Architecture in the Data-driven City

Thèse N° 9554

Présentée le 17 juillet 2019

à la Faculté informatique et communications
Laboratoire de design et media (IC/ENAC)
Programme doctoral en architecture et sciences de la ville

pour l'obtention du grade de Docteur ès Sciences

par

Frederick Peter ORTNER

Acceptée sur proposition du jury

Prof. N. Braghieri, président du jury
Prof. J. Huang, directeur de thèse
Prof. M. Carpo, rapporteur
Prof. M. Hensel, rapporteur
Prof. D. Dietz, rapporteur

2019

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Abstract

In the last ten years, new sources of urban big data have made it possible for algorithms to increasingly control how the city is perceived, understood and managed by its inhabitants; this is the data-driven city.

New efforts in the social sciences, like critical data studies, are beginning to describe the ways in which urban data is never completely objective and how its logics influence and shape our everyday physical world. In this thesis I transfer insights from critical data studies to architecture, asking how the emergence of data-driven urbanism is influencing architecture as practice and artifact and, conversely, what impact architecture can make in an urban context dominated by big data.

To answer these questions I take on three case studies in global cities which highlight controversial urban problems managed by automated practices of measuring, mapping and procedural response: aviation noise near Heathrow Airport, storm floods in Amsterdam and population density in Singapore. Though data-driven, the cases nonetheless demonstrate the persistent importance of the design of the built environment to the function of these urban systems.

To make a comparative analysis of the three case studies and to provide a framework to interrogate the impact of architectural interventions, I introduce a new conceptual tool: the data-genealogy tree. I use the data-genealogy tree to (1) chart how metrics, institutions, architectural elements and software are brought into a data-mediated socio-technical system, (2) to assess over time the growing embeddedness of this socio-technical system in each case study, and (3) to identify reorientation points when motivations of the socio-technical system have changed and innovations emerged. Examining the association of architectural artifacts with the reorientation points charted in the data-genealogy tree makes possible an assessment of the impact of architectural interventions and provides a basis for describing more generally how the architect may seek to influence the development of the data-driven city.

As an ensemble, the architectural interventions described in the case studies also provide evidence for a description of the formal evolution of architecture in the data-driven city. The case studies suggest that singular architectural artifacts are less relevant to this context than catalogues of architectural elements which are made open to quantification and tracking and can assemble into many possible configurations in response to the demands of urban/ environmental systems. Finally, I consider how design process is changing in the data-driven city, describing how architects in the case studies have worked with urban data to cross disciplinary silos or recruit wider stakeholder participation in consensus design solutions.

Keywords:

Architecture
Urbanism
Smart City
Big Data
Epistemology

Résumé

Au cours des dix dernières années, de nouvelles sources de ‘big data’ urbaines ont permis aux algorithmes de contrôler de plus en plus la façon dont la ville est perçue, comprise et gérée par ses habitants; c’est la ville pilotée par les données.

De nouveaux efforts en sciences sociales, tels que ‘critical data studies’, commencent à décrire la manière dont les données urbaines ne sont jamais complètement objectives et comment leurs logiques influencent notre monde quotidien. Dans cette thèse, j’applique des concepts de ‘critical data studies’ à l’étude de l’architecture, en interrogeant comment l’architecture s’est évolué en parallèle à l’émergence de l’urbanisme piloté par les données et, inversement, quel impact l’architecte peut-il avoir dans un contexte urbain dominé par ‘big data.’

Pour répondre à ces questions, je développe trois études de cas de villes mondiales, mettant en lumière des problèmes urbains controversés qui sont gérés par des pratiques automatisées de mesure, de cartographie et de réponse procédurale: les nuisances sonores près de l’aéroport d’Heathrow, la crue soudaine à Amsterdam, et la densité de population à Singapour. Bien que fondés sur les données, les cas démontrent néanmoins l’importance persistante de la conception de l’environnement bâti pour le fonctionnement de ces systèmes urbains.

Afin de faire une analyse comparative des trois études de cas, et de fournir un cadre pour interroger l’impact des interventions architecturales, je présente un nouvel outil conceptuel, l’arbre généalogique des données (data-genealogy tree), dans la thèse. J’utilise l’arbre généalogique des données pour (1) décrire la manière dont les métriques, les institutions, les éléments architecturaux et les logiciels sont intégrés dans un système sociotechnique, (2) pour évaluer au fil du temps le rallongement croissant du système sociotechnique, et (3) identifier les points de réorientation lorsque les motivations du système sociotechnique ont changé et des innovations sont apparues. L’étude de l’association d’artefacts architecturaux avec les points de réorientation de l’arbre généalogique des données permet d’évaluer l’impact des interventions architecturales et fournit une base pour décrire plus généralement comment l’architecte peut chercher à influencer le développement de la ville pilotée par les données.

Ensemble, les interventions architecturales des études de cas permettent une description de l’adaptation de la forme architecturale à la ville pilotée par les données. Les études de cas suggèrent que les artefacts singuliers d’architecture sont moins pertinents dans ce contexte que des catalogues d’éléments architecturaux, ouverts à la quantification et au suivi numérique, et capables de s’assembler dans de nombreuses configurations possibles en réponse aux demandes des systèmes urbains. Finalement, j’examine comment le processus de conception peut changer dans la ville basée sur les données, en particulier comment les architectes dans les études de cas ont utilisé les données urbaines pour surmonter les silos disciplinaires ou encourager une participation plus large des parties prenantes dans la conception consensuelle.

Mots-clés :

Architecture
Urbanisme
La ville intelligente
Big Data
Épistémologie

Table of Contents:

List of Figures:

(Unless otherwise stated, figures are the work of the author.)

Chapter 1

Chapter 2

Chapter 2 continued

Chapter 3

Chapter 3 continued

Chapter 4

Chapter 4 continued

Chapter 5

Chapter 5 continued

Acknowledgements

This thesis would never have been written without the sustained support of my advisor Prof. Jeffrey Huang with whom I have had the great pleasure of sharing many academic discussions, design debates, and even jokes over the last six years.

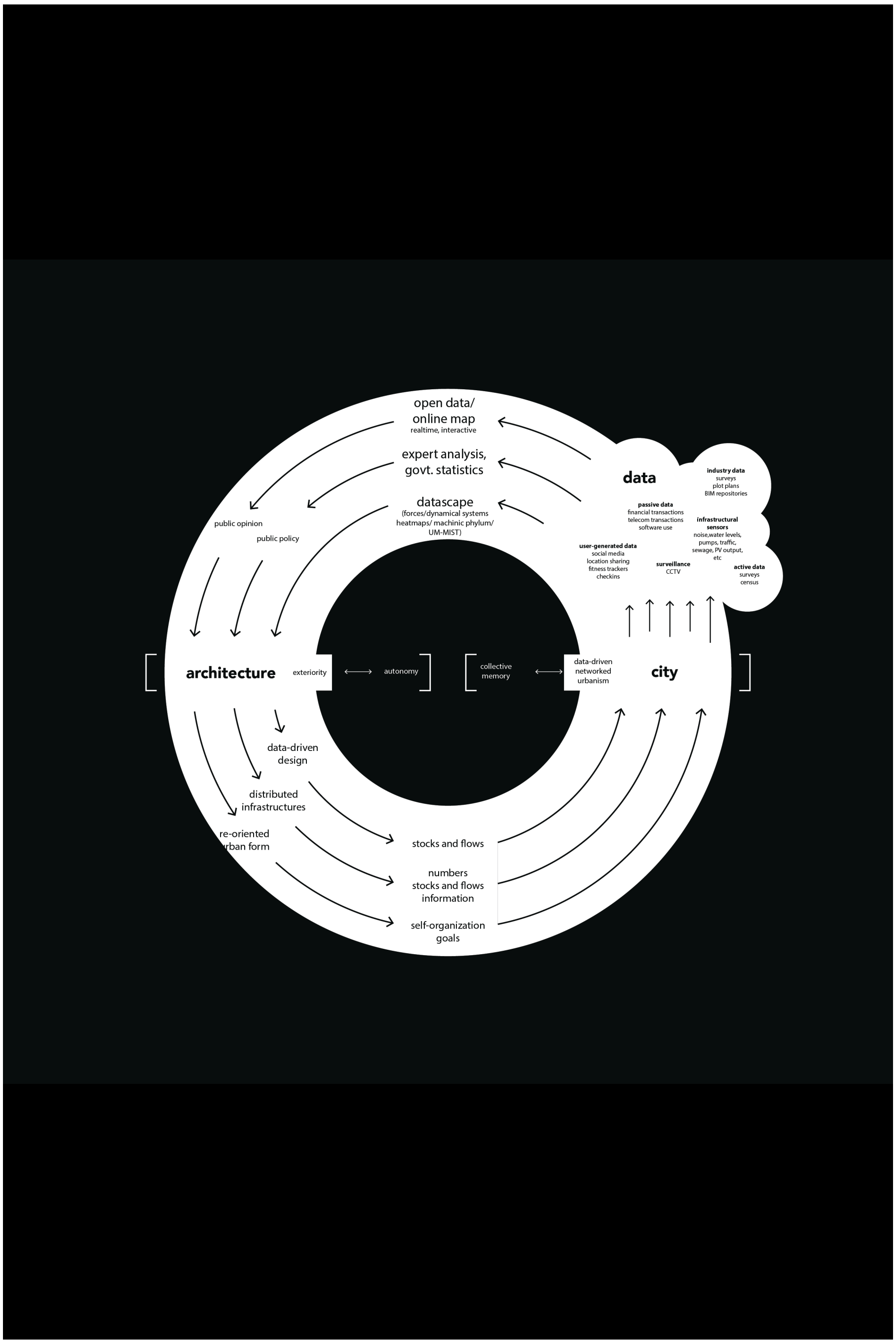
The community of the Media x Design Lab has been the single greatest academic resource for me during this time. I am indebted to Trevor Patt who showed me the ropes in general and introduced me to many of the writings that would be key in formulating my research. Selena Savic provided reflections on what it means to do research as a designer. Shih-Yuan Wang and Immanuel Koh were continual sources of design inspiration and technical knowledge. Fred Kim, Christina Doumpioti and Christoph Holz have been great allies in the studio and I wish them luck in their ongoing efforts at EPFL. I can not overstate the value of Monique Amhof's presence in the lab, who has provided friendship and a sense of dependability and order even at moments of crisis.

During my thesis I was very fortunate to be able to collaborate with Prof. Kees Christiaanse of the Chair of Architecture and Urban Design, ETH Zurich. In this collaboration, which ultimately allowed me to contribute a chapter to the book *The Noise Landscape* I had the pleasure of working with Ben Boucsein, Eirini Kasioumi, Christian Salewski, and Joris Jehle each of whom provided critical feedback and inspiration for the second chapter of this thesis. Anna Gasco of Future Cities Lab Singapore also very generously gave me advice on urban research when I met with her early in my doctoral studies.

Prof. Erwin Viray was supportive of my research when I was using the resources of the SUTD library to complete my case study of Singapore's public housing. Prof. Michael Hensel provided a pivotal critique as I was preparing my results and conclusions. Prof. Muriel Waldvogel graciously invited me to present my research on Heathrow's noise landscape at the Fribourg Haute Ecole d'Ingénierie et d'Architecture, offering sage advice on this and numerous other occasions.

I should express my gratitude to several members of the EPFL community: Thibault Romany has been a great discussion partner for the last four years and helped guide my forays into the literature of the social sciences. Darío Negueruela and Matthew Skjonsberg have been friendly and erudite presences open to my questions and supportive of my research.

To Maya, Charlie and Freya, my father and my sister Katie, thank you for supporting me as I struggled through this thesis and for understanding when I needed to put in long hours. I should also thank Maya and my father for suffering through many early drafts- in retrospect a cruel and unusual punishment that was nonetheless of great benefit to me.


open data/
online map
realtime, interactive
expert analysis,
govt. statistics
datascape
(forces/dynamical systems
heatmaps/ machinic phylum/
UM-MIST)
public opinion
public policy
data
industry data
surveys
plot plans
BIM repositories
passive data
financial transactions
telecom transactions
software use
infrastructural
sensors
noise,water levels,
pumps, traffic,
sewage, PV output,
etc
user-generated data
social media
location sharing
fitness trackers
checkins
surveillance
CCTV
active data
surveys
census
architecture
exteriority
autonomy
collective
memory
data-driven
networked
urbanism
city
data-driven
design
distributed
infrastructures
re-oriented
urban form
stocks and flows
numbers
stocks and flows
information
self-organization
goals

1 Architecture in the data-driven city: introduction

1.0 The role of the architect in the data-driven city

While the rise of big urban data is proclaimed by the popular press and tech industry boosters as the beginning of a new era of efficient, clean and safe 'smart cities', the relevance of architecture and design to the future of the city has seemed usurped or left behind. Rem Koolhaas has attacked the 'smart city' as an implicit critique of the 'stupid' city built by the architectural profession. He sees little hope for the future of architecture in cities dominated by software.[1] Zeynep Celik Alexander and Shannon Mattern detect an epistemic slippage, with traditionally humanistic disciplines of architecture and urbanism becoming increasingly dominated by the quantitative with other forms of knowledge increasingly marginalized.[2] The fear of creeping scientification is countered, however, by Mario Carpo who notes that science itself is undergoing a radical change in the era of big data and that designers are leading the way in adapting to an era of post-human complexity.[3] The possibility of an emerging urban intelligence, fed by big data, has fascinated architectural historian Antoine Picon, who describes this non-human intelligence as a liquid that permeates the city, while seemingly leaving architectural form unchanged or left behind.[4] Regardless of the position taken, data have become an increasingly urgent subject of architectural and urban studies in the last decade, as driver of post-human complexity, food for new automated intelligences, or as a supposedly pernicious epistemic unit undermining the humanist tradition.

In the data-rich context, the *Data-driven City* constitutes a field of research, related to but distinct from the concerns of the *Smart City*, that architects and urbanists cannot afford to ignore. This field requires us to confront data, not as ready-made product that we can uncritically consume, but as a

1 Koolhaas. 2015. '*The Smart* Landscape' April 2015 ARTFORUM. 'There seems to be little possibility of merging the knowledge accumulated over centuries with the narrow range of practices considered 'smart' today.'
2 Alexander. 2014. "Neo-Naturalism." *Log*, no. 31: 23–30.| Mattern. 2017. 'The City is Not A Computer.' *Places Journal.*
3 Carpo. 2017. *The Second Digital Turn.* pp. 39,48.
4 Picon. 2015. *Smart Cities.* p.113 'Through connected individuals and sensors, city intelligence seems to be present everywhere, like a sort of fluid that could give urban structures access to a higher level of existence. We are witnessing *not so much the transformation of these structures, but rather their reinterpretation*.' p.114 'It is not so much the form of the city that has changed, but more its map, or maps.'

medium we must actively engage not only in how we understand and advocate for our work, but in the way we create the architectural artifact to accommodate or resist regimes of quantification. Finally we must confront urban data as a universal solvent that is bringing disparate domains of the city together into new forms of interplay. In this data-rich soup, it behooves us to rethink architecture not as an autonomous discipline, but as a tradition of thought and practice embedded in a rapidly developing technological ecology. The embedded understanding of architecture provokes us to consider the architectural artifact not in isolation, like a sculpture in a park, but as an element in interplay with a data-driven system, contributing to urban-scale functions, but also staking out its own set of affordances and potentialities, some just waiting to be activated.

1.1 The data-driven city

1.1.1 Key terms: data-driven economy

The universe of digital data is growing exponentially- measured at about four zetabytes (4×10^{21} bytes) in 2013 it is expected to grow by an order of magnitude to 40 zetabytes in 2020. The growth in data is no longer being driven by humans alone but also by a growing array of devices connected to the internet and exchanging messages with humans and with each other. This network of non-humans using the internet is popularly termed the Internet of Things (IoT). These rapidly growing streams of data are essential to the growing industry of big-data analytics- a field that uses statistical algorithms and machine learning to extract knowledge from databases too large to be processed by the human mind.

The valuable insights gleamed from the automated analysis of big-data along with other data-driven byproducts are driving demand for more data collection, more data sharing and more data processing: this the new Data Economy. A frequently-used analogy is that data will drive the 21st century economy in the way that oil drove that of the 20th century.[5] Alphabet Chairman, Eric Schmidt, has gone even further to claim big-data is so valuable that nation states will go to war over it.[6] The internet of things has made the city the site for the collection of particularly valuable information- the personal data of urban consumers. Architecture, as the site of the most intimate details of human life, has become the tech industry's oil field with a rash of new internet-connected objects invading architectural spaces over the last decade. Koolhaas has taken a particularly pessimistic view of this development: 'the intelligent building is a euphemism for an agent of intelligence. Soon your house could betray you.'[7]

1.1.2 Key terms: data-driven city

Data generated by the city is distinct from data generated by the internet, though there are overlaps between the two. Data from the internet is largely concerned with 'eyeballs'- the number of viewers on a given site and the amount of time they spend there- this data feeds predictive analytics and targeted marketing. Urban Data is generated by the metabolism of the city- flows of people and things

5 Alex Pentland quotes Meglena Kuneva, 'Personal data is the new oil of the Internet and the currency of the digital world." In *Social Physics,* p.177.

6 Price, Rob. 2017. "Google's Eric Schmidt: 'Big Data Is so Powerful That Nation-States Will Fight' over It." *Business Insider*. Accessed April 14. http://uk.businessinsider.com/google-eric-schmidt-countries-will-fight-over-big-data-alphabet-cloud-2017-3.

7 Koolhaas, *The Smart Landscape* 2015

are registered by card swipes, rotations of turnstiles, mobile phones moving from one radio cell to the next. Data is collected by a variety of different actors: retailers, infrastructure operators, cellular service providers, financial institutions, and many others. The diversity of data sources and their numerous collectors mean that urban data does not provide a panoptic view of the city- but, as Rob Kitchin has emphasized, an oligoptic view, characterized by a multiplicity of partial viewpoints.[8]

- **Data** is a measurement made on scale that can be understood by both recorder and some larger audience.

- **Datum,** the singular form of data, is also used to refer to a standard point of reference, widely shared, which makes possible the collection and dissemination of data.

- **Data-driven urbanism** is an urban mode of production characterized by automated or semi-automated feedback loops between large-scale data collection (IoT derived Big Data) and the control and configuration of urban flows, forms and systems. Alex Pentland calls these accelerating feedback loops the *feedback framework*, and describes them thus: We must [...] reinvent societies' systems within a *feedback framework*: one that first senses the situation; then combines these observations with models of demand and dynamic reaction; and finally, uses the resulting predictions to tune the system to match demands being made of them." The feedback loops of data-driven urbanism are not exclusively machinic, but often incorporate human actors in cyborg assemblages.

- **Data Assemblages** are the constituent elements of data-driven urbanism which geographer Rob Kitchin has defined as complex socio-technical assemblages composed of many apparatuses and elements which frame what is possible, desirable and expected of data. Kitchin calls the constituent elements of the data-assemblage 'apparatuses', listing the following: (1) systems of thought, (2) forms of knowledge, (3) finance, (4) political economy, (5) governmentalities and legalities, (6) materialities and infrastructures, (7) practices, (8) organizations and institutions, (9) subjectivities and communities, (10) places, and (11) (data) marketplace.[9] Within the *data-assemblage* architecture as an artifact occupies the position of materiality/infrastructure and arguably form of knowledge, while architecture as a profession occupies the position of system of thought and practice. In my use I have modified Kitchin's data-assemblage, see 1.4.4 and 5.1.1

- **Data-driven architecture**, in distinction to data-driven urbanism, is architectural form that is procedurally derived from a database or stream. Markus Novak created an early version with his *data-driven forms* of 1997-1998.[10] Data-driven architecture, once instantiated in the city (or even as a proposal), can contribute to and influence urban data flows. The case studies of data-driven urbanism in this thesis do not necessarily contain instances of data-driven architecture.

8 Kitchin, *The Data Revolution* p. 133
9 Kitchin. 2014. *The Data Revolution.* pp. 24-26
10 Novak. 2003. 'Data-driven forms.' in *The Metapolis Dictionary of Advanced Architecture.* p.150.

As data-driven urbanism and architecture both occupy dynamic positions relative to shared flows of data they have the ability to enter into a complex relationship of co-production, where data-driven urbanism may change architectural form, but architectural practice may also impact data-driven urbanism.

Though the proliferation of sensors in the city and the data they collect has been a major feature of the development of data-driven urbanism over the last two decades, my research is more closely concerned with the feedback loops between urban data and the functioning of the city- essentially with what urban data can do. (1) Urban data is used to communicate the functioning of the city back to its residents- a sort of cyborg human/computer feedback loop that functions primarily through maps. The new cartography of real-time urban maps have been the focus of scholars like William Rankin, Alex Pentland and Antoine Picon.[11] (2) Urban feedback loops are also used to regulate flows in the city- as in congestion pricing that automatically rises with traffic volume in the city of Singapore. Efficiency, or optimization of flows is the goal of these feedback loops and they are often justified with references to sustainable resource use. (3) Urban data feedback loops are also used for prediction and control, a notable example is New York Police Department's Domain Awareness System which combines surveillance with databases of known criminals to predict high crime areas.[12] More subtle forms of control through automated urban feedback are often referred to as 'management'- as is the case for the noise management systems deployed around Heathrow Airport that I describe in my first case study. (See 2.3.2)

The impact of data-driven urban feedback on architecture, however, is poorly understood- and is considered by some scholars to be still undetermined. Picon has said this: 'City intelligence must again be envisaged as profoundly spatial, even if the impact of information and communications technology on urban form is not obvious as yet.'[13] This uncertainty lends importance to my chosen research area, while at the same time complicating the process of defining the object of the research as there is little consensus on exactly architecture in the data-driven city is, or how it would be different from any other architecture. I will return to this uncertainty when I address the research question and the choice of case studies.

1.1.3 Key motivators: threat of ecological collapse versus threat of determinism

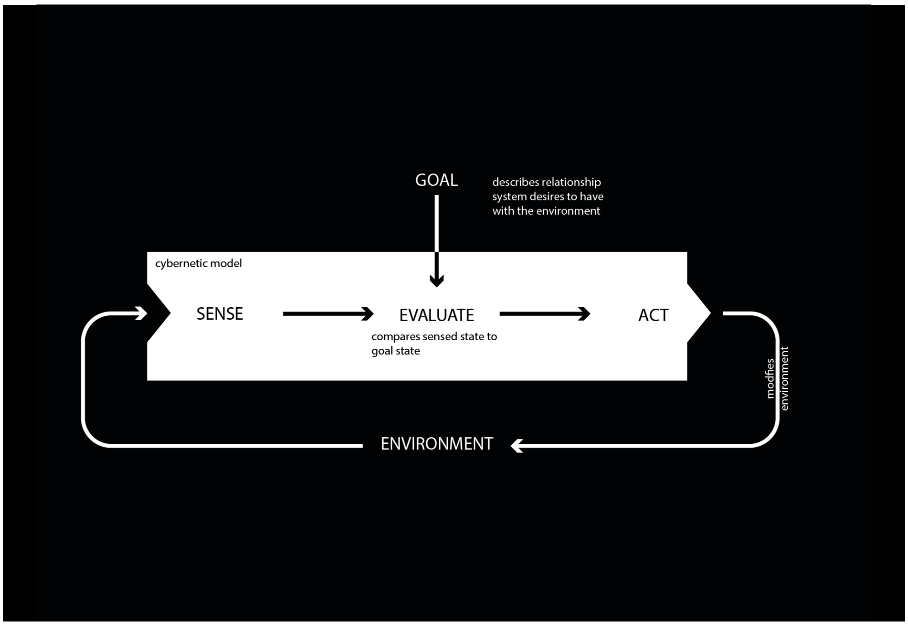
The use of data-driven feedback to optimize the use of material resources in the city is often lent urgency by threat of ecological disaster due to over-population, depletion of resources and environmental degradation.[14] Data-driven 'smart' systems are argued for as a method to introduce sustainable efficiencies into urban systems while maintaining quality of life. Several criticisms of this narrative have been put forward. Anthony Townsend has wondered if the incremental changes and limited efficiencies of smart urban systems are adequate to stave of ecological disaster. He suggests

11 Rankin. 2016. *After the Map.* | Picon, *Smart Cities* see Chapter 3: Urban Intelligence, Space and Maps 105. Pentland writes: "The key to citizen involvement in management of a data-rich city is visualizing the data.." Social Physics. 2014. p. 141.

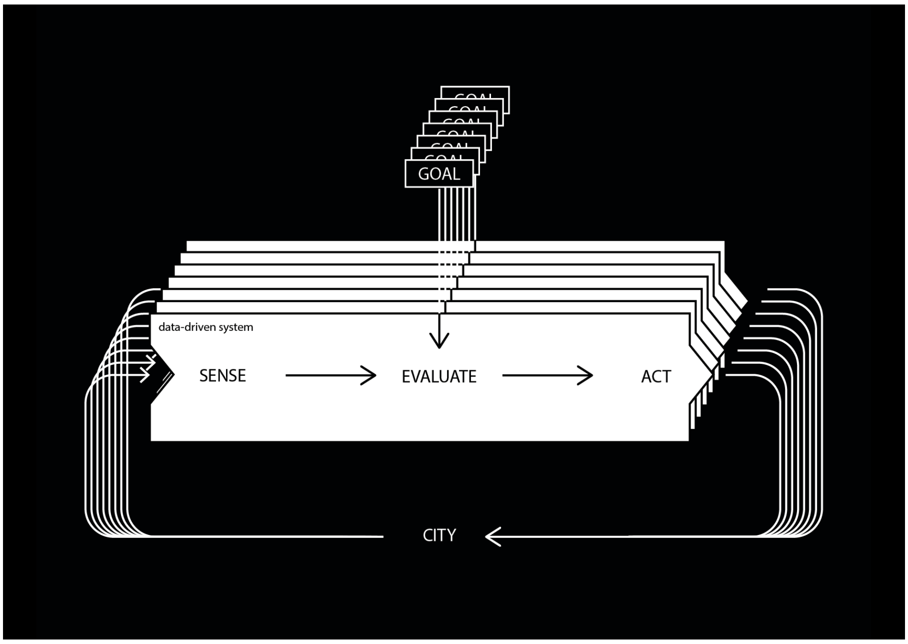
12 Mattern, *Instrumental City* p.10/27

13 Picon, *Smart Cities* p.105

14 The connection between neo-malthusian predictions of ecological doom and systems thinking have an intriguing history of co-dependence. *The Limits to Growth* used techniques incubated in the lab of Jay Forrester at MIT to predict ecological and human population collapse in the mid 21st century. Forrester had used the same techniques in his book *Urban Dynamics*, which as Townsend discusses find new relevance today as the inspiration for Smart City initiatives like those of IBM.



1. The basic cybernetic model senses its environment, makes an evaluation realtive to its goal condition and then acts. Subsequent iterations evaluate the impact of previous action.



2. The data-driven city combines many overlapping cybernetic loops: the ‘feedback framework’ suggested by Alex Pentland in ‘Social Physics.’

that such systems may only be bandages that temporarily disguise deeper problems.[15] The implication is that smart systems cannot produce the radical change necessary to make 21st century megacities livable.

Koolhaas has also attacked what he calls the new holy trinity of 'comfort, security and sustainability'.[16] He asks if smart urban systems will only produce, "the endless reinforcement of routine- a system proud to deliver more of the same? These relations can only turn in on themselves: the world as an endless tautological repetition of cause and effect."[17] This statement reflects a wider fear that data-driven urban systems will take on the logic of computational systems and impose them on the life-patterns of urban dwellers.

The inventor of systems analysis, Jay Forrester, created a set of techniques for urban modeling in the late 1960s that he called *Urban Dynamics*.[18] These models were later discredited for their reductivism and opacity, most famously by Douglas Lee.[19] The concern today, is that these reductivist models of the city will become the city's new operating system through data-driven systems of automated feedback. Mattern, referencing Hannah Arendt's *The Human Condition* articulates the fear in this way: "the very instruments used to measure behavior are indicative of, and constitutive of, societies of automatism and 'sterile passivity.'"[20] Architecture, as a primary element in the material organization of the city, must inevitably play a role in the debate over the ecological hopes for smart urban systems, and fears that they will lead to 'societies of automatism'.

1.1.4 Key motivators: data vs. collective memory, an epistemological divide

The larger context of my research is an epistemological debate that is already centuries-old. This debate places the knowledge derived from the humanities in opposition to the knowledge derived from the sciences. Rob Kitchin links much of big-data analytics used in the social sciences today to the ideas of *positivism*.[21] *Positivism* dates back at least to the 18th century when thinkers like Saint Simon maintained that all authentic knowledge allows verification, and that all authentic knowledge was scientific. August Comte, a major actor in the creation of sociology and follower of Saint Simon, is credited with formulating the tenants of positivism.[22] The positivist position was challenged by the German hermeneutic philosopher Dilthey (in the 19th century) who countered that authentic knowledge was humanistic and provided insight into thoughts, feelings, and desires.

15 Townsend, *Smart Cities* 2013 p. xiii 'The real killer app for smart cities' new technologies is the survival of our species. [...] These companies- IBM, Cisco, Siemens, among others- have crafted a seductive pitch. [...]Resource shortages and climate change don't have to mean cutting back. Smart cities can simply use technology to do more with less, and tame and green the chaos of booming cities. Time will be the judge of these audacious promises."

16 Koolhaas. 2015. "The Smart Landscape."

17 Ibid.

18 Forrester, Jay, *Urban Dynamics* 1969

19 Lee, Douglass, 1973. *A Requiem for Large Scale Models.* p. 174. "What is most disturbing about this model is the gulf between what it is and what Forrester claims it is. The model is unsuitable for policy analysis because it has only a single response, which is built in; other responses could be and have been built in, but they are different formulations of the same or different problems from different viewpoints. There is no 'correct' model."

20 Mattern. 2016. "Instrumental City." (paraphrasing Hannah Arendt).

21 Kitchin, *The Data Revolution 2014* p.144. 'Just as with earlier critiques of quantitative and positivist social sciences, computational social sciences are taken to task by post-positivists as being mechanistic, atomizing and parochial, reducing diverse individuals and complex multi-dimensional social structures to mere data points.

22 Comte. 1844. *Discours sur l'Esprit positif.* For example: "C'est là, sans doute, le dernier office fondamental qui doive lui être propre dans le développement général de la raison humaine, qui, une fois parvenue chez tous à une vraie positivité, devra marcher ensuite sous une nouvelle impulsion philosophique, directement émanée de la science finale, dès lors investie à jamais de sa présence normale."

Today the positivist position is being given new vigor in what Jim Gray has called a fourth paradigm of science- a new data-intensive empiricism.[23] In urban studies the data-driven approach is epitomized by a hard-core group of physicists and mathematicians from the Santa Fe Institute like Luis Bettencourt who published a widely-read paper on the scaling properties of cities in 2007. Perhaps even more significant as a booster of data-driven social science is Alex Pentland of MIT, who has developed what he calls 'social physics': a sort of big-data driven algorithmic sociology. Pentland explains that he borrowed the name, 'Social Physics,' from Comte and considers his work a next evolutionary step along the same lines.[24] He has applied his methods directly to studying and designing the city.

Measuring and encouraging 'idea flow,' is one of Pentland's major focuses. For example, Pentland says this about Beijing: 'Due to its traffic jams, however, Beijing is de facto divided into many smaller cities with limited transportation capacity between them. As a result Beijing does not have as high an idea flow as cities that have a lower population density but better public transport.'[25] Pentland goes on to describe an ideal city that would have, 'both the high levels of social engagement characteristic of traditional villages (and hence their lower crime rate), and the high levels of exploration characteristic of sophisticated business and cultural areas (and hence their greater creative output)'.[26] He goes on to propose is a version of the garden city- clusters of medium sized towns around a metropolitan center- Zürich is the example that he cites as being closest to this ideal. What is epistemologically relevant in this series of statements is that Pentland claims to be able to calculate the best size for this city, (100,000 people per residential cluster) based on the math of social physics (actually it is Dunbar's number squared). The belief that the optimal size of a city can be calculated could be a litmus test for which side of the neo-positivist, post-positivist divide a thinker falls. To some this claim is absurd, to others perfectly reasonable.

Pentland has been further criticized for the determinism inherent in his ideas. He notoriously has written: 'the sort of person you are is largely determined by your social context, so if I can see some of your behaviors, I can infer the rest, just by comparing you to the people in your crowd.'[27] While this statement may be appealing to someone trying to market a product over the internet, most social scientists would consider this assumption to be questionable and an overextension of the capabilities of predictive algorithms in social science.

A contrasting point of view has been taken by Mario Carpo, who emphasizes that the data-rich context, combined with computational power to 'search' and not 'sort', is fundamentally changing the nature of science:

> "The new science of search may soon replace the method of experimental science in its entirety, simply because simulation and search can solve problems that the formalistic approach of modern science could never tackle."[28]

23 Kitchin. 2014. *The Data Revolution.* p.130. See also: Hey et al. "Jim Gray on eScience: A Transformed Scientific Method."
24 Pentland. *Social Physics.*op. cit. p. ix. "This new understanding of human behavior and society is called social physics, *a name coined two centuries ago by Auguste Comte*, the creator of sociology. [...] His theories were in many ways too simplistic, but he was going in the right direction: in this book you will see that modern mathematics and big data produce a description of humanity that is driven not by fixed ideas, but by the flow of ideas between people."
25 Pentland, *Social Physics* p.166
26 Ibid. p.168
27 Taken from Kitchin's *The Data Revolution* p. 144 where it is attributed to Pentland's *Reinventing Society in the Wake of Big Data* 2012
28 Carpo. *The Second Digital Turn.* p. 48.

The consequence of this epistemic shift for architectural form, Carpo argues, is the advent of 'post-human complexity.' This new complexity, 'belies interpretation,' by the human mind, transcending, 'transparent, human-friendly causal models.'[29] Carpo describes how designers have climbed to the forefront of this epistemic shift via research into non-deterministic algorithms (cellular automata) and manufacturing (structural behavior of heterogeneous materials, semi-autonomous robotic manufacturing).

In contrast to the post-human complexity of the data-rich context, is the open data movement (of which Pentland has been a notable proponent[30]) which seeks to ensure wide public access to new data sources, to be used as common resources. The open data movement in some ways echoes the Web 2.0 movement of the early 2000s which democratized online content creation, making it more participatory.[31] While Carpo acknowledges that the model of open participation could impact architectural form-making, he suggests architects have thus far remained more conservative and will likely remain so:

> "It took centuries, starting with Renaissance humanism, to establish modern architecture as an authorial, allographic notational art of design [...] Many of today's designers may just not be inclined to give that up without a fight."[32]

Though skeptical of the participatory project in architecture, Carpo does re-affirm that digital design has proposed several models of layered, split, or hybrid agencies- citing most prominently Bernard Cache's *objectile.*[33] With accumulation of big data Carpo also emphasizes that intelligence is increasingly a collective property: "we can draw on the collective intelligence of a group, be apprised of the frequency of an event [...] and act accordingly."[34] Though the participatory turn in Carpo's words, "never was", its echoes continue to haunt computational processes of architectural form creation. With growing emphasis on integrating urban data-flows in the process of creating the city, we are left to wonder if the *authorial, notational art of design* may not also evolve in response to our data-driven present.

In contrast to Pentland's data-enthusiasm and Carpo's idea of the designer as leader in the data-rich world, is a position similar to the one carved out by Dilthey's in the 19th century which is being taken up today by a group of post-positivists. Media studies theorist Shannon Mattern, representative of this group, has for example written, "Instead of more gratuitous parametric modeling, we need to think about urban epistemologies that embrace memory and history."[35] Among architects, Zeynep Celik Alexander has advanced a particularly determined attack on neo-positivist architectural thought 'predicated on the epistemic unit of data.'[36] She points out that positivism, 'neo-naturalism' in her

29 Ibid.
30 See 'The New Deal on Data.' in Pentland. 2014. *Social Physics.* p. 180.
31 See Carpo. *The Second Digital Turn.* p. 131-132. for discussion of the 'participatory spirit of Web 2.0' and its lack of impact on the design professions.
32 Carpo. 2017. 'The Participatory Turn That Never Was.' in *The Second Digital Turn.* p.143.
33 Ibid. p. 140.
34 Ibid. p. 135.
35 Mattern, *A City is Not a Computer* 2017. p.9/12
36 Alexander, *Neo-naturalism.* Log 31, 2014. p.24

words, is a transdisciplinary force, 'closely related to institutional pressures about funding. [...] any space dedicated to the kinds of knowledge that seemingly have not immediate usefulness has to be justified.'[37] Alexander rightly points out that this epistemological shift has ethical and political implications. Much like Mattern, Alexander concludes that architectural discourse needs a new historical ontology, capable of breaking down the technological amalgamation of artifacts, techniques, discourses.[38]

Rob Kitchin, a geographer who has become a guide for social scientists interested in the *Data-Revolution* (the title of his 2014 book), seems to fall squarely into a post-positivist camp when he writes: 'Positivistic approaches willfully ignore the metaphysical aspects of human life (concerned with meaning, beliefs, experiences) and normative questions (ethical and moral dilemmas about how things should be as opposed to how they are)'.[39] He qualifies this position by explaining that quantitative approaches are useful- but only if their limitations are recognized and they are paired with 'other approaches.'[40] The field of Science and Technology Studies deserves mention among the post-positivists as well for their efforts to unveil the entanglement of apparently purely empirical research with political power. Sheila Jasanoff, among others, has put forward the concept of co-production which, instead of positing scientific knowledge as socially constructed, proposes a complex model of iterative interaction between domains of society and science.[41]

Architecture occupies an unstable middle ground in the epistemological divide between data-driven positivists and data-skeptical post-positivists. Buildings, as functional objects which obey the laws of static mechanics, have long been subject to reductive analysis and design. However, architecture as a discipline has defined itself as a separate domain of knowledge from engineering since the 19th century emergence of that discipline. The dividing line between the two disciplines has been marked by architecture's focus on its history, the communicative power of built form, and the social implications of its organization. In an effort to situate the discipline and its artifacts relative to a newly invigorated positivistic science of the city, it is necessary to re-examine the goals of architecture, how they are best achieved, measured, explained, and understood as a domain of knowledge.

A data-driven urban science turned toward architecture would ask, for example, 'What are the key performance indicators for architecture?, and 'Is it possible optimize architecture?' These questions alone are suggestive of a possible future for the discipline of architecture that would adhere more closely to the tenets of positivism. Alternatively, through my research I hope to raise the possibility that architecture may, introduce into data-driven urban systems an awareness of its own disciplinary knowledge- the history of built form as communication, as mirror to society, as a physical framework for collective memory.

When Mattern promotes the development of a post-positivist epistemology based on 'memory and history' I am reminded of the writings of Aldo Rossi and their emphasis on the work of human geographer Maurice Halbwachs who defined the ultimate reality of the city in the collective memory of

37 Ibid. p.26
38 A rough paraphrasing of Alexander's argument at p. 30 of *Neo-naturalism.*
39 Kitchin, *The Data Revolution* 2014 p.145
40 Ibid.
41 Jasanoff, Sheila, *States of Knowledge: The co-production of science and social order.* p.19 'Varieties of co-production'

its inhabitants.[42] By this definition the urban domain becomes at least in part unknowable and open to poetic interpretation. Rossi's architecture famously was based on a series of prototypical architectural forms, derived both from a deep knowledge of architectural history and personal experience and memory. Rossi maintained that these forms, like the theater of Marcellus in Rome, persisted long after their functional use was exhausted as a physical memory for the city.

An alternative to the purely historicist epistemology proposed by Rossi is offered by Colin Rowe who struggled with the traditionalist implications of Karl Popper's philosophy for modern urbanism. Rowe was powerfully convinced by Popper's arguments for the open society, and for the role that tradition could play in society as the equivalent of a hypothesis in science: something that can be studied, criticized and changed. Despite his acceptance of tradition, Rowe refused to categorically reject Utopia, which Popper characterized as 'dangerous and pernicious'.[43] Instead Rowe advocates for 'vest-pocket utopias' which permit 'the enjoyment of utopian poetics without [...] the embarrassment of utopian politics.'[44] Utopian vision can serve a role in the city for Rowe, but only if its teleological aspirations are neutered by irony. This lesson is learned in part through reflection on the failure of modernist urban design which valued 'unity, continuity, system' as opposed to modern art's 'irony, obliquity, and multiple reference.'[45] If architecture has anything to offer the new masters of the smart city, it should be the memory of the failed utopian plans of the mid-twentieth century, and the techniques that were invented to overcome the tendency of the greatest architects to be seduced by, 'the government of nobody, the totalitarianism of technique.'[46] Collage, assemblage, participatory urbanism all deserve mention here as alternatives to modernist urbanism which have the potential to contrast with or enrich data-driven positivism's effort to understand and reform the city.

Within my current research I am looking for a reciprocal co-evolution between the domains of architecture and urban design on one side, and data-driven urbanism on the other side. This search holds open the possibility that architecture may be infected by positivist or neo-naturalist practices as Alexander has claimed. Loosely following the Science and Technology Studies idiom of *co-production*, however, I will also examine the possibility that the disciplinary knowledge and values of the design professions may impact and or change the production of data-driven urbanism. Examining the epistemological divide also highlights the importance of considering the contested ethical and political ends of data-driven urbanism. Mattern, Alexander push for a city as a repository of human memory, Rowe for an open city of collaged micro-utopias, Alex Pentland for a city of frictionless information exchange. While my research question, as we will see, focuses decidedly on architectural form, there is an urgency to addressing the ethical ends of data-driven urbanism that will color any research conclusion.

42 Rossi. (1966 original) *The Architecture of the City* p.29. 'There are people who do not like a place because it is associated with some ominous moment in the lives; others attribute an auspicious character to a place. *All these experiences, their sum, constitute the city*.'
43 Rowe, Collage City p.122
44 Ibid. p.149
45 Ibid. p.138
46 Ibid. p.146 This is a quote Rowe attributes to Hannah Arendt via Kenneth Frampton without being able to specify the source.

1.2 Research questions: co-production of architecture and data-driven urbanism

Over the course of my research it became necessary to reformulate my initial research question as three separate questions. To provide insight into the evolving nature of my research I am including the initial research question, and its explanation below, and subsequently describing how the question has evolved.

My initial research question was formulated as follows: ***"What is the formal basis and formal potential of architecture in data-driven urbanism."***

The duality of this research question- split between formal basis and formal potential- seeks to engage the idiom of co-production by allowing that while architecture's formal basis may be determined to some extent by newly forming urban *data assemblage*s, it has also a potential to act upon the *data assemblage* that envelopes it. The non-linear nature of this relationship raises the possibility for complex patterns of adaptation between artifact and environment. Whether or not this self-organization actually occurs is one of the key questions that I ask of my cases studies.
The formal basis of architecture, the first object of my research question, unsurprisingly has been defined before. Kenneth Frampton, for example, has defined the formal basis of architecture with the trinity of topos, typos and tectonic- which loosely interpreted are equivalent to typology, context and constructional expression. Peter Eisenman has also proposed a trinity for the formal basis of architecture- exteriority, anteriority and interiority.

Typos (typology)/ anteriority are roughly equivalent; they are the embodied knowledge inscribed into the many thousands of architectural artifacts that we have inherited over more than two thousand years of architectural practice. This embodied knowledge has the epistemic unit of the type: a semi-stable cluster of artifacts sharing similar properties and indicative of a generic approach to a certain architectural problem like, for example, a church. Tradition, so important for Colin Rowe, is inscribed in the type. Collective memory, the touchstone for Aldo Rossi's understanding of the city, is also embedded in type. In the epistemology of the data-driven city Zeynep Celik Alexander suggests that type and data exist in opposition.[47]

Tectonic and interiority make an uneasy pair. Each represents the agenda of its author- tectonics for Frampton, and architectural autonomy for Eisenman. Each, however, constitutes an intellectual space where architecture constructs its own logics independent of outside forces. While I won't pretend to collapse these terms into a single concept, I will leave them paired together. Both tectonics and interiority are susceptible to the procedural logic of the data-driven city. The computational focus of Eisenman's protégés like Greg Lynn and Scott Cohen attest to this affinity. As the bastion of architectural autonomy, however, interiority/tectonics do not represent the primary pressure point of the data-driven city on architectural form.

Topos/exteriority, as the context to which architectural form responds (city, society, environment, climate, biotope, Twittersphere), is the main point of interaction between the discipline of architecture and the data-driven city. As the city is increasingly quantified and knowable through the broad and

47 Alexander, *Neo-naturalism.* Log 31, 2014.

high-resolution data sets of social physics it is becoming possible to explicitly establish architecture's relationship with its context. The relationship between hyper-quantified city and architectural form can be procedurally described (coded), simulated, measured and ultimately optimized. As I have noted already in this introduction, this relationship comes with epistemological and ethical implications for the discipline of architecture (and beyond) that have already been exposed to debate and critique. As this has all been written to unpack the meaning of the 'formal basis of architecture' I should add that it gives my research the latitude to examine not only purely data-driven form (which may not exist), but also hybrid conditions where anteriority/typology, interiority/tectonics are combined with data-driven topos/ exteriority. Finally, I would like to leave open the space to consider pathways by which data-driven methods may impact typology and tectonics/interiority. The research question should permit these speculations where they are suggested by the case study.

The second object of the research question raises 'the formal potential of architecture' (what architecture can do) within the larger assemblage of the data-driven city. The implication is that the data-driven city is changing and that this change can be influenced by internal pressures from its constituent elements. Donella Meadows has called these pressure points, 'places to intervene in a system' and suggested that key leverage points can allow small actions to affect much larger systems.[48] Meadows lists nine possible places in ascending order from least to most leverage: (9) numbers, (8) material stocks and flows, (7) regulating negative feedback loops, (6) driving positive feedback loops, (5) information flows, (4). The rules of the system, (3) Self-organization, (2) System goals, (1) Paradigms. The research question, asks not only if architecture has the potential to act upon the larger data-assemblage, but more specifically what leverage points it is acting on and what impact (measurable or not) is being made. If architectural form impacts only material stocks and flows its leverage will not be as great as if it were able to influence the system goals or paradigms. Evidence is more or less easy to muster depending on which leverage points are under consideration. Demonstrating impact on system-wide paradigms could be seen as little more than speculation, or worse, wishful thinking.

The final implication of the research question is that between the shifting formal basis and formal potential of architecture in the data-driven city there may be some emergent end of the co-evolution (a teleology) or some convergent goal of the co-production. I am interested in the possibility of a convergence between the disciplines of architecture and the data-driven practices of the smart city. This convergence could be led by the efforts of key stakeholders toward desired political or ethical end, a hopeful alternative to the 'totalitarianism of technique' that post-positivists like Mattern warn may be the future of the data-driven city.

Over the course of my research it became necessary to reformulate my research initial research question into three separate questions. There were four key motivations for this reformulation which I discuss after listing the reformulated research questions.

1. If architect and architectural artifact participate in an urban data-assemblage, ***what position do they take, what connections do they make, and what roles do they play?***

48 Meadows, Donella. 1997. 'Places to Intervene in a System.' *Whole Earth.*

2. Secondarily, If the urban data-assemblage is formed through co-production of technology and culture, ***by what means have architect or architectural artifact attempted to exert an influence on the development of data-driven networked urbanism? To what extent is it possible to assess the potential impact of architect or architectural artifact in the on-going evolution of the data-assemblage?***

3. Thirdly, if the architectural artifact is embedded in an urban data-assemblage, and if it participates in a form of co-production, i***s there evidence of a formal change in architecture or its elements associated with embeddedness in the data-driven context?***

First, I felt the need to reframe the research question specifically according to three key concepts from critical data theory: the data-assemblage, co-production, and the linked ideas of embeddedness and obduracy. Though each of these ideas are inter-linked, separating them permits greater theoretical clarity and allows each concept to be addressed individually. In the initial research question each of the three concepts was implicit; interrogating the reciprocal formal basis and formal potential of architecture was meant to evoke an embedded architectural artifact, engaged in a process of reciprocal influence with a technological assemblage, and possibly even working against its obduracy. In the restated research questions below I have worked to state each question with greater clarity, by first raising each relevant theoretical concept in a conditional clause, and following up with a question built upon that condition.

Second, as I conducted research it became necessary to distinguish between roles and actions carried out by a human architect or designer, and roles and actions carried out by architectural artifacts and/or architectural elements. This was particularly important in describing the growth of the data-assemblage, as architectural elements were at times recruited into the assemblage without the intervention of the architectural designer, often many years after the architectural artifact had been designed and built. While my initial research question took only the architectural artifact as its object, I have subsequently pragmatically split this object into human architect and non-human architectural artifact to acknowledge their decoupling in the data-assemblage.

Third, as I gathered resources I found I was able to marshal different kinds of evidence relative to different aspects of the research question. For instance, in each case-study the existence of a data-assemblage and the relationship of architectural elements to this data-assemblage was possible to ascertain from numerous primary sources. However, the impact of an architectural idea or artifact on the technological development of the data-assemblage, proved to be more difficult to demonstrate.

Evidence taken from the drawings and writings of the designers readily supported the claim that their work was intended make an impact on an instance of data-driven urbanism. This evidence also often elucidated how they hoped to make this impact. In many instances, however, it proved difficult to gather concrete evidence demonstrating what, if any, impact the architectural artifact had made on the data-assemblage. And, even if I found no evidence of a designer's impact, I felt that my inability to find evidence did not put me on solid footing to make the definitive claim that no impact had been made, especially when the impact is directed toward high-level changes in population perceptions or paradigm shifts. In spite of these difficulties I retain references to Donella Meadows' leverage points as a significant touchstone for categorizing types of impact. In response to problems of evidence related to impact I split the question of co-production in two, first asking what impact the designer attempted to make on the data-assemblage, and following up by asking if evidence exists to ascertain existence or extent of impact.

Finally, the evolution of architectural form in the data-assemblage, which constituted the primary focus of the initial research question, presented a dual problem. First, identifying formal change required a very specific form of evidence: drawings, ideally before and after drawings, showing a clearly identifiable change, and evidence to support that this change was the result of some aspect of data-driven urbanism. While working with the case studies, insisting on asserting a cause-effect link often felt strained to the point of deliberately forcing evidence to meet a desired conclusion. The evidence I was working with suggested association without proving causation. For the purposes of this research I have decided to accept this level of evidence as adequate to creating understanding of architecture in the context of the data-driven city.

The inspiration for my initial research question had been the doctoral thesis of Peter Eisenman, *The Formal Basis of Modern Architecture*. The thesis describes vectors of force that deform geometric solids into distinct masterworks of modern architecture by the likes of Giuseppe Terragni and Le Corbusier. I found in my case studes, at least, that evidence of formal change depended on comparing past and current instances of types like housing blocks or airport terminals. I have reworded this research question to acknowledge that the formal evolution I am studying is not within a single work of architecture, but between a series of architectural artifacts.

The final challenge to the question of architectural form in the data-driven city stemmed from my struggle with the ontological instability of the architectural object in the data-driven context. The participation of architecture in data-driven urbanism often seems to occur not through autonomous works of architecture, but rather at the smaller scale of architectural elements that participate in urban assemblages independently from the architectural artifact they are joined to. While the architectural artifact seems less relevant to data-driven urbanism, the work of the architect and the architectural element in its possible assemblages seemed to have retained their relevance. In recognition of the instability of the architectural artifact in the data-driven context I include the possibility of formal change manifesting itself via the independent evolution or organization of architectural elements.

1.3 Relevance of the object of research: a historiography of data-driven cities

The case study portion of my research is in part historical; thus, the relevance of my research is determined by what histories of data-driven cities have already been written, how they have been written and what they have achieved. To establish the relevance of my research area and my research questions I have formulated a brief historiography of data-driven cities. Though this historiography may not be comprehensive, by studying the works and bibliographies of several key historians I have developed an overview of the field adequate to the establishing the relevance of my research objectives.

Though I maintain that research into the data-driven city is distinct from smart city or cyber city research, if we group the histories of these closely linked topics together they appear to be rewritten cyclically every decade or so. These cycles seem to roughly follow economic cycles of expansion in ICT investment as scholars have worked to process these mini-revolutions. 1995, the year the internet was fully commercialized in the United States saw the publication of Bill Mitchell's *City of Bits*. Christine Boyer's *CyberCities* followed in 1996 and Antoine Picon's essay *La Ville Territoire des Cyborgs* dates to 1998. The dotcom bubble popped in 2001 and interest in the field dropped, though Mitchell remained committed with the 2003 publication of *Me++:The Cyborg Self and the Networked City*. This was the same year he founded the Smart Cities group at MIT Media Lab. Stephen Graham's *The Cybercities Reader* came out in 2004.

A resurgence in interest in Smart Cities after the financial crisis of 2007/2008 mirrored renewed investment by companies like IBM, Cisco, and Siemens who sought to dominate the growing field of urban-integrated Internet of Things.[49] At this point many voices began to weigh in: Townsend's *Smart Cities* dates to 2013, Picon re-entered the field in 2013 with *Smart cities, théorie et critique d'un idéal autoréalisateur* (2015 in English by Wiley), Adam Greenfield contributed *Against the Smart City* in 2013. Richard Sennett staked out a critical position with *The Stupefying Smart City* (2012). Rem Koolhaas built critique of the Smart City into his Venice Biennale research, *Elements* (2014), and followed up with *The Smart Landscape* in 2015.

Data-driven urbanism as a distinct topic emerges at the same time as the new wave of writing about the *Smart City* as interest in *Big Data* was transferred from the internet to the city. Kitchin's *The real-time city? Big data and smart urbanism* and *The Data Revolution* date to 2014. Alex Pentland published *Social Physics* in 2014. Shannon Mattern's *Methodolatry and the Art of Measure* dates to 2013. Ali Fard and Taraneh Meshkani edited *Geographies of Information* (an edition of the New Geographies journal) in 2015 which brought together many disparate voices on data-driven cities.

Condensing each of these histories, and they all do contain at least some historical element, into an overall timeline is difficult- but many contain similar key events that map out the contours of the field. Staking out these points in time and place provides the context for my own research and helps to justify its relevance.

1.3.1 Origins of the data-driven city

Data-driven cities have roots that stretch back further in time than cyber cities or smart cities all the way to the beginning of the scientific study of the city. After all, the city has been studied and acted upon through quantitative measure and accumulation of databases for centuries already. John Snow's 1854 map of the Broad Street cholera epidemic in London, known as the foundational moment for the science of epidemiology, may also constitute a reasonable starting point for data-driven urbanism.(fig. 3) The solution to the epidemic was as simple as removing the handle from the pump at the polluted well. Snow's map of the Broad Street epidemic, visualizing the number of cholera cases as stacks of black bars and showing a clear concentration at the Broad Street pump, was drawn after the epidemic was over as evidence in a campaign to change sanitation in the city of London. Snow's efforts were ultimately successful in convincing urban officials to change the sanitation infrastructure of the city of

49 IBM's Smarter Cities Group was created in 2008. Siemens began its smart cities initiative in 2011.

London to prevent fecal contamination of drinking water.[50](fig. 4 shows the proximity between sewer and well which, due to faulty masonry, allowed fecal matter to pollute the Broad Street pump's well water.) This historical example is significant to data-driven urbanism not only because urban data was produced and visualized, but because this data was instrumental in changing the physical configuration of the city and the opinions and behaviors of its residents. When proponents of smart cities argue that they can provide a data-driven solution to urban sustainability they likely have John Snow's cholera map in the backs of their minds.

Many cyber city and smart city histories start their timelines at the end of the second world war with *The Human Use of Human Beings* (1950), Norbert Weiner's book that popularized the term *cybernetics*, and laid out the fundamentals of systems of feedback and control between humans and machines (including the newly developed computers). Antoine Picon, Joe Flood, Anthony Townsend, Ali Fard and Taraneh Meshkani all more or less agree on this one crucial point as the precursor of data-driven urbanism/ smart cities where the ingredients of automation, feedback loops and theories of communication and control were brought together with reflections on future directions for politics and society.[51] Other frequently cited touchpoints in the post-war/cold war era include the development of the large scale computer networks of American Air Force's SAGE system by Jay Forrester. John Von Neumann's *Game Theory* and contributions to computer science like *cellular automata*, Buckminster Fuller's use computational systems in global modeling, and Marshall McLuhan's research on social effects of electronic communication.

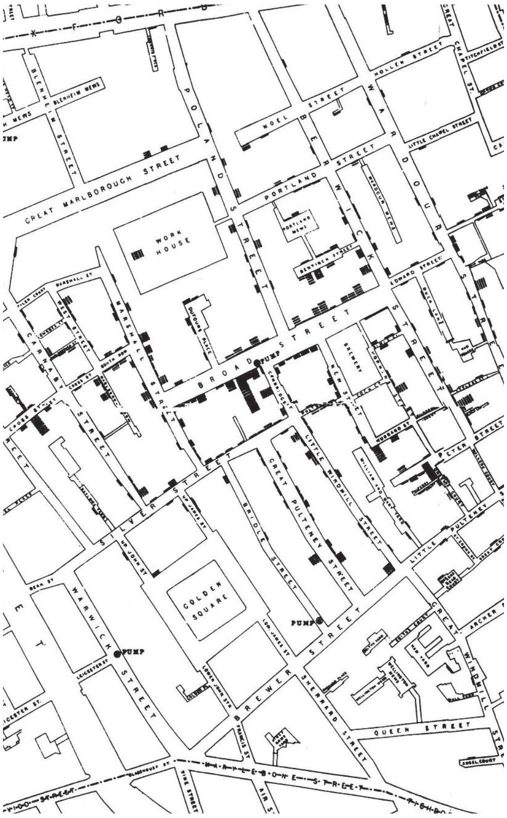
Among early architecture/cybernetic projects the work of Gordon Pask with Cedric Price on the *Fun Palace* is remarkably resonant with contemporary projects on (and concerns about) the *smart city*. Some provocative ideas emerged from this collaboration, among them that an architect may just be a form of cybernetician:

> "Architects are first and foremost system designers who have been forced, over the last 100 years or so, to take an increasing interest in the organizational (i.e. non-tangible) system properties of development, communication and control."[52]

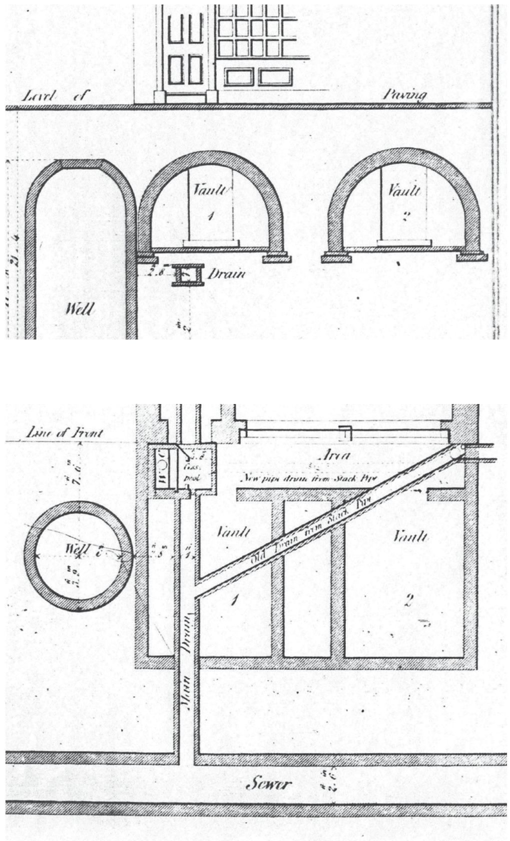
Architectural form was also seen by Pask as holistically embedded in the larger urban scale and its temporal evolution.[53] This "functionalist/mutualist" cybernetic viewpoint led to provocative ideas about the nature of the architectural artifact, which paralleled Price's work on the *Potteries Thinkbelt:*

> "A University need not be conceived as a set of buildings around a courtyard with living accommodation and lecture theatre. The educational system might, in certain circumstances, be spatially distributed rather than localized."[54]

50 See for example: Johnson, Steven. 2006. *The Ghost Map : The Story of London's Most Terrifying Epidemic - and How It Changed Science, Cities, and the Modern World.* New York: New York : Riverhead Books.
51 Fard and Meshkani in the introduction to *New Geographies 7: Geographies of Information* concisely cover much of this history.
52 Pask, Gordon. 1969. "The Architectural Relevance of Cybernetics." *Architectural Design.*p.494.
53 Ibid. "A functionally interpreted building can only be usefully considered in the context of a city." "Structures make sense as parts of larger systems that include human components and the architect is primarily concerned with these larger systems; *they* (not just the bricks and mortar part) are what architects design."
54 Ibid. p. 496.



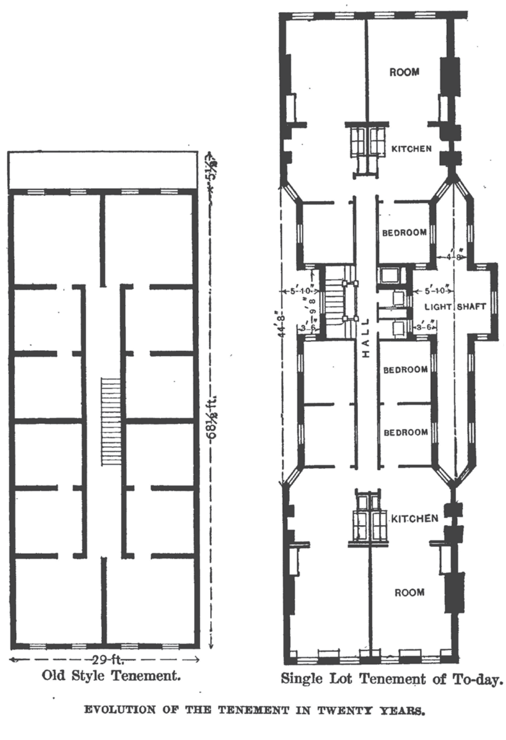
3. John Snow. Cholera Map (Broad Street pump detail). 1854.



4. Broad street pump well and proximate sewer. 1855.

Density of population to the square mile in 1880, Manhattan Island (census)	41,264
Density of population to the square mile in 1880, Tenth Ward (census)	276,672
Density of population to the square mile in 1880, Eleventh Ward (census)	224,576
Density of population to the square mile in 1880, Thirteenth Ward (census)	226,048
Density of population to the square mile in 1890, New York City (census)	38,451
Density of population to the square mile in 1890, Manhattan Island (census)	73,299
Density of population to the square mile in 1890, Tenth Ward (census)	334,080
Density of population to the square mile in 1890, Eleventh Ward (census)	246,040
Density of population to the square mile in 1890, Thirteenth Ward (census)	274,432
Number of persons to a dwelling in New York, 1880 (census)	16.37
Number of persons to a dwelling in London, 1881 (census)	7.9
Number of persons to a dwelling in Philadelphia, 1880 (census)	5.79
Number of persons to a dwelling in Brooklyn, 1880 (census)	9.11
Number of persons to a dwelling in Boston, 1880 (census)	8.26
Number of deaths in New York, 1880	31,937
" " London, 1881	81,431
" " Philadelphia, 1880	17,711
" " Brooklyn, 1880	13,222
" " Boston, 1880	8,612
Death-rate of New York, 1880	26.47
" London, 1881	21.3
" Philadelphia, 1880	20.91
" Brooklyn, 1880	23.33
" Boston, 1880	23.75
Number of deaths in New York, 1889	39,679

5. Jacob Riis. Urban density and death rate comparison. 1890.



6. Jacob Riis. Tenement plan evolution, with air shaft. 1890.

The collaboration also yielded one of the earliest and most trenchant descriptions of an interactive environment, or what would today be called a 'smart' system:

> "A computer controls the visual and tactile properties of environmental materials [...] These materials contain sensors, tactile or visual as the case may be, which return messages to the computer at several levels of generality. [...] If there is a human being in the environment, computer, material and all, engages him in dialogue and, within quite wide limits, is able to learn about and adapt to his behaviour pattern. There is thus one sense in which the reactive environment is a controller and another in which it is controlled by its inhabitants."[55]

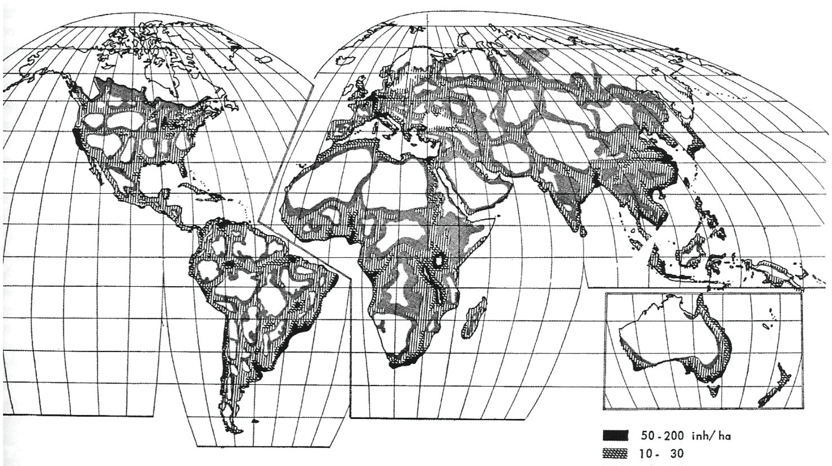
With the expansion of the smart environment from a small experiment to the scale of the city, the question of who is controller and who is controlled has moved from philosophical speculation to real political concern. John Frazer has notably been active in memorializing the work of Gordon Pask and his collaborators and articulating its relevance to digital design and contemporary society.[56]

Earlier origins of the intellectual basis of data-driven urbanism have been excavated by Joe Flood, a historian of New York City, who draws his history, *The Fires: How a Computer Formula Burned Down New York City- and Determined the Future of American Cities (2010),* all the way back to the *Reform Era*. Jacob Riis' *How the Other Half Lives* (1890) marks for him the beginning of the history of New York as a data-driven city. Riis' book inspired the reform era slum clearance in New York City by combining persuasive photographic evidence of the squalid conditions in tenements with statistical tables detailing the extent of the squalor. (fig. 5) Riis' work was instrumental in changing the form of New York City's tenements, introducing hygienic innovations like the airshaft.(fig. 6)

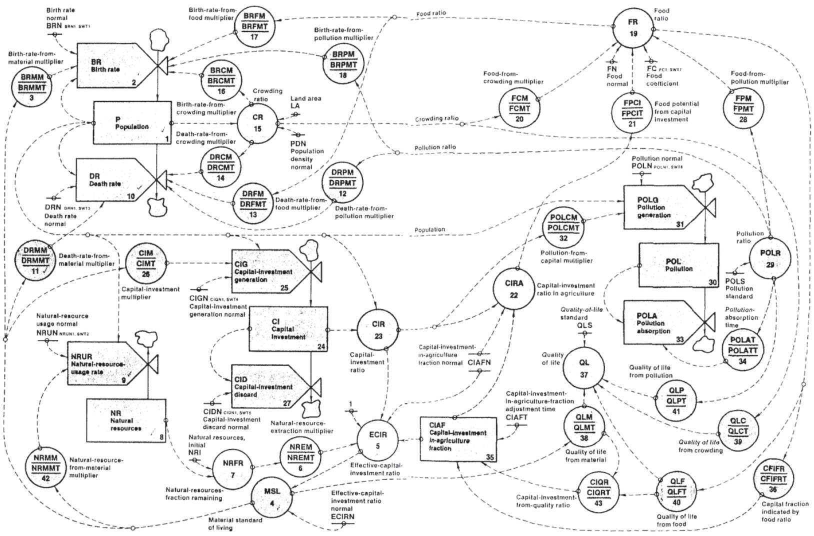
Flood's history centers on the consulting work of the RAND corporation for New York in the late 1960s. RAND, a think tank created during the cold war to analyze scenarios for nuclear war, branched out into the computational simulation and management of cities in the 1960s. Flood, a former RAND consultant, contends that the roots of the think tank and its methods can be traced back to the statistical analysis methods developed in American business schools before WWII. These techniques were then incorporated in the management of the American military during the war and subsequently entered American politics. He traces this trajectory in the career of Robert McNamara who began his career as a professor of accounting at Harvard, moved the USAF Office of Statistical Control during the war, and eventually served as Secretary of State to Kennedy and Johnson during the Vietnam War.

Though McNamara never worked at RAND, his career closely parallels the forces that brought together that institution. The idea that society can be scientifically managed using statistics, which is perhaps the fundamental basis of the smart city, can thus be traced back to an early twentieth century revolution in American business management and its eventual amplification through the American war machine of the 1940s and 50s.

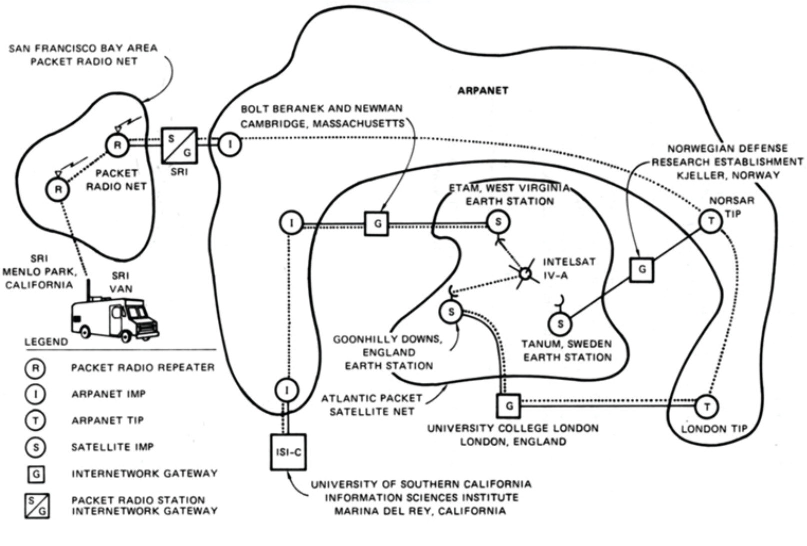
55 Ibid.
56 Frazer, John H. 2001. *The Cybernetics of Architecture: A Tribute to the Contribution of Gordon Pask.* Kybernetes. The International Journal of Systems & Cybernetics 30(5/6):pp. 641-651.



7. Constantinos Doxiadis. Ecumenopolis (World City) 2100. 1974.



8. Jay Forrester. World System. 1971.



9. Vint Cerf and Bob Kahn. Arpanet TCP/IP internetworking protocol test. 1977

The use of statistics and computation by Greek architect Constantinos Doxiadis, especially at the urban scale (Ecumenopolis) cannot be overlooked in this brief review. Through his global practice and the *International Journal of Ekistics* which he founded, he created a culture of data-informed design that was prevalent in the late 1950s and throughout the 1960s.[57] Mark Wigley has given us an engrossing vision of this era in his writings on Buckminster Fuller and his collaborations with Doxiadis. In his essay, *Network Fever* (2001), and later in his overview of the work of Fuller, *Buckminster Fuller Inc: Architecture in the Age of Radio* (2015), he makes direct links between this era and contemporary design. Wigley complains that contemporary designers are often oblivious to this historical connection, that many 'network' ideas presented in contemporary schools of architecture are not as original as their proponents may think, and that contemporary designers are naively perusing parallel paths to their predecessors without awareness of the pitfalls the original trailblazers encountered.

A significant turning point in the early history of data-driven urbanism was the academic and political rejection of computational urban modeling in the 1970s. Jay Forrester's *Urban Dynamics* (1969) marked a high point in the reputation of computational urban modeling when many politicians sought to use these models to inform (and justify) their decisions. The book, however, contributed to a loss of interest in the field- its methods were highly reductive and its results were at best counter-intuitive. (Although Forrester prized counter-intuitive results.) Computer scientist Douglass Lee famously criticized Forrester's models among other, in his 1973 essay *A Requiem for Large-Scale Models*. Urban modeling was relegated to the backwaters of academia for the next thirty years till it was revived by IBM's Smart Cities Group in 2011, an occurrence that Townsend has covered with careful skepticism.

Architects and designers remained fascinated with the potential of the computer to procedurally generate space in the 1970s. Cedric Price's collaboration with John and Julia Frazer on *Generator* in the late 1970s amounts to one of the earliest efforts to create a computational generated environment. They went so far as to propose that the computer would continuously monitor the use of the building and with an automatic crane would periodically modify the position of the modules. The program even had a 'boredom' function which would begin to make interventions if the site remained inactive longer than a given period of time. The designers attributed a degree of autonomous intelligence to the program- a clear precursor to 'smart' technologies being widely deployed today. Townsend devotes several pages of his history of smart cities to Cedric Price and *Generator*, including it as a key moment in his Smart Cities timeline.

1.3.2 Advent of the internet and cybercities

Without the appearance of the internet, research into cyber cities, bit cities, and eventually smart cities, simply would not exist. The history of the internet, its multiple inventions and reinventions between the 1960s and 1990s has been extensively documented. It has become a cultural cliché for out of touch luddites to refer to the internet in the plural as, 'the internets' – but historically this is not false, with multiple iterations in its development and historically simultaneous alternatives. From Arpanet of the 1970s to the Internet of the 1980s and the world wide web of the 1990s, there have been many 'internets'. Not to be forgotten, the word *telecommunications* once stood in for the many

57 The original Delos Eleven included Singaporean architect William Lim who was a frequent contributor to Ekistics. Singaporean architects seem to have been disproportionately represented in Ekistics, making it a frequent source in my case study on Singapore's public housing.

early ancestors of the internet (the fax machine, the Minitel) but this short gloss on the internet would be overwhelmed by this more-than-extensive family tree which has already been thoroughly covered elsewhere.[58] Of particular relevance to my research are cultural histories of the internet which demonstrate how the roles of producer and user have overlapped – each imprinting their needs, interests and values on to the form and function of the internet.[59]

Janet Abbate's history, *Inventing the Internet* (1999), demonstrates the combination of military and academic cultures that influenced the internet's development. Cold-war paranoia led the original ARPANET to be designed for survivability in a nuclear attack. It was highly-redundant, decentralized and encryptable.[60] Abbate goes on to describe how the internet's characteristics of, "collegiality, decentralization of authority, open exchange of information," were the contribution of academic scientists who became important early users of ARPANET.[61] The invention of the world wide web by Tim Berners Lee at CERN in Geneva allowed the internet to evolve into the cultural-technical juggernaut that today seems to dominate most waking hours of this planet's sentient life. While these cultural changes were still new in the mid-1990s, architects, urbanists, theorists and historians created a new branch of discourse and research exploring cultural changes wrought by this new technology and speculated about where it might lead us.

When Christine Boyer wrote in 1996, "the specifics of time, space and architecture that Sigfried Giedion discussed in the early 1940s have been condensed or eradicated by our instantaneous modes of telecommunications, telemarketing, telepresence, and telesurveillance,"[62] she was working to absorb the impact of the internet on the culture of architecture and urbanism. Her observation overlaps with the observations of Bill Mitchell, who in the same year published, *City of Bits*, in which he wrote:

> " The network is the urban site before us, an invitation to design and construct the City of Bits (capital of the twenty-first century), [...] a city unrooted to any definite spot on the surface of the earth, shaped by connectivity and bandwidth constraints rather than accessibility and land values, largely asynchronous in its operation, and inhabited by disembodied and fragmented subjects […]."[63]

While the data-driven city, the context of my research, does relate to the cyber city discourse in the 1990s, I would argue that it has a separate origin and a separate set of concerns. The advent of the internet, as we have seen, provoked reassessments of proximity, identity, image and reality. The impetus for research into the data-driven city, though contemporaneous with the internet, was provoked by a different challenge to architecture: maximization.

58 See for example: Huurdeman, *The Worldwide History of Telecommunications.* 2003.
59 This claim comes directly from Janet Abbate's account which I cite more completely later.
60 In describing the impact of military culture of the cold war on the creation of the internet, Abbate highlights the contributions of Paul Baran an engineer at RAND corporation's Computer Science department in creating a survivable communications system that would avoid a 'Dr. Strangelove' style collapse of the chain of command in case of nuclear attack.
61 The quoted text is from Abbate, p.5. See also for example also p. 94 where academics, "created unusual or even illicit links between the ARPANET and other communication systems.")
62 Boyer. Cybercities. 1996. p.11.
63 Mitchell. City of Bits. 1996. p.24

1.3.3 Datascapes: from massive uniqueness to architecture maximized

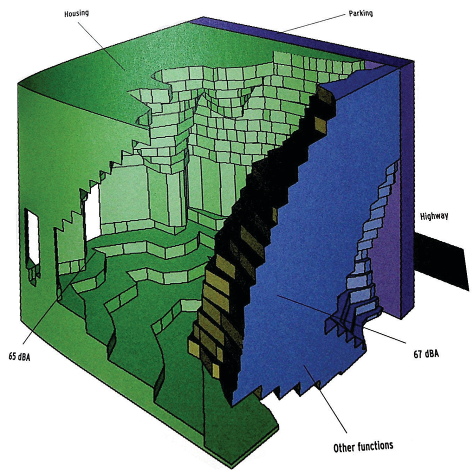
In 1996, the same year that saw the publication of Boyer's *CyberCities* and Mitchell's *City of Bits*, the architect Winy Maas wrote a brief, treatise he titled *Datascape* which provides another viable point of origin for the concepts of data-driven city and data-driven design. Maas explains that he came to the idea of the *Datascape* as a result of a frustration with the massive uniqueness of contemporary architecture. "the expression of the individual object has become ridiculous: in a massive 'sea of uniqueness' the individual object simply ceases to exist."[64] Confronted with the impossibility of producing new iconic form, Maas proposes that architecture will bifurcate in its focus, turning either toward the interior or toward urbanism.

"When architecture becomes urbanism, it enters the realms of quantities and infrastructure, of time and relativism."[65] Maas observes that the urban realm seems to be ruled by quantitative relationships. In his account, very large-scale urban forms appear automatically in response to a combination of official statistics, policy, and market-forces. Maas lists eight urban forms to illustrate his point and gives each a nickname connoting its massiveness or out-of-control self-perpetuation: mountains of program, slicks or cancers of suburban housing, piles of residential blocks. These massive man-made environments are no longer landscapes, but physical manifestations (scapes) of an uncontrolled data-driven process. In Maas' words: "All these manifestations can be seen as "scapes" of the data behind it."[66]

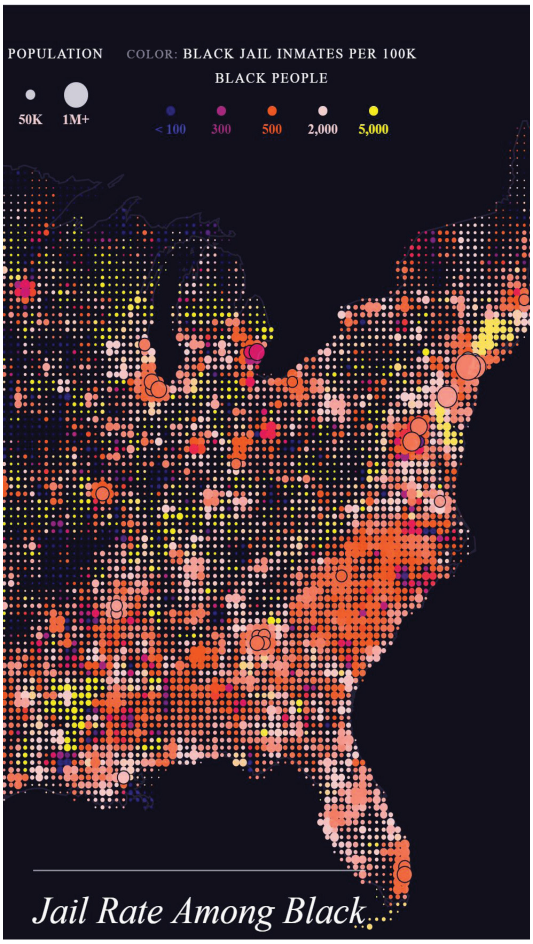
Maas emphasizes that maximization is necessarily quantitative and rule-based, suggesting that much urban form is being automatically written by a software-like process defined by policy and fed by quantitative data. "Assuming a possible maximization (the word 'maximum' already implies rules), society will be confronted with the laws and by-laws that it has set up and that are extrapolated with an iron logic."[67] Extrapolation, the statistical process of inferring unknown data by fitting a curve to known data and extending it beyond the existing dataset, is proposed by Maas as a technique of architectural research, exploring the hidden (or ignored) logics of the generation of urban form.

Maas advocates using the logic of the datascape as a form of architectural research, "In order to understand the behavior of massiveness, we have to push it to the limits and adopt this 'extremizing' as a technique of architectural research." For Maas this research constitutes an exploration of the rule-based techniques of urban maximization and where those rules lead when take to their logical extremes. "More massiveness and higher densities leads to the question of whether we still should use our light and air regulations. Or if we should cope with noise in another way." For Maas the investigation and creation of datascapes is a form of critical research: "Form becomes the result of such an extrapolation or assumption as a 'datascape' of the demands behind it. It shows the demands and norms, balancing between ridicule and critique, sublimizing pragmatics."[68]

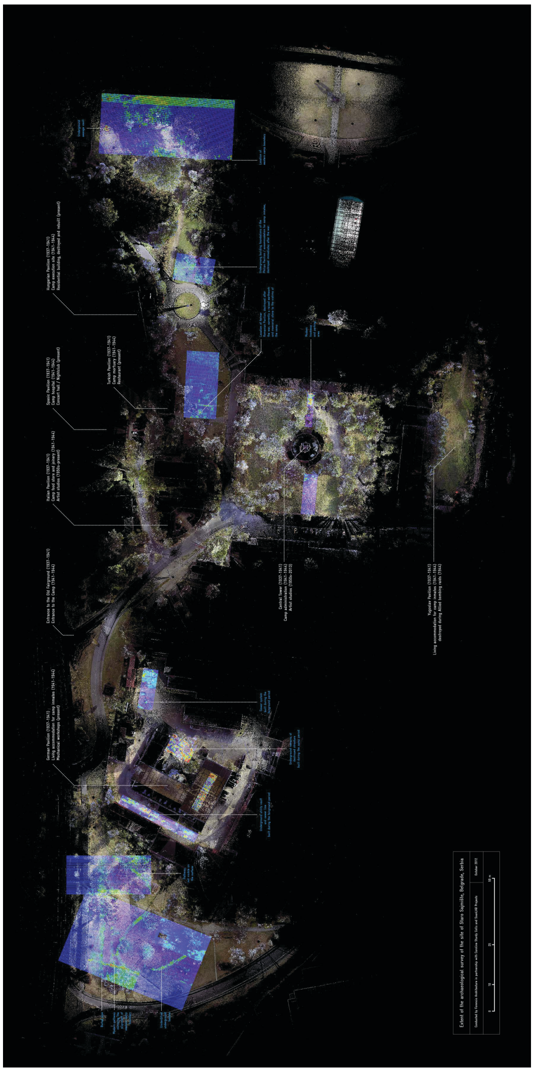
64 FARMAX. p.100.
65 Ibid. p.101.
66 Ibid. p.102.
67 Ibid. p.103.
68 Ibid. p.103.



10. Penelope Dean (MVRDV). *Noisescape*. 1997.



11. William Rankin. [Radical Cartography]. 'Jail Incarceration Rate in 2010'. 2017



12. Eyal Weizman [Forensic Architecture]. LIDAR and Ground Penetrating Radar imaging of Semlin Death Camp in Belgrade. 2013.

13. Christian Kerez. Swiss Pavillion, Venice Biennale. 2016

When Maas describes datascape as a technique of form generation, it is difficult not to see an overlap with the use of paranoid-critical method by his mentor Rem Koolhaas. Maas writes, "Under maximized circumstances, every demand, rule or logic is manifested in pure and unexpected forms that go beyond artistic intuition or known geometry and replace it with 'research.'" Koolhaas advocated for the use of the Dadaist paranoid-critical method in *Delirious New York*, explaining that:

> Paranoid Critical Method is a sequence of two consecutive but discrete operations: 1. the synthetic reproduction of the paranoiac's way of seeing the world in a new light - with its rich harvest of unsuspected correspondences, analogies and patterns; and 2. the compression of these gaseous speculations to a critical point where they achieve the density of fact: the critical part of the method consists of the fabrication of objectifying "souvenirs" of the paranoid tourism, of concrete evidence that brings the "discoveries" of those excursions back to the rest of mankind, ideally in forms as obvious and undeniable as snapshots."[69]

Koolhaas employed the paranoid-critical method to circumvent, *'*Reality Shortage*,'* (the diminishing significance of reality in mass-consumer, mass-media society) by applying a conceptual recycling to the 'worn, consumed contents of the world'.[70] Maas, confronting a similar problem (the fatigue of massive uniqueness is not that different from the *Reality Shortage*) proposes a design method which drops the paranoid fantasy and instead begins with the critical crutch of data, and by driving it to an extreme produces automatically something new and unexpected- not unlike the paranoiac's distorted and therefore fascinatingly new perception of the world. So, while Maas emphasizes that the datascape is a technique of architectural research, we must also consider it as an extension of the tradition of avant-garde formalism based in 20th century modern art.

Perhaps confusingly, Maas uses the word datascape to refer both to already-existing urban phenomena ('white cancer of suburban housing') and to a technique of form-generation as research. The term data-driven city is a very close match to the first use of datascape, designating urban phenomena. Rob Kitchin's definition of data-driven networked urbanism for example has clear similarities to this meaning of datascape: "urban operational governance and city services are becoming highly responsive to a form of networked urbanism in which big data systems are *prefiguring* and setting the urban agenda and are influencing and controlling how city systems respond and perform."[71] While Kitchin's interest is more in urban systems than in urban form, the similarity to Maas' concerns with automatically produced urban landscapes is clear. This use of data-scape corresponds closely to my research interest in the data-driven city as a formal basis for architecture – a contextual condition that automatically generates and or instrumentalizes architectural form.

Datascape, as technique of form-generation, as architectural research, and as critique, however is a very different thing. In Maas' writing datascape has a two-fold role as form-generator. First it is an investigation of the automated generation of urban form through response to quantified contextual conditions, often using techniques of optimization. FARMAX notably contains an early implementation of optimization (simulated annealing) applied to urban form. This aspect of datascape is a design method that is very similar to data-driven design as I have defined it earlier (see definitions 1.1.2).

69 Koolhaas. 1978. Delirious New York. p. 238
70 Ibid. p. 241
71 Kitchin. "Data-driven Networked Urbanism." 2015 (italics added)

Second, Maas argues that datascape is a kind of design research that will allow the architect to reflect on society: 'society will be confronted with the laws and by-laws it has set up [...] It will begin questioning these regulations." That *datascape* is meant to be critical is an important distinction from data-driven design which need not have a reflective or critical capacity. Maas writes that the *datascape*, "connects the moral with the normal," by exploring the under-appreciated ethical implications of seemingly banal data-driven urban processes when they are taken to their logical extremes. The moral function of the *datascape,* awkward in the bubbly years of the late 1990s, is topical today, mirroring calls to closely examine the ethical implications of automated regimes of city management.[72]

In the early 2000s the datascape was absorbed into the methodology of landscape urbanism with Jim Corner describing it as one of his design techniques.[73] Among the first generation of parametric designers, Peter Trummer prominently used urban heat-maps as generating devices for his 'associative urbanism,' in a method that owes a debt to Maas' datascape.[74]

The objectivity, and instrumentality of urban data and the datascape was comprehensively reviewed in 2005 by William Rankin, historian of science and architecture.[75] His skepticism of the objectivity of urban data is characteristic of the field of *science and technology studies*, from which Rankin draws his critique. "It is not a simply question of whether to engage statistics, but of who creates them, and how, and for what ends."[76] Ranking uses noise maps as the primary illustration of the problem of objectivity in urban data in this article. He explores critique of datascape as 'apotheosis of capitalism' (a claim made by Stanford Kwinter) or 'resurgence of democracy' (a claim by Bart Lootsma). Rankin emphasizes the difference between actively creating ones own datasets, or passively consuming pre-existing data, a process he calls *data-diffusion:*

> "The difference between data-diffusion and data-creation is profound: while increasing access to data does allow for new forms of critique and accountability (the democratic potential of MVRDV that Lootsma discusses), no amount of data flow allows for access to the hidden assumptions of the "raw" data itself. By the time the "new cartography" has become available for architects, *the basic givens of governmental planning have already been designed into it*."[77]

Rankin's assessment of datascape is skeptical: the data that architects receive from 'governmental planning' risks being tainted by the pre-embedded motivations of a non-objective source. In the decade and a half since Rankin's essay, not only has quantity of urban data grown, but so have its sources. Rankin's contemporary work in cartography, as we will see, builds off massive troves of historical data to attack political and ethical controversies in a method that recalls MVRDV's *datascapes*. (fig. 11)

72 See Mattern, 'Instrumental City.' Op. cit.
73 See for example: Corner, James. 1999. "Eidetic Operations and New Landscapes."
74 See Trummer, Peter. 2009. "Morphogenetic Urbanism." As well as Trummer, Peter. 2011. "Associative Design: From Type to Population."
75 Rankin,William. 'Noise, Mapping, and Architecture of Statistics.' in "93rd ACSA Annual Meeting Proceedings, The Art of Architecture/The Science of Architecture." ed. Hejduk, R. and Van Oudenallen, H. 2005.
76 Ibid. p. 374.
77 Ibid. p.376.(italics added)

1.3.4 The Smart Era and big data

Marc Weiser's research on Ubiquitous Computing (Ubicomp) at Xerox PARC in the late eighties first heralded the 'smart' era by proposing the distribution of small networked computational devices throughout the home and city. Picon has noted that Weiser's article in the Scientific American on Ubicomp reads like a manifesto – in particular the now famous statement that, 'The most profound technologies disappear.' Ubicomp and the closely associated 'internet of things' often referred to as 'IoT' mark the beginning of distribution of sensors throughout the city, the gathering of digital data, and the development of small computational devices that could autonomously act upon this data. The smart phone- now almost entirely ubiquitous in any city- is a descendant of early experiments at Xerox PARC like the PARC Tab.

Urban *big data* is produced as a direct result of the realization of Weiser's vision of ubiquitous computing. Over the last three decades digital devices have been integrated at an accelerating rate into countless urban touchpoints. Each of these devices produces a stream of data that it shares with other devices in a growing cascade- the data deluge. We are familiar with many of these devices: smart phones, credit card readers, digital turnstiles for public transport, smart thermostats, voice-activated digital assistants. Some of them, however, are less invisible to the average urban resident: noise and air quality monitoring stations, traffic surveillance systems, the smart grid. The sum of all these data-streams, including data from the internet, is undeniably *big*.

Rob Kitchin has defined *big data* as 'vast quantities of dynamic, varied digital data that are easily conjoined, shared and distributed across ICT networks, and analyzed by a new generation of data analytics designed to cope with data abundance as opposed to data scarcity.'[78] Urban Big-data is also increasingly generated and visible in real-time, with digital maps reflecting back to us the traffic conditions, air quality, and twitter storms as they happen in our cities.

The era of *big data* began in the early 21st century with the data-mining that companies like Google were able to do with information generated by traffic on their websites. Google, for example, developed an algorithm that could predict when flu outbreaks were about to happen based on the types of searches people were making. This type of predictive modeling led Chris Anderson of WIRED magazine to write a now notorious article titled *The End of Theory: The Data Deluge Makes the Scientific Method Obsolete* in 2008. While this claim was hotly contested, it seems to have marked the beginning of a new era in urban research and urban design where the bigness of one's data has increasingly been seen as a mark of the quality and seriousness of one's research.

The architectural implications of big data's impact on the sciences has been parsed by Mario Carpo, who, in *The Second Digital Turn*, describes the resulting emergence of a new formal complexity that exceeds human interpretation. Design in this context is impossible without the use of computational search of multitudinous data points, whether they are gathered from real-world experiment or automated simulation.[79] Architectural artifacts reflecting this new post-human complexity include Hansmeyer and Dillenburger's *Digital Grotesque* (2013), Retsin and Jimenez-Garcia's *CurVoxels, 3D printed chair* (2015), and Christian Kerez's *Incidental Space* (2016).[80] (fig. 13)

78 Kitchin. 2014. *The Data Revolution.* See preface p.XV.
79 Carpo. 2017. *The Second Digital Turn.* p. 80. Carpo discusses estrangement' and 'weird realism' as presented by Michael Young.
80 Ibid. pp. 40, 42,76-78,82-85. See also Carpo. 2016. "Christian Kerez's Art of the Incidental" in *Release Architecture: Incidental Space by Christian Kerez.* ARCH+ Verlag GmbH, Berlin. May 2016. pp. 70-

Carpo's observations on new architectural form are accompanied in this book by an interrogation of the multiplication and complexification of digitally mediated socio-economic micro-transactions which are breaking down the scales and standards of 20th century industrial economy.[81] This breakdown implies, for Carpo, a coming irrelevance of the modern nation-state and its large-scale industries and the emergence smaller-scale self-organizing entities (he recalls the example of the city-states of medieval Europe).[82] The rise in economic and political power of small-scale, self-organizing groups in the data-driven city has enormous implications for how the city is lived and made, but its ultimate results remain undecided.

Some contemporary architectural work leverages the data-rich context in an attempt to further human understanding and pursue political or ethical ends. Antoine Picon's observation that the interactive map of the *Smart City* seems to both constitute its ability of self-reflection and provoke a conflation of aesthetics and politics is borne out by the work of architects like Eyal Weizman.[83] Weizman and his colleagues at *Forensic Architecture* have responded to the new data-rich context by developing political and ethical projects. For them, growth in the means of gathering, creating and sharing data means that smaller groups of individuals have greater leverage in bringing to light crucial matters of concern. *Forensic Architecture's* maps of the Semlin Death Camp in Belgrade use contemporary data-rich techniques of LIDAR and Ground Penetrating Radar Scanning to create visualizations that bring to light unpleasant truths which have been hidden from view.[84](fig. 12)

William Rankin, in his *Critical Cartography* projects, has similarly worked to leverage big data to support human understanding of controversial political and ethical problems. In a recent series of interactive maps he compares the spatial history of slavery in the United States with contemporary concentrations of the incarceration of African Americans.[85](fig. 11) This work uses software to extract insights from many large databases (historic slavery records and 150 years of census and incarceration records) and present them in a visually comprehensible and compelling manner. The bigness of data and the power of analytic algorithms is deployed by Rankin toward a political and ethical end: helping us understand the persistence of the effects of American slavery to the present day.

1.4 Case study methodology

In this section I describe why I have chosen to work with a case study method of research, how it differs from other recent studies, and I give specific detail on how I intend to carry out each study.

1.4.1 Situated case studies of data-driven urbanism vs. thematic studies of smart cities

Studies of smart cities tend to be partial and thematic. They jump from city to city, from digital systems to physical infrastructure back and forth in the pursuit of themes like metabolism or sentience in order to give an overview of an emerging field. This is the case for Antoine Picon's *Smart Cities* which moves from Rio to Songdo to Paris and beyond. Picon remarks that the term smart city is itself contentious

81 Ibid. See 5.3 'The Digital Mass-Customization of Social Practices.'
82 Ibid. p.156.
83 Picon. 2014. *Smart Cities.* p. 136, 138. See also 5.3.3 in this thesis.
84 Weizman, Eyal. 2017. *Forensic Architecture : Violence at the Threshold of Detectability.* New York: New York : Zone Books. p. 60
85 Rankin and Daniels. *The Shape of Slavery.* https://pudding.cool/2017/01/shape-of-slavery/

and can refer to a range of existing and possible urban scenarios. He prefers instead to categorize smart urbanism on an axis from the *neo-cybernetic city*, governed by the pure logic of efficiency, to the *senseable city*- a notion of a city of new digital intensities. Anthony Townsend remarks in his book *Smart Cities* that he ranges very widely in his study- he attributes this to the fact that no smart city is the same, and that smart cities are constantly changing. Carlo Ratti's recent smart city book, 'The City of Tomorrow' opts to address very broad themes like energy, mobility, and urban data flow. In none of these books does the author attempt focused historical case studies of a specific city or place. However, all the authors cited also go to great lengths to emphasize that each smart city is different, and that local approaches are often better attuned to local needs than the out-of-the box examples proposed by tech industry titans like CISCO or IBM.

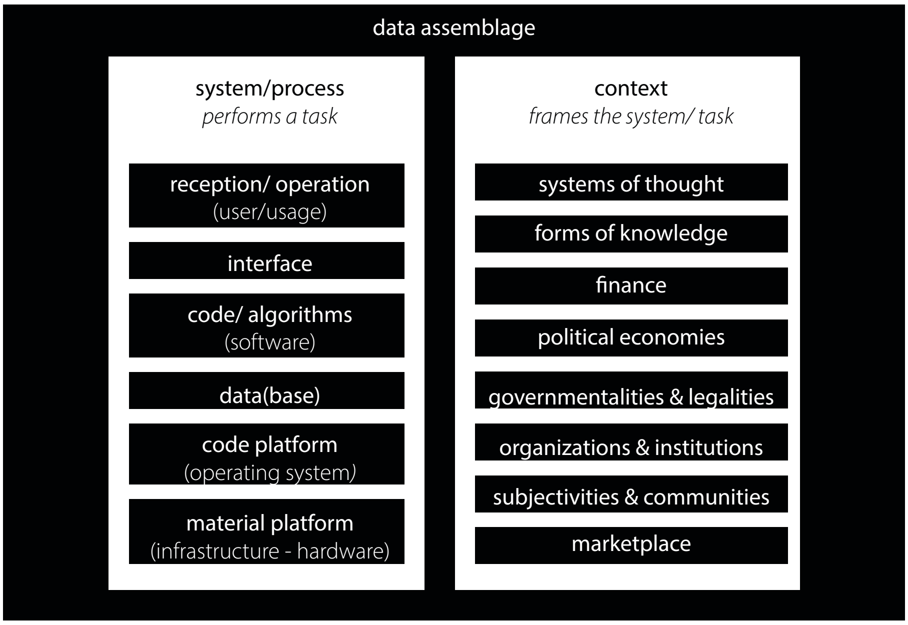
As the goal of my research is to consider how architectural design and architectural artifacts can work as interventions in data-driven urban systems, it is preferable to consider the *data assemblage* and architectural artifacts as situated, and motivated by place. For this research it is necessary to drill down in detail on the history of the city, its architectural culture, and the development of its data-driven systems. Given that my goal is not to produce an overarching guide to smart cities (as is the case for Townsend, Picon or Ratti), but rather an architectural strategy guide for acting within data-driven urbanism, I have decided to focus the research on place-specific case studies and understanding how intervention in a data-driven system plays out in time and space within this context.

1.4.2 Case studies: paradigmatic or actually-existing data-driven urbanism

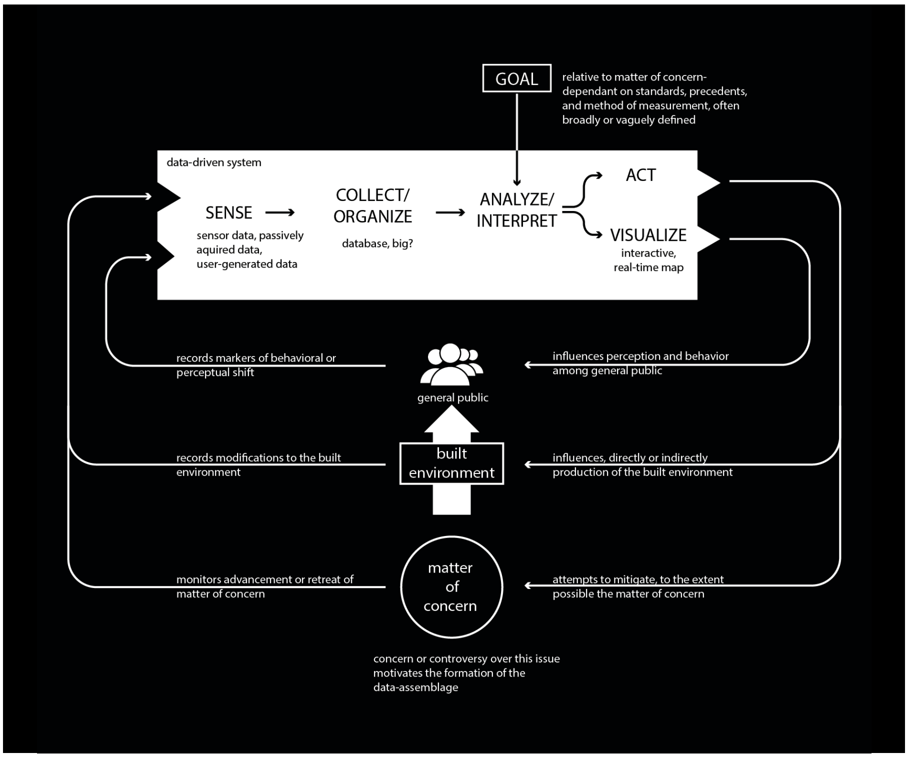
In my choice of case studies in data driven urbanism I have focused on Global Cities over paradigmatic smart cities as they provide a richer web of urban actors and strongly-established architectural cultures. Paradigmatic smart cities, like New Songdo, South Korea, Masdar, UAE, or PlanIT Valley, Portugal draw a great deal of popular attention via tech industry boosterism. Geographer Matthew Zook has contrasted these paradigmatic smart cities with what he calls 'actually existing smart cities' where radical changes in data-driven systems are embedded within the complex everyday reality of pre-existing cities.[86] Zook has focused his studies on Philadelphia and Louisville. For the purposes of my research I agree that paradigmatic smart cities lack the history, institutions and culture that might make culturally-inflected self-organization of data-driven urbanism possible. Without the resistance of these pre-existing urban foundations the paradigmatic smart city built from a tabula rasa is rarely more than the unquestioned vision of the cabal of real-estate developers, traffic engineers, and tech entrepreneurs.

Zook's arguments, however, overlook the importance of the global cities in acting as proving grounds for the urban integration of data-driven technologies. These cities were first identified in the 1990s by Saskia Sassen as key nodal points in a growing global network of commerce and communication. For the global cities, data-driven urbanism is only a further step in a series of political and technological changes that began in the 1980s and have been described by intellectual touchstones like Castell's *The Rise of the Network Society* and Harvey's *Neoliberalism*. These cities are often the leaders in bottom-up innovation in data-driven systems as they have the economic clout and institutional savoir-faire

86 Shelton, Taylor, Matthew Zook, and Alan Wiig. 2015. "The 'Actually Existing Smart City'"



14. Rob Kitchin's diagram of the data assemblage. Redrawn from Kitchin. 2014. *Data-driven networked urbanism*.



15. A redrawing of the feedback framework of data-driven networked urbanism placing the built environment in a mediating position between a data-monitored matter of concern and the concerned public.

to create their own 'smart' systems or to adapt existing systems to their needs. Global cities, like New York and London, it could be argued are the true hotspots of data-driven urbanism- in that their systems evolve out of a pre-existing urban complexity and not in the greenfield vacuum of the Masdars and Songdos.

Architecture culture, more importantly, is a rare global commodity that is fostered almost exclusively in the hearts of a few primate global cities. As my research takes on architectural form as its primary object, the choice of global cities with distinct native architectural cultures presents a natural, if not necessary, counterpart to the choice of particularly 'smart' cities. There are in fact only a few global hotspots where distinct architecture culture is working with (or pitted against) advanced and extensive instances of data-driven urban systems. These potential case studies could include the following 'Alpha' global cities ranked by Globalization and World Cities Research Network:[87]

> **Alpha++** world cities: London, New York
>
> **Alpha+** world cities: Singapore, Hong Kong, Paris, Beijing, Tokyo, Dubai, Shanghai
>
> **Alpha** world cities: Sydney, Sao Paulo, Milan, Chicago, Mexico City, Mumbai, Moscow, Frankfurt, Madrid, Warsaw, Johannesburg, Toronto, Seoul, Istanbul, Kuala Lumpur, Jakarta, Amsterdam, Brussels, Los Angeles

Of these possible case studies, each of which would be fruitful to pursue, I have chosen London (Heathrow), Singapore (HDB), and Amsterdam (Buiksloterham). These three case studies provide provocative interaction of architectural culture within a data-driven context. Heathrow provides an example of a particularly divisive debate over noise, mediated (and manipulated) by data, where urban form has become a primary tool of policy. Singapore, in contrast, provides an example of a more unified implementation of data-driven urbanism, where a singular focus on rebuilding the country produced massive urban changes based on evolving quantitative criteria of density. Amsterdam (Buiksloterham) finally provides an example of self-organization, where existing strands of the data-assemblage are gathered up by local designers to produce an alternative vision for how data can make a difference in the city.

1.4.3 Place-based cases

To find 'actually-existing' data-driven urbanism I have expanded my search beyond sites specifically presented as smart districts. Though I do not diminish the importance of the 'smart district' as a part of data-driven urbanism, I have taken care to additionally examine sites at the periphery of the city where new development, globalized mobility, and ecological and social pressures present persistent challenges for urban design and architecture. I have sought out urban spaces where data driven systems are being deployed to manage societal or environmental challenges- or conversely where urban aspirations are being buoyed by the deployment of data-driven systems. I have been sensitive

87 GaWC. The World According to GaWC 2016. www.lboro.ac.uk/gawc/gawcworlds.html.

in seeking out controversy over the use of data-driven systems.[88] Illogical or contradictory claims about the impacts of data-driven systems have also been of particular interest. Controversy, or self-contradictory claims indicate an undecided nature to the data-driven system- one that would seem to indicate the possibility for evolution based on negotiation between the plethora of urban actors. In these controversial spaces, I feel there is the most potential to find instances where architecture culture has impacted the development of data-driven urbanism.

In each place-based case studies I identify a different matter of concern (noise, flooding, and congestion) and explore the development of a data-driven regime for its management. Quantification of the matter of concern serves to provide an objective viewpoint of the problem it poses (how high is the water in the street?) and to facilitate mediation between opposing viewpoints by providing precision/ nuance that overcomes diametrical opposition. Comparing 40, to 65, to 70 dB LAEq and all the variants between allows nuanced negotiation in a way that simple pro-con positions cannot. Quantitative data also provides evidence of success or failure of attempts at management.

Quantification of public perception in these case studies is as important, if not more important than the measurement of the matter of concern: numbers of noise complaints do a better job of explaining controversy over aviation noise, that time-averaged decibel contours. After all, noise is nothing more than unwanted sound. Flooding is unwanted water. Congestion is unwanted density. The reason these phenomena are 'matters of concern' is that they are unwanted, controversial and persistent. So beyond just the quantification of the matter of concern we must recognize that these data-driven regimes also quantify and track people's perception of the matter of concern and are active tools in influencing perception of the matter of concern. (fig 15.) In this context, architecture is instrumentalized not only to provide shelter from the matter of concern, but also, possibly, to shift perceptions of the matter of concern.

1.4.4 The data assemblage and its methods

Often architectural writing about urban data has been imprecise, a case in point is Winy Maas' *Datascape* manifesto which conflates under the term data not only official statistics, but also government policy, and market forces. Developing precision and consistency in the study of data and its complex links to society, infrastructure and urban form is the first task of the researcher in the era of the data-deluge. I am not alone in this observation, nor am I the first to attempt to apply an analytic grid to the problem of the cultural linkages of urban data. Rob Kitchin, with notable colleagues like Craig M. Dalton and Jim Thatcher, have taken up these tasks in developing a field they call *critical data studies*.[89] Kitchin developed the concept of the *data-assemblage* as an analytic tool to support this work, (already briefly defined under key terms) as a framework against which researchers can measure the ways that data is embedded not just in technological systems, but in social practice and in physical spaces.

88 Latour. 2005. *Reassembling the Social.* pp.114 "The discussion begins to shift for good when one introduces not matters of fact, but what I now call matters of concern. While highly uncertain and loudly disputed, these real, objective, atypical and, above all, interesting agencies are taken not exactly as object but rather as gatherings."
89 Dalton, C., L. Taylor and J. Thatcher. 2016. Critical Data Studies – a dialogue on space. Big Data & Society. January-June 2016: 1-9

In my research I employ the *data-assemblage* to the extent possible (our research objects are not identical). By employing this analytic grid, however, I do not suggest that it is perfectly matched to my research object. To better address my research object and explain the results of my research I introduce a related analytic concept, the *Data Genealogy Map,* in 5.1.1. Nonetheless, I believe there is value in producing research that shares points of reference with other prominent work, as this commonality will make it more possible for comparative evaluation of my research, and for the results of my work to be relevant to the larger project of studying the data-driven city.

Kitchin's *data-assemblage* provides a grid to organize the processes and contexts that work collectively to produce and instrumentalize urban data.

> "Data and their assemblage are co-determinous and mutually constituted, bound together in a set of contingent, relational and contextual discourses and material practices and relations."[90]

Kitchin's assemblage is illustrated in two stacks. (fig. 14) The first stack organizes systems and processes that gather, disseminate or instrumentalize data. The second stack organizes significant contextual apparatuses which frame the task being carried out with/by data. In describing the appratuses, Kitchin lists a number of sub-elements with an ellipsis at the end: the list is open-ended and we are expected to add to the framework as needed.[91] In my case, instead of exhaustively working to identify each apparatus and element as described by Kitchin, I have followed the lead of each case-study's history. An urban controversy – noise for example – leads to protest, groups pro and contra, institutional study, new metrics, new techniques of measurement, new mappings, policy changes and changing urban form. At each step of the history I work to bring each new element into relation with the grid of the *data-assemblage*, and to trace its connections with other elements (or apparatuses). This working method has led me to develop the *Data Genealogy Map* described in greater detail in Chapter 5, as an extension of the *data-assemblage* concept.

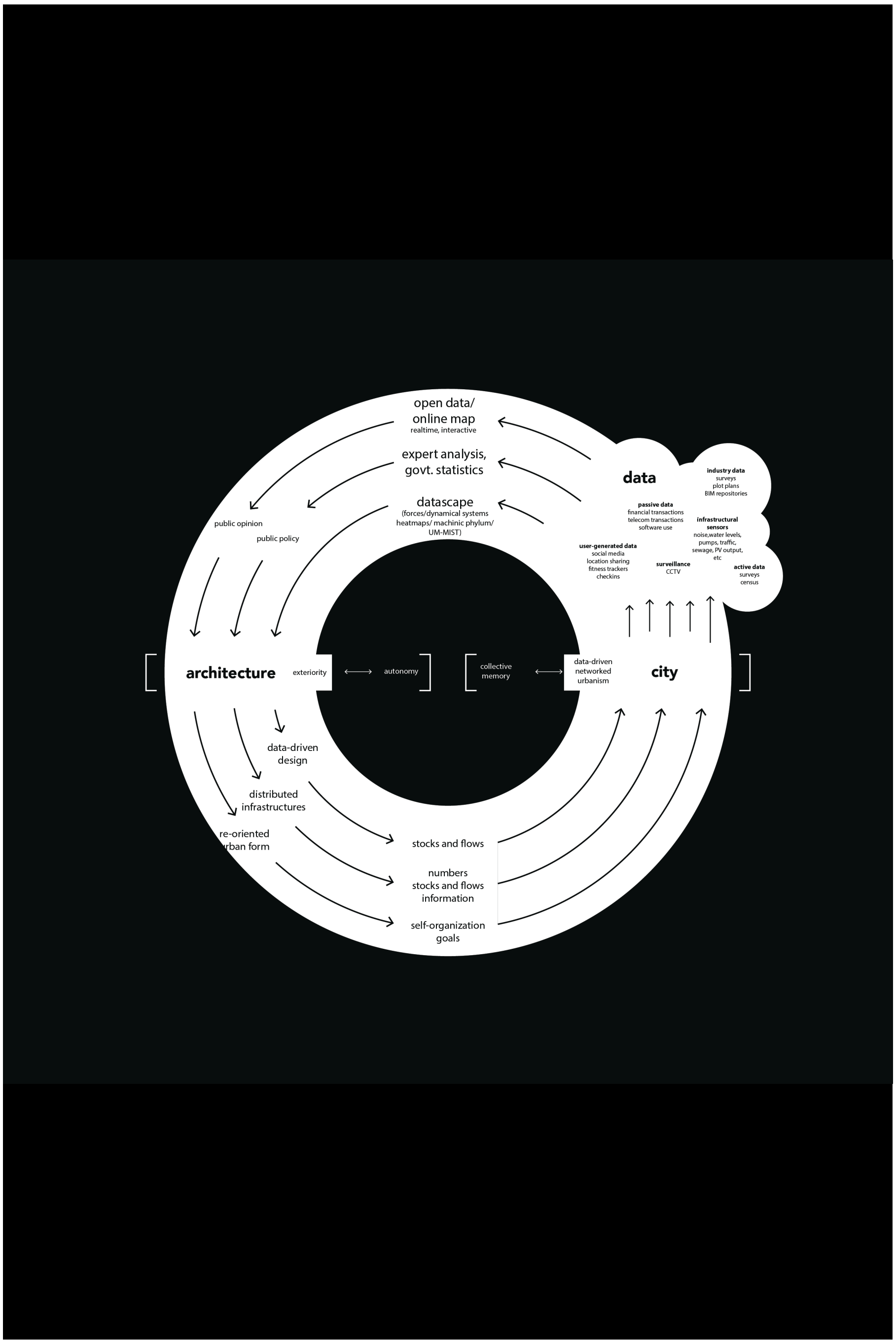
Just as the *data-assemblage* provides an analytic grid common to other prominent studies, research into the *data-assemblage* has a group of shared methods. Kitchin describes five methods of studying *data assemblages*: "genealogies, deconstruction, ethnographies, and observant participation [...] and mapping."[92] He emphasizes that this list is not definitive, and that the methods are best used together to provide a richer depiction of the *data assemblage*. Kitchin writes:

> "Each method seeks to carefully identify and unpack social phenomena […] by using them in combination the unfolding discursive and material production of data assemblages can be dissected, providing […] contextual stories and insights about data and their production."[93]

To use Kitchin's terminology, in my research I employ primarily the methods of genealogy and deconstruction. More plainly, the case studies are historical (genealogical) and they are based on the close reading of primary documents (deconstruction). I am sensible to Kitchin's warnings on teleology:

> "Genealogy is most often used to trace out the contingent unfolding of a system of thought or set of actions over time and space, rather than producing a *sanitized teleological historiography* (Crowley 2009). It

90 Kitchin. 2014. *The Data Revolution.* op. cit. p.25
91 Kitchin and Lauriault. 2018. *Toward Critical Data Studies: Charting and Unpacking Data Assemblages and Their Work.* p.10
92 Kitchin, 2014. p. 189.
93 Ibid.



16. A diagram of the co-production of architecture and data-driven networked urbanism.

> illustrates how the future is built upon the past but is not necessarily determined by it in simple cause-effect ways. As such, genealogy is employed to untangle and make sense historically of the multiple, complex and sometimes contradictory or paradoxical iterations of an assemblage."[94]

Unlike the genealogies described by Kitchin, which focus closely on data, the case study histories that I have written emphasize the role of urban form and architecture within the *data-assemblage*. From the point of view of Kitchin this would possibly be a distortion of the over-all image of the *data-assemblage*. The emphasis on architecture means the case studies that I have written have more in common with other histories of architecture than with general histories of urban data. In writing a history that moves cyclically from context in to artifact and actor, and then back out from actor to artifact to context I am following a pattern of inquiry particular to the humanities and often referred to as the *hermeneutic cycle*.[95] The cyclical pattern of close reading, and contextual interrogation I have found is complementary to the method Kitchin calls 'deconstruction,' and it has permitted me to trace a (somewhat peripatetic) path through a broader history of the *matter of concern* and *data-assemblage*, find my research object, and interrogate its entanglement in this context. The method of tracing this path and the diagram it produces, *Data Genealogy Map,* has made it possible for me to extract generalized knowledge from my case studies which I highlight in section 5.1 of my results and conclusions.

1.4.5 Embeddedness, obduracy, and path-dependence

Science and technology studies (STS) has increasingly become intertwined with urban studies over the last three decades. This follows naturally from the recognition that cities and urban form are deeply influenced by technologies of transport, communication and public health – and from the fact that construction, engineering and even architecture are themselves technological practices. The field of science and technology studies came of age in the 1980s and 90s in parallel with the advent of the internet, though it has its origins in earlier works like Latour's *Laboratory Life* in 1979 or Thomas Kuhn's *The Structure of Scientific Revolutions* of 1962.[96] Work that mixes the insights and methods of STS with urban studies dates more or less to the 1990s with Stephen Graham and Simon Marvin publishing *Telecommunications and the City* in 1996.[97] The interest, the value of STS, for my thesis is two-fold. The first is epistemological, in that STS first shed light on how consensus on scientific fact emerges through social processes. The second is methodological, in that STS provides tools for studying how the city's social life and urban form co-evolve and valuable examples of how these sorts of studies have been carried out.

The epistemological questions that STS has raised about the objectivity of scientific fact are highly controversial. That science is conducted by human beings, and that the creation and spread of scientific paradigms and facts is determined by the social interaction of human beings is now widely accepted and discussed. Before the advent of STS the social construction of science was little

94 Ibid. p. 190. (italics added)
95 See earlier discussion of Dilthey in 1.5 Key Motivators: Data vs Collective Memory.
96 See also Thomas Hughes, ***Networks of Power, 1983 …*** (borrowed from the extensive STS bibliography of Hommels. 2005.)
97 Graham and Marvin cite Lewis Mumford as one very few earlier writers who studied technology and the city together.

understood or discussed, while today it makes the cover of the New York Times Magazine.[98] While STS has complicated our understanding of scientific objectivity, it has also increasingly come to reflect back to us how necessary scientific inquiry is to our society. In 2004 Latour published an article, "Why Has Critique Run Out of Steam?" in which he deplores the use of skepticism about scientific consensus as a tool to obfuscate the urgency of action on global climate change:

> "I myself have spent some time in the past trying to show '"the lack of scientific certainty"' inherent in the construction of facts. I too made it a '"primary issue."' But I did not exactly aim at fooling the public by obscuring the certainty of a closed argument—or did I? After all, I have been accused of just that sin. Still, I'd like to believe that, on the contrary, I intended to emancipate the public from prematurely naturalized objectified facts."[99]

Latour, in a reversal, now feels a need to support scientific consensus, and to look at ways that the 'anti-fact,' or 'alternative-fact' world can be made to hear reason[100].

For architects and urban designers the wider debates about the nature of and value of scientific fact taking place in STS connect to disciplinary controversies (discussed earlier) over the role of data in design and of its potential to displace the humanistic core of the discipline. Latour's struggle, and STS's struggle more generally, with the Anthropocene has forced a reassessment of critique. As the design disciplines meet the limitations and challenges of the Anthropocene – limited resources, out-of-control secondary effects like noise and air pollution, paralyzing congestion – we will similarly have to assess and modulate our deployment of critique and evidence-based or data-driven method. The case studies that I explore in this thesis are all reflective in some sense of the challenges design professionals face in the Anthropocene, of possible ways of working (savoir faire) with data, and of the limits to evidence-based approaches (which have often called their methods 'scientific'.)

The methodological value of STS to my case studies comes from the work of individuals like Anique Hommels who have worked to apply the methods of STS to the city and specifically how change can happen in the city. Hommels has conducted a case-study based research into, 'Obduracy in Urban Sociotechnical Change,' using the methods of STS. As she describes it, the idea of obduracy – the resistance of a socio-technical system to change- is central to STS investigation of technology. Her research methods provide ways of teasing apart and evaluating obduracy and its converse, change, and are thus of direct relevance to my research question which considers how architecture can effect urban change in the context of data-driven urbanism.

Hommels rejects four 'common-sense' explanations of obduracy: that change is too expensive, conflicts of interest prevent change, powerful voices protect the status quo, or that the physical material of the city is too difficult to change. Instead she proposes three models of obduracy based on the ideas of STS: (1) dominant frames, (2) persistent traditions, and (3) *embeddedness*. The dominant frames model suggests that urban actors are so deeply immersed in their own disciplinary mindsets

98 Kofman, Ava. "Bruno Latour, the Post-Truth Philosopher, Mounts a Defense of Science." ***The New York Times***, 25 Oct. 2018. ***NYTimes.com***, https://www.nytimes.com/2018/10/25/magazine/bruno-latour-post-truth-philosopher-science.html.

99 Latour, "Why Has Critique Run Out of Steam?" In *Critical Inquiry*, Winter 2004, p227

100 Kofman. 2018. "Instead of accusing Trump supporters and climate denialists of irrationality, Latour argues that it is untenable to talk about scientific facts as though their rightness alone will be persuasive. In this respect, "Down to Earth" extends the sociological analysis that he brought to bear on factory workers in Abidjan and scientists in California to the minds of anti-scientific voters, looking at the ways in which the reception of seemingly universal knowledge is shaped by the values and local circumstances of those to whom it is being communicated."

(frames) that they cannot conceive of and implement a shared vision of change.[101] The dominant frames model of obduracy emphasized the importance of human and disciplinary mindsets in producing new urban visions and the 'inclusion' of an actor's frame in the vision.

The *persistent traditions* model of urban obduracy highlights the power of widely-shared cultural traditions, archetypes and values. Hommel illustrates *persistent traditions* with the railroad station architecture in the US. Hommels explains that four archetypal train stations (Grand Central, Penn Station, Union Station, and Chicago's Terminal Station)[102] exerted an influence of the design of subsequent large railway terminals.[103] To an architect this suggests a link between the idea of persistent traditions and concepts of architectural typology both as deliberate design technique, and as cultural phenomenon. Hommels argues that this model of urban obduracy provides the best description of the influence of 'long-term (cultural) traditions,' in contrast to embeddedness or dominant frames.

The *embeddedness* model of urban obduracy, in contrast emphasizes the co-evolution of technology and society, where society creates technology but technology also in tandem recreates society. This model builds along the lines of *Actor Network Theory*, as developed by Bruno Latour and others, by assigning agency both to humans and non-humans. In this conception of urban obduracy, new technologies are progressively supported by a network of proponents: users, infrastructures, etc. As the technology develops and ages this network becomes larger and larger. The sheer size and complexity of the network producing and perpetuating the technology makes it resistant to change – or obdurate.[104] The concept of embeddedness has been deployed by urban theorists like Stephen Graham and Simon Marvin in studies of infrastructure-driven urbanism. Hommels notes that Graham and Marvin used the concept of *embeddedness* to rank different urban infrastructures in *Splintering Urbanisms* (2001).[105] According to this analysis highly-embedded infrastructures (like water or sewage infrastructure) are hard to change, with Graham and Marvin citing sunk investments as the main reason. Low-embedded infrastructures, like some forms of telecom infrastructure with fewer sunk costs, may be easier to change.

Embeddedness¸according to Hommels, is a seemingly mono-directional, *irreversible* process, like cooking an egg.[106] The concept of irreversibility that we encounter with embeddedness, is echoed in the related concept of *path-dependence.* Path-dependence, like obduracy, can be described as the result of embeddedness in an expanding socio-technical system, but also as the result of the idiosyncrasies of history. The QWERTY keyboard is an often-cited example of path-dependence, where an obsolete system intended to decrease type-bar clash in 19th century typewriters persists to present day in spite of its repeatedly demonstrated inefficiencies (and viable alternatives.) Economist and historian Paul David presented the QWERTY history and path-dependence concept in *Clio and the*

101 Hommels, Anique. 2005. *Unbuilding Cities : Obduracy in Urban Socio-Technical Change.* She cites, among others, the idea of 'technological frame' developed by Wiebe Bijker. pp. 22,23.
102 Ibid. pp. 33-34 Here Hommel cites Sally Kitt Chappell. 1989. "Urban Ideals and the Design of Railroad Stations," TECHNOLOGY AND CULTURE, April, 1989
103 Ibid.
104 Ibid. P. 28
105 Ibid. p.29. The reference is to pg. 193-194 in ***Splintering Urbanisms.*** **(2001)**
106 Ibid. p. 27.

Economics of QWERTY (1985) where he described associated concepts of *lock-in* and *irreversibility*.[107] In the QWERTY history, the persistent efforts of August Dvorak to introduce the *Dvorak Simplified Keyboard* beginning in 1936 were unable to overcome socio-technical *lock-in* rooted in the practice of *sight-typing.* Even Apple Computer's promotion of the Dvorak keyboard in 1984 with the *Apple IIc* did little to shift the world away from the wasted time and effort of QWERTY typing. In this case, it seems undeniable that we collectively are caught in an illogical and irreversible socio-technical *lock-in*.

The concepts of embeddedness and path dependence are important to this thesis for two reasons, the first methodological and the second relating more broadly to the research's motivations. First, if we want to ask if or how an architect can make an impact on the data-driven city, then we need a method to understand how hard is it to change this 'thing.' Is it an early stage technology that is not yet deeply embedded in a networks of users? Then perhaps it will be easier to change. Or on the other hand is it a hundred-year old technological behemoth, embedded in a multi-billion dollar transport network (like Heathrow Airport)? Then it will likely be more difficult to change. *Embeddedness* allows us to think not only how difficult a socio-technical assemblage is to change, but also to consider what means are employed to make the change (what part of the assemblage is being acted on). The concept also allows us to consider non-human agencies in making change in the assemblage: to consider if, or how the architectural artifact or element may independently be able to make change in this context.

My second interest in the ideas of *embeddedness* and *path-dependence* is that it suggests that designers working on the form of the data-driven city inevitably contribute to its growing *obduracy* or may even be instrumental in producing a detrimental path-dependency. How could we not wonder if we, like the creators of the QWERTY keyboard, are building systems that provide short term conveniences at the expense of long-term structural deficits. QWERTY, for example, was designed so that 19th century salesmen could easily type the work *TYPERWRITER* (the brand-name of their product) with all the letters on the top row of keys.[108] In the 1870s this was marketing genius, but 150 years later we recognize it to be short-sighted.

As designers, we are well equipped to consider long-term scenarios, and to contribute to discussion about the best way smart urban technologies develop. Collectively we should develop the ability to argue for the importance of longer-term goals. We should also build an understanding of the ways that technological lock-in happens, so that we may build our cities in ways that, conversely, permit flexibility and reconfiguration, particularly in regards to newly developing technologies. In each case study, as I consider the possible impact of designer and artifact within the data-assemblage, I also make an effort to consider the adaptability of the interventions, with a view to understanding not only how change is made, but also how affordances for future change can be built into urban socio-technical systems.

107 David, Paul. 1985. "Clio and the Economics of QWERTY." pp. 332-337
108 David. op. cit. p. 333.

References

Books and Articles:

Alexander, Zeynep Çelik. 2014. “Neo-Naturalism.” Log, no. 31: 23–30.

Anderson, Chris. 2017. “The End of Theory: The Data Deluge Makes the Scientific Method Obsolete.” WIRED. Accessed April 26. https://www.wired.com/2008/06/pb-theory/.

Bateson, Gregory. 1973. *Steps to an Ecology of Mind : Collected Essays in Anthropology, Psychiatry, Evolution and Epistemology.* London: London.

Bijker, Wiebe E. 1992. *Shaping Technology - Building Society : Studies in Sociotechnical Change.* Cambridge, Mass: Cambridge, Mass. : MIT Press.

Boyer, M. Christine. 1996. *CyberCities : Visual Perception in the Age of Electronic Communication.* New York, New York: New York, New York : Princeton Architectural Press.

Castells, Manuel. 2010. *The Rise of the Network Society.* 2nd edition with a new preface (2010). Vol. 1, 2 (2010). Oxford: Oxford : Wiley-Blackwell.

Cava, John, Kenneth Frampton, and Graham Foundation for Advanced Studies in the Fine Arts. 1995. *Studies in Tectonic Culture : The Poetics of Construction in Nineteenth and Twentieth Century Architecture.* Cambridge, Mass. : MIT Press.

Chappell, Sally Kitt. 1989. ”Urban Ideals and the Design of Railroad Stations,” TECHNOLOGY AND CULTURE, April, 1989.

Carpo, Mario. 2011. *The Alphabet and the Algorithm.* Cambridge, Mass: Cambridge, Mass. : MIT Press.

Carpo, Mario, ed. 2013. *The Digital Turn in Architecture 1992-2012.* Chichester: Chichester : Wiley.

Carpo, Mario. 2016. “Christian Kerez’s Art of the Incidental” in *Release Architecture: Incidental Space by Christian Kerez*. ARCH+ Verlag GmbH, Berlin. May 2016

Carpo, Mario. 2017. *The Second Digital Turn : Design beyond Intelligence*. Cambridge Massachusetts: Cambridge, Massachusetts : The MIT Press.

Comte, Auguste. 1844. *Discours Sur L’esprit Positif.* Paris: Paris : Carilian-Goeury et V. Dalmont.

Dalton, C., L. Taylor and J. Thatcher. 2016. “Critical Data Studies – a dialogue on space.” *Big Data & Society.* January-June 2016: 1-9

Delos Eleven, 1974. “Declaration of Delos Eleven.” *Ekistics*, vol. 38, no. 229. pp. 398–402.

De Landa, Manuel. 2006. *A New Philosophy of Society : Assemblage Theory and Social Complexity.* London: London : Continuum.

Deleuze, Gilles, and Félix Guattari. *Mille Plateaux.* Paris: Éditions De Minuit, 1980.

Doxiadis, Konstantinos A. 1963. *Architecture in Transition.* London : Hutchinson.

Doxiadis, Konstantinos A. 1967. *Ecumenopolis : The Settlement of the Future.* Vol. 1. Athens : Technological org.

Eisenman, Peter. 1963. *The Formal Basis of Modern Architecture.* Cambridge. (Reprint 2018 Auflage., Zürich: Müller, Lars.)

Eisenman, Peter David. 1999. *Peter Eisenman : Diagram, Diaries.* London: London : Thames & Hudson.

Fard, Ali, and Taraneh Meshkani. 2015. "Geographies of Information." *New Geographies.* Vol. 7. Cambridge : Harvard University Press.

Forrester, Jay W. 1969. *Urban Dynamics.* Cambridge, Massachusetts: Cambridge, Massachusetts : MIT Press.

Foscari, Giulia. 2014. *Elements of Venice.* Zürich: Zürich : Lars Müller Publishers.

Flood, Joe. *The fires: how a computer formula burned down New York City--and determined the future of American cities.* New York: Riverhead Books, 2010.

Frazer, John H. 2001. "The Cybernetics of Architecture: A Tribute to the Contribution of Gordon Pask." *Kybernetes. The International Journal of Systems & Cybernetics* 30(5/6):pp. 641-651.

Gausa, Manuel. 2003. *The Metapolis Dictionary of Advanced Architecture : City, Technology and Society in the Information Age.* Barcelona: Barcelona : Actar.

Graham, Stephen, and Simon Marvin. 1997. *Telecommunications and the City : Electronic Spaces, Urban Places*. Reprinted. London: London : Routledge.

Graham, Stephen D.N., and Simon Marvin. 2001. *Splintering Urbanism : Networked Infrastructures, Technological Mobilities and the Urban Condition.* London: Routledge.

Graham, Stephen D.N. 2005. "Software-Sorted Geographies" In *Progress in Human Geography.* 29 (5): 562–80. doi:10.1191/0309132505ph568oa.

Graham, Stephen. 2004. *The Cybercities Reader.* London: London : Routledge.

Harvey, David. 2005. *A Brief History of Neoliberalism.* Oxford: Oxford : Oxford University Press.

Hey, Anthony J. G., Stewart Tansley, and Kristin M. Tolle. 2009. “Jim Gray on eScience: A Transformed Scientific Method.” In *The Fourth Paradigm*.

Hommels, Anique. 2005. *Unbuilding Cities : Obduracy in Urban Socio-Technical Change*. Cambridge, Massachusetts: MIT Press.

Hughes, Thomas Parke. 1983. *Networks of Power : Electrification in Western Society, 1880-1930.* Baltimore: Baltimore : John Hopkins University Press.

Jasanoff, Sheila. 2006. *States of Knowledge : The Co-Production of Science and Social Order.* Paperback edition. London: London, New York : Routledge.

Johnson, Steven. 2006. The Ghost Map : The Story of London’s Most Terrifying Epidemic- and How It Changed Science, Cities, and the Modern World. New York: New York : Riverhead Books.

Kitchin, Rob. 2014a. “Real-Time City? Big Data and Smart Urbanism.” *GeoJournal* 79 (1): 1–14.

Kitchin, Rob. 2014b. *The Data Revolution : Big Data, Open Data, Data Infrastructures & Their Consequences.* Los Angeles: SAGE.

Kitchin, Rob. 2015. “Data-Driven, Networked Urbanism” (August 10, 2015). Available at SSRN: https://ssrn.com/abstract=2641802 or http://dx.doi.org/10.2139/ssrn.2641802

Kitchin, Rob, and Tracey Lauriault. 2018. “Toward Critical Data Studies:: Charting and Unpacking Data Assemblages and Their Work.” In Thatcher, Jim. *Thinking Big Data in Geography : New Regimes, New Research*. Lincoln: University of Nebraska Press.

Kofman, Ava. 2018. ‘Bruno Latour, the Post-Truth Philosopher, Mounts a Defense of Science’ In *The New York Times Magazine,* Oct. 25, 2018.

Koolhaas, Rem, James Westcott, Stephan Trüby, Ben Davis, Harvard University. Graduate School of Design, and Mostra internazionale di architettura. 2014. ***Elements of Architecture.*** Elements. Venice: [Venice] : Marsilio.

Koolhaas, Rem 2015. “The Smart Landscape: Intelligent Architecture” *Artforum International*. Vol. 53, No. 8. April.

Latour, Bruno. 2004. “Why Has Critique Run out of Steam? From Matters of Fact to Matters of Concern” In *Critical Inquiry.* 30 (2): 225–48. doi:10.1086/421123.

Latour. 2007. *Reassembling the Social : An Introduction to Actor-Network-Theory.* Oxford: Oxford : Oxford University Press.

Lee, Jr, Douglass. 1975. “Requiem for Large-Scale Models” In *Journal of the American Institute of Planners*. 6 (2–3): 16–29. doi:10.1145/1102945.1102950.

Lootsma, Bart. 2003. “What is (really) to be Done? The theoretical concepts of MVRDV.” In Patteeuw, Véronique, et al. *Reading MVRDV.* Rotterdam : NAi Publishers.24-63.

Maas, Winy. 1996. “Datascape.” In *FARMAX: Excursions on Density.* edited Winy Maas and MVRDV. Rotterdam: 010 Publishers, 1998. 98-102.

Mattern, Shannon. 2017. “A City Is Not a Computer,” *Places Journal*, February. https://doi.org/10.22269/170207

Meadows, Donella H, Jørgen Randers, and Dennis L Meadows. 2004. *Limits to Growth : The 30-Year Update.* [Rev. ed.]. White River Junction: White River Junction : Chelsea Green Publishing.

Meadows, Donella H. “Places to Intervene in a System.” In *Whole Earth Review* (Winter) 1997. revised and republished as “Leverage Points: Places to Intervene in a System.” Sustainability Institute. 1999. http://donellameadows.org/archives/leverage-points-places-to-intervene-in-a-system/ accessed 14.08.2018

Mitchell, William John. 1995. *City of Bits : Space, Place, and the Infobahn.* Cambridge, Massachusetts [etc.: Cambridge, Massachusetts [etc.] : MIT Press.

Mitchell, William John. 2000. *E-Topia : “Urban Life, Jim - but Not as We Know It.”* Second printing. Cambridge, MA: Cambridge, MA : MIT Press.

Mitchell, William John. 2003. *Me++ : The Cyborg Self and the Networked City.* Cambridge, Mass: Cambridge, Mass. : MIT Press.

Pask, Gordon. 1969. ‘The Architectural Relevance of Cybernetics’, *Architectural Design*, September issue No 7/6, John Wiley & Sons Ltd (London), pp. 494-6.

Pentland, Alex P. 2014. *Social Physics : How Good Ideas Spread : The Lessons from a New Science.* New York: New York : Penguin Press.

Picon, Antoine. 1999. “La Ville Territoire Des Cyborgs.” *Flux* 15 (36): 76–79. doi:10.3406/flux.1999.1718.

Picon, Antoine. 2013. *Smart Cities : Théorie et Critique D’un Idéal Auto-Réalisateur.* Paris: Paris : B2.

Picon, Antoine. 2015. S*mart Cities : A Spatialised Intelligence.* Chichester West Sussex: Chichester, West Sussex : Wiley.

Price, Rob. 2017. “Google’s Eric Schmidt: ‘Big Data Is so Powerful That Nation-States Will Fight’ over It.” *Business Insider.* http://uk.businessinsider.com/google-eric-schmidt-countries-will-fight-over-big-data-alphabet-cloud-2017-3. (as of 14.04.2017)

Rankin, William. 2016. *After the Map: Cartography, Navigation and the Transformation of Territory in the Twentieth Century.* University of Chicago Press, Chicago.

Rankin, William. 'Noise, Mapping, and Architecture of Statistics.' in *93rd ACSA Annual Meeting Proceedings, The Art of Architecture/The Science of Architecture*. ed. Hejduk, R. and Van Oudenallen, H. 2005

Ratti, Carlo. 2014. *Decoding the City: Urbanism in the Age of Big Data.* Basel: Basel De Gruyter.

Ratti, Carlo and Claudel, Matthew. 2016. *The City of Tomorrow : Sensors, Networks, Hackers, and the Future of Urban Life.* New Haven: New Haven : Yale University Press.

Ratti, Carlo, and Matthew Claudel. 2015. *Open Source Architecture.* London: London : Thames & Hudson.

Riis, Jacob A. 1890. *How the Other Half Lives : Studies among the Tenements of New York.* Cambridge, Mass: Cambridge, Mass. : The Belknap Press of Harvard Univ. Press. 1970 reprint.

Rossi, Aldo. 1982. *The Architecture of the City.* American ed. Cambridge, Mass: Cambridge, Mass. : MIT Press.

Rowe, Colin. 1980. *Collage City.* 3rd printing. Cambridge, Mass: Cambridge, Mass. : MIT Press.

Sassen, Saskia. 2001. *The Global City : New York, London, Tokyo.* 2nd ed. Princeton N.J: Princeton N.J. : Princeton University Press.

Sennett, Richard. 2012. "The Stupefying Smart City." LSE Cities. https://lsecities.net/media/objects/articles/the-stupefying-smart-city/en-gb/.(as of 26.04.2017)

Sennett, Richard. *The Guardian.* 2012. "No One Likes a City That's Too Smart," December 4, sec. Opinion. https://www.theguardian.com/commentisfree/2012/dec/04/smart-city-rio-songdo-masdar.

Shelton, Taylor, Matthew Zook, and Alan Wiig. 2015. "The 'Actually Existing Smart City'" In *The Cambridge Journal of Regions.* 8 (1): 13–25. doi:10.1093/cjres/rsu026.

Simon, Herbert Alexander. 1969. *The Sciences of the Artificial.* MIT Press.

Townsend, Anthony M. 2013. *Smart Cities : Big Data, Civic Hackers, and the Quest for a New Utopia.* New York: New York : W.W. Norton.

Trummer, Peter. 2009. "Morphogenetic Urbanism." In *Architectural Design* 79(4): 64-67.

Trummer, Peter. 2011. "Associative Design: From Type to Population." In *Computational Design Thinking.* Ed. Menges, Achim and Ahlquist, Sean. AD Reader, Wiley, West Sussex.

Weiser, Mark. “The Computer for the 21st Century.” *Scientific American* 265.3 (1991): 94-104.

Weizman, Eyal. 2017. *Forensic Architecture : Violence at the Threshold of Detectability.* New York: New York : Zone Books.

Wiener, Norbert. 1950. *The Human Use of Human Beings : Cybernetics and Society.* London: London : Eyre and Spottiswoode.

Wigley, Mark. 2001. “Network Fever.” *Grey Room*, no. 4: 83–122.

Wigley, Mark. 2015. *Buckminster Fuller Inc. : Architecture in the Age of Radio.* Zurich : Lars Muller Publishers.

Websites:

Rankin, William (data, map), Matt Daniels (code, story.) *The Shape of Slavery.* https://pudding.cool/2017/01/shape-of-slavery/ (as of 02.06.2019)

GaWC. *The World According to GaWC 2016.* https://www.lboro.ac.uk/gawc/gawcworlds.html (as of 02.06.2019)

Films:

All Watched Over by Machines of Loving Grace. Directed by Adam Curtis. United Kingdom: BBC, 2011. TV Series. Episodes 1&2

2 Metric as Mediator: Data-driven Negotiations over Heathrow's Noise Landscape

2.1 Introduction: Heathrow's data-driven noise landscape

Heathrow's noise landscape is uniquely contentious: as the most urban of Europe's hub-airports there has been controversy since the creation of the airport over the effect of aviation noise on local communities. Negotiation over Heathrow's noise landscape has sought to balance the pragmatic concerns of flight, the economic benefits of the airport to the UK, and disruption to the lives of local residents. Quantification of noise as data has been, since at least the 1960s, the mediator that permits negotiations over sound to occur. Mappings of noise contours, clusters of complaints and reams (now petabytes) of other data have allowed the airport operator, the UK government, and local communities to communicate and negotiate their positions relative to the noise landscape.[1]

To gather, analyze, disseminate, and act upon Heathrow's noise data, a complex data assemblage has grown and evolved since its inception in the early 1960s. To tease out the impact of this data assemblage on the architecture and urban form of the Heathrow territory I first sketch out the development of the data-assemblage. I emphasize the development of policy as a primary vector of the data-assemblage for impacting architecture. A degree of *path-dependence* has developed around historic regimes of noise measurement and the policies of noise management that rely on them.[2] However, new technologies for urban sensing and data-sharing in tandem with upheaval from plans to build a third runway provide an opportunity to question long-standing regimes of noise measurement and to re-evaluate the role of the architecture in the Heathrow territory (2.3). With the outline of the data-assemblage and its impact on urban form delineated, I address in a fourth section (2.4) examples of architecture that seeks to re-orient the data-assemblage by acting on specific *leverage points*.[3] A final section evaluates the complex interactions between communities, places and data-markets that have the potential to produce emergent data/spatial organizations in response to the challenges facing the Heathrow territory today.

1 See Boucsein et al. 2017. *The Noise Landscape.* Portions of this chapter have already been published in this book as, "Metric as Mediator: Data-driven negotiations about Heathrow's Noise Landscape." pp. 215-226.

2 Bijsterveld. 2008. *Mechanical Sound: Technology, Culture, and Public Problems of Noise in the Twentieth Century.* See 'A Sound History of Technological Culture' pp. 233-262.

3 My framework for understanding ways to interact with complex systems is based on Meadows' 'Places to Intervene in a System.' This text and my use of it is discussed at length elsewhere in the text.

2.1.1 Heathrow before the airport

Before the second world war, Heathrow was a patch of farm land serving a ring of quaint English country-side villages dating back at least to the middle ages. The Bath Road that runs to the north of the Heathrow airfield was the primary route from London to the English town of Bath, and took up its name in the late 1680s when Queen Anne became a frequent inhabitant of that city. Aviation was attracted to the area, apart from its proximity to central London, for the same reason that farming had previously been so prevalent: the flatness of the landscape. The Royal Air Force made some use of the Hounslow Heath area (adjacent to present day Heathrow) already during the first world, and from 1919-1920 London's first aerodrome was located in the same spot.[4] In 1939 the village of Cranford (which still in part exists to the east of Heathrow) was already threatened with destruction by plans for the expansion of the Heston Aerodrome. A contemporary news article warned, "Pretty little Cranford, one of the last remaining villages in the London area is doomed." The owner of a local farm complained: "The land [...] is the best agricultural land in Middlesex."[5] Aviation has had a presence on the site for more than a century, and conflict over its presence is almost as old.

During World War two the RAF continued using the area as an airfield. Aviation evolved considerably during the years of the war, making runways longer. In 1943, with the European war seen to be ending and preparations for a second phase in Japan beginning, the Air Ministry requisitioned a larger portion of land at Heathrow under war-time powers for an extended airfield. Patrick Abercrombie's *Greater London Plan* of 1944 shows Heathrow as the site of a major civil airport, and as the largest and most important of a new network of airports serving the British capital.[6] The choice of the site made continuing conflict over noise inevitable: prevailing winds dictated a primary east-west orientation of the runways and resulted in aircraft approach paths that ran over densely populated west London in the east, and in the west over Windsor.[7]

During the post-war years Heathrow airport was an economic center that drove the creation of the current sprawling morphology of its territory. Heathrow was converted to a civilian airport in 1946 and began to expand traffic so rapidly that by the end of the decade there was a need to find an additional airport to take on excess traffic in peak periods. Growth in aviation attracted new business like British Airways and British Midland International and bolstered existing industrial employers like AEC in Southall.[8] This economic growth was exceptional in post-war London where much of the industrial base of employment was lost in this period. Economic vitality near Heathrow drove a surge of population in the Heathrow villages and produced much of the residential fabric visible today. The

4 Sherwood. 2009. *Heathrow: 2000 Years of History.*

5 The quotes are form The Evening Standard, Friday April 28 1939- as reproduced in Philip Sherwood's Heathrow 2000 Years of History.

6 See Abercrombie. 1944. Greater London Plan. p.79. Heathrow is proposed as 'chief airport' for London among nine other sites including Gatwick. An illustration of 'Airways' (facing p. 86) shows the Heathrow site next to a proposed 'orbital parkway.'

7 Barrat, Nick p.451. See also, Sherwood p. 76. See also Hall, Peter p. 17 highlighting the problem of prevailing winds ensuring traffic over populated areas of London. As a side note, contemporary conflict over the third runway to be built north of present-day Heathrow was anticipated by Abercrombie who already proposed in the 1940s that these lands should be reserved for the airport: "In fixing a site which will obviously be of extreme importance it is desirable to secure ample room.[...] The portion north of Bath Road has been included as it is desirable to provide for possible future needs; it would be unfortunate if a major airport was developed and later had to be abandoned because land in its vicinity had not been kept open." Abercrombie. 1944. Greater London Plan. p.79

8 Barrat, Nick. P.416 "The area was transformed [after the opening of Heathrow]. Villages became service centers; Harlington, Harmondsworth, Longford, Cranford, Hounslow, Hatton, Bedford, Stanwell, and even Colnbrook (situated just outside Greater London), all started to sprawl into one another, several of them now connected to central London via the Piccadilly line." "Aviation was very much the exception to London's industrial decline." On page 415: "One of the very few growth areas after the war was aviation, or, more particularly, Heathrow." On page 455: "As nearby Heathrow Airport expanded in the 1970s and 1980s, creating further employment in the area [...] new housing encroached on such open fields and market gardens as there still were, and the suburb acquired the look and feel it has today."

spaces between the historical Heathrow villages were filled in by semi-detached homes with thin strips of yard. Bath Road, to the immediate north of Heathrow, became the site of many new hotels serving the airport and Southall became the site of a cosmopolitan and industrially-oriented community.

2.2 History of monitoring noise, mitigating noise at Heathrow

The data-assemblage which measures and manages Heathrow's aircraft noise first emerged in the 1960s in response to a crisis over the disruptive noise of new civilian jets. Compared to earlier propeller planes, new jets like the Boeing B707 produced a louder and higher frequency 'screaming' noise that traveled greater distances.[9] Combined with a rapidly increasing number of flights moving through the airport, the Heathrow territory was experiencing unprecedented levels of noise by the late 1950s. In 1959 popular outcry over increasing aircraft noise contributed to the founding of the Noise Abatement Society (NAS) by pioneering noise protester John O'Donnell (who famously also campaigned to introduce rubber dustbin lids throughout Britain).[10] The NAS organized a series of noise protests; the most notorious of which was held at 2 a.m. in front of the home of the Aviation Minister to drive home to the government the disruption caused by night flights at Heathrow.

In response to petitioning from the NAS, parliament passed the Noise Abatement Act of 1960, instituting new controls on noise throughout the UK. However, in a setback for the communities surrounding Heathrow, the Noise Abatement Act upheld a prohibition on legal action for nuisance arising from civil aircraft. This restriction was justified as a necessary protection for the British aviation industry.[11] Without legal recourse, the residents of the Heathrow villages would be helpless to influence the ever-increasing level of noise enveloping their communities. In compensation the Minister of Aviation recognized an obligation to 'take steps to minimize the nuisance' from aviation noise.[12] A first step toward the fulfillment of this obligation was the appointment of a committee to study England's noise problem with an emphasis on Heathrow. The so-called 'Wilson' Report on Noise, named after the chairman of the committee, was presented to Parliament in 1963 and addressed the problem of aviation noise at Heathrow first through social research on noise impacts and second by suggesting policies for mitigation.

2.2.1 Noise monitoring: the Wilson report on noise, 1963

The Wilson report created the first noise quantifications and maps of the Heathrow noise landscape. The authors of the report visited the Heathrow site, surveyed its residents, and reviewed what records existed. They noticed that noise complaints had increased at the end of the 1950s at the time of the introduction of the new jet airliners and continued to increase in proportion to the growing number of flights.[13] This observation led them to assume that noise disturbance increases in direct proportion to both the noise level of flights and to their frequency. Based on this assumption they invented a new noise disturbance metric, the Noise and Number Index (NNI), which averages out the noise and

9 Bijsterveld p.196-197.
10 Goldsmith, Mike. 2012. Discord : The Story of Noise.
11 Committee on the Problem of Noise, Noise: Final Report, (London, Her Majesty's Stationery Office, 1963), p.65, s.260. "Sections 40 and 41 of the Civil Aviation Act, 1949, broadly prohibit actions for nuisance arising from civil aircraft in flight or on aerodromes. [...] The main reason for this protection was that unless the individual's right to take action for nuisance was restricted, it was feared that civil aviation in this country would be unable to continue." See also s.261, "Since legal action against aircraft noise nuisance is severely restricted, the Minister of Aviation considers himself under an obligation to take steps to minimise the nuisance."
12 Ibid. p.65, s.261.
13 Ibid. p.63, s.250, Table X.

number of aircraft overflying a geographic point for a specific period of time[14]. NNI represents an early predecessor of the LAeq metric used today.

By polling residents on their degree of noise disturbance and comparing this to the noise and number of flights overhead the authors of the Wilson report established certain key thresholds of aviation noise disturbance. In particular, they made the conjecture that 50 to 60 NNI was 'the critical range above which annoyance becomes intolerable.'[15](fig. 1) Interpolating between noise measurements they drew a noise contour map of Heathrow for the year 1961 which shows concentric contours around Heathrow starting at 50 NNI and going up to 70.(fig. 4) With this mapping technique they also created of a projected noise contour map for ten years in the future (1971), which predicted the noise problem growing in severity as flight numbers increased.

A first effort at noise mitigation through the modification of jet engines had mixed results and seemed insufficient to the magnitude of the problem. The study found that the addition of noise suppressors to the jet engines resulted in some mitigation of noise, though they did little to change the whine of compressors during landing.[16] Changes in flight procedure also resulted in some noise mitigation, with steeper take-off trajectories limiting the area impacted by noise. Yet, aircraft of the time were unable in practice to deviate from a three-degree approach angle, which meant that areas under the Heathrow approach path could expect little relief from changes in flight procedure. In spite of these efforts to mitigate aviation noise at its source, the Wilson report found that, 'there are many dwellings so near to London Airport that it is impossible to reduce the noise at particular inhabited locations to levels which most people would find reasonable.'[17] The committee concluded that Heathrow's noise contours would continue to expand through the sixties and beyond no matter what noise suppression technology was applied to jet engines. They came to the pragmatic conclusion that if people were to continue living in the Heathrow territory they would need to be shielded from increasingly severe aviation noise.

2.2.2 Noise mitigation: insulating homes

The British *Building Research Station* at Garston collaborated with the author's of the Wilson Report to test modifications that might make existing homes more sound-proof.[18](fig. 2, 3) These efforts were motivated by evidence collected from medical experts and community members suggesting that noise disturbance was most acute at night when residents were sleeping. It was thought that modifying home construction to reduce noise would at least protect this one sensitive period of time. At the research station a series of experiments were run comparing standard single windows to new double windows combined with noise-dampening ventilation systems. The researchers found that a noise reduction of 40 dB could be achieved using a combination of these two techniques: an increase of 20

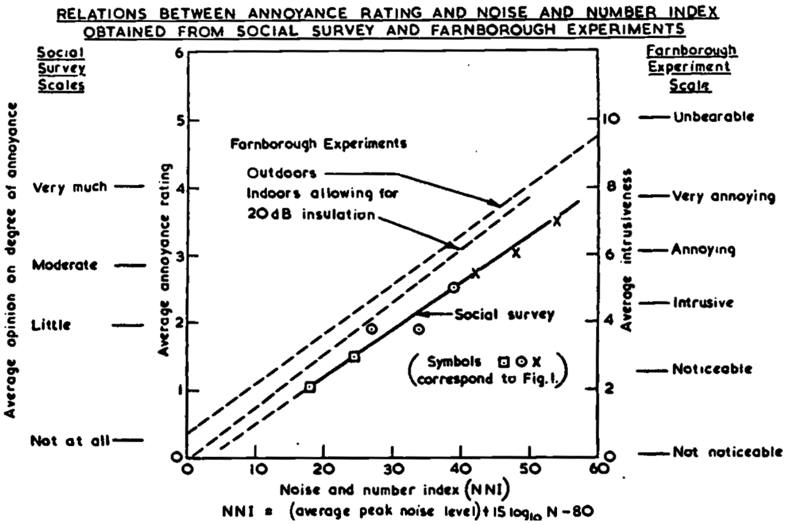
14 Ibid. p.74, s.299. "The results of the survey show that, as was to be expected, annoyance increases with the number of aircraft heard and with their average peak noise level, and there was a fairly definite correlation between the effect on annoyance due to an increase in noise level and the effect due to an increase in number. This led us to our third conclusion, namely that the survey provides a tentative basis for establishing a combined "noise and number index," defining the total noise exposure which causes annoyance. This is, in a way, a measure of the total noise energy reaching the area in a given time, or a measure of the number of seconds of speech interference in a given time"

15 Ibid. p.75, s.302.

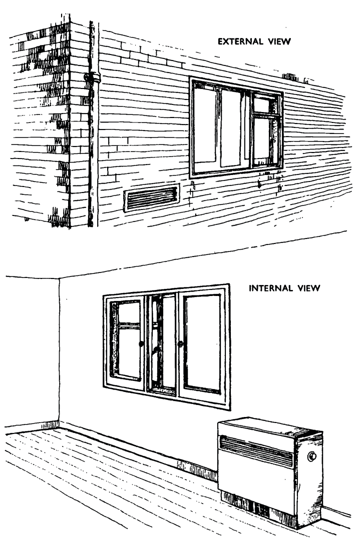
16 Ibid. p.65-66, s.262-265.

17 Ibid. p.76, s.305.

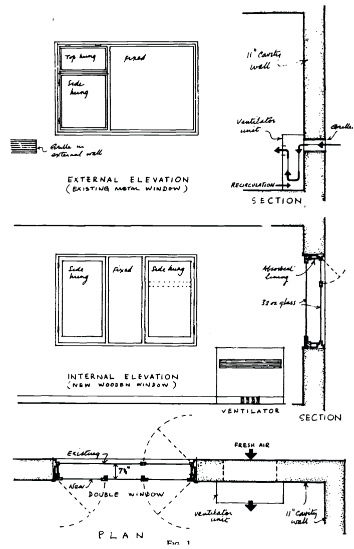
18 Ibid. p. 76 "To assist us the *Building Research Station* installed open-able double windows, together with a mechanical ventilator incorporating a noise attenuator, in each of two rooms in a building at Garston, and later in a house near Heathrow." See also Appendix XIII.5 "Both the buildings used for the trials were of traditional load-bearing brick house construction, two-storey, with pitched tiled roofs. Measurements of noise reduction from outside to inside were made with single windows, double windows, and double windows with ventilator unit." Parenthetically, this institution still exists today as the *Building Research Establishment* (BRE), though privatized, and is responsible for the creation of sustainable building assessment systems like *BREEAM.*



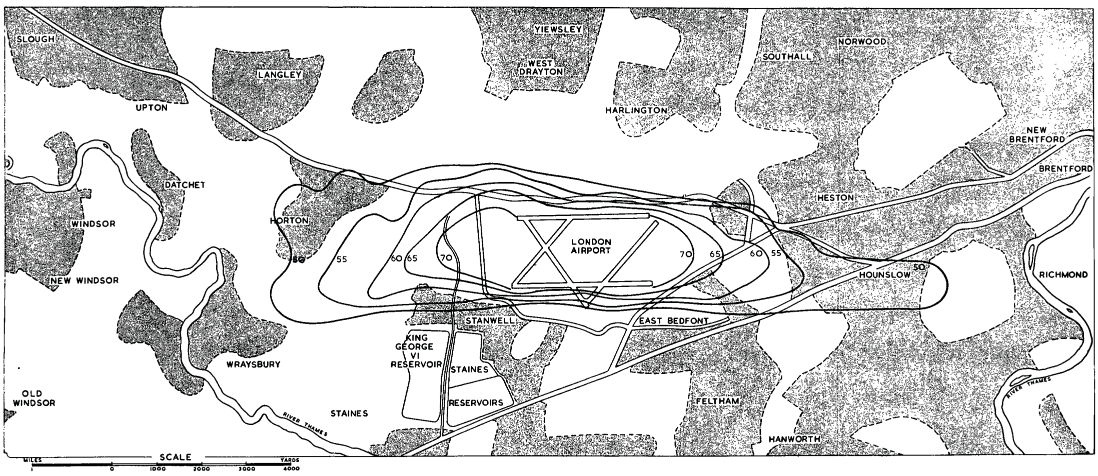
1. Wilson Report: comparing Noise and Number Index to survey results



2. Wilson Report: proposals for insulated windows and ventilation units



3. Wilson Report: proposals for insulated windows and ventilation units



4. Wilson Report: NNI contour map Heathrow 1961

dB over the standard assembly.[19] The Wilson Report concluded that a policy of insulating homes in the Heathrow area was, 'the only practicable means of ameliorating the lot of those who are subjected to excessive noise.'[20]

If insulating homes presented the only practical solution to noise in the Heathrow territory, the authors of the report were left with the questions of who should pay for this insulation, and who might be eligible.[21] The final recommendation of the report was that any grant for home insulation would be provided by the airport and would only cover part of the costs of the purchase and installation of insulated windows and adapted ventilation systems.[22] Crucially, the report also suggested that hospitals and schools also be insulated against noise. To be eligible to receive a noise insulation grant, the Wilson Report suggested that residents should live within the critical 50/60 NNI contour. The NNI metric, originally an approximate designation used to study the phenomenon of noise disturbance, was thus re-applied as a policy threshold making it possible to implement the home insulation grants in only the areas deemed most impacted by aircraft noise.

Though a pragmatic solution, in retrospect the fairness of excluding individuals from the insulation grants based on what even the Wilson report acknowledged was an approximation is at least questionable.[23] A further complication resulted from the use of a metric developed for urban study as a threshold for implementing urban policy. By implementing a policy on home insulation within an NNI contour, the authors of the report were fundamentally altering the way noise disturbance was spatially-distributed within the noise landscape. This would contribute to decoupling the NNI metrics from the community's actual experience of aviation noise. In the second survey of noise disruption at Heathrow, conducted in 1967, it was found that community attitudes toward noise were 'hardening'; a possible indication of this sort of complex feedback between social research and public policy.[24]

Everyday architecture was instrumentalized by the Wilson report as a data-driven tool to mitigate aviation noise, an unpleasant secondary effect of the revolution in global mobility of the 1960s. As a tool of territorial policy, architectural elements were used as a distributed array of public-private financed infrastructure, functioning together to make the territory livable. The codification of the Wilson report's recommendations in public policy, as occurred over subsequent years, enforced the idea that jet noise would be an inevitable feature of the exterior environment in the Heathrow territory, and significantly, that the only protection from this noise would be interior, built space, (or migration away from Heathrow.) Insulated homes, like the space-capsule of the 1950s, would allow residents of the newly hostile (or at least unpleasant) exterior environment to survive.[25] Everything existing outside of the architectural envelope would be unprotected by the policies first suggested in the Wilson report. While architecture was the primary vector for mitigating noise near Heathrow,

19 Ibid.
20 Ibid. p.78, s.317.
21 Ibid. p 79, s. 319 b, "The noise in the residential areas close to the airport is the worst known in this country, and the people who suffer from it have no right of legal action to secure its abatement. Also, a grant for improving sound insulation is more akin to a house improvement grant than to compensation for living in a noisy area. We accordingly recommend that grants should be paid towards the cost of improving the sound insulation of existing houses near Heathrow Airport."
22 Ibid. p 79, s. 321 b, "The noise and number index is the obvious criterion to be applied in deciding which householders should be eligible for a grant. There is, however, abundant evidence that personal factors have great influence on the degree of annoyance which is induced by the noise. [...] In the areas where the noise exposure is such that a grant should be payable it is still necessary to discriminate between the seriously annoyed and those who are less troubled. The former will wish to do something to reduce the nuisance, whereas the latter will not. We propose, therefore, that the grant should never be the whole of the cost."
23 Ibid, p.75, s.303.
24 MIL Research Limited, Office of Population Censuses and Surveys, Social Survey Division. (1980). Second Survey of Aircraft Noise Annoyance around London (Heathrow) Airport, 1967. [data collection]. UK Data Service. SN: 1539, http://doi.org/10.5255/UKDA-SN-1539-1. See also Goldsmith, ***Discord***, op. cit. (note 2), 249.
25 Gagarin and Glenn launched in their insulated pods in 1961 and 1962 respectively, during the drafting of the Wilson report.

it was also the unacknowledged limit of intervention. There is no discussion of larger scale efforts to shield neighborhoods from noise.[26] Backyards, sidewalks, parks, squares, plazas, wilderness areas: any impact of noise on these spaces is left unmentioned by the Wilson report.

Many of the Wilson Report's policy proposals, including the drawing of noise contours, establishment of annoyance thresholds, and subsidized shielding of buildings, still exist in only slightly modified form today, and are evidence of a strong *path-dependence* in this socio-technical assemblage. Looking forward we can see that advancing technologies and the expansion of Heathrow are changing the relations of mutual interaction between the urban form of the Heathrow villages and the noise-oriented data assemblage.

2.3 Reorientation: a growing population, an expanding airport

Aviation noise in West London remains controversial because of the intersection of ever-growing air traffic through Heathrow and the frenetic real-estate market of the London megalopolis. Recent changes in population density in London and jet-engine technology are having significant impact on Heathrow's noise landscape. Although the number of passengers per annum flying through Heathrow has steadily grown since the 1960s (Heathrow has been and remains one of the busiest airports in the world) this growth has not resulted in a directly-proportional increase in noise pollution. New generations of efficient engines have greatly reduced the noise generated by the newest classes of commercial jets. This technological evolution has resulted in a shrinking of the area of noise contours near Heathrow despite consistent growth in the number of aircraft movement and passengers per annum.[27]

While Heathrow's noise contours may have decreased in area in the last thirty years, the overall population of its territory has continued to grow, and density has increased even in heavily noise-impacted zones. A brief review of London's census data shows that Hounslow and Hillingdon (the Boroughs containing the Heathrow territory) grew rapidly between 1939 and 1971 while the rest of London declined in population. As population growth resumed in Greater London from 1991 to 2015, the Heathrow boroughs continued growing at a similar rate.[28]

Future plans suggest there will be continued population growth of the Heathrow territory: the London Plan as updated in 2016 names Heathrow an opportunity area and establishes a minimum goal of 9,000 new homes to be built in the territory.[29] The mayor's office in this document also sharply opposed any expansion at Heathrow: "noise problems and poor air quality at Heathrow have reached such levels that further increases in the number of air traffic movements there are untenable."[30] These plans, the most updated at the time of writing, were made before the approval of the expansion of Heathrow.

The operator of Heathrow, for its part, seems to believe the city's plans to increase housing in the area

26 The Wilson report saves its reflections on territorial planning for future airports. See p. 81 s. 333, "On the evidence at Heathrow this system of consultation and advice does not appear to be adequate, and we think that, from the time that the development of an airport is first considered, planning control should be used to secure a pattern of development which is compatible with the future noise condition."

27 For an overview of why contemporary aircraft are quieter from a technological and policy perspective (with a good overview of the International Civil Aircraft Organization's (ICAO) ***Balanced Approach*** and the noise ***Quota Count*** system used for London Airports) see Leylekian, L., et al. , "An Overview of Aircraft Noise Reduction Technologies." 2014. Heathrow's operator often trumpets its shrinking noise contours in their press releases, see for example: "A Quieter Heathrow" p. 14 fig 4.3 and 4.4

28 See historical London Census data at https://ukdataexplorer.com/census/london/

29 Mayor of London. 2016. ***The London Plan: The Spatial Development Strategy for London Consolidated with Alterations Since 2011.***

30 Ibid Section 6.28 p.253 See also UK Government's *Aviation Policy Framework* 2013. "Our overall objective on noise is to limit and where possible reduce the number of people in the UK significantly affected by aircraft noise."

are misguided, or at least insufficiently controlled: "CAA figures show that there are 16 per cent more homes now than in 1991 within the 57 decibel Leq noise contour around Heathrow. This means that the progress by the aviation industry in introducing new planes and procedures to shrink the noise contour has not been matched by progress in limiting noise sensitive developments near the airport."[31] Heathrow's position is that land use in the airport territory should be limited, at least within the 57 dB Leq contour, to less 'sensitive' programs like business and industry.

Looking to the future, conflict between Heathrow and the communities in its territory is likely to increase in intensity as plans for the third runway north of Bath Road move forward. (An Airports Commission Report of 2015 recommended the expansion of Heathrow, in 2016 this recommendation was approved by the British government, and in 2018 Parliament voted in favor of the expansion.) Noise impact on local communities (not to mention displacement) will be a major point of contention. Heathrow has evolved its policy of 'noise management' in recent years, with the knowledge that their success in community relations would impact the government's decision on the third runway.[32] New efforts at noise management by Heathrow seek not only to monitor noise levels and subsidize noise mitigation, but to also build community tolerance through better communication. By making more data more accessible, and by automating systems of complaint and subsidies, Heathrow hopes to increase community 'tolerance' to aircraft noise and convert conflict to partnership. As before, we will see that architecture continues to serve as a policy tool in this conflict, shielding residents in the noisiest areas.

2.3.1 New techniques of noise tracking, noise management

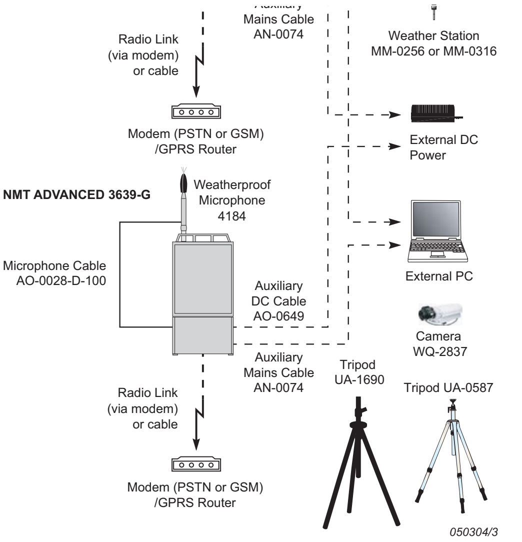
A turning point in the evolution of Heathrow's noise-management system began with the recognition in the *Aviation Policy Framework* of 2013 that the noise contour is less than perfect at facilitating communication between airport and community about noise events. Noise contours are averaged out over the course of the day, with a complicated set of weights for night noise versus day noise, and then averaged again over the course of the year. Frequency and pattern of flights are not expressed, nor are the highest peaks of noise- which create the greatest discomfort. Though noise contours do predict areas where inhabitants are more likely to be annoyed by aircraft noise, the particular annoyance of one individual with one flight is not relevant to its delineation. The *Aviation Policy Framework* goes on to state, "the Government encourages airport operators to use alternative measures which better reflect how aircraft noise is experienced in different localities [...] The objective should be to ensure a better understanding of noise impacts and to inform the development of targeted noise mitigation measures."[33] Following this shift in the goals of noise-data visualization, away from expert-only communication to communication with non-expert stakeholders, Heathrow has begun exploring new ways of sharing noise data with the community.

A significant new development in noise data sharing at Heathrow has been the creation of interactive

31 "A Quieter Heathrow." p. 27

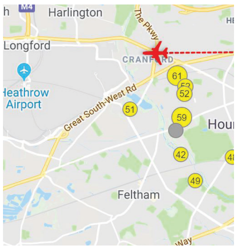
32 See introduction to 'A Quieter Heathrow." "If Heathrow is to grow, a comprehensive package of measures to tackle noise will need to be put forward at the appropriate time. Before the Airports Commission reports in the summer of 2015,we will need to be able to demonstrate that Heathrow can grow quietly. There will not be a choice between more flights or less noise – we will need to deliver both." See also "Heathrow responds to Airports Commissions conditions."

33 Aviation Policy Framework. 2013. See s. 3.3.

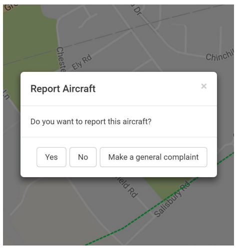


5. B&K Noise Monitoring Station Components

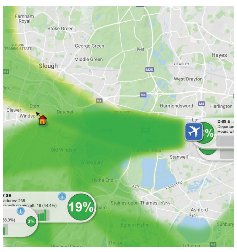
6. Heathrow Noise Monitoring Station- Hounslow Heath



7. B&K *WebTrak*

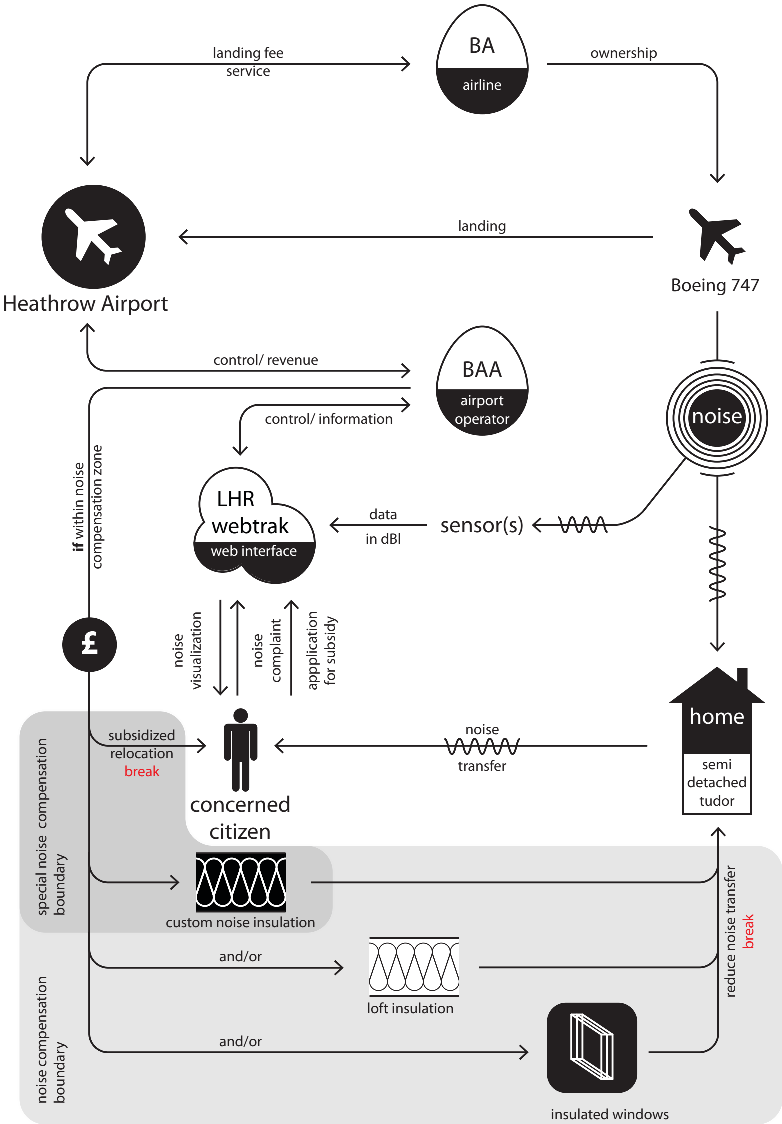


8. B&K *WebTrak*, Complaint



9. B&K *MyNeighborhood*

10. Heathrow Quieter Homes Scheme



11. Heathrow feedback framework

on-line maps. Heathrow's current online noise map uses a noise tracking software developed by Danish acoustics engineers *Brüel & Kjær* (B&K), called *WebTrak*. The site displays an animation of flights arriving and departing from Heathrow overlaid on a navigable background map.(fig. 7) When a flight icon is clicked on the noise-tracking map, a popup window appears detailing the flight number, aircraft type, altitude and speed at the given moment. A timeline and date menu allow a huge range of historical flights to be reviewed. A delay of between twenty minutes to an hour (or more) makes it impossible to see flights currently overhead. An array of circles marks the location of noise sensors in the Heathrow territory, each with a number at its center representing the measured decibel level of noise at that location. Currently there are more than thirty active sensors mostly clustered immediately to the east and west of Heathrow under the primary approach/ departure paths. (Although, some sensors are as far away as central London.)

The noise monitors themselves can be located while walking through the Heathrow territory with a little guidance from the *WebTrak* webpage.(figs. 5,6) The sensors generally occupy a small fenced-in plot and look like large microphones mounted on metal poles accompanied by a small metal shed. Occasionally a weather station shares the pole with the microphone. When I visited the Heathrow area in 2016 some sensors were dubiously placed, for example surrounded by thick foliage that may have blocked noise. Since that visit, however, the number of sensors listed on the *WebTrak* site has more than tripled, a development which signals not only a likely increase in the fidelity of Heathrow's noise monitoring, but also the intensity of interest in noise near Heathrow and the importance of noise monitoring to Heathrow's plans for expansion. Press releases for *Brüel & Kjær* state that 50 noise sensors will eventually be installed in the Heathrow territory, a mix of stationary/permanent and portable terminals.[34]

The *WebTrak* map also makes it possible the user to file a noise complaint for a specific flight.(fig. 8) When clicking on a flight, a button with a text bubble icon appears- clicking leads to a pop-up, 'Do you want to report this flight?' Possible response to this prompt include 'Yes', 'No', and 'Make a General Complaint.' The complaint form includes fields for an address of the reported noise incident, and this geo-located complaint data (along with other complaints made by phone) are integrated into another set of maps that record historical/geographical patterns of complaints. While the maps of complaints seems to exist primarily for the review of the airport, its consultants and the government- they are nonetheless regularly published by the airport operator on its website with an archive going back to 2015.[35] (fig. 26)

2.3.2 Noise management

A second software tool within the online map, *WebTrak myNeighborhood*, also created by B&K, is oriented not to the identification and reporting of the noisiest aircraft but to creating understanding of large-scale patterns of air traffic.(fig. 9) The *myNeighborhood* tool prompts the user for an address, and for this address will display a flow-like representation of nearby flights over a given period of time. Infographic bubbles hover over individual paths within the flow and explain the percentages of flights taking this path and their heaviest periods of usage. The *myNeighborhood* tool gives residents of noisy areas an understanding over long periods of time, the shortest being one month, of what aircraft pass by their homes, how frequently, at what times of the day, and whether they are arriving or departing. The option to look specifically at day-time, evening and night-time flights allows the user to focus in on periods of the day important to him/her. The goal of this tool is broader than that of identifying

34 "Brüel & Kjær to Provide Heathrow Airport with 50 Noise Monitoring Terminals." Environmental XPRT.
35 Heathrow Airport. "Noise Complaints Reports." https://www.heathrow.com/noise/reports-and-statistics/

and reporting one annoying flight, instead the long-term noise data visualization works to change community perception of noise.

Beyond just sharing information, *WebTrak* My Neighborhood seeks to 'manage' noise within the Heathrow territory. Douglas Manvell, a *B&K* engineer, advocates for the deployment of noise management tools over noise monitoring:

> "Noise management is defined by Brüel & Kjær as the management of the environmental noise capacity by reducing impact on and building tolerance in the surrounding community.[...] Monitoring, being after the fact, can only inform about past problems and is usually based on relatively simple legal limits (for example, the hourly LAeq level must be less than 68dB(A)) rather than on the current situation. Thus, it means that the community is negatively impacted before the system tells you to do something about it. Management, however, can avoid problems and, in addition, capture trends reflecting what is currently happening. Thus, management aims to address the issues before any negative impact is felt and is therefore generally more successful as it avoids upsetting stakeholders at all."[36]

Noise management, thus has two aspects. First, it shortens the feedback loop between identifying noise "trends" and making changes before, "negative impact is felt." This accelerated feedback and action loop is familiar as a typical selling point of data-driven urban systems. The second aspect of management, tolerance building, is less prevalently discussed; that sharing data about noise (or any urban nuisance) might change a community's threshold of acceptance for the nuisance. The *WebTrak myNeighborhood* tool uses the long time-scale data visualizations to transform one individuals seemingly random experiences of noise nuisance into a repetitive and understandable global pattern. This act of reconceptualizing one's annoyance within the larger pattern of the airport's operations overlaps with 'cognitive participation' as a sociological technique of normalization.[37] If aircraft noise is understood as part of an understandable, predictable, and accepted pattern, then responsibility for noise annoyance shifts away from the airport or airline and to the individual who can make lifestyle choices to avoid annoyance.

Furthermore, the idea of building tolerance is related to observations about the subjectivity of noise annoyance made by psychologists and sociologists, who emphasize the importance of the "feeling of being in control" in reducing noise nuisance.[38] If the response to aircraft noise is partially psychological, then that psychological state can be managed by providing clear information about noise and fast and effective means of registering a complaint, thereby creating a sense of empowerment instead of helplessness. The sociological theory of normalization even suggests that the registering of a complaint, ostensibly an act of defiance, may act as a form of 'reflexive monitoring,' in which the individual is enrolled as a participant in the normalization of aircraft noise by validating the process of its assessment.[39] The importance of empowerment to Heathrow's tolerance building campaign is suggested by the language of the Heathrow website where the *WebTrak* software is accessed by a link labeled, "What you can do."[40]

---

36 Manvell, Douglas. 2015. "Noise management is defined by *Brüel & Kjær* as the management of the environmental noise capacity by reducing impact on and building tolerance in the surrounding community. This involves not only the collection of data but the utilisation of it for those 2 purposes. Noise and other data can be collected, processed and disseminated to different stakeholders to help manage environmental noise compliance and impact and inform interested parties on the current situation, trends and issues."

37 May, Carl, and Tracy Finch. 2009. 'Implementing, Embedding, and Integrating Practices: An Outline of Normalization Process Theory.' Vol. 43, 2009. See. "Cognitive Participation" and later "Reflexive Monitoring."

38 Bijsterveld. 2008. p.254 She references among others: Broer, Christian (2006) Beleid vormt overlast: Hoe beleidsdiscoursen de beleving van geluid bepalen. Amsterdam: Aksant.

39 See May, Carl and Tracy Finch. 2009. op. cit.

40 Heathrow. https://www.heathrow.com/noise/what-you-can-do

In parallel with online noise data visualization tools much of the information surrounding subsidies for home insulation has been introduced on the website. On the Heathrow noise website, a dropdown menu titled 'What You Can Do,' lists in the following order: 'Track flights on maps, Make a complaint about noise, and Apply for help.' Applying for help means applying either for a subsidy for home insulation (including the Adobe Huts for schools which will be discussed later) or for a subsidy to move away from the Heathrow area:'Eligible homeowners receive a lump sum of £5,000, plus 1.5% of the sale price of the property (up to a maximum of £12,500). There is only one payment per person and per property.'[41](fig. 10) While the noise monitoring and complaint system can be safely described as data-driven, in that it collects, analyzes and disseminates data in a highly automated manner, the application for and implementation of noise insulation, or subsidized displacement remains less than automatic. The ultimate application for insulation or relocation is currently made by phone or email, processed on an individual basis, installations are done by one of two contractors pre-approved by Heathrow and the wait apparently is up to 4 years.[41]

2.4 Built form: protection and protest

The use of insulated interior environments as a policy tool to make the areas closest to Heathrow livable is the architectural legacy of the 1960s Wilson report. This policy was first formulated in response to the effects of aviation noise on public health that were beginning to be understood at the time of the Wilson report and have been increasingly well-established since. The population-wide impacts of aviation noise on sleep, on learning in schools and patient health in hospitals have all been the subject of study. In each case the detrimental effects of aviation noise have been repeatedly demonstrated.[42] At Heathrow the policy first proposed by the Wilson report is still in force: homes within a certain noise contour have a right to receive subsidies from the airport for noise insulation. Similarly, government policy dictates that schools and hospitals within certain noise contours will be insulated at the cost of the airport. The consequence of these public-health oriented policies, however, is community-wide reliance on sealed interior environments at night as well as day. Life in the open air is put at a lower priority, and little thought is given to what consequences noise may have here.

There is a general understanding that public space near Heathrow is not of the same quality as public space elsewhere.(fig. 15) This is expressed, for example, in the open space strategy for the borough of Hounslow which observes that residents near Heathrow in neighborhoods like Cranford tend to travel more often by car to access open space for recreation.[43] To what extent noise from the airport impacts the use of public space is difficult to establish, but an anecdote from a local school suggests that it significantly modifies patterns of social contact in exterior space.

2.4.1 Adobe noise shelters for school children

In 2011 administrators at Hounslow Heath School, directly under the approach path to Heathrow, became concerned about the disruption aircraft noise was causing to the students' outdoor playtime and learning. One account claims that at peak times the play area is overflown every sixty seconds, and

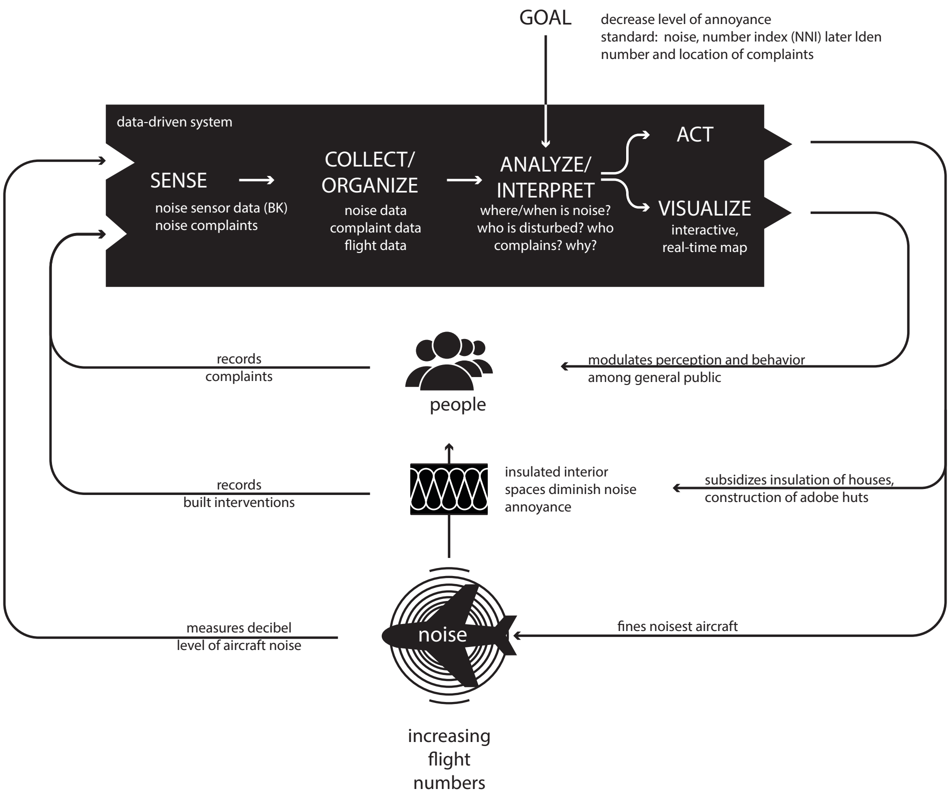
41 Heathrow. "Quieter Homes." https://www.heathrow.com/file_source/HeathrowNoise/Static/Heathrow_Quieter_Homes_Q_and_A.pdf
42 J. Stewart and A. Bronzaft. 2011. *Why noise matters : A worldwide perspective on the problems, policies and solutions.* p. 52-56. See also: Hansell, Anna et al. 2013 "Aircraft noise and cardiovascular disease near Heathrow airport in London: small area study." *BMJ* (The British Medical Journal); 347 :f5432
43 London Borough of Hounslow. 2013. *Open Space Strategy: Final Draft*, April 2013. p.6-7, s.1.14.

12. Adobe Hut, Hounslow Heath School

13. Adobe Hut, Hounslow Heath School

14. Adobe Hut, Hounslow Heath School

15. River Crane Public Park in Cranford, near Cranford Primary School



16. Generalized schema of the Heathrow feedback framework

that the noise for each flight lasts on average thirty seconds.[44] School administrators and Hounslow city council members supported their concern about the effects of the noise with findings from psychological studies that demonstrated developmental delay in students attending school in areas heavily-affected by aircraft noise.[45] In response to this challenge, school administrators developed a strategy for shielding exterior areas from noise with a series of open-air adobe domes.(figs. 12-14) The domes block and dampen noise coming from overhead while still permitting an open-air experience for playing and learning. Heathrow contributed in part to the financing of the adobe huts, and after an apparent success has committed to fund the construction of huts at twenty-one other local schools, with an additional eight being built by 2016.[46] The success and expansion of the adobe huts program raises further questions about the impact of aircraft noise on community-wide public space. What can be done to protect public space, and is shielding a viable solution?

The case study of Heathrow thus far has shown us architecture subsumed into the assemblage of technological systems and public policy. We have described the deployment of everyday architecture as a distributed infrastructure, shielding the Heathrow territory from aviation noise.(fig. 16) Noise insulation subsidies, have been shown effective in bringing about large scale territorial assemblages- a large-scale public infrastructure compose of many small private structures. The analytic frame we have used thus far has moved from the history of conflict over noise at Heathrow and zoomed in toward the built environment. This method has tended to depict the architectural artifact as lacking agency, as an implement of very large-scale policy goals. While accurate on its own terms, this is only a partial depiction of the role of architecture in the data-driven city. A closer examination of a few key projects offers an understanding of how the creators of the built-environment can have an impact on larger scale urban systems.

The Heathrow case study also provides us with examples of architecture with the potential to influence the evolution of the data-driven city. A first example, Grimshaw's proposal for the expansion of Heathrow, extends the logic of noise-shielding to public space, broadening the scope of the pre-existing trend and providing a form of positive feedback to the data-driven urbanization of the Heathrow territory.[47] A second example, Luis Callejas' project to block the expansion of Heathrow, provides an example of how architecture might attempt to push back on the data-driven city.

2.4.2 The Grimshaw vision for the expansion of Heathrow

The British architectural office Grimshaw released in 2016 a vision for the future expansion of Heathrow. This vision, an abbreviated, aspirational masterplan, proposes an expansion in scope of the policy of noise shielding through the application of a new architectural technique. This proposal amounts to an expansion of the working methods of the data-assemblage as it has been defined so far. The Heathrow data-assemblage displays features of *path-dependence*; where initial system design features are perpetuated in time, in spite of their flaws, because it is less costly to proceed with the status quo than to effectuate a radical overhaul.[48] Karin Bijsterveld has provided, elsewhere, a compelling description of path-dependency in airport noise measurement with Heathrow as a case

44 R. Cadbury. 2011. 'Ruth Cadbury: Adobe Outdoor Classroom- Not an Igloo!' 6 June 2011.
45 P. Cerar. 2013. 'Heathrow Noise Hinders Pupils Reading Progress', *London Evening Standard* (London), 28 March 2013.
46 G. Topham, 2013. 'Heathrow Pays £1.8m for Adobe Huts to Protect Pupils' Ears from Aircraft Noise.' *The Guardian* (London)
47 Meadows, Donella. 1997. 'Places to Intervene in a System.' *Whole Earth.* See leverage point 6, "Driving positive feedback loops."
48 David, Paul. 1985. "Clio and the Economics of QWERTY." pp. 332-337.

study.[49] The contemporary practice of insulating buildings near Heathrow, based on technological and policy experiments of the 1960s, it can be argued are examples of path-dependency. In the case of the Grimshaw vision, however, we see the original goals of the Heathrow data-assemblage (noise mitigation) extended with a new technological tool and a larger physical and social scope. These extensions amount to more than *path-dependence* and constitute architecturally-induced *positive feedback* for the policy of noise shielding.

The Grimshaw vision of the Heathrow territory depicts the airfield with the third runway already built and operating and an array of new architectural objects populating the territory, attaching to and replacing existing elements. (fig. 20) A series of large transparent canopies punctuate the Heathrow territory. At the center of the airfield, between the runways, the canopies attach to existing and newly-proposed terminals. The canopies also appear at the periphery of the master plan, at the center of clusters of what appear to be office blocks. These clusters of new office blocks abut the Heathrow villages and attach to the public road network. With their arrays of generic slabs and courtyard buildings at much larger scale than the buildings of the Heathrow villages, these clusters of buildings connote the emergence of, if not an airport city, an airport urbanization. The transparent canopies occupy the center of these clusters, mimicking the urban organizational function of the plaza: a central space for public gathering and exchange. Some ambiguity however remains; they are identical in appearance to the canopies which serve the terminals. Has a piazza been attached to the terminal, or an airport terminal colonized a public space? (fig. 19)

Significantly, the canopies separate a interior environment from the exterior environment, shielding these spaces from weather and from noise and air pollution.[50] If exposure to aircraft noise is a problem for outdoor public space, and our analysis of the Heathrow territory thus far suggests it is, the Grimshaw canopy proposes to solve this problem by inserting a very large membrane between a problematic exterior environment and noise-sensitive human activity.[51] In comparison to the shielding of private homes or school playgrounds, this is a much larger scale intervention that functions as a central organizing element in a new neighborhood instead of as an after-the-fact modification in a pre-existing urban condition. The generic nature of the proposed urbanism and its deliberate repetition in the illustration three times around the periphery of the airport suggest a new mode of urbanization.

The highly-transparent canopies proposed by Grimshaw would not be the first light weight large scale canopies introduced at Heathrow. A large inflatable canopy dating to 2006 already covers the coach and bus terminal at Heathrow's center; the product of a collaboration between the balloonist Pier Lindstrand and D5 architects. The canopy is a semi-transparent vault composed of a series of tubular cross-sections in a linear array that modulates subtly along the length of the building. It is a strangely beautiful and atmospheric architectural element in an otherwise mundane context. Terminal 2,

49 Bijsterveld, Karin. 2008. *Mechanical sound : technology, culture, and public problems of noise in the twentieth century.* See conclusion.
50 McIntyre, Fiona. 2017. "Heathrow Looks to Canopy for Future Proofing." *New Civil Engineer.* "The canopy will have a fully transparent, ethylene tetrafluoroethylene (ETFE) cushioned roof and planting inside to give the space and outdoor feel. As it is modular, the canopy can be expanded or altered as the number or position of buildings underneath changes. […] [Phil] Wilbraham elaborated on a lightweight canopy structure for a new terminal[…]. Designed by Grimshaw architects, who worked on the Eden Project in Cornwall, the modular canopy will cover the terminal buildings below. As a crossover between an indoor and outdoor space, the canopy area would require minimal heating or cooling, making it greener and cheaper."
51 Though not an ideal noise insulating material, a recent study has measured exterior traffic noise reductions of up to 19dB for ETFE cushion roof assemblies that combine "a double cushion with one laminated and stiffened ETFE top layer." This is greater than the noise reduction of 17dB achieved by the adobe huts at Hounslow Heath Infant School (see earlier discussion.) Bron-van der Jagt, Susanne, et al. 2015. "Description of the acoustic characteristics of ETFE roof structures." Proceedings of Euronoise 2015, C. Glorieux, Ed., Maastricht.

designed by Luis Vidal and completed in 2014, has a large-span roof with a transparent fabric ceiling which covers a massive exterior entrance space (where Richard Wilson's sculpture 'Slipstream' is located.) ETFE foil canopies can also be found around the airport in prominent locations, covering notably the train station attached to Terminal 5 (HOK) and a recent forecourt added to the pre-existing terminal 3. (NovumStructures, Foster + Partners) The combination of these individual architectural efforts, each by a different author, reflects the guiding influence of Heathrow's operator's sustainability efforts- where the lightness of construction and the extensive natural daylighting are visible proof of reduced energy use- and a form of larger-scale aesthetic/marketing component in the airport's architectural identity.[52]

The Grimshaw vision rendering marks the first time, to my knowledge, that the transparent canopy feature at Heathrow has been deployed at or beyond the perimeter of the airfield and into situations that appear to be more urban and public space-oriented than transport-oriented. Though Heathrow's operator disputes the encroachment of residential programs near the airport perimeter as we have seen earlier, they evidently seek to promote their own idea of urban development at the airport periphery using the canopy feature originally from the airport terminal to shield and make viable a form of public space.

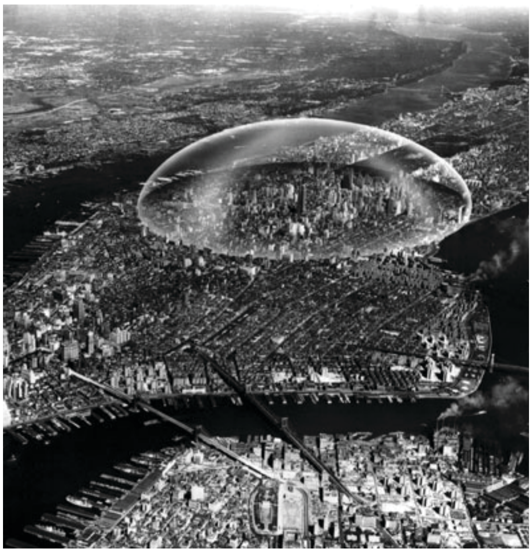
The architectural details of the canopies offer more indications of positive feedback to the noise-shielding regime. The canopies are rendered as extremely transparent, but with two layers of undulating material which laminates and delaminates in a diamond pattern creating a quilt-like field of pillows. This construction system recalls the ETFE foil pillows which form the double membrane of Grimshaw's project, the Eden biomes.(fig. 18) The Eden project is an artificial biosphere constructed from multiple mutually-intersecting spheres arranged along curved lines conforming to a hilly local topography. The spheres are broken down into hexagonal structural units which also contain an ETFE pillow that acts as membrane and insulator for the interior environment. Artificial regulation of interior climate allows for the cultivation of exotic plant species; the project is a distant relative of Victorian-era hothouses.

The inspiration for the Eden Project, and undoubtedly the Heathrow canopy as well, is Buckminster Fuller's geodesic dome. In particular we might recall the very large domes that were proposed (but not built) to cover cities, including, famously, midtown Manhattan.(fig. 17) Fuller described his city-scale domes as *controlled clouds*:

> "The domed-over cities will be so high and their structural members so delicate that their structural members will be approximately invisible. They will operate like a controlled cloud to bring shadow when shadow is desirable and bring sun when sun is desirable, always keeping out rain, snow, and storms as well as exterior industrial fumes, while collecting all the rainwater in reservoirs."[53] (emphasis added)

Mark Wigley has described Fuller's urban domes as the dematerialization of architecture to pure envelope, the condition for the recreation of the Garden of Eden: 'a framed technological image of a pre-technological world.' Wigley connects the dematerialized total environment of the Fullerian urban domes to, 'a single fantasized surface through which to look at the unseen world- a lens that superimposes data onto the world.'[54]

52 See quotes from Phil Wilbraham in McIntyre, Fiona. 2017. op. cit.
53 Fuller, Buckminster. 1969. *Utopia or Oblivion.* p.431 'Epilogue' in 2008 Edition.
54 Wigley, Mark. 2015. 'Planetary Homeboy' in *Buckminster Fuller Inc.* p 235, 236. Reference to Eden on p. 235. (The Eden Project, it should be emphasized is not the intended referent of Wigley's comment.)



17. Buckminster Fuller- Dome Over Manhattan, 1959,1962

18. Grimshaw. Eden Project. 2001.

19. Grimshaw. Heathrow Vision. 2016- interior view

20. Grimshaw. Heathrow Vision. 2016- aerial view

While the Heathrow canopy and the Eden project share a similar constructional system and a similar goal of creating a large artificially-controlled interior environment, their architectural deployment is based on fundamentally different geometric system. The Eden project is based on a spherical unit, whereas the Heathrow canopy is based on a square grid. The domes of the Eden project demarcate a clear beginning and endpoint defined by a centroid and a radius: their spatial extension is limited. Even if they do intersect with other spheres, each sphere still has a definable extent and locus. The grid of the Heathrow canopy, however, does not represent a punctual moment in space but rather a neutral spatial condition that is indefinitely extensible. This distinction is carried through by the constructional system – while a dome like the Eden project needs to touch down on the ground for support, the Heathrow canopy is carried on a grid of piers that pierce up above the canopy and from which it hangs. The architectonic implication of this solution is one of limitless extension: that problems of the exterior environment like sound or air pollution can be side-stepped by the creation of an unending interior.

The renderings of the Grimshaw vision of course do not infinitely extend the ETFE canopy in the manner of Superstudio's *Continuous Monument* of 1969. The canopies do, however, instantiate the same constructional system throughout the masterplan area with minimal enough modification that the canopies become visible markers of a continuous environmental/urban condition- the combination of noise, air pollution, and generic urbanization that has elsewhere been called *the Noise Landscape*.[55] This method of instantiation is characteristic of the urban application of architectural parametricism.

Parametricism in architecture describes a technique where the designer assembles an algorithm to generate form relative to parameters like scale or orientation. Once the algorithm has been generated it can be applied to any number of differing environmental conditions, defined as parameters, with each unique environmental condition producing a unique formal output. Parametricism, thus defined, could be considered a form of data-driven design, in that varying data conditions automatically produce different design outputs without the designer's direct intervention. Grimshaw's Heathrow canopy displays characteristics of this parametricism: each instance of the canopy is visibly the same in its components and constructional logic, and yet each instance adapts uniquely to its surroundings, becoming longer or narrower, wrapping around existing elements, and rotating to align to contextual elements. The logic of varied instantiation, whether parametric or not, suggests another type of infinite extensibility: the punctual emergence of a generic prototype anywhere in the urban territory. The prototype contributes to an overall homogenization of the territory through repetitive propagation at the same time as it acts as an index of changing conditions within the landscape through its limited range of adaptations to the territory. As Heathrow's Noise Landscape grows, the ETFE canopies could follow, popping up like mushrooms in a field of grass.

When describing positive feedback, Donella Meadows writes, 'A positive feedback loop is self-reinforcing. The more it works, the more it has power to work some more.'[56] Grimshaw's canopies provide this type of reinforcing feedback to the noise-shielding policy in the Heathrow territory. What previously could function only as an adaptation to a pre-existing urban context, is now presented as a central element in a new form of urbanization. If the limiting factor to the extension of Heathrow previously was aviation noise (admittedly this is only one limiting factor) then the propagation of noise shielded urbanism and public space removes this limit to the continued growth of aviation. If we follow

55 Boucsein. 2017. *The Noise Landscape.*
56 Meadows, Donella. 1997. 'Places to Intervene in a System.' *Whole Earth.*

this loop forward, as aviation activity is permitted to continue growing, larger and larger areas will be exposed to noise and incentivized to convert to noise-shielded forms of urbanization. This example suggests that architecture can be instrumental in the extension and encouragement of data-driven urbanism. However, it would be naïve to suggest that Heathrow and its aviation activity can grow indefinitely without encountering some limit condition. Eventually, the growth of the airport and the use of its airspace will encounter enough pushback that they will cease to grow and will either level off or diminish. A contrary example to the Grimshaw vision of the Heathrow territory, a competition entry by Luis Callejas' office LCLA, suggests ways in which architecture might act to define these systemic limits.

2.4.3 Protest at Heathrow: the Greenpeace Airplot competition

In contrast with the positive feedback evidenced in the Grimshaw proposal for the Heathrow territory, an oppositional view is expressed by the architect Luis Callejas in a proposal for an airborne blockade of the Heathrow airspace. Callejas uses the tools of data-driven design, in particular indexical operations, but defines his goal function not in terms of maximization of efficiency, but optimization of obstruction.

Callejas' proposal is a response to a competition brief from the environmental defense organization *Greenpeace*. *Greenpeace* purchased a piece of land near Heathrow in 2009 which they named the *AirPlot,* with the intention to use the legal rights to that land to block the expansion of Heathrow and construction of a third runway.[57] The purchase of the land and the subsequent protests, including the spelling out of 'OUR CLIMATE, OUR LAND,' in ten-foot tall letters on the ground visible to landing planes, was a massive media event. Celebrities like Emma Thompson signed on as co-owners of the land and sponsors to the protest. David Cameron, who became prime minister in 2010, had a tree planted on the site in his name.[58]

The *AirPlot* architectural competition, with its final submission in spring of 2010, sought to build off media attention to attract design talent to produce a permanent structure on the *AirPlot* site that would effectively block the expansion of Heathrow. The goals stated for the competition were multiple, representing a coalition of local land-owners and national and international environmentalists: protect local land rights, prevent the spread of noise and air-pollution in London, and ultimately to fight climate change. The contribution of the architect in the words of the organizers was to, 'fortify the airplot that will help us to finally defeat the third runway.'[52] The design was meant to, 'be an exemplary piece of sustainable design: a practical solution with cultural and aesthetic power to match the depth and importance of what's at stake.'[59] The architect, evidently was meant to provide both a physical barrier to the expansion of the airport, but also a political and aesthetic statement. The goal was both a physical limitation and a powerful cultural statement. In the language of systems and leverage points it would be both a material constraint (impeding a flow) and an impact on the system's paradigm.

In response to this brief Luis Callejas proposed an array of balloons, in the shape of existing houses in

57 Callejas, Luis. 2013. *Islands and Atoll*s – Pamphlet Architecture 33. p. 42

58 For these two anecdotes see: Topham, Gwyn. [Transport] 2015. "Land Bought by *Greenpeace* to Defy Heathrow Expansion Quietly Sold for £1." ***The Guardian***, June 25, 2015, sec. Environment.

59 The original competition brief is no longer available on the *Greenpeace* website. I am drawing from an archived copy at https://www.e-architect.co.uk/competitions/greenpeace-competition. I am happy to provide a copy in the future should this copy be eventually removed.

the Heathrow villages, tethered at ground level to the existing house and the reaching up to float in the flight paths of Heathrow airport.(figs. 21-23) The proposal has a historical precedent: in the second world war the British deployed an array of zeppelin-like balloons linked to the ground and one another in an airborne barrage to protect its airspace from German bombers. These *barrage balloons* provided one of the iconic images of war-time London with far-reaching cultural echoes.[60] Callejas' use of the *barrage balloons*, however, significantly differs from the scope and nature of the competition. He has expanded a site-based and architectural brief into a territorial and social project with a significant data-driven component.

2.4.4 *Weightless* : Luis Callejas' cloud of barrage balloons

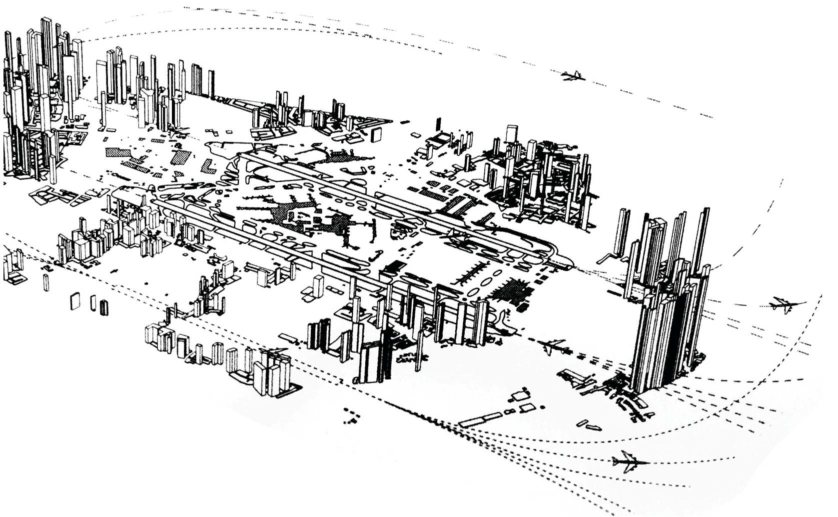
The data-driven logic of Callejas' Weightless is evident in the following quote from the architect which uses the language of an optimization function. The balloons have been placed, he writes, in the 'ideal location [...] to maximize interference with air traffic.'[61] (fig. 21) Callejas' barrage balloons are not confined to the single site purchased by *Greenpeace* but are distributed throughout the Heathrow territory. Furthermore, the distribution is not uniform, but is varied in response to its proximity to the airfield and flight paths. In the illustrations we see that the barrage balloons are densest and highest to the immediate east and west of the Heathrow runways, blocking the key vectors of approaching and departing flights. The process of varying a distributed field of elements according to their quantitative relationship to landscape features is an *indexical* operation, a common technique in data-visualization and the most basic technique of what we have called data-driven design.

As a transference of data (here the density of flight paths) into spatial and physical form, Callejas' array of barrage balloons is similar to MVRDV's *datascapes* of the 1990s. If we compare it to one of the original *datascape* examples, the *Noisescape* of 1997, produced by student Penelope Dean, we notice some significant differences.(fig. 24) *Noisescape* takes a visualization of highway noise, constructs it in three dimensions, and then imagines these spaces as inhabited by different programs. In this example noise visualization is directly converted into built form, a deliberate misinterpretation of original data that furnishes unexpected insights or possibilities through the *misuse of data*. The Callejas project, in contrast, is the result of overlapping two indices: flight density near Heathrow and density of residential inhabitation of the land. The overlap between these two layers of data indexically represents the source of the conflict at Heathrow over noise, and it is at these intersections that Callejas proposes deploying the barrage balloons.

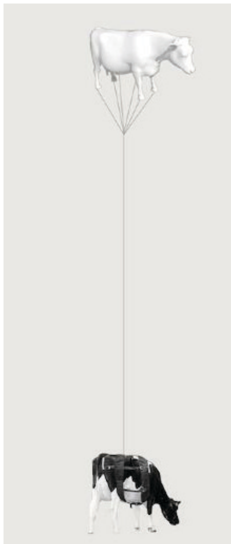
Callejas' intervention, however, does not discover something new or unexpected in the use of the index, instead he uses it as a tool to pinpoint the *optimal* position to block the flow of flights near Heathrow. MVRDV's deliberate *misuse* of noise-data visualizations seeks to inhabit the noisescape while accepting that it will continue to exist. (That the *Noisescape* intervention would fundamentally change the way noise propagates and is experienced is frustratingly under-explored in this 1997 example.) For Callejas, the project is a tool for stopping the system dead in its tracks (an optimal end in this case), but not a site for discovering unexpected insights or possibilities. But what unexpected insights might the indexical mapping of noise conflict at Heathrow bring?

The distribution of the barrage balloons in *Weightless* is not only spatial, but also social. Each balloon

60 Arthur C. Clarke was inspired by a vision of the London barrage balloons to write *Childhood's End* about the extinction of humanity.
61 Callejas, Luis. 2013. *Islands and Atolls* – Pamphlet Architecture 33. caption fig.3 p. 74

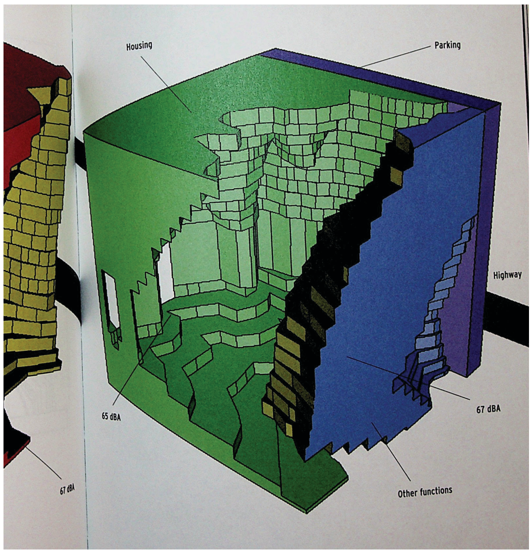


21. LCLA. Diagram- Building foot prints extruded to intersect wth flight paths.



22. LCLA. Cow Balloon.

23. LCLA. Pilot’s view of Heathrow Barrage.



24. MVRDV. Noisescape illustration.

is the project not just of one institution (*Greenpeace*) but belongs to and is symbolically reflective of a specific resident of the territory: farmer, homeowner, or even cow.(fig. 22) This social engagement expands the scope of the competition beyond *Greenpeace*'s initial brief, in a way that moves the point of confrontation from institution vs. institution to actor vs actor, and more specifically home owner vs. airport. Callejas emphasizes this social engagement through the a symbolic component of the design: the barrage balloons are not proposed in the functional zeppelin shape of the WWII barrage, but instead take on the form of the objects they are tethered to at ground level, houses or animals.

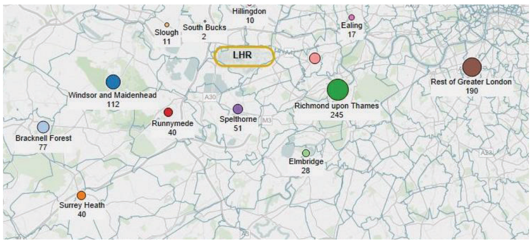
The balloon acts as asymbolic avatar, permitting its ground-based owner to occupy a space (here airspace) which it can not physically access. Callejas created the avatar as a tool to allow residents to assert a symbolic right to the airspace above them. He writes, 'the law recognizes that landowners have property rights in the lower reaches of the airspace of their property [...] landowners cannot arbitrarily try to prevent aircraft from flying overhead [...] however they may make any *legitimate use* of their property they want, even if it interferes with aircraft overflying the land.'[62] Callejas' symbolic action seeks to push against the legal definition of *legitimate use* of a landowner's air space. The question of the exchange between the public's interest in freedom of air navigation and the landowner's rights over airspace is value-based and therefore socially negotiated.[63] Callejas work *mediates* between the disparate domains of airspace and land use, through symbolic conversion and *datascape*-like indexical operations, in order to provoke a debate that is ultimately about values and political legitimacy.

Mediation, in the sense of finding middle ground, however seems to be a poor descriptor for a demonstration project like *Airplot* that maximizes a partisan position. In counter-example to Callejas' project for Heathrow, I would like to consider Loren Carpenter's *Collaborative Control Pong* experiment from the 1991 Sigraph conference.[64] Carpenter created an interface that allowed a crowd of people holding red or green flags to collaboratively control the videogame *Pong*. Without instruction or a central coordinator the group was intuitively able to play the game successfully. This early illustration of the power of crowd coordination is one of the aspirations of the data-driven city: that more extensive and granular data can give voice to people, animals, and even inanimate objects in ways that permit an emergent (and assumedly fairer) consensus to emerge. An extension of this aspiration often encountered in popular journalism on Big Data is that the automated accumulation and cross-examination of facts will reveal equitable solutions to seemingly intractable social/environmental problems. To what extent this hope is naïve is discussed in the introduction of this dissertation, however we can claim that this is one central purpose of the data-driven city.

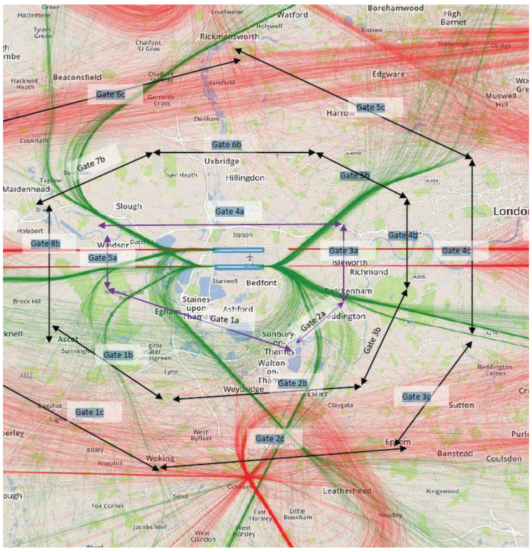
Like Loren Carpenter's colored paddles, let us imagine that instead of blocking the sky at all times of the day, Callejas' balloons had the ability to be deployed and retracted at different times depending on the needs of the resident. If each home-owner were able to vote with his balloon, expressing when their children need to play outside, when or where they would like to sleep or have dinner, or conversely when they are gone at work, or gone on vacation, would some new and more equitable

62 Ibid. p. 73.
63 If we accept the judgment of Hanna Arendt, 'Values are social commodities that have no significance of their own, but, like other commodities, exist only in the ever-changing relativity of social linkages and commerce.' See: 'Tradition and the Modern Age.' in *Between Past and Future*. p. 32.
64 See Curtis. 2011. *All Watched Over by Machines of Loving Grace.* 8:30

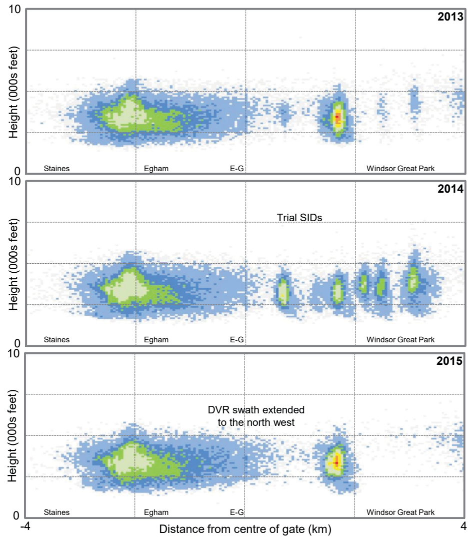
25. Expansion of Heathrow Noise Contours predicted with 3rd runway



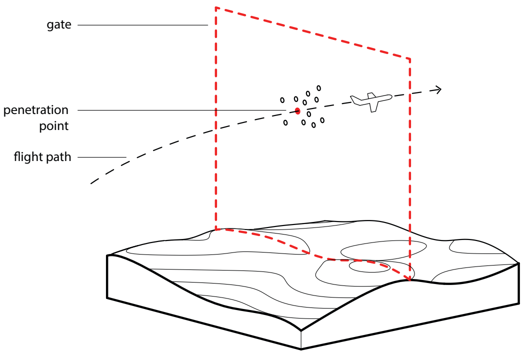
26. Map of Complaints near Heathrow, first quarter 2016



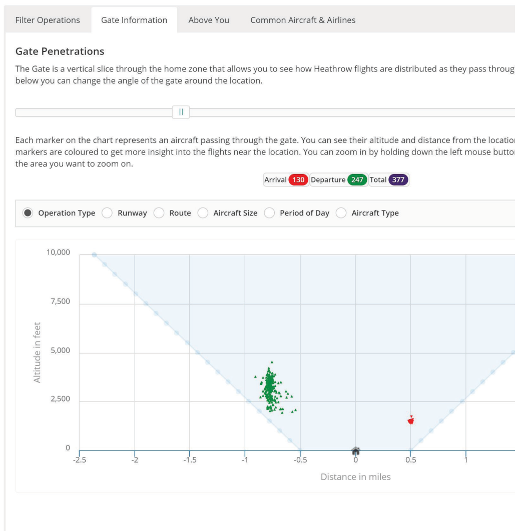
27. Penetration Gates studied by Heathrow Community Noise Forum



28. Penetration Gate Analysis above Englefield Green 2013-15. PA Consulting



29. Diagram of penetration gate.



30. B&K Penetration Gate online interface *XPlane.*

logic for the use of the airspace emerge? Could these balloons represent the needs of protecting the environment, as well as the need for international mobility and exchange? If these placeholders were put into play together in good faith, perhaps new solutions, more equitable accommodations could be found, or perhaps the necessity of a barricade could even be established in a pluri-partisan manner. This would be the argument of a proponent of the *data-driven city.*

Exacerbation of opposition in *Weightless*, over the possible emergence of accommodation, makes the project a *demonstration* in Callejas' words. It is not an attempt to solve a dilemma, but rather an effort to more emphatically state and lend power to the position of one side in a dispute – a demonstration of force or moral right on the part of one side. Callejas, positions his architecture not so much as a data-driven mediation, but as an attack on a paradigm, aiming straight for the most powerful (but least attainable) of the leverage points on a system as defined by Donella Meadows.[65] Whether or not the project is a misuse or a successful detournement of data-driven design is a *Rorschach*-like test of ideological position.

The winner of the *AirPlot* competition was not LCLA's Weightless, but a collaboration of Amsterdam architects *space&matter* and *Specialist Operations*.[66] They proposed a cemetery entitled, 'Rest in GreenPeace,' with the legal rights of interred bodies meant to proscribe the construction of Heathrow's third runway. Callejas' entry received a jury commendation 'for outstanding conceptual ideas or tactics'.[67]

The winning entry of the *Airplot* competition was not built. By 2012 *GreenPeace* had returned the *AirPlot* land to its original owner, unwilling to extend its lease, and in 2015 the Airports Commission recommended expansion of Heathrow, a development that has been followed up on since by the government. Any trees planted on the site, by David Cameron or others, appear to have since died. *Greenpeace* has pulled its *AirPlot* webpage to its archive.

Callejas, however, has gone on to republish his proposal in venues as diverse as a *LIGA* exhibit in Mexico City in 2011, and in his book *Islands and Atoll*, of 2013. As a component in his ongoing research on architecture at a territorial scale, the Heathrow barrage balloons illustrate the sublime aesthetic of large cloud-like collections of elements, as well as an (unrealized) example of political engagement. As evidence of the ability of architecture to effect paradigm shift in the data-driven city, however, the project offers a sobering lesson in limitations. If anything, the paradigm is shifting in the opposite direction with the expansion of Heathrow now approved and moving forward.

2.5 Conclusions: limits of the built environment, and holistic airspace planning

If we set aside the architectural solutions to the problem of noise at Heathrow, there are possibilities today for a holistic data-driven consensus over landuse and airspace planning to emerge as the expansion of the airport is planned. This approach could address the public space of the territory at the same time as the flight paths over the territory, modifying both together instead of separately. Recent government reports suggest that expansion at Heathrow would be combined with *noise envelopes* and periods of respite.[68] These suggestions represent steps in the direction of territorial-

65 See bullet point 01 in Meadows. 1997. 'Places to Intervene in a System.' *Whole Earth*

66 For more on *space&matter* see chapter 3 on Amsterdam's Buiksloterham district.

67 LONDON / Weightless - LCLA Office. http://www.luiscallejas.com/filter/territorial/LONDON-Weightless.

68 Airports Commission, ***Final Report***, op. cit. p. 278.

scale planning that could better protect public space. The *noise envelope*, however, is defined for the moment without geographic specificity. It refers only to capping the area of land or number of people contained within an LAeq contour of variable shape. For a noise envelope to contribute to holistic open space strategy, it would need to control the geographic shape of the noise envelope both temporally and spatially. Using policy to design the shape of the noise envelope would make it possible to plan a configuration complementary to open public space on the ground.

Experiments with the design of the airspace over Heathrow are already going on: in 2014 the airport ran trials of different patterns of flight concentration along Noise Preferential Routes (NPRs).[69] The NPRs are 3km wide corridors established in the 1960s to help mitigate aviation noise by concentrating it over less-inhabited areas. Heathrow's 2014 experiments used new satellite-based navigation tools to direct flights to precise areas within the NPR corridors, thereby changing patterns of noise across the territory. These flight concentrations can be best visualized using a graphic device called a *penetration gate*: an imaginary vertical plane cut through the airspace above a specific line in the territory.(figs 27-30) Clusters of dots depict the position of flights as they pass through this vertical plane over a given period of time. Comparing recent penetration gates running between Englefield green and Windsor Great park (a sensitive area of the Heathrow noise landscape), a large central cluster of flights present in 2013 splits into five smaller dispersed clusters in 2014 during the Heathrow airspace tests. (fig.28) In 2015, after the trial has ceased, the larger cluster reappears. While the dispersal of flights more evenly across the territory may share the noise burden more equitably, it is not necessarily greeted with enthusiasm by residents. Heathrow's 2014 airspace experiments provoked confusion and resentment in some communities, particularly where over-flight increased, and prior outreach was inadequate.[70] A massive effort to engage and understand the needs of people living in affected areas would be needed to effectively design airspace in complement to the urban realm.

Community efforts to shape Heathrow's airspace have been led by the *Heathrow Community Noise Forum* (HCNF). The forum has begun analyzing the Heathrow airspace using a set of penetration gates of their choosing. (fig. 26) These 'gates' represent particularly sensitive strips of land, with a view to ultimately better control noise in the areas they represent. While the gates are currently used only to analyze flight distribution over the territory, they have potential to be used as a policy tool for shaping airspace relative to specific territorial zones. A series of gates could be used not only to describe the historical airspace, but also in negotiations over a future shape for the government's proposed noise envelope. Taken together HCNF's analytic efforts and Heathrow's flight-control experiments could contribute to a holistic planning strategy that re-engages the problem of aviation noise in the Heathrow territory's open space.

Heathrow's noise landscape will remain contentious for the foreseeable future. The planned third runway will greatly enlarge areas affected by noise and can be expected to provoke resentment among members of the affected communities.(fig. 25) Despite this expansion many residents also rely on the airport for their livelihoods and view its closeness as a convenience. Furthermore, the economy of Greater London is heavily reliant on Heathrow for its connectivity to the wider world. In this complex political ecology new techniques of measuring the noise landscape and sharing data are bringing about small but significant changes. We have seen how access to data on noise and flight paths has given

69 Anderson Acoustics. 2015 *Westerly and Easterly Departure Trials 2014- Noise Analysis & Community Response*, July 2015.
70 BBC News, 'Heathrow Airspace Trials: Life under the Flight Path', 12 November 2014

local communities greater leverage in negotiation, allowing them to better articulate their grievances and their demands. Additionally, the airport today has greater control than ever over the routing of flights over the territory and increasing motivation to act transparently and cooperate with local communities over airspace planning. The production of data, its visualization and its dissemination are driving these changes and creating opportunity for more equitable policy that considers aspects of the noise landscape that could neither be measured nor coordinated in the past.

The history of Heathrow's noise landscape suggests that these hopeful developments should be accompanied by skepticism as well: data can be biased and can be used as a tool to legitimize the status quo. If the bigness of noise data can be matched by the broadness of its distribution it can be a fertile ground for new ideas, new solutions, and the dissolution of old oppositions. Openly collected and distributed data about the noise landscape is the necessary base condition for negotiating a better solution to the problem of noise at Heathrow; a solution that can address the urban realm instead of abandoning it.

References

Books and Journal Articles:

Abercrombie, Patrick, and Standing Conference on London Regional Planning. 1945. ***Greater London Plan 1944: A Report Prepared on Behalf of the Standing Conference on London Regional Planning ... at the Request of the Minister of Town and Country Planning.*** London: H.M. Stationery Office.

Arendt, H., and J. Kohn. 1961. ***Between Past and Future***. New York, NY: The Viking Press.

Barratt, Nick. 2012. ***Greater London : The Story of the Suburbs.*** London : Random House Books.

Bijsterveld, Karin. 2008. ***Mechanical Sound : Technology, Culture, and Public Problems of Noise in the Twentieth Century.*** Cambridge, Mass. : MIT Press.

Boucsein, Benedikt, et al. 2017. ***The Noise Landscape : A Spatial Exploration of Airports and Cities.*** Rotterdam : nai010 publishers.

Boucsein, B., Ortner, F., and Jehle, J. 2017. "London Heathrow [LHR]." In ***The Noise Landscape : A Spatial Exploration of Airports and Cities***, edited by Benedikt Boucsein, 121-137. Rotterdam : nai010 publishers.

Bron-van der Jagt, Susanne, et al. 2015. "Description of the acoustic characteristics of ETFE roof structures." ***Proceedings of Euronoise 2015,*** C. Glorieux, Ed., Maastricht, June 1-3.

Callejas, Luis. 2013. ***Islands & Atolls.*** Vol. 33, New York : Princeton Architectural Press.

David, Paul. 1985. "Clio and the Economics of QWERTY." The American Economic Review, Vol. 75, No. 2. (May, 1985), pp. 332-337.

Fuller, Richard Buckminster, and Jaime Snyder. 2008. ***Utopia or Oblivion : The Prospects for Humanity***. New ed., Baden : Lars Muller.

Goldsmith, Mike. 2012. ***Discord : The Story of Noise.*** Oxford : Oxford University Press.

Hall, Peter. 1982. "London's Third Airport" In ***Great Planning Disasters.*** Berkeley, Calif. : University of California Press.

Hansell, Anna et al. 2013 "Aircraft noise and cardiovascular disease near Heathrow airport in London: small area study." BMJ (The British Medical Journal); 347 :f5432

Kitchin, Rob. 2014. ***The Data Revolution : Big Data, Open Data, Data Infrastructures & Their Consequences.*** Los Angeles : SAGE.

Latour, Bruno. 2007. ***Reassembling the Social : An Introduction to Actor-Network-Theory.*** Oxford : Oxford University Press.

Leylekian, L., et al. 2014. "An Overview of Aircraft Noise Reduction Technologies." ***Aerospace-Lab Journal.*** Vol. 7. doi : 10.12762/2014.AL07-01

Maas, Winy, and MVRDV. 1998. ***FARMAX : Excursions on Density.*** Rotterdam: 010 Publishers.

Manvell, Douglas. 2015. "From noise monitoring to noise management: A better way to deal with noise issues." In I***NTER-NOISE and NOISE-CON Congress and Conference Proceedings***, InterNoise15, San Francisco, CA. Institute of Noise Control Engineering. 2361-3321, 2473-2484(12)

May, Carl, and Tracy Finch. 2009. "Implementing, Embedding, and Integrating Practices: An Outline of Normalization Process Theory." In ***Sociology.*** Vol. 43.

Meadows, Donella H. 1997. "Places to Intervene in a System." In ***Whole Earth Review*** (Winter). revised and republished as "Leverage Points: Places to Intervene in a System." Sustainability Institute. 1999. http://donellameadows.org/archives/leverage-points-places-to-intervene-in-a-system/ accessed 14.08.2018

Ortner, F. Peter. 2017. "Metric As Mediator: Data-Driven Negotiations over Heathrow's Noise Landscape." In ***The Noise Landscape : A Spatial Exploration of Airports and Cities***, edited by Benedikt Boucsein, 215-226. Rotterdam : nai010 publishers.

Sherwood, Philip. 2009. ***Heathrow: 2000 Years of History.*** Stroud, Gloucestershire : The History Press.

Stewart J. and Bronzaft A. 2011. ***Why noise matters : A worldwide perspective on the problems, policies and solutions.*** London: Earthscan. pp.52-56.

Wigley, Mark. 2015. ***Buckminster Fuller Inc. : Architecture in the Age of Radio.*** Zurich : Lars Muller Publishers.

Government/ Institutional Documents:

Airports Commission. 2015. ***Final Report*** (London, The Stationery Office, July 2015) Online. Available HTTP: https://www.gov.uk/government/publications/airports-commission-final-report (accessed 10 October 2016)

Anderson Acoustics. 2015. ***Westerly and Easterly Departure Trials Noise Report, Presentation to the Heathrow Community Noise Forum***. (September 2015) Online. Available: https://www.heathrow.com/file_source/HeathrowNoise/Static/Noise-impacts-summary-trial-reports.pdf. Accessed 06 September 2018.

Brüel & Kjær. 2016. "Brüel & Kjær to Provide Heathrow Airport with 50 Noise Monitoring Terminals." Press Release. 30 August 2016. https://www.environmental-expert.com/news/brueel-kjaer-to-provide-heathrow-airport-with-50-noise-monitoring-terminals-671894 (accessed 06 September 2018.)

Committee on the Problem of Noise. 1963. ***Noise: Final Report***, (London, Her Majesty's Stationery Office)

Department for Transport. 2013. ***Aviation Policy Framework*** (London, The Stationery Office)

Heathrow Airport Limited. 2013. ***A Quieter Heathrow***. (April 2013) https://www.heathrow.com/file_source/HeathrowNoise/Static/a_quieter_heathrow_2013.pdf. (accessed 06 September 2018.)

London Borough of Hounslow. 2013. ***Open Space Strategy: Final Draft*** (London, Borough of Hounslow, April 2013) Online. Available HTTP: http://www.hounslow.gov.uk/london_borough_of_hounslow_-_open_space_strategy.pdf (accessed 10 October 2016), p.6-7, s.1.14.

Mayor of London. 2016. ***The London Plan: The Spatial Development Strategy for London Consolidated with Alterations Since 2011.*** (London: Office of the Mayor of London. March 2016)

MIL Research Limited, Office of Population Censuses and Surveys, Social Survey Division. 1980. ***Second Survey of Aircraft Noise Annoyance around London (Heathrow) Airport, 1967.*** [data collection]. UK Data Service. SN: 1539, http://doi.org/10.5255/UKDA-SN-1539-1

Popular Press:

Topham, G. 2013. 'Heathrow Pays £1.8m for Adobe Huts to Protect Pupils' Ears from Aircraft Noise.' The Guardian (London), 8 November 2013. Online. Available HTTP: https://www.theguardian.com/environment/2013/nov/08/heathrow-school-adobe-huts-protect-pupils-hearing

Cerar, P. 2013. 'Heathrow Noise Hinders Pupils Reading Progress', *London Evening Standard* (London), 28 March 2013. Online. Available HTTP: http://www.standard.co.uk/news/transport/heathrow-noise-hinders-pupils-reading-progress-8552639.html (accessed 10 October 2016).

McIntyre, Fiona. 2017. "Heathrow Looks to Canopy for Future Proofing." *New Civil Engineer.* 18 May 2017. https://www.newcivilengineer.com/heathrow-looks-to-canopy-for-future-proofing/10020028.article. (accessed 22 April 2019).

BBC News. 2014. 'Heathrow Airspace Trials: Life under the Flight Path', 12 November 2014 Online. Available HTTP: http://www.bbc.com/news/uk-england-29597561 (accessed 10 October 2016).

Websites:

Heathrow Airport. "What You Can Do | Noise | Heathrow." https://www.heathrow.com/noise/what-you-can-do. (accessed 23 April 2019).

Heathrow Airport. "Noise Complaints Reports." https://www.heathrow.com/noise/reports-and-statistics/reports/noise-complaints-reports. (accessed 23 April 2019).

Heathrow Webtrak: https://webtrak.emsbk.com/lhr (accessed 06 September 2018).

Heathrow Webtrak MyNeighborhood: http://myneighbourhood.bksv.com/lhr/ (accessed 06 September 2018).

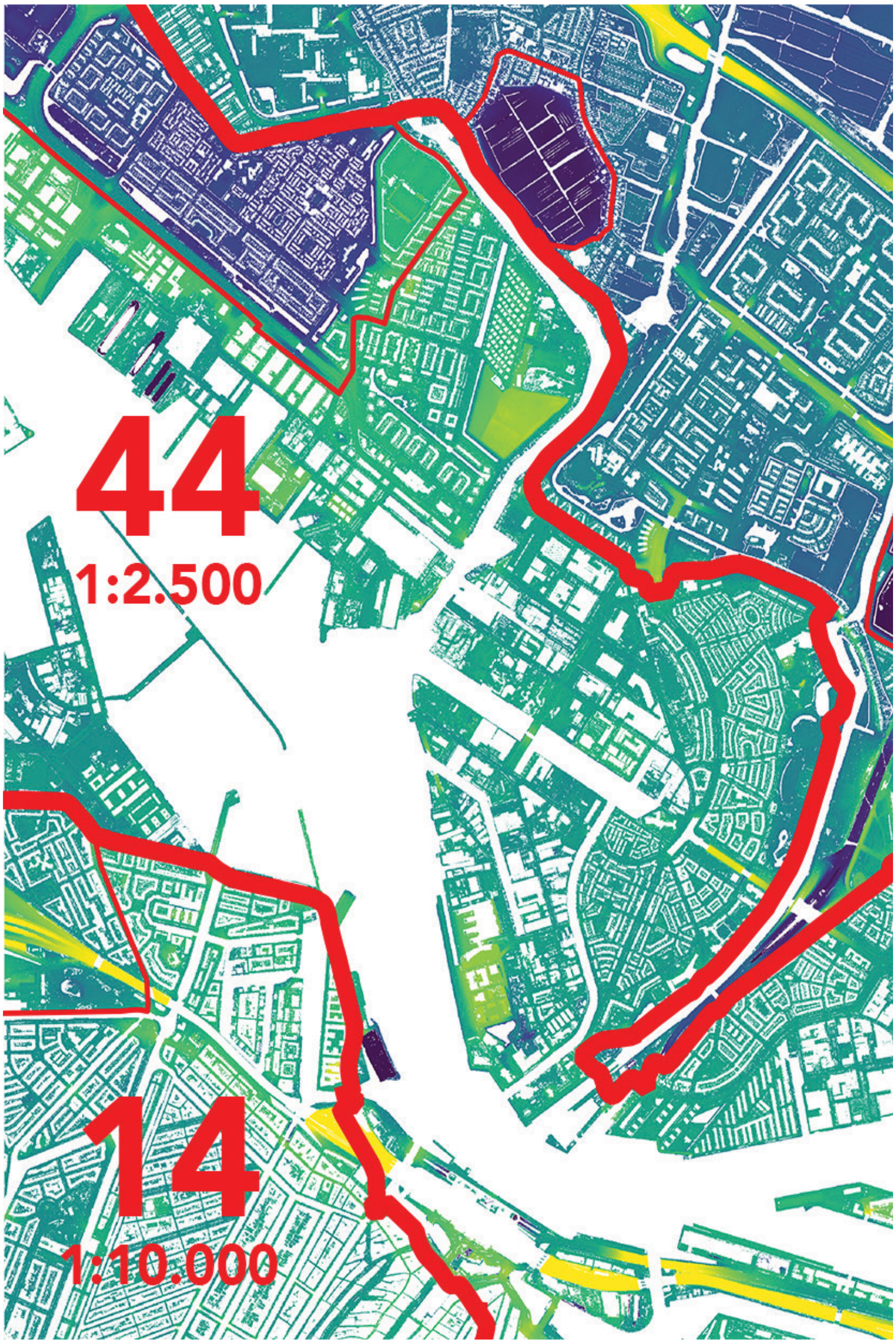
Heathrow XPlane: http://xplane.bksv.com/xplane/ (accessed 06 September 2018).

Heathrow Community Noise Forum: https://www.heathrow.com/noise/heathrow-community-noise-forum/ (accessed 06 September 2018).

LCLA Office: LONDON / Weightless. http://www.luiscallejas.com/filter/territorial/LONDON-Weightless. (accessed 23 April 2019).

Films:

All Watched Over by Machines of Loving Grace. Dir. Adam Curtis. British Broadcasting Corporation (BBC), 2011. Television Documentary.


44
1:2.500
14
1:10.000

3 Risk and resource: Inhabiting Amsterdam's data-driven waterscape

3.1 Introduction: data, water management and Amsterdam's urban form

The form of the city of Amsterdam- its canals, locks, bridges and dikes, but also its clusters of rowhouses, historic defenses, transportation corridors, its airport, it's industrial (and now post-industrial) port- is defined by the control of water. Though other histories have described how water management has determined the form of the city, in this case study I will delineate how a data-assemblage emerged to manage water in Amsterdam, and its ongoing interaction with the built environment of the city.[1] While the physical infrastructure of water control is mostly visible and self-evident, managing water in the Netherlands has for centuries required an invisible infrastructure to measure water flows and levels, anticipate changes, and decide how to work together to create and maintain the dikes, dams and bridges. The assemblage of tools and practices for gathering water data and responding to it has continuously evolved. It is from this data-intensive and infrastructurally dependent context that the culture of Dutch city planning and architecture has evolved. That the idea of *datascape* first emerged in the Netherlands is no coincidence.[2] Today an increasingly digitized assemblage controls Amsterdam's response to water, providing a data-driven context to the city's architecture, but also directly looping in architectural elements as micro-infrastructures.

Some 7,000 km2 of the Netherlands is reclaimed land, about 20% of the country. Amsterdam's airport, Schiphol, sits at 3 meters below sea level on the bottom of a 185 km2 drained lake- the Haarlemmermeer. Even more dramatic is the province of Flevoland, directly to the east of Amsterdam, where some 1,400 km2 of land were reclaimed in around 30 years beginning in the late 1920s. If this figure leaves you unmoved, consider that the nation of Singapore and its 5 million inhabitants occupy only 700 square-kilometers, one-half of Flevoland.

1 The historical connection between the form of Amsterdam and its water management system has been established notably by Burke. 1956. *The Making of Dutch Towns: A Study in Urban Development from the Tenth to the Seventeenth Centuries*. and Hooimeijer. 2014. *The Making of Polder Cities: A Fine Dutch Tradition.*

2 See Maas. 1996. *Datascape.* and Lootsma. 2003. "What is (really) to be Done? The theoretical concepts of MVRDV." For extensive discussion see Introduction section 1.3.3.

3.2 History of water and data in Amsterdam

3.2.1 A complex assemblage: reclaimed land, water, politics and data

The Dutch call a patch of reclaimed land a *polder*. The technique for creating a polder is fundamentally the same today as it was a thousand years ago: a dike is built surrounding a swampy area and the water inside is pumped out. Inside is new farmland. A *polder*, however, requires constant attention: as water is pumped out the swampy land sinks even further, increasing the height-difference between the water outside the dike and the land within. Water must be constantly captured and pumped out, and the surrounding dike wall must be surveyed and maintained. It has become a cliché among Dutch politicians to refer to Dutch democracy as the *poldermodel*, but there is no doubt that the technique of managing this reclaimed land has required a willingness to work cooperatively, communicate as a group, and create institutions to guarantee the continued oversight of the water infrastructure.

Bart Lootsma, for example, cites the *poldermodel* as an inspiration for MVRDV's development of the datascape concept in the mid 1990s.[3] Lootsma defines the poldermodel as "a refined version of Western democracy involving continual advocacy and negotiations between traditionally opposing parties in order to reach consensus at every level." The need to achieve consensus in spite of opposition makes nuanced negotiation necessary, a process facilitated by a tradition of indefatigable face-to-face haggling, and necessarily the gathering and sharing of dependable empirical data.

3.2.2 Legger and Keur: data legacy of the Waterschappen

The *Waterschappen* or water authorities, were the first institutions to manage water in the Netherlands. The first official water authority, the *Hoogheemraadschap van Rijnland*, was founded in 1255 to manage land that included the present-day site of Schiphol Airport. Informal groups had cooperatively managed dikes and polders long before. To plan and maintain water infrastructure the water authorities developed tools to map the extents of the works, to tabulate their components, their desired water levels, their periodic upkeep, as well as their cost and the taxes that would be levied to pay for them. This database has been formalized in contemporary times as the *legger*, a combination of maps and tables that provide an overall view of the infrastructure the waterboard oversees. Today the *legger* for each water authority is maintained electronically, and is publicly accessible via the internet as an interactive map.[4] Each water authority also issues a *keur*, a traditional name for a body of rules, describing required and forbidden actions for individuals using or abutting the water infrastructure. The double-body of knowledge on spatial data and land-use regulation established by the waterboards represents the first historic element of water management data-assemblage in the Netherlands, and remains prominent today with the digitized *legger* and the *keur.*

3 Lootsma. op cit. p. 55. "If MVRDV indeed believe in the ability to make a democratic society, the real problem may not be the technological aspect but rather the democratic aspect. Perhaps they had the Netherlands in mind, but even the Dutch '*polder model*'- a refined version of Western democracy involving continual advocacy and negotiations between traditionally opposing parties in order to reach consensus at every level- in its heyday during the 1990s, has recently and suddenly fallen out of favour."

4 The waterboard controlling Amsterdam and surrounding areas, the AGV, provides an online *legger.* https://www.agv.nl/onze-taken/legger/

3.2.3 Historical water management and the growth of Amsterdam

Amsterdam historically does not sit at *polder* level, but was established as a dam city with the medieval core sitting above the water level of the Amstel river. As the city expanded into the surrounding agricultural lowlands (*polder*s) it was necessary to choose whether or not this land would be raised before it would be built up. Only a few neighborhoods of Amsterdam are at *polder* level – like Watergraafsmeer in the south or Buiklsotermeer in the north – and these areas were not added to the city until relatively recently in its history.[5]

As Amsterdam expanded with the *Grachtengordel* district (begun 1609) and *Jordaan* district (begun 1612), adjoining agricultural *polder* lands were filled to a higher elevation first by digging and expanding canals and then using the excavated material to fill-in and raise the land. It was also necessary to bring in fill (particularly sand) from outside the city. In the *Jordaan* the orientation of the original agricultural canals remains visible in the layout of the street grid. To create the land for this district the agricultural *polder* canals were alternatingly dug deeper or filled in, thus leaving their imprint in the final district plan.[6](fig. 2, right-most district with canals color-coded red.) The *Grachtengordel*, in contrast, replaced the layout of the *polder* with a system that mimics the canals of contemporary Dutch fortress design. (fig 2, to the immediate left of the *Jordaan,* color-coded dark blue.)

The difference in the design of these two 17th century districts is due in part to the socio-economic status of their intended occupants. The *Grachtengordel* was built as a new district for Amsterdam's wealthy merchants, where as the *Jordaan* was to house refugees. The elevation of the land in these two districts is also reflective of this socio-economic difference. Filling land to a higher elevation is of course costly, and the Jordaan was built to a lower elevation than the Grachtengordel (and both were built to a lower elevation than the medieval core.)[7]

With the complexities of Amsterdam's multiple water levels, a lower *polder* level, a higher dam-level within the city, and an even higher and variable sea level in the IJ to the north (which remained a sea inlet until 1872), it became necessary to establish a standard level from which all measurements could be taken. This standardization would be the basis for making the records needed to manage water in the city's canals, and would contribute to the eventual establishment of urban planning guidelines to be shared throughout the city.[8]

3.2.4 The Amsterdam datum: Johannes Hudde and the NAP

Data, a measurement made on scale that can be understood by both recorder and some larger audience, cannot exist without a widely promulgated-scale and some basic points of reference. Datum, the singular form of data, also describes a point of reference necessary for the creation of data. In Amsterdam a water level datum was first widely implemented in the 1680s by mathematician and Amsterdam *burgemeester* (mayor) Johannes Hudde. As a mathematician Hudde had influenced the

5 Amsterdam's parks also sometimes lie at *polder* level- this is why one walks down a slope into *Vondelpark*.
6 Hooimeijer. op. cit. pp. 51-53.
7 Ibid.
8 Ibid. p. 132. diagram p. 133.

development of calculus, corresponding with both Leibniz and Newton.[9] As Hudde oversaw an overall improvement of Amsterdam's water management system, emphasizing hygiene (preventing human excrement from being disposed of in the canals) and defenses from flooding.

After flooding in 1675, Hudde was a central figure in raising the height of the sea dyke along the southern bank of the IJ, a process that was completed in the early 1680s. With the completion of this new piece of infrastructure Hudde also had an array of markers built into eight of the city's locks along the southern bank of the IJ.[10] In the still existing Huddesteen in the Eenhoornsluis (the unicorn lock) the following message is inscribed:

> "ZEE DYKS HOOGHTE, ZYNDE NEGEN FOOT VYF DUYM ABOVE STADTSPEYL" (Sea dike height, being nine feet five inches above city level.)
>
> – Inscription, Huddesteen at Eenhoornsluis.

The marker-stone shows the height of the sea dike, and relative to this height defines the *stadtspeyl* or city level (*stadspeil* in modern Dutch). While records of other definitions of the city level exist before this date, this inscription of the city level into the city's infrastructure marks the creation of a widely accepted standard. The accurate placement of the datum stones was possible due to a revolution in mathematics and geodetic surveying technique a century earlier, led by Dutch mathematicians like Gemma Frisius.[11]

To keep Amsterdam's canals clean, the tidal salt waters of the IJ were used to flush the canals on a regular basis. For this purpose regular and close observation of the sea level was necessary.[12] Figures 1 and 2 show the schedule and procedure for canal flushing (fig. 1) and the map of the different sub-elements in the canal network (fig. 2) as they were used in the late 17th century. The *Stadswaterkantoor* (Amsterdam City Water Office) by 1700 kept hourly records of the sea level using the *stadspeil* datum. This was a 24-hour effort, that required rotating staff at a centralized water management station. The method of measuring the water height, simple enough, required lowering a dip stick inscribed with the *stadspeil* level into the water and recording how high the water reached. These readings were taken without major interruption for the subsequent three hundred years – albeit with increasingly sophisticated methods. In the late 18th century the hourly readings of water levels at the *Stadswaterkantoor* began to be accompanied by meteorological data. This data set is famous as the earliest hourly-recorded meteorological dataset in the world.

The *stadspeil* also came to be widely used in the regulation of the city's urban planning. Regulations on the elevation to which city land must be raised, and even the depth to which piles must be driven has been defined relative to the *stadspeil* with increasing precision and legal enforcement in the 19th century.[13]

9 Hudde contributed to a Latin translation of Descartes' La Geometrie, to which he added a study of maxima and minima.

10 Eenhoornsluis , Nieuwe Haarlemmersluis , Oude Haarlemmersluis , Nieuwe Brugsluis, Kolksluis, Kraansluis, West Indian lock and Scharrebiersluis – of which only the stone in Eenhoornsluis still exists.

11 Frisius was founding figure in the golden age of Dutch cartography, who invented the method of triangulated surveying in 1533 and refined surveying instruments like the cross staff. Hooimeijer op cit. discusses Frisius and Dutch cartography's contribution to Dutch city design.

12 Wallbrink, H and T Brandsma. [KNMI] 2008. "DIGISTAD: Disclosure of the hourly meteorological observations of the Amsterdam City Water Office 1784-1963." "These observations are unique in the sense that they constitute the earliest known hourly long-term meteorological time series in the World."

13 Hooimeijer. op. cit. p. 132. "since 1870 regulations about raising to boezem level have been enforced and in 190s these are legally implemented." See also, p.40. "The heavier the building, the longer the piles have to be in order to reach stable soils. In Amsterdam the usual depth is 7m, while piles are driven to the second layer of sand, 11m below Amsterdam Mean Sea Level (N.A.P)"

1. Schedule/ procedure for flushing Amsterdam's canals,1680. Archive AGV Waterboard.

2. Color-coded map of Amsterdam canal flushing. 1665. Archive AGV Waterboard.

The Amsterdam *stadspeil* (referred to as A.P.) was applied to the rest of the Netherlands in the 19th century as a national standard, and was normalized in 1885 and 1894 and thereafter referred to as the N.A.P. The N.A.P., as a well established standard datum, was adopted in Prussia in 1879 and in 1955 by the other European countries. It is the basis for the contemporary European Vertical Reference System (EVRS).[14] Data requires an initial reference point, or datum, and early authoritative exemplars often become widely adopted. The *stadspeil* marks not only the initiation of the water management data assemblage in Amsterdam, but also provides a fascinating illustration of the growing *embeddedness* of urban data, where politics, mathematics, urban infrastructure and institutional practices combine to produce a system of generating data, onto which many other forms of data monitoring and standardization accrued. As we will see with the example of Cornelis van Eesteren and Theodoor Van Lohuizen's General Expansion Plan (AUP 1934) of Amsterdam, the data-driven management of water became deeply ingrained in the planning and development of Amsterdam's urban form in the 20th century. First, however, it is important to recognize the importance of other water management institutions in the history of the Netherlands, and their influence on construction of modern Dutch water infrastructure and the eventual isolation of the IJ from the sea.

3.2.5 Birth of the industrial waterfront of the IJ

Today Amsterdam lies in a completely artificial water system, rigorously planned over centuries to provide navigational access to the North Sea, protection from flooding, adequate stock of fresh water, and space for development. Data rules this artificial landscape, from the tabulation of water levels and dike heights, to the calculation of risk, allocation of resources, and the planning and development of the built environment.

The modern era of water-management in Amsterdam began in the nineteenth century, when the North Sea Canal was dug to connect the IJ to the North Sea in the west, giving Amsterdam a much shorter connection to the open ocean.[15] A series of locks at the North Sea Canal and at the connection to the *Zuiderzee* (Orange Locks, 1872) cut off the connection between the open ocean and the IJ, ending tidal fluctuation of water levels along its banks. With dependable water levels, the banks of the IJ began to attract industrial development, and were filled in with dredge from the North Sea canal and its ports.

It was during this time that the Buiksloterham area, the subject of the final section of this case study, was first populated by industrial ship yards, petroleum refineries, and other industries. These industrial plants sat on the new banks of the IJ that had been constructed with infill from the IJ.[16] The northern banks of the IJ were difficult to reach from central Amsterdam on the opposite side of IJ. Workers in the industrial north, executives and laborers alike, sought housing proximate to the IJ bank industrial sites due to the difficulty of reaching more popular housing areas to the south. Small 'garden-city' type towns were built in the first decades of the 20th century, inland from the industrial water front and adjacent to the Noordhollandsch Kanaal.[17] As Amsterdam grew rapidly in the early 20th century the

14 See for example: Ihde J., Augath W. 2002. "The European Vertical Reference System (EVRS), Its relation to a World Height System and to the ITRS."

15 Previously it was necessary to travel east along the IJ, then north through the Zuiderzee before reaching the North Sea.

16 ARCAM, the Amsterdam Center for Architecture with the input of Amsterdam's ***Bureau Monumenten en Archeologie*** and ***Historisch Centrum Amsterdam-Noord*** created the ***Architecture Map Amsterdam Noord*** which consolidates many of the facts and dates presented in this paragraph.

17 See for example the Van Der Pekbuurt residential area designed by Amsterdam architect Jan Ernst van der Pek in the 1920s.

problem of coordinating population growth with the development of the city's water system was taken up by urban designers Cornelis van Eesteren and Theodoor van Lohuizen in the Amsterdam General Expansion Plan of 1934.

3.2.6 The Amsterdam General Expansion Plan (AUP) of 1934

The Algemeen Uitbreidingsplan (AUP) or General Expansion Plan of Amsterdam of 1934 is a plan for the growth of Amsterdam. Its primary motivator is accommodating population growth with new housing, and its primary constraint is water. In an initial chapter the AUP tackles the problem of population growth through demographic projections, predicting that Amsterdam will in the future have a maximum population of around 1,100,000. To understand population growth in a spatial way these demographic projections are later paired with projections of different land uses in the city, in a series of three bar graphs describing the city in the years 1903, 1930 and 2000. (fig. 3) This data visualization shows increases in the ratio of recreational space (yellow) and green space (green) relative to living space (red). Water spaces, including the harbor, are shown expanding in proportion to the expansion of living space. As the city expands, so must its water surfaces – and all at the expense of surrounding agricultural lands (pale green) shown on the left and shrinking considerably between each period. The mechanism linking the growth of residential space and green/recreational space with the expansion of water is explored in detail in the text accompanying the AUP.

The problem of water as treated in the AUP is dominated by technical, quantitatively defined concerns. The constraints water imposes on the growth of the city include (1) the question of what elevation land must be raised to before it can be built on, (2) the type of fill to be used to raise the land (wet or dry), (3) where fill is to be obtained (on site through dredging or brought in by train), (4) how much rain water will be absorbed by the new ground and how much will run off to the canal, (5) if rain water can be sent directly to the outlet waterways (*boezem*), or if it needs to be pumped up to the level of the outlet waterway, (6) the depth of storm sewers, (7) the level of ground water, and (8) how to maintain ground water level to prevent pile foundations from degrading.[18] Because of the technical complexity of the water system, the AUP relied on a report by external experts to recommend what level to raise the ground for new building.[19] The text of the AUP explains the need for the technical report thus:

> "The answer to the question whether the city should be built in the future as a "boezem city," so on land raised above boezem level, or whether the expansions will be constructed as a "polder city", is of such great influence on the design of the expansion plan, that the related issues had to be studied in advance."[20]

In addition to providing general data on the problem of water management and land raising, the commission gave several general recommendations. First, Amsterdam should continue to be raised to *boezem* level (higher than the outlet canals) within the ring of railroads surrounding the city. Beyond this line, however they concluded it would be more economical to leave land at the *polder*

18 See description by Hooimