningful association with the data invited in.

Today, architects exploring advanced human and machine collaboration consider data a vital part of practice. Mapping becomes the primary mode in practice, requiring the architect to define design parameters and set rules for material combinations that start as geometrical abstractions and result in physical form. This mapping between virtual and physical forms increasingly equates data's relationship with information with architecture. This geometrical and material abstraction concept requires new skills to generate and interpret architecture through logical routine and repetition. In doing so, the architect gains control over instruction, which becomes a site of creativity, such as exploring ambiguity and intervention resulting in human and material agency.

In ever intensive digital architectural practice, data's 'flow' is the central character that design now understands. Through the computer and associated network connections, data has found a means to flow, which architects and designers have recognised as a profound simulating connection between observing, designing, and materialising form. Data is the essence of a seamless communication flow that replaces traditional representation techniques rather than mimicking, and releases new forms of making and material assembly that have no historical precedent. The radical communication flow now harnessed in practice gives control over material in ways never experienced. However, at the same time, there is a danger of placing excessive demands onto this communication flow as evidence indicates a tendency to overstate data's role and significance to justify architectural propositions.

After understanding data's character and influence in present-day digital fabrication approaches, the following chapter shifts focus away from the architect's direct involvement to contemplate the built urban environment. Critically examining urban development and operation conceptualised through advanced data exchange recognises how the digital economy exerts a new set of architectural practice requirements that link space to commercial behaviour and real estate.

Chapter 7: Ambient Field

Until this point, the thesis has considered data's character and influence from an architect and disciplinary perspective. Data increasingly exerts influence on our urban spaces as technical sensing absorbs into the built environment to track and manage resources. This version of data does not register directly in practice, but its urban presence increasingly governs the forecasting focus for architectural services. To consider this indirect influence, this chapter considers how architects design and operate in urban environments saturated with technical sensory surveillance capabilities. Interrogating Shoshana Zubboff's political-economic theory of surveillance capitalism (Zuboff, 2019) provides a foundational set of relationships for the chapter, between architecture, technical monitoring, human behaviour, and capital, that place new demands on the built environment. Progressively, technology companies seek to disrupt the inefficient traditional building and development sector with advanced sensing and data-driven automation. As this change happens, there is a need to question what data-driven urban environments change for architectural practice. The abandoned Sidewalk Labs Toronto Quayside development provides an example where these relationships at one time coalesced into urban development and architectural proposals that envisioned folding ubiquitous computing into urban form.

The chapter argues that when urban assets become managed and organised around a technical image of human behaviour, the architect's skills recalibrate from shaping space for human activity to optimising space for data extraction and exchange. Consequently, under the pressures of behavioural data-hungry urban development, architectural products are required to respond at the speed and precision of technical surveillance. Architectural briefs become imbued with new commercial requirements to coordinate material and sensing, producing new urban expectations of rapid material assembly and perpetual renovation. The chapter concludes that, as surveillant layers encroach on the built environment, they will reduce architectural influence over shaping the city, and rich architectural thinking regarding human and non-human interaction will give way to commercial value extraction regimes.

7.1 A New Material Value

Kazys Varnelis argues that Web 2.0 did not just change expectations of consumption and production; it also culturally conditioned users to give and receive (Varnelis & Nissenbaum, 2012). This transactional shift to sharing personal information through technical interfaces assigns character to data through the web and ubiquitous computing. This modal shift to sharing alters social practices and provides commercially valuable attention in return for information and entertainment. This conscious and unconscious surrender via digital media generates great wealth when coupled with precise, targeted, commercial, and political messaging. Shoshana Zuboff, a social psychologist, highlights that digital platforms' business models rely on recording online interactions to predict commercially beneficial behaviour suitable for targeted commercial messaging (Zuboff, 2019). Commercial value extraction becomes the material and spatial organisation driver when interaction measurement escapes personal computers and infuses the built environment.

Material calibration

In contrast to the late twentieth and early twenty-first-century modes of production that utilised scientific measurement and monitoring to extract value from natural resources, Zuboff argues that a new surveillance capitalism extracts value directly from prediction of human behaviour. Zuboff puts forward a critical position that the increased cultural acceptance of ubiquitous computing and an associated reliance on networked technology for social identity means behavioural surveillance exists as much in the virtual as in the physical. An implication for the built environment is an increasing commercial desire for behavioural prediction, leading to integrated digital sensing under the guise of social benefit. What is more, Zuboff warns of covert efforts to measure unconscious actions, seen in platforms offering a more accurate and valuable view of behaviour than conscious interaction (Zuboff, 2019); this means that data infrastructure risks disappearing into the built fabric altogether.

Surveillance capitalism extracts value through correlating human behaviour with economic forces by combining digital sensing and algorithmic analysis. Digital sensing and algorithmic analysis positions surveillance capitalism within two distinct discourses, the internet of things (IoT) and cybernetics. From the perspective of IoT, the technological ambition to network and integrate computing into all objects happens under the auspices of 'data-wrangling', a term Bruce Sterling uses to describe commercial control over behavioural extraction (Sterling, 2013). Data-wrangling shifts the focus of extraction from the virtual space of the internet into physical space, transferring ideas developed within the digital onto managing the physical world through digital infrastructure. From the perspective of cybernetics, Zuboff makes it clear that social individualisation occurring in the mid twentieth century underpins social media and surveillance capitalism (Zuboff, 2019). As established earlier in the thesis, cybernetics ushered in new thinking about psychology and environment that changed notions of collective and individual pursuit. In the 1960s and 70s cybernetics provided architects with a theoretical framework to engage with non-human perspectives and explore complexity in material and informational systems. Simultaneously, outside architecture, cybernetics influenced radical scientific progress by predicting and controlling the physical world, setting the foundations for contemporary western neo-liberal political economies (Curtis, 2011).

Achieving objective urban surveillance towards physical and social control requires infrastructural control over data collection. Just as industrial mass production sought to shape new social identities of consuming individuals, Zuboff argues, digital economies algorithmically do the same for data producers (Zuboff, 2019). Zuboff's primary concern is that cities become increasingly formed around the success of technical measurement and not human life (Zuboff, 2019). Adam Greenfield, an urbanist, similarly observes that much of the built environment, in a western context, increasingly shapes around the demands and success of non-human technologies rather than the human inhabitants (Greenfield, 2017). Zuboff argues that material form could become an extraction and communication feedback source, helping shape rather than merely predict human behaviour (Zuboff, 2019). Such environments already exist in commercial malls where material, space, and digital visual communication coax users into spaces of profitable activities. As a result, commercial buildings increasingly organise through surveying and manipulating humans towards profitable outcomes.

The automated entry system is an example where surveillance and manipulation become a point of control in the built environment. Access relies on interaction with sensors; however, non-human detection also underwrites spatial privileges and verifies identification, meaning it is ultimately about a person's capacity to interact with a system and feed information into a database. However, access also correlates to existing and constructed digital identities. Castells refers to this distinction as 'the net and the self', a separate human identity created via network interactions rather than self-description

(Castells, 2000). Automated aspects of the built environment rely on both the net and the self to guide physically significant actions, meaning our urban identities become fabricated by unseen surveillance systems. In an urban context, the ability to interact and exchange potentially overlays a hierarchy of access. Therefore, freedom of movement and use of space through access become governed by invisible systems beyond our control.

In contrast to the subjective self, the urban surveillance 'net' constructs individual identities based on their data consuming or producing capacity. Subsequently, controlling commercially beneficial behaviour becomes an alternative model for organising the built environment, placing importance on two factors: sensing and representing human activity in urban space, and controlling what extracted information feeds back to inhabitants, and where. Therefore, it follows that the spaces and thresholds required to appease a surveillance capitalist approach would promote material form as an instrument to calibrate extraction. As a result, the architect's brief starts to absorb the language and requirements of behavioural extraction alongside its traditional responsibility for human inhabitants.

Urban feedback

Rob Kitchin and Martin Dodge's research on software's spatial impact highlights how surveillance and information management interact with everyday life (Kitchin et al., 2011). According to Kitchen and Dodge, the visible and tangible effects software cause occur through dispersed computations that 'generate, distribute, monitor, and process capta' (Kitchin et al., 2011, p. 5). Kitchen and Dodge's reference to 'capta' as 'what is selectively captured through measurement' (Kitchin et al., 2011, p. 5) indicates a conscious partiality occurring through software design. When software inputs these measurements and feedback information based on a designed intent, it produces spatial influence. Kitchin and Dodge provide an example in airport check-in areas, networked offices, and cafés that transform into workspaces when laptops and wireless access temporally alter spatial use (Kitchin et al., 2011). Architecture and monitoring infrastructure rub up and influence each other; built form shapes space that invites software and technology use, and in turn, infrastructure alters spatial use, producing a different understanding of building programs.

Unlike other infrastructural systems that enable the circulation of physical goods and people, monitoring infrastructure supports the circulation of information. The basis of the smart city is to manage human experience by monitoring and producing valuable information. Vasilis Niaros, a smart city researcher, highlights that organising material resources through controlling data extraction is the main concern, whether centrally, locally, or communally governed (Niaros, 2016). Michael Jemtrud and Keith Ragsdale tie this resource management to urban expenditures, such as time and energy, which become the metrics used to optimise and control the city (Jemtrud & Ragsdale, 2015). Therefore, the smart city is the urban outcome of an optimised performance paradigm employed to manage expenditure through material and infrastructure resources.

Optimised performance extends beyond resource management and material flow in commercial land value extraction in some smart cities. Orit Halpern identifies Songdo smart city, in South Korea, as organising urban space through a real estate value mechanism (Halpern, 2015). In contrast to the traditional notion of material ownership as a store of value, Halpern argues Songdo shifts value to technical sensing and personal information extraction as it manages and encourages programmatic transience and optimised real-estate returns (Halpern, 2015). In Halpern's Songdo example, potential extracted value gains greater importance than built architecture, meaning that where surveillance once benefited spatial arrangement, space now benefits data extraction.

When surveillant extraction becomes a source of economic value in development, there is a risk that monitoring of infrastructures begins to govern material and spatial conditions. In this scenario, decisions concerning material form and infrastructure are driven by the same concerns over prediction, communication, and analysis, influencing development's material consequences. Zuboff refers to Sidewalk Labs as a digital platform wise to the real-estate revenue potential of extracting urban behaviour through infrastructure. Zuboff describes Sidewalk Lab's technical sensing infrastructure as producing 'economies of action' where it draws information from vast data collection and intervenes in urban use through software, controlling production and consumption (Zuboff, 2019, p. 4165). Surveillance infrastructure consists of sensors, transfer mediums and technical interfaces that overlay the urban fabric, creating an apparatus that 'interrupt[s] the flow of personal experience to influence, modify and direct our behaviour' (Zuboff, 2019, p. 4185). Within this system, technical interfaces extract and feedback information representations that intervene in human action, such as 'nudge, tune, herd, manipulate, and modify behaviour in specific directions by executing actions as subtle as inserting a specific phrase into your Facebook news feed' (Zuboff, 2019, p. 3644). While not all urban users face this threat, the proliferation of social media and technology in present-day cities places this possibility onto most. Valuable spatial use extraction necessitates maximum interaction with interfaces, requiring mass interface adoption to promote cultural normalisation of technological intervention and human interaction.

The consequence of smart city governance becoming part of urban development is that material forms distribute through a technical sensing logic, leading to data becoming more a controlled urban product than something collected or curated by architects. While Zuboff's claims suffer a degree of technological determinism and are sometimes sensationalist enough to sell book units, there is a clear extension of online behavioural surveillance into the physical world. The new potential concentration of surveillance infrastructure and interfacial apparatus into urban fabrics controls the physical by understanding and influencing human action. Significantly for architecture, this infrastructure and apparatus becomes the primary means of representing spatial use and risks becoming the sole urban development focus. By abstracting the urban into metric-based patterns rather than understanding lived experience, the smart city extends the cybernetic ideology first found in Jay Forrester's decontextualising urban dynamics (Forrester, 1969) as discussed in chapter 4.

In summary, the logic of online data surveillance applied to the real world provides value through predicting human spatial behaviour. If urban spaces and thresholds follow a surveillance capitalist approach, material form becomes an instrument to calibrate value extraction. In contrast to the architect's spatial and experiential cues, urban fabric shaped by value extraction organises around understanding and influencing human action. In this move, a logic of building performance transposes onto a logic of human urban performance. As material form distributes through technical sensing and human performance prediction logic, monitoring becomes the primary focus for development interests who then hold responsibility for data production, not deriving them from an individual or set of agreed measurements. Data extraction offers a sophisticated means for actors with urban development interests to calibrate material decisions with human performance. Just as imposing a framework of building performance sets an evaluative framework over architecture, understanding urban form and space through human performance metrics centres around what technical monitoring provides. This focus on certain types of valuable data that give potential organising information to urban form means that data takes on more value than the material, as urban feedback occurs at a much higher resolution than a building. When data occurs at the scale of the body and immediate space, a material organisation can respond at the exact resolution. As analysed patterns from urban sense data indicate where potential behavioural value extraction is possible, and material organisation assists in realising that value, data, and material enter into a new commercial association. Where measurement previously represented the material, materials now adjust to continuous technical monitoring which associate architecture's material elements with a new type of economic value.

Shoshana Zuboff's writing highlights the newfound value imbalance introduced to built environment, one suggesting a change in focus for urban management and commercial development. If environments now generate data and their successful performance relies on it, then urban objects and spaces are likely described in these terms. This potentially shifts the architect's commercial responsibility and value provision for stakeholders, from offering human beneficial conditions to designing for data extraction. If space forms around data maximisation, then it could supplant human needs as the traditional focus in architecture. Designing for data could produce second order human benefits as measurement generates awareness of urban phenomena previously undetected, but it could also place the urban inhabitant as an unwilling unit of production for surveillance capitalist interests.

7.2 Urban Material Instability

Understanding the influence of data on architecture through urban pressures of behavioural extraction requires a case study to verify whether infrastructure, urban planning and architectural design intersect. Zuboff's use of Sidewalk Lab's abandoned Toronto Quayside project provides a case for surveillance, but she does not consider the architectural consequences of the proposed project. Sidewalk Labs operate as an 'urban innovation' company, alongside Google within the Alphabet holding company. In 2017 Sidewalk Labs won a bid to develop the Quayside area of Toronto, Canada, on the back of a proposal utilising advanced digital technology to make the urban space more adaptable and efficient (Labs, 2017). Although the Sidewalk Toronto project only ran from 2017 until 2020 and did not break ground, Sidewalk Labs continue developing and testing integrated urban technologies under a broader commercial mission to make cities more sustainable and affordable (Labs, 2019d).

A data-space typology

The first question is how Sidewalk Labs understand data in the Quayside project, and where does it register in their urban planning approach? Publicly available planning documents associated with the development provide a set of types. Table 7-1 shows how Sidewalk labs categorise across three distinctions, the sensors or technical infrastructure required for monitoring, the ‘spatial realm’ sensing operates, and the ‘access’ offered to data once collected.

Table 7-1 - Types of data governance planned for Toronto Quayside (Labs, 2018, p. 16)

Type	**Sensor**	**Spatial Realm**	**Access**
Urban 1	Street-facing cameras Pedestrian counters Common Space App Energy use and environmental conditions Adaptive traffic management technology and adaptive traffic lights. Real-time building monitoring to enable mixed-use.	Public realm data BUT 'Private control or collection of any data that is personally identifiable requires substantive review by Data Trust'	Public access
Urban 2	Internal cameras Energy use and environmental conditions Real-time monitoring of building conditions to enable a mix of uses	Collected in privately-owned but publicly accessible spaces	Public access to 'Large scale data' Private control of 'Small scale data'
Urban 3	Home security cameras, Smart Home Devices Thermostats, Sensors for building code compliance	Collected in fully private spaces, generally homes or offices	Private Control 'Data not a public asset'
'Traditionally' Collected		Direct Consent (websites and apps)	'Issue that extends beyond Quayside.'

The first clear distinction across the types is the origins of technical apparatus. Sidewalk's urban strategy integrates and distributes sensing technologies through entrepreneurial tech companies, including Sidewalk Labs themselves. Sidewalk Labs refer to this as 'open architecture—one that enables and encourages collaboration and experimentation' (Labs, 2018, p. 30). This 'Open Architecture' translates as an infrastructure of networking that extracts through variable sensing apparatus.

Table 7-1 offers three distinct spatial realms, the public, the publicly accessible–privately owned, and the privately owned. While nothing about this distinction contrasts with traditional urban or architectural theory, there is a curious relationship with infrastructure's pervasiveness across the realms. Cameras exist across all three realms. In the public realm, cameras are 'street-facing', suggesting they exist as part of the material makeup of the street. In contrast, 'internal cameras' and 'home security cameras' suggest a more discrete presence, receding into the background away from visibility. Technical surveillance and public space have an uneasy relationship. As Nicole Gardner highlights, the visibility of surveillance technology alters perceptions of public space (Gardener, 2017) and Thomas Fisher warns of the influence surveillance technology imposes in reducing public sphere engagement (Fisher, 2018). An early signal in Sidewalk Labs' attitude begins to emerge; where the traditional city organises through architecture's demarcation of public and private space, overlaying technical sensing supplants material division to extend private control into all physical space.

Sidewalk Labs use the same public/private distinction when accessing data. According to Sidewalk Labs, access correlates to public 'large scale data' and private 'small scale data'. As previously discussed, a point of measurement is inseparable from a time and location; Sidewalk Labs acknowledge this when stating that sensing is 'anchored to geography, unlike data collected through websites and mobile phones, and lends itself to local governance' (Labs, 2018, p. 14). Sidewalk Labs' data governance types relate scale to a degree of personal identification, producing a gradient between a non-personal public and a potentially personal private oversight. For Sidewalk Labs, sensing redefines the urban and architectural subject between a *collective public* and a *personalised private.*

This distinction between collective public and personalised private also relates to authority, with the public gaining 'access' to general and non-personal data. At the same time, privately owned spaces gain 'control' over their data (Labs, 2018, p. 14). In a draft proposal for digital governance of Toronto's Quayside, published in October 2018, Sidewalk Labs defined their strategy to respond to fears regarding ownership, community surveillance and invasions of privacy through identification (Labs, 2018). The outcome, an independent third-party Civic Data Trust, attempted to counter the public worries regarding privacy by producing equal access to consensual and 'de-identified' measurement, 'eliminating the concept of data ownership' (Labs, 2018, p. 37). While the Civic Data Trust promised equal access, Sidewalk Labs retained responsibility for the underlying infrastructure, as detailed in Table 7-2. Table 7-2 shows the digital infrastructure that Sidewalk proposes.

Table 7-2 - Sidewalk Labs Infrastructure at Toronto Quayside (Labs, 2018, p. 28)

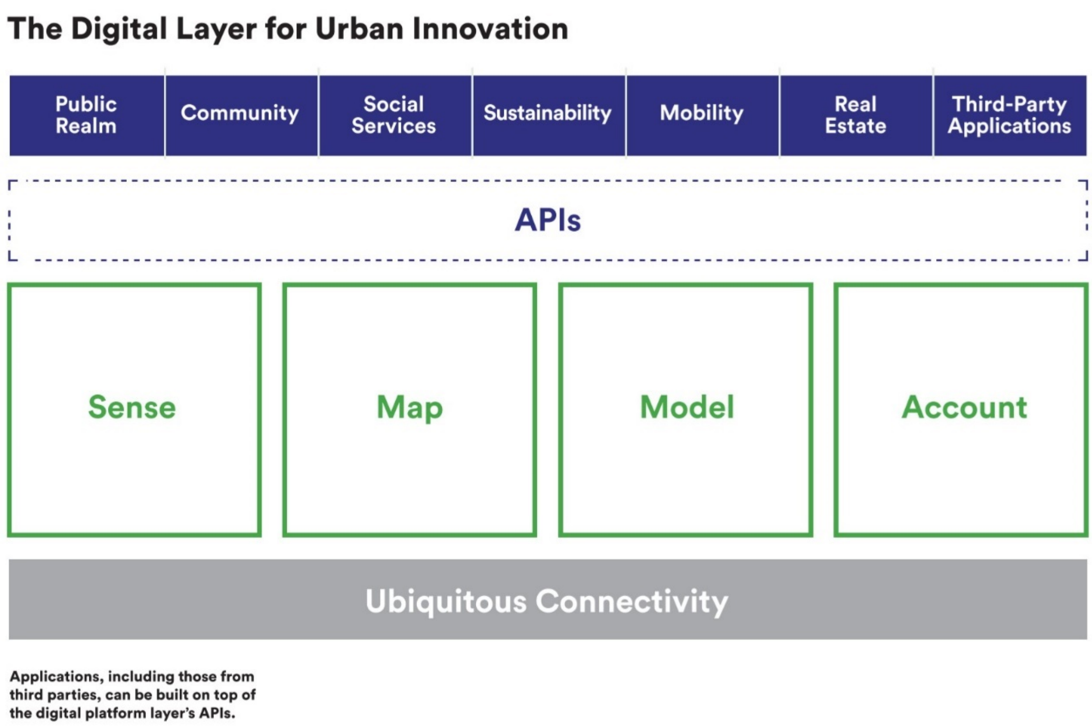
Data Infrastructure
Ubiquitous WIFI connectivity
Standardised mounts and power
A high-resolution 3D map of the neighbourhood
An open data hub will provide real-time access to data in standard formats through well-documented interfaces.

While the existence of 'open data hub' and 'civic data trust' appears to contradict Zuboff's fears of behavioural surplus extraction through ownership, Sidewalk Labs only address the ownership issue, ignoring the significant advantage it held regarding infrastructure.

Given that Sidewalk Labs would have access to a suite of advanced technologies to analyse and extract valuable patterns from sensing, their advantage lies in processing data, rather than merely accessing data. One of the leading public concerns associated with Toronto Quayside before its abandonment was the role of monetisation within the Sidewalk Labs business model. To appease concerns, Sidewalk Labs responded that 'no private entity can gain unfettered access to and ownership of data collected in Quayside' (Labs, 2018, p. 38), claiming the digital infrastructure operated as an 'open system'. This ownership removal indicates that access and control were not the intended sites of value. Through the lens of surveillance capitalism, value arrives from a superior technical ability to analyse and visualise the patterns hidden in data, which Sidewalk Labs potentially had in plenty.

While Sidewalk Labs seem to provide a neutral infrastructure to sensing and access, an imbalance arises when considering the capacity to process and make sense of the publicly available data. While access and control are possible for all, Sidewalk Labs hold an infrastructural advantage in using detected patterns and presenting information back to the public domain. An example of this advantage is the proposed 3D maps of the neighbourhood as detailed in Sidewalk Toronto's Project Vision document (Labs, 2019b). As part of the 'digital layer' (Figure 7-1), the mapping component captures locations for infrastructure, buildings, and shared resources to track all fixed and mobile objects and manage their movement (Labs, 2017).

Figure 7-1 - Sidewalk Labs Toronto - Digital Layer (Labs, 2017, p. 67)



As established in Chapter 1, a map is never a neutral image; it captures data and translates it into a partial version of information. In Toronto Sidewalk, maps provide spatial influence by embedding information into Google Maps commercial advertising platform. Therefore, by distracting the conversation away from a discourse of ownership and control that speaks to public/private spatial access, the real ambition is to organise movement by feeding information into the urban realm.

Quantifying environment

The schema presented in Figure 7-1 shows two other important aspects of the urban digital layer, sensing, and modelling. While sensing anticipates monitoring the urban environment in real-time, modelling utilises analytics to predict behavioural and material performance (Labs, 2017). Analytics, modelling, and mapping combine to monitor and manage a performative and manipulable environment. Understanding the urban as a physical and technical environment significantly diverts from the traditional spatial concern of planning. Sidewalk Toronto's interest in the environment as an urban condition is not solely about human comfort as claimed; it is a driver for mixed spatial use and, therefore, acts as a real estate administration tool. In the process of planning and promoting Toronto Quayside, Sidewalk Labs provide little information regarding revenue streams and return on investment, focusing instead on constructing a narrative around economic benefit for Toronto (Lum, 2019). However, leaked documents from the company to the *Toronto Star* newspaper uncovered that Sidewalk expected to recoup investment through 'a portion of property taxes, development fees and siphon off tax revenue generated by increased property values in the region' (Dellinger, 2019). Sidewalk Labs made a point of promoting their ambitions for affordability and economic growth, as both find positive reception from political and broader public audiences. However, efforts towards affordability and economic development read more as veiled attempts to manipulate value through spatial use.

One of the main strategies proposed by Sidewalk Labs to increase spatial use was to mix uses. In a statement that ignores much of urban design history, Sidewalk Labs claims a new approach to urban development. They proclaim, 'for most of the twentieth century, cities separated residential, commercial, and industrial uses geographically to protect homes from noise, air pollution, and other nuisances. This discouraged an active mix of home, work, and retail into the same neighbourhood — let alone the same building, often creating districts that were deserted at certain times and increasing travel for workers.' (Labs, 2019f, p. 19). They aimed to avoid deserted districts from a civic perspective, but their planning strategy reveals a deeper mixed-use requirement. Sidewalk Labs' economic strategy begins to appear when they state:

buildings should be able to accommodate a diverse range of tenants — residential, commercial, retail, and light industrial. However, it is important to minimize the nuisances that commercial and light industrial tenants might create for their neighbours, including machinery noise, odours and vibration from industrial processes, so there needs to be some way to monitor these nuisances and give feedback. (Labs, 2019f, p. 20)

The above quote links monitoring and feedback to knowing and acting on environmental conditions to enable mixed-use at urban and architectural scales. In this relationship, data connects to space by governing activity through measured performance rather than measuring the human body. Therefore, the sensor and the quantified environment becomes the primary drivers of spatial knowledge for Sidewalk Labs.

Table 7-3 shows a digital transparency survey (Labs, 2019c), describing eleven types of sensors proposed for the Quayside. These environmental sensors provide a quantifiable understanding of energy use and physical phenomena impacting the sensory experience. Sidewalk Labs argue that this helps set environmental conditioning and helps solve disputes over sharing space (Labs, 2019c). Sidewalk Toronto quantifiably represents 'environment' to relate into equally quantifiable real-estate management. Managing the built environment through data leads to managing space through the lens of what data offers. As Fisher states through Giambattista Vico, data only uncover what humans or machines create (Fisher, 2018). While the twentieth century understanding of 'environment' connected human and ecological survival, Sidewalk Toronto's new type of urban environment creates conditions for technical and human coexistence.

Table 7-3 - A collation of Sidewalk Labs Sensor Types at Toronto Waterfront by the author

Sensor Type	Measurement
Infrared Motion Sensor	Occupancy for energy efficiency
Security Camera	Object movement/identification
Traffic Sensor	Object movement
Temperature Sensor	Energy efficiency
Infrared Depth Sensors	Occupancy for energy efficiency
Smoke Detector	Fire
Thermostat	Energy efficiency and comfort
Light Switches	Automated lighting
Faucet Switches	Water efficiency
Door Lock	Identity card recognition

While mixed-use in urban space promotes a beneficial diversity of activity, which Sidewalk claims it does, mixed-use also provides an urban strategy to maximise real estate revenue channels. To make real estate as profitable as possible requires generating tenant demand, which requires knowing the risks involved in potential commercial success and portraying a desirable situation. Technical surveillance becomes critical to monitoring the environment and mixing spatial use. The material consequence of environmental and spatial surveillance is a desire for flexibility to minimise the time between action and appraisal. Sidewalk Labs make this relationship clear when they propose marrying data with material systems. They claim architecture becomes 'flexible infrastructure' that will 'make physical space as low risk and dynamic as digital space: Flexible/modifiable space, micro lease terms, business in a box services' (Labs, 2019e). Zuboff's concern that online surveillance will migrate to offline spaces appear in Sidewalk's ambition to treat the physical like the digital. When applied to the material, the micro surveillance of the digital manifests in an adjustable and replaceable architecture, enabling and governed by commercial leasing terms that interact with the speed and detail of surveillance. A mixture of environmental control and flexibility in material organisations creates the ideal conditions for plugging in, swapping out, testing, replacing, evicting, expanding, and relocating, all calibrated through the lens of real estate and made visible by patterns uncovered from environmental sensing.

Perpetual renovation

Sidewalk Lab's use of technical sensing provides a means to manage use and optimise real-estate returns through shaping use and movement within the precinct. Spatial use and movement quantified through digital measurement shift planning attention away from architecture's material forms to shaping an environment. Extraction through fixed and personal technical apparatus is most intense at the scales of body and street. When coupled with an urban strategy of flexibility through renovation, there is a strong desire to provide adjustable conditions for material decisions occurring at the body's scale. As a non-visual influence, technical analytics govern material decisions and require the physical environment to adjust to sensing feedback. Decision-making comes through an ability to influence analysis and uncover valuable information. However, unlike data-driven design, which constructs information for decision making, Sidewalk Labs view information as feedback from an automated sensory environment.

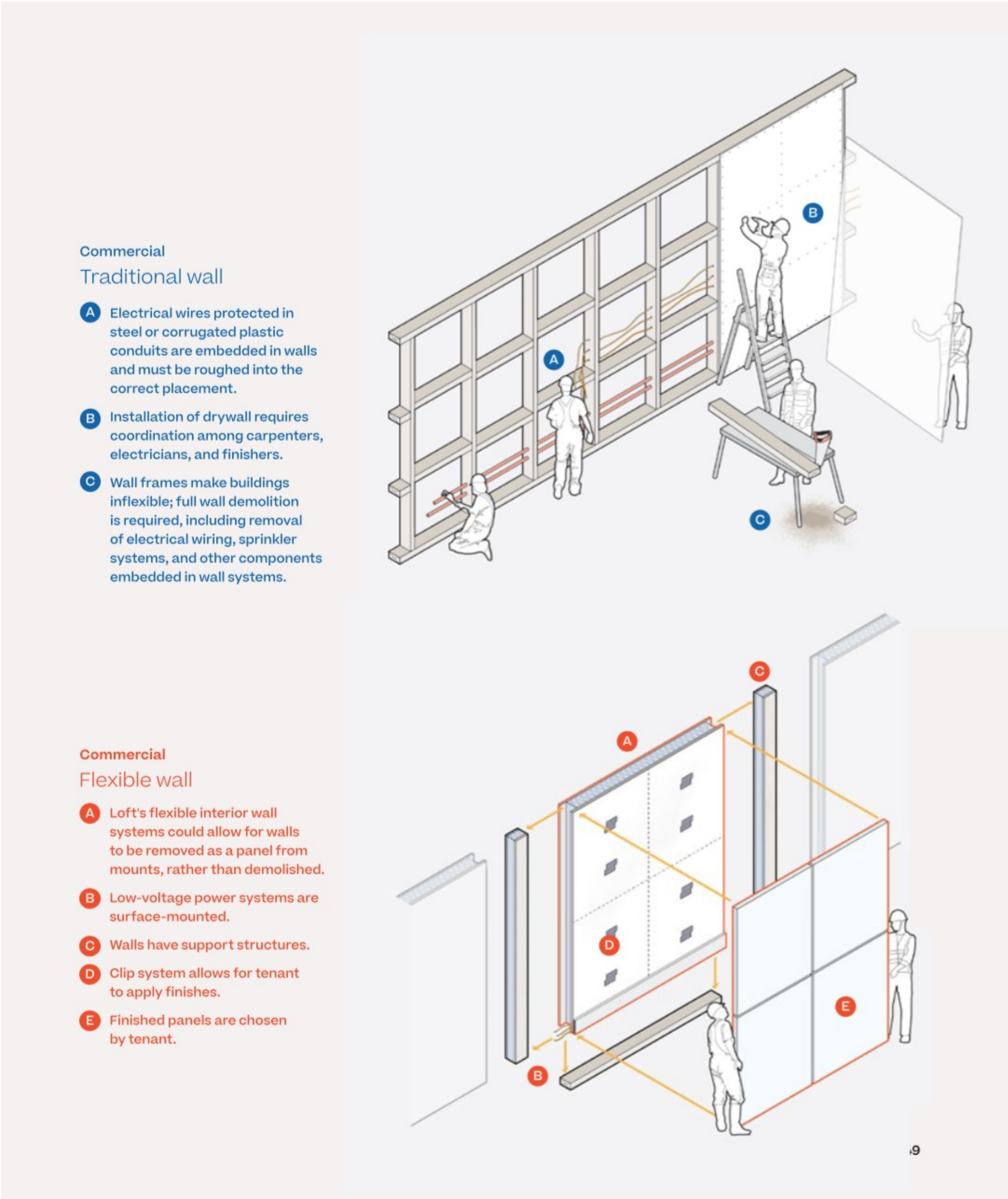
This control over the urban sensory environment registers in the kinds of material assemblies Sidewalk propose would adapt to environmental feedback and appease their renovation strategy. Reviewing Sidewalk Labs' planning documents uncover a clear set of requirements and constraints they impose on material organisation. A basis for the development is using large, free span Cross Laminated Timber (CLT) as a locally manufactured material and a structural capacity to achieve large span open-grid structures. This grid first appears in Michael Green's visualisation of large span timber buildings, with a series of deployable structures at street level (Figure 7-2). Michael Green's architectural proposal centres around a prominent timber tectonic providing large span open space, an accentuated version of the modernist free plan. Green's proposal begins to suggest a visual aesthetic of flexibility, infill units, differing in scale for commercial or residential use and allowing multiple and quickly changing uses. The architecture arranges to accommodate future uses and consumer behaviours. The structural grid with clearly defined interventions sets up what Eleanor Gibson identifies as an appearance of 'modulation' using a 'modular kit of parts' (Gibson, 2019).

Figure 7-2 - Quayside Proposal - Michael Green Architecture (Hillberg, 2019)

The brief supplied by Sidewalk Labs to Michael Greene, Snøhetta and Heatherwick studios stipulated using a library of parts, expecting each architect to design through a limited palette of modular components. This parts library consists of six core components, exterior façades and windows, exterior wall systems, structural elements, interior wall systems, kitchens, bathrooms, and building roofs (Labs, 2019b). Sidewalk

Labs argue that a restricted palette of materials ‘can improve predictability of design’ (Labs, 2019a, p. 11), but its real influence appears in its ambition for flexibility. Through a series of diagrams, Sidewalk Labs explain their concept of flexibility as an arrangement of ‘flexible walls’ within the cellular organisation of a timber building (Figure 7-3). The flexible wall places a different construction logic onto the interior space, one of integration and modulation, reminiscent of Cedric Price’s Generator project. Visually, the flexible wall conjures up a similar image of Price’s Generator proposal, the architecture of which references the modular logic of the computer circuit board. However, closer inspection reveals that the two concepts differ in their attitude to material change. Price aimed for adaptation based on an inhabitant’s lifestyle, while Sidewalk Labs align adaptability through a capacity for rapid renovation. While Sidewalk Labs’ argument for modulation exists at a material production level, its actual influence is at the material organisation level, allowing rapid change and spatial provision based on predicted behaviour.

Figure 7-3 - Flexible Wall (Labs, 2019a, p. 9)



A closer examination of Sidewalk Lab's modular system uncovers the wall's importance as a device to control the environment and flexibility. The 'flexible interior wall', as shown in Figure 7-3, modularises infill and integrates power and networking into a discrete unit. The wall panel's discrete nature introduces two comparisons: environmental resolution and material organisation. Compared to the homogenised 'traditional wall', the modular panel enables fine control over environmental performance through surface materials, which influences space based on environmental sensing. Swapping out wall units introduces a discrete quality onto the architecture, imagined as digital bits. However, unlike Retsin's digital discrete, the flexible wall covertly reads as a continuous system and conforms to industrial standards and visual expectations. Sidewalk Labs tackle surveillance, environment, and renovation through material choice, producing flexibility within the precinct and restricting architectural involvement. Also, the mandated kit of parts produces a relatively neutral and definable background that enables clarity in sensing and makes the environment more readable.

Inspection of the architectural proposals at Toronto Quayside reveals three conditions of flexibility and climatic control. These conditions appear differently in the sealed interior, the 'micro-climate' canopy, and the street furniture zone, all arranged within and around the architectural grid structure. While flexible spaces initiate a starting condition, they exist to adapt to residential and commercial requirements. This adaptation means space flexibility results from constant monitoring rather than an architectural proposal; flexible space becomes a management process through the market's self-organising logic.

The three conditions of flexibility exist across three scales, the 'loft' shaped by the structural grid, the 'residential unit' organised via the flexible wall and rental market, and the 'Stoa' Sidewalk's concept of a flexible urban realm based on the 'traditional Greek marketplace' (Labs, 2019a). According to neighbourhood needs, the Stoa presents a spatial infill strategy of sub-division responding to the requirements of retail, production, or community spaces (Labs, 2019b). The Stoa concept provides a framework to evolve material organisations. However, unlike the biological idea of evolution as a process of generational fitness, material evolution demands perpetual renovation by overlaying the market's logic onto urban development. The difference between data-driven and data-surveillance is that while the former correlates material decisions with the market's logic, the latter uses market forces to organise material assemblies and extraction, creating a feedback loop.

Rendered visualisations provided by Snøhetta and Heatherwick studios present the high gloss imagery used to sell the Toronto Quayside (Figure 7-4/Figure 7-5Figure 7-5). While this imagery offers photographic realism, it shares a material language introduced in the earlier drawings of Michael Greene. The formal similarities suggest that the kit of parts sets up a material and formal palette, restricting the space for architectural expression. Comparison of two street-level images by Snøhetta and Heatherwick shows a similarity in full-span pillar beam construction such that visual distinction can only exist on the surface of a building envelope. Material flexibility set up through environmental and behavioural sensing restricts architectural influence to the building envelope, the solid physical edge materially unable to adjust. The spaces in between buildings provide moments of infrastructure interaction and adjust to feedback over hours and days rather than months or years. The material requirements of the in-between architectural space do not disappear, but they are beyond the architect's influence and the time scale of their practice.

Figure 7-4 - Toronto Quayside Proposal - Interior Courtyard – Snøhetta (Labs, 2019b, p. 187)

Figure 7-5 - Toronto Quayside Proposal Innovation Zone - Heatherwick Studio (Labs, 2019b 438)

The influence of data in the urban strategy of perpetual renovation also reveals itself in Sidewalk Lab's strategy of 'outcome-based' urban spatial use management. Sidewalk Labs states:

‘by setting an ‘outcome-based’ standard, a real-time code system can better protect all uses and support a broader mix of uses at the building and district scales, including the integration of production spaces and small-scale industries within a residential and commercial building or neighbourhood.’ (Labs, 2019b, p. 252)

Just as data-driven design aligns the physical past with future predictability, Sidewalk Labs’ ‘outcome-based’ approach ties historical monitoring to future outcomes. However, Sidewalk Labs’ mode of organising by employing spatial rules or ‘codes’ differs from the data-driven and speaks to the pattern-based experiments of the late twentieth century. This ‘outcomes-based’ approach to management marries real-time measurement to use through defining rules, like an algorithm for governing activity. Sidewalk Labs’ proposal to use sensing and analytics to define and manage environment and behaviour set up a new type of relationship between material and space. Rather than architects using material forms to forecast expected use, the material perpetually renovates, calibrates, and optimises in response to precisely measured and analytically predicted use.

Therefore, materials organise around the data, not the spatial, in turn reversing the historic relationship and establishing a new era of architecture. However, rather than placing software’s immaterial status onto architecture, as was the case in the late twentieth century, architecture destabilises to make space reconfigure like software. For Sidewalk to manage the built environment in the image of software, building forms require lighter and more integrated material systems. Sidewalk Labs would have us think this is a new condition, but this idea traces back to architectural thinking around the environment and adaptability, recognisable in Nicholas Negroponte’s work. The idea of materials self-organising through feedback binds the 1960s communication environment with today’s automated approach. In Sidewalk’s case, the city acts as Negroponte’s ‘cyclic’ materials through ‘complicated but well-stated contingences - if this and if that, then this and this’ (Negroponte, 1975, p. 135). Both approaches compare their attitude to environmental and behavioural sensing and management governing the material through the market's logic, making material form a consequence of objective assembly rules. Sidewalk and Negroponte sit on a trajectory first recognised in the work of Neufert, whose centralised control over measurements and material standards has evolved into controlling infrastructure to reorganise the material. Sidewalk Toronto’s infrastructural material management reads as the next iteration of Neufert’s handbook. Today, data escapes the static confines of paper and book to float ubiquitously in urban space, awaiting sensing, analysing, mapping, and modelling.

The case of Toronto Quayside presents a view of the built environment as a destabilised material substrate where infill of space, services, and circulation become determined by rules informed through constant technical sensing and analytical feedback. This relationship between construction systems, sensing analytics, and perpetual renovation demands architecture and urban space to operate like quantified computer data; flexibility and replaceability are born through equivalence. Data equates to access and ownership in the public eye, but its covert use is to organise and optimise commercial space as a management tool. A new set of expectations are placed onto the built environment to destabilise and reconfigure in response to the constantly changing, quantified behaviour and environment feedback. Urban districts governed by data become spaces of material instability when developers idealise the physical world to behave like software.

7.3 Real-estate craft

Urban space in Sidewalk Labs' abandoned Toronto Quayside relied on precise measurement infrastructure to distribute material resources and extract value. Toronto Quayside reads as a proposition where the mid- to late twentieth-century idea of the automated design interface environment migrates from the architect's practice to form an ambient urban condition. The interface, as the exchange threshold between human information and computer bits, becomes instrumentalised by commercial forces in this migration process. This migration limits and possibly eradicates a trajectory of practice exploring the interface as an architectural material. Architectural engagements with technical interfaces link back to Nicholas Negroponte's Architecture Machine Group and provide a rich history of experiments, leading to the specific definition of interactive architecture. This section traces how the migration of interfaces into the built environment, under the guidance of urban planning, co-opts and instrumentalises innovations developed in interactive architecture, reducing the discipline's influence and agency. The interface concept helps understand and explain how data and material become controlled by urban governance; consequently, material form shapes around extraction and not by the architect's intentions.

Spatial interfaces

Understanding how humans interface with complex infrastructure and monitoring systems in the proposed Toronto project requires understanding the interface in technological and architectural terms. Most importantly for architecture, an interface is not exclusive to data or information; it relates to any transition zone between two systems. Benjamin Bratton describes the interface as 'any point of contact between two complex systems that govern the conditions of exchange between those systems' (Bratton, 2015, p. 220). As such, interfaces occur wherever points of exchange occur between complex architectural systems. For instance, Molly Wright-Steenson refers to Christopher Alexander's pattern language as an 'interface' connecting complex systems of space, information, form and people (Wright-Steenson, 2017). Alexander's interface occurred through his text- and diagram-described patterns coupled with the architect's traditional drawn modes of representation.

Technological graphical user interfaces, designed to facilitate exchange from humans to information technology, emerged in 1962 with Ivan Sutherland's Sketch Pad software, regarded as an early form of computer-aided design software (Hughes, 2014). Today, the graphical user interface holds cultural significance due to the social ubiquity of smartphones and handheld computation. Adam Greenfield identifies the modern-day smartphone as the 'ultimate interface', designed to enable and manipulate communication with the 'intangible infrastructure' of the dematerialised economy (Greenfield, 2017). Like Zuboff, Greenfield identifies the smartphone and its graphical interface as a highly curated data-producing interaction, increasingly shaped by commercial applications and online platforms. Zuboff and Greenfield show how contemporary technology increasingly promotes collection and exchange to correlate visual communication with location-based behaviour, and culturally condition humans to interact with interfaces in the built environment.

Although our contemporary cultural understanding of user interfaces relates to handheld and web technology, architects have played a role in interface design development since Sutherland's innovation. As discussed in chapter five, Nicholas Negroponte's concept of an architectural machine used computing to design an interface between architect and intelligent machine. Negroponte's approach holds similarity with Christopher Alexander's patterned logic, but the architectural machine specifically designed an interface to invite and transform user input into digitally manipulatable forms. Interface design lay at the centre of design focus for the architectural machine to succeed, providing a material threshold that allowed input and then fed back human interpretable information. Wright-Steenson demonstrates that the Architecture Machine Group in the United States, and later Cedric Price and Gordon Pask in the United Kingdom, heavily influenced the spatial ideas explored in interactive interface design before engineers and computer scientists took over in the 1990s (Wright-Steenson, 2014).

As architects, Cedric Price and Nicholas Negroponte provided technologists with spatial problems and architectural metaphors to help imagine innovation. For instance, Wright-Steenson describes the architectural machine as 'the spatialization of data and information as an interface surrounding its users' (Wright-Steenson, 2014, p. 5), which would start an intense exploration of media and technology at MIT into the present-day Media Lab. This spatialization occurred through sensors that could detect and measure, processors that could manipulate data, and actuators that could then act back onto a physical context and produce movement, such as electric motors. The key to architectural uptake in institutional settings lay in the combination of intense military-industrial research funding and new access to such technology.

As technology progressed, architects became less involved in designing user interfaces and focused more on manipulating digital information within a design. However, those involved in developing ubiquitous technology, taking the user interface from the computer to the smartphone, continued to apply architectural metaphors to aid imagination and application. An example of architectural metaphor use exists in Mark Weiser's early efforts to conceptualise the interface in ubiquitous computing. In his highly referenced think piece 'The computer for the 21st century' (Weiser, 1999), Weiser mined architecture for a set of metaphors to imagine his new take on computing. In a described day in the life interacting with the '21st-century computer', Weiser regularly refers to the computer as a 'window' allowing 'electronic trails', or providing access to other rooms, or as a 'fore view mirror' to check events beyond the immediate vicinity, or the 'sharing of a visual office' through gestural passing of information (Weiser, 1999). As a result, the initial interface of ubiquitous computing took on the visual traits of material objects, a 'skeuomorphism' that sought to translate a person's existing knowledge of an object onto the system (Bratton, 2015). Ubiquitous computing research used existing cultural meaning associated with material forms, meaning architects provided ubiquitous computing with a set of stable and established relationships to guide intuitive interaction.

Architectural innovations in technical graphic user interfaces have a clear relationship with architects, providing much creative energy in early development. Architectural interest lay in how the architect could collaborate with a computer, but as interfaces reduced in size and sophistication, technologists took over their development into what we experience today. Today, two trajectories connect explorations of the interface's spatial potential; firstly, an architectural focus develops into interactive architecture; secondly, interfaces are absorbed into everyday material objects as experienced through the internet of things. Weaving ambient computing into urban environments introduced an interfacial influence outside architectural interests.

Environmental interaction

In the 1980s, influenced by Gordon Pask and Cedric Price, architects such as Steven Gage and Ranulph Glanville began exploring the spatial potential of mixing human and non-human sensory environments. Explorations from the Architectural Association and the Bartlett in London continued experimenting with sensing technology to design artificial environments where human inhabitants and interfaces became participants. A cohort of students studying under Gage and Glanville, graduating in the 1990s and 2000s, collided with radically lower costing sensing and actuating technology. One of these students, Usman Haque, took on a conceptualised architecture as a zone of conversation between a person and fluid and dynamic sensory infrastructure and explored through off-the-shelf technology, leading to design of what he refers to as the 'interface' (Haque, 2007, p. 7). With direct reference to Gordon Pask's description of communications — human-human, human-machine, machine-machine — as 'conversations' (Pask, 1969), Haque promoted a new type of architectural experience through sensory interaction. Haque's interactive architecture locates data at the point where an interface detects human input and conceptualises its use as a source of intelligence through computational pattern recognition. In interactive architecture, the architect's design responsibility shifts from considering material-spatial sensory experience as one-way to shaping a system of interaction between the body and a material interface.

Interactive architecture understands the interface as a responsive material threshold between the body and computational pattern recognition. In contrast to the architectural machine that positioned the interface as a collaborative medium between people and machines, interactive architecture imagines the interface as an active spatial participant

(Glynn, 2011). Rather than the static and immutable status of material form, interactive architecture focuses on material qualities that provide a dynamic, responsive and conversant character (Haque, 2015). Interactive architecture uses data to craft space through human and non-human interaction. The designed interface participates in constructing a new artificial sensory environment that imbues architecture with animative qualities and equally supports humans and the non-human.

Reinterpreting architecture as an artificial sensory environment requires a material form to translate between human and digital data. The interface mediating between human and non-human must invite interactive exchange between space and computational systems that map interaction into meaningful behaviour. Usman Haque argues that subsequently, the interface must disrupt traditional architectural systems of static form and space to produce a participatory learnt communication. Interactive architecture encourages the 'user' and computer system to learn about each other within an interactive environment, just as Negroponte's architectural machine proposed. In contrast to Negroponte's design use, interactive architecture recasts the interactive environment into built forms, conceptualising the interface as a spatial-material assembly that maps interaction to a response. The implication for interactive architecture is that material design choice occurs through the lens of sensory phenomena rather than for structural or sheltering reasons. For instance, materials that offer audio or electromagnetic sensing provide what Haque's labels a 'choreography of sensations' (Haque, 2015) that detect, respond and change over time. Consequently, interactive architecture conceptualises the interface as a material-spatial assembly that choreographs sensory interaction. In this scenario, mapping becomes a critical aspect of practice as automated user input translation must tie to a physical reaction.

When architectural experience occurs through physical reactions, its communicative capacity shifts from saying something, to doing. Doing rather than saying ties interactive architecture and the interface to new types of human and non-human interactive systems that produce meaning through use rather than through existing cultural references. Combining non-human and human interfaces at different scales, locations and times introduces both subjective and technical data origins. Danelle Briscoe argues that designing an interface offers opportunities to engage with 'cultural-data' (Briscoe & Marble, 2016), information passed into algorithmic analysis describing an individual's context. For Briscoe, cultural-data operates in the space of correlation between designed actions and 'user behaviours', presenting interactive architecture as a media overlay onto architecture (Briscoe & Marble, 2016). Briscoe helps further highlight the dichotomy between the temporal, transient, specific nature of technical sensing and the permanent and generic status of architectural structures. Rather than focusing on the material abilities of the interface, interactive architecture focuses on the moment of translation that creates a 'technological formalism' (Briscoe & Marble, 2016). A technological formalism brings meaning through interaction and reimagines architecture through media overlay. This media overlay is increasingly sensuous and non-tangible, producing sensory phenomena separate from material form. Lucy Bullivant refers to this phenomenon as imposing a 'soft space' (Bullivant, 2006) that is not a surface threshold but creates an inhabitable mediating space.

Additionally, the shift from saying to doing alters the architects concern from aesthetics to performance. Michael Fox highlights how those who conceptualise architecture as an interface shift practice away from representation and questions of what architecture looks like to concentrate on processes and behaviours (Fox, 2016). Fox claims that interactive architecture's evolution reads like a history of the interface, moving from human to human, then device to device, and finally to ecologies of humans and technical objects (Fox, 2016). The result is an architecture of digital media layers, which Fox claims brings a 'true communicative layer' (Fox, 2016, p. 10). Interactive architecture positions architectural communication as an interpretable field, with data as a 'layer' in mediated space. Consequently, the idea of an interface extends from screen-based digital information to become an ambient field stretched across scale, location, and time.

Interactive architecture offers a subset of material-spatial practice that operates through interfacial interaction. The architect's concerns shift radically from material form or design process to engage directly with technical systems and sensory environments in this subset. The sensory interface becomes the primary design focus to define space through human and non-human phenomena, giving data a diffuse interpretable field. Architecture becomes recast as an interface when this diffuse interpretable field becomes an active participant in spatial experience. In the hands of architectural thinking, ubiquitous computing becomes a material-shaping exchange between humans and non-humans that brings together measurement-based material standards with cybernetic monitoring.

Toronto's interfacial migration

The Toronto Quayside case study presents an alternative attitude to monitoring and manipulating behaviour in the built environment, where rapid renovation imposes a cultural expectation of adaptation drawn from surveillance. As technical surveillance increasingly drives material decisions, sensing overlays architecture with its rapid and high-resolution qualities, requiring instability in non-structural components to respond. Sidewalk Labs potentially gain control over a real-time process by controlling construction and infrastructure through treating the urban context as one extensive interface. Alexander Galloway helps us understand this logic when he highlights how interfaces do not just control information flow; they also control physical and virtual access. An interface is 'not something that appears before you but rather is a gateway that opens up and allows passage to someplace beyond' (Galloway, 2012, p. 30). Galloway argues that interface is not a thing; it is always a process, a translation or effect (Galloway, 2012). As a result, interfaces in urban conditions constantly translate and produce effects that drive material consequences.

Galloway's idea of the interface as an infrastructural process connects to Toronto's environmental management towards achieving mixed-use. Extending Galloway's notion of the interfacial field into Toronto, we begin to understand digital infrastructure's technical and behavioural impact. At a technical level, measurement and analysis produce information about the built environment that enables spatial and environmental management. Understanding Toronto as one large interface limits how adaptation occurs across the precinct; instead, it helps to imagine Toronto as an orchestra of interfaces with different material qualities to extract, register, translate and informationally translate. This sophisticated and complex arrangement of interacting interfaces links back to the cybernetic explorations embedded within interactive architecture, such as Cedric Price's generator, except that architects are no longer involved in design or application.

Conceptualising Toronto's Quayside as an orchestrated field of interfaces casts technical sensing and analytics as a resource and interaction as the primary focus of value extraction by shaping behaviour through an environment. This interfacial intention applies to Sidewalk's proposed Stoa space, made adaptable through prefabricated elements, coupled with the market's spatial organisation and commercial logic. The Stoa is an automated real-estate valuation system that measures spatial, material, and commercial performance to optimise financial management. Material adaptation would then occur through a cybernetic logic of information flows between inhabitants and orchestrated interfaces, achieving a self-organising behaviour. Therefore, materials locate through a logic of environmental management rather than spatial experience via feedback from orchestrated interfaces. This automated material allocation means that environmental monitoring now drives material arrangements rather than architects forming environments. Complex handheld and embedded interface systems represent architecture as environmental performance to continually adjust to extract value, recasting the urban fabric's role as shaping interfacial space. Toronto Quayside proposed a development similar to other commercially driven developments, with the innovative exception that land value extraction would exist as a continual process in urban space rather than a one-off transaction.

Deferring material decisions to an orchestra of interfacial environmental monitoring removes the architect's responsibility to provide urban exchange moments. Martijn de Waal argues that urban form has historically existed as a collection of urban media technologies that produce places where 'independent and often unrelated systems meet and act on or communicate with each other' (de Waal, 2014, p. 12). Architects and urbanists practising through urban media technologies conceived of urban space itself as an interface, which, de Waal argues, they have done for centuries (de Waal, 2014). However, architectural involvement today is undermined by the forces exerted through technical sensing that overlay an incessant desire for value extraction, leading to new financial paradigms such as micro-payments and micro-leases. In response, De Waal proposes we think of contemporary urban space as governed by bits, a gradient of digital interfaces acting as a membrane between material forms and ubiquitous computing. Architects once engaged in encouraging social exchange through material and spatial interfaces are now not involved in the technologically driven pursuit of materially configured value extraction.

This interfacial social exchange reduces and almost eradicates the architect's influence. This loss of influence aligns with Keller Easterling's interest in how information infrastructure overlays urban space through the logic of economy and politics whilst creating a framework for urbanism and architectural infill (Easterling, 2014). This 'extrastatecraft' results in architecture organising to serve efficient information flow, meaning the built environment becomes material, and spatial outcomes of infrastructure and buildings become tools to organise consumption (Easterling, 2014). Therefore, it is a concern with technical urban surveillance that 'determine[s] how objects and content are organised and circulated', which Easterling argues creates 'an operating system for shaping the city' (Easterling, 2014, p. 3). When cities form under information flow, architectural practice disengages from urban material decisions when developed through a real estate value and an economic consumption logic. Reproducible building patterns, determined by material logistics and economic forces, act as 'object forms', while the protocols, routines, schedules and choices provided for organising consumption provide 'active forms' defining spatial relationships inside and between buildings (Easterling, 2014). Active forms are unrepresentable as they operate at the speed of information change. The architect's communication role in manipulating materials transfers to the orchestra of interfaces that measure and respond to human behaviour. Easterling's 'active form' concept is helpful for understanding Toronto Quayside's intentions to organise materials through the ongoing value extraction achieved by urban interface space, rather than the sporadic process of architectural design and representation. This architectural removal also registers Zuboff's notion of the 'action economy' (Zuboff, 2019), where data extends from online surveillance into the physical world, taking control over the physical to extract value.

Urban space, developed and organised around flows of information afforded by orchestras of interfaces, encourages interactive exchange as the dominant driver for organising the built environment. As layers of data surveillance infrastructure extend from the digital into physical domains through ubiquitous computing, the interface becomes vital to condition and control valuable exchange. Understanding the city through measured value extraction redirects design to the interfacial exchange between spatial behaviour and consumption. These coexisting registers of space and consumption produce an interfacial folding of control in the Toronto Quayside proposal that removes any architectural notion of urban space, such as a program or public/private, and replaces it with an interfacial mediation of time and location-based environmental management.

This interfacial mediation is the territory that Sidewalk Labs operate in the space between material architecture and spatial software. Representing the urban as a system of virtual and material flows dynamically alters spatial use, converting the architectural program into a platform that mobilises activity and disperses people across space. Urban form emerges through material organisations' layering at differing speeds through different interfacial capabilities and different surveillant requirements through an interfacial regime. The consequence for architecture is that interactive interfaces' spatial potential escapes the discipline's edges and migrates into the built environment, controlled by others to monetise space.

Although architects and architectural metaphors are central to the data interface concept, technologists took over their development and produced the minute and sophisticated versions we experience today. Interactive architecture provides a unique example of architecture's standardised measurement-based material systems combined with cybernetic behavioural feedback of monitoring. Toronto Quayside takes this combination and migrates the interfacial potential of environmental exchange into the urban, becoming a primary infrastructure focus. As these spatial interfaces embed into the urban fabric and become part of familiar material forms, they become part of an apparatus for urban development centred around micro real estate value extraction. Consequently, organising and managing the urban through an orchestra of interfacial interactions understands architecture as infrastructure within a wider real-estate-craft of techniques to extract value from space.

7.4 Conclusion - Material Subservience

As urban development increasingly seeks to manage and optimise asset value through technical surveillance, the emerging 'smart city' provides an alternative identity and influence that is important for architects to comprehend. Urban environments that organise through micro-spatial transactions of attention become increasingly driven through an interface interaction logic that maximises data extraction.

As technical surveillance data can produce micro-spatial behavioural insight, an urban development paradigm shift has occurred from patchwork ownership to coordinated tenancies that organise around real-time measurement. Consequently, as data can help manage valuable material assets while holding value itself, development increasingly promotes technical data extraction over material spatial concerns. Today's urban assets are expected to reconfigure at the perceived speed of data requiring rapid tenancy change and renovation. For rapid renovation to adapt and anticipate use, urban development and governance becomes conceptualised as an interface exchange system, portraying data as part of the urban environment, working alongside built form to organise resources and events. In the abandoned Sidewalk Labs Toronto Quayside development, urban form and technical sensing interface between urban life and lucrative real estate value. Sidewalk's architecture-as-interface operates as information technology, but instead of expressing visual information like a computer screen it reconfigures material and spatial outcomes to maximise exchange. For Toronto Quayside to achieve this they needed to decompose, rearrange, and re-organise materials leading to a tangible outcome of destabilised structures and temporary spatial settings. Similar to data providing architecture a metaphor for rapid quantised assembly, Sidewalk Labs imagined urban fabric to reflect the speed and instability of micro-spatial and environmental feedback.

Such surveillance driven urban development potentially alters built form role as long term material-spatial concerns give way to temporal to optimised uses. This temporal urban use radically changes asset management logics from traditional static measurement and long-term ownership to real-time monitored micro-leasing. The new economic imbalance caused by this shift means architecture becomes part of the urban surveillant interface, distributed through an exchange rationality that seeks, detects, and correlates continuous change with commercial investment return. Where ubiquitous data surveillance once mimicked or overlayed the existing stability of urban space, urban space now becomes subservient to technical sensing that drives spatial decisions around maximising interactions.

Through the lens of surveillance capitalism and micro-leased real estate, a new character for the built environment emerges, understood as an ambient field of potential insight, made tangible by an interfacial orchestration that folds sensing and mobile technology into architecture. Urban interfacial management recasts architecture's material systems as an infrastructure for organising exchange and providing a framework for adaptable commodified space. In this new, subservient material instability, the spatial and sensory environments explored within interactive architecture practices escape the discipline and migrate into urban planning for use as a commercial instrument. Commercial actors dominating infrastructural control and value extraction reduce the possibility of interfaces inserting spatial wonder and cultural communication into architecture. In the future, the architect's role will recede to providing the material and structural framework to accommodate micro real-estate management, their design brief taking on new responsibilities to maximise the relationship between data, asset management and architectural space.

Chapter 8: The Architect’s Measure

The present-day architect is increasingly reliant on data to design and deliver architecture. Despite this, there is little research that specifically considers an architectural understanding. The research counters the prevailing discourse that only consider data in technical terms and addresses a gap in understanding data’s influence on architectural practice. The thesis constructs a foundational data understanding by tracing and critically discussing data practice through architectural discourse and case study analysis. The research provides an original contribution to knowledge by centring data not as by-product of technical processes but as critical aspect of change in architectural theory and practice.

At the core of the thesis is the argument that despite data’s close relationship with the digital, data is not a purely digital phenomenon, and that abstract measurement has always been a part of the architect’s role. Producing and applying abstract representation is critical for architects to connect knowledge with proposing material form. The framework set in the first chapter provided a guide for recognising data in architecture through literature and case study analysis. The framework’s three distinct stages in practice identifies how architects link observation with forecasting and instructing towards imagining and realising material assemblies.

Through the framework the research addresses two key research questions developed from the knowledge gap: the first concerning data’s character in the architect’s hands; the other, understanding the influence it brings to material practice. This research contributes to the discipline by introducing the topic into discourse and providing a foundational understanding to inform future thinking and discussion about the architect’s relationship with data. The findings shine a light on the relationship between how architects’ author, acquire and utilise abstract measurements that frame decision-making within design and construction, illuminating a significant influence on architecture that has often resisted compilation or broader comparison. The thesis argues that data has always had a profound cultural and material influence on the discipline through how agreed systems of abstract representation allow architects to control knowledge and communication in architectural production. Consequently, data’s practical affordances and cultural image have regularly influenced shifts in how society and the profession understand the architects’ role, responsibilities, and impact.

8.1 Data in the Architect's Hands

The thesis shows that data has had multiple roles for architects, and its impact has evolved over time. Throughout the thesis, architectural data use is presented as a series of cultural adaptations that explore and exploit human sensory perception and cognition enhancements.

The chapter, 'Translated Observation', used Leon Battista Alberti's codified maps of Rome and Jean Nicolas Louis Durand's quantised ratio as a starting point and uncovered a critical distinction between data's role in knowledge production or communication transfer. Alberti and Durand used quantity to measure and abstract the physical world, but their intended outcomes contrasted through an attitude to applied meaning. Alberti assigned all meaning generation to a mechanical apparatus that could visually plot coordinates with minimal translation loss. At the same time, Durand expected the architect to become an expert in generating meaning by extracting a pattern from architectural observation. Durand's abstract quantified measurement produced and utilised architectural knowledge through proportional pattern, while Alberti controlled a process of communication by outsourcing pattern recognition to a machine. For Alberti, the architect used data to control efficient communication, while for Durand, the architect used numbers to generate patterns that encapsulated knowledge. These patterns served to guide decision making by maintaining and applying rules of composition.

The chapter, 'Optimal Metrics', recognised that a temporal significance arrived through scientific management in the early twentieth century and dramatically influenced architecture to take on a desire, and in some cases a mandate, for efficiency and optimisation. Scientific techniques that mapped physical phenomena to limited value ranges, such as time or energy, argued and culturally propagated the possibility of an optimal and ideal. The concept of an architectural data set took hold, meaning that numbers became a disciplinary assemblage. This assemblage enabled the architect to index design services and spatial outcomes to material and time efficiencies, then seen as a moral responsibility. Abstracting, evaluating, and justifying architecture through this assemblage gave the architect power over production and collaboration through a repeatable set of spatial and material configurations.

‘Signal Pattern’ explored the period beyond Claude Shannon’s information theory that set forward a new data existence, as a statistical probability for communication. This new understanding critically detached data from human meaning to understand all systems in terms of quantified communication signals. With Shannon’s innovation came a change in data’s possible origin, as much a result of technical as biological and empirical observation. Data and information became discussed as patterns of order, and practices of measurement and historical progression culturally transitioned to explore pattern recognition in monitoring. For the architect, combinations of human and non-human knowledge and communication introduced the possibility of new information forms, rather than relying on existing or previous sources. Where the architect previously relied on discrete and static measurement, signals now set up a condition of monitoring. Monitoring, or having a presence with data, released architectural form from any determinable or predictable function and introduced notions of programmatic adaptation. This change from specific recording to constant detection altered data’s character from static measure to dynamic monitoring. Non-human sensory detection introduced previously unseen considerations and set an expectation of continual change and adaptation, leading to a sharp disruption to the architect’s traditional values of stasis and permanence. The newfound ability to manipulate data to construct and synthesise information meant an end to repetition and inspired attempts to avoid predetermining proposed outcomes. Through Shannon, a significant trajectory of data thinking passed through architecture, one that discounted the importance of human signs to explore the potential of the digital signal.

‘Design Currency’ set the first of three present-day use cases and recognised a unique character associated with large scale and complex projects. In such projects, quantity becomes a design material that integrates all stages of professional responsibility. The architect must establish and maintain an elevated status for data as unquestionable evidence, operating as currency linking services to client and stakeholder requirements. This data-driven decision-making paradigm enables architects to coordinate and compete in professional services markets that coordinate complex combinations of material parts and consultant input, while presenting architecture in the language of property speculation. To participate and thrive in this system, the architect develops skills of data visualisation to make information that drives and justifies decisions, becoming as important as architectural form. The value associated with deferring decisions directly to data changes the architect’s focus from directly composing material assemblies to constructing information that indexes commercial requirements with material form and space. Commercial speculation places primacy on quantifiable and predictable physical phenomena, thus producing architectural objects locked into a narrow evaluative framework of utility and performance.

'Communication Flow' traced data's character through the dramatic shift caused by the effects of web technologies. Data's character and influence appear through two trajectories as the radical capacity to communicate and share information manifests in different architectural approaches. Architects that continue the late twentieth century focus of data communication move towards form-making as a scientific calculation. Calculation practices that algorithmically generate and aggregate form transfer a cultural material significance onto data. Alternatively, architects exploring participatory design and construction systems re-engage data's knowledge forming capacity and link unskilled users observation input with architectural form. In both cases, architecture becomes information and material elements are architecture's data, the architect becomes responsible for constructing and maintaining a hermetic data flow that resists any signification, connecting observation, forecasting and realisation through non-human communication. In short, manipulating bits becomes a model for assembling atoms. For the architect, data provides a radical opportunity in communication, where distinct stages of representation once occurred a continuous data flow now operates. This data flow enables architects to set up sophisticated collaborations between humans and machines, continuing the twentieth century interfacial ideas of Nicholas Negroponte and Cedric Price.

'Ambient Field' traces data's influence as a new logic for connecting design evaluation, architectural proposition, and data-encoded fabrication into the emerging context of smart city governance. Urban developments managed by mapping human behaviour to commercial return provide an alternative set of abstract measurements that define architecture outside the architect's influence. A consequence of recasting the city as an environment of micro-tracked real estate value is that the architect no longer influences material conditions where monitoring occurs. Instead, adaptive material systems organise space to maximise ubiquitous data production and consumption. This maximisation means material decisions defer to surveillance and create conditions to optimise human interaction with technical interfaces. Decisions regarding the urban environment consequently align with data's extractive value. The architect's design brief becomes filled with requirements to maximise data surveillance and value, meaning that where data previously traced the material, the material is now subservient to data.

8.2 Tracing Data's Future

This thesis bridges the gap in understanding how architects characterise data and the influence it has on their practice. Tracing data through architectural discourse and analysing case studies detects macro trends which suggest alternative pathways and approaches for architects to leverage data.

Data's Character

When comparing all the characterisations found in the research, architecture's data history exists as a series of material-cultural innovations that have altered not only how architects create and utilize knowledge, but also how they abstract, generate and manage communication. At its core, any abstraction into data representation relates to an architectural attitude to information. The research recognises that data's role is to either help the architect to mobilise knowledge or to establish communication, each relying on information. Architectural information has many uses, it can lead to new forms of knowledge as much as it can guide action towards construction. The duality detected early in the research between how architects utilise data for knowledge or communication is significant as it maps between how architects produce information to understand the world or manipulate information to communicate.

However, the difference between making and manipulating information means a difference between the architect directly observing and recording or accepting data and information into practice. Across the research, the architect historically jumps between modes of use, at times taking responsibility for collecting data through observation to discover what works, at others inviting data into practice to support a-priori assertions. Throughout the thesis, the topic of observation is inseparable from data's existence. Initially, the architect placed themselves as the measurer of reality, but soon machine observation became part of an objective ideology for the architect to understand and manipulate the physical. The coupling of data with systems thinking in the twentieth century introduced new practical avenues through multiple human and non-human observation points, producing a continually changing, unstable and relational world view. While this trajectory of thinking remains in some architectural discourse, data use today favours machine observation and introduces second-hand abstractions and predictive actions governed by a beyond human resolution. Submitting design and built objects to non-human abstraction logic and observation resolution provides accuracy in material organisation and prediction, in turn it recasts architecture as a problem of optimisation and efficiency.

The identified link between observation and communication is how architects define and apply patterns. Pattern recognition and application throughout history has informed the culturally established rules and axioms that shape the discipline. Just as a data pattern produces information, a pattern becomes a way in architecture to connect observation with a framework of thinking. Until the late twentieth century, measurement provided a way to reconcile observation, forecasting and instruction. Over time, measurement and coordination accuracy increased through technical assistance to become precisely monitored. Today this precision escapes the computer and absorbs into architecture's material systems that attempt to self-organise through restricting interfacial choices in assembly.

Architects today do not treat data as a given input into practice, locked into existing informational forms such as proportion or axioms; instead, they consider it a temporal and contextual reference in design requiring methods to produce, monitor, access, analyse and utilise in constructing information relevant for architectural problems. Data's format, such as quantity, key: value pairs or coordinates, rely on a cultural system of production, such as agreed measurement, object analysis or location definition. Although data has always existed in practice, its present-day digital intensity invites greater influence through how architects synthesise knowledge and control communication. The trend for the architect is that where discrete moments of knowledge application and communication once occurred in observation, forecasting and realisation, the architect now engages data benefit from non-human abstraction able to manage complex and information rich relationships. This means that today, architecture's rules and axioms are positively more diverse and fluid, and can help deal with organisation complexities, but there is a risk that they become detached from the disciples shared knowledge.

For architects today, practice is often a process of shaping, curating, and organising data into information representations via the computer. In the process, data's character shifts between human and technical utility. Present-day digital practices use this conversion to abstract and reconfigure information and physical behaviours by linking a beyond-human understanding to structural performance, organisation, and fabrication in design. Consequently, non-human inputs take on the role that material once fulfilled, assigning material actions such as forming, shaping, and melding, and utilising the kinds of actions and conceptual frameworks traditionally reserved for material assembly. This means that over time data's character has transitioned from being a constructed artefact used to compose and justify design outcomes, to today becoming a technique for architectural organisation.

Data's influence

Another overarching distinction emerging from the research is data's relationship with scientific thinking and method. When architects use data, they engage in a scientific paradigm that reduces the world into parts, in order to act back on the world. As a result, data's influence historically relates to thinking imparted from its origin. For instance, empirical observation placed the architect as a direct measure giving them control over information and knowledge. This was before architecture gained a disciplinary assemblage they could protect and utilise providing certainty for the professionalising practitioner. The technical and relational systems of the late twentieth century demoted the architect's direct experience and introduced a dynamic outlook opening the architect to complexity and contextual feedback. Today, data originating from project parameters and from design outputs means the architect gains sophisticated control over their knowledge and commercial services. However, a shift exists where contemporary data driven architecture restrict design into continuous communication flows within technical apparatus. The carefully constructed representations that architects are traditionally known for, give way to a variety of automated data visualisations.

Automation lies at the distinction between human and non-human technical abstraction, which threads across the research. While human sensory patterns construct cultural systems of understanding, non-human technical systems rationally apply patterns to encrypt or decrypt information. In human and technical use, pattern is critical to the architects' understanding and patterns found in abstraction become rules of synthesis. Across data's historical uses, architects extract rules through analysis patterns that have a trusted connection back to an observable and existing origin. Therefore, data connects architecture to a material reality of objects and disciplinary knowledge. However, today's utilisation and reliance on non-human synthetic data mean that architecture's rules and axioms do not necessarily connect to a recognisable observed input; they are part of the design process and impart liberty to the architect to impose their own rules and axioms. While material and spatial compositional rules once existed from the architect producing data, today the radical manipulation produced by electronic signals means data's patterns become dynamically controlled through software. As data abstracts away from human observation and representations, decisions and actions defer to non-human patterns and associated rules. Being architecturally engaged with data today means curating and maintaining correlations between data and assembling material order. An architect practising with data today has a unique responsibility to generate the rules specific to a design outcome.

Establishing rules offers a creative space and becomes part of the design process. When architects today work with data, they are part of a dialogue with various historical interfaces that constrain what and how abstract measurements enter practice. Present-day architects increasingly incorporate non-human resolutions into practice in response to intense professional and economic pressures. The increased use of digital abstraction restricts what architects turn into data through how a designed interface detects and represents observations. Today's architectural reliance on technical interfaces speaks to how tools now shape and constrain actions, just as shaping wood or bending metal previously shaped construction. The importance of the interface in practice redirects architectural focus to its tools to connect design with construction, in the same way traditional architects connected their drawn information with tools for working stone or timber. The interface's significance is not confined to practice, now able to migrate from the office into architecture and the city. The conceptualisation of a built environment as an interface between urban performance and predictable human behaviour is an emerging condition where architects lose influence in urban development. This loss of influence speaks to future scenarios where practice and the built environment become saturated with dynamic measurements and abstract representations that have no origin in the architect's observations or disciplinary knowledge, becoming disconnected from their traditional concerns.

Research Contribution

At this stage of the research, it is important to clarify the contribution by situating the findings within the existing literature. The introduction chapter identified four existing areas where gaps in data understanding existed: the architect's authorial role, the dominance of scientific inquiry in the discipline, the broader societal changes caused by data, and the focus on data as a cultural force in the architect's practice.

The research conclusions resonate closest with Orit Halpern (Halpern, 2015) and Molly Wright-Steenson's (Wright-Steenson, 2014) respective data tracings across design and technology practices. This research commonly identifies data as a consistent presence in practice, with multiple shifting characters and influence. However, while Halpern and Wright-Steenson restrict focus to the electronic twentieth century, this research uniquely crosses the electronic divide and bridges the gap between analogue and digital abstraction. Significantly, the contribution to this understanding is that while the mode of abstract representation changed in architecture, the relationship between observation and communication, and practical decision making has always existed.

Mark Jarzombek's recognition of data's role in digital media is the closest viewpoint to the research outcomes (Jarzombek, 2017). Similarly, to this research, Jarzombek identifies the shift from empirical pre-digital stability and scarcity to current day technological dynamism and surplus. He predicts an "ontological shift" resulting from contesting data flow, between humans understanding themselves and media manipulation into interactive consumption. This research contributes to this discussion by highlighting how in architectural data manipulation, flow is comparable but different. Architects encourage data flow to control assembly and form. While media platforms manipulate human behaviour through establishing and maintaining flow, architects manage a flow between material behaviour and form, but stem the flow once a building is created. The life of data continues after to buildings, however, but away from the architect's control. Once released as material assets, systems of real estate value extraction re-establish flow and continue its lucrative circulation around the built environment.

Data can give architects greater capabilities in knowing and communicating, but it only represents what can be easily submitted to measured abstraction. This identified limitation contributes to rebalance an overt techno-innovation discourse. The migration in practice focus towards performance, efficiency and complexity will continue under data's influence and will help architects address important issues. But aspects like narrative, poetics and memory recede and potentially become something lost in data-centric approaches. As contemporary architects' design practices become increasingly data-rich, it is important to consider and extrapolate the possible consequences. At the core of the data discussion is the calibration between human and non-human knowledge and communication for decision making and material action. Data's ubiquity and intensity through technical interfaces will extend its role as a shared commercial language and design currency, influencing how we experience and interpret architecture. Meanwhile, the dominant western political economy is centred around free-market liberalism.

Today, data connects and spans observation, organisation, design, performance, fabrication, and assembly, whereas previously the architect separated processes and systems through stages of representation. Data visualisations now integrate a continuous communication channel between observation and built outcomes, replacing the need for different media uses such as mapping, drawing, modelling, and construction information. Do architects relinquish these modes of representation to appease value extraction, or do they consciously work to re-establish their authorship?

Speculating on data

While data is not exclusively a digital concern, the capabilities associated with digitisation make it increasingly valuable for architecture to compare, coordinate and construct information. Data has always existed, but our present-day understanding is associated with how architects interact with digital information systems and visual interfaces. These systems introduce a non-human influence that can bring radical improvements in precision, accuracy, and complexity, but migrate data away from the human's analogue practice and practical qualities. Following this path of intense use and reliance on digital abstraction will not occur without consequences. Today, architecture finds itself indexed to the comparative logic of quantified and metricised markets. The market organises material resources, and data serves the market; therefore, architecture becomes data and part of this economic fold. Architects require commercial relationships but often remain uncritical to an underlying economic logic that imposes an abstract evaluative framework on architecture. This framework provides a commercially valuable language of performance and gains the architect unquestionable authorial reasoning through optimisation, efficiency, and prediction, but risks losing connection to the inherent qualities of human experience.

An alternative future looks towards knowing where to direct monitoring, intervene in sensory extraction and explore alternative modes of sampling and application. Taking control over moments of interfacial exchange that prioritise human experience could provide architectural possibilities to accentuate freedom in choice and engage designer intuition and serendipity. There are opportunities where human and non-human collaboration can celebrate their unique traits to coordinate and organise knowledge and communication, rather than architects removing human influence and imposing a hermetic quantising force on the built environment. Architects can engage in alternative measurement and evaluative systems that do not index materials and space to monitor value and commercial gain. Additionally, an opportunity exists to utilise beyond-human accuracy and precise monitoring to highlight parts of architecture that are ignored by capital extraction, such as embodied carbon or energy use, that would benefit broader human and ecological survival.

Given that architects have always engaged with data and that a foundational understanding of its character and influence now exists, architects must proceed with greater awareness and concern in future practice.

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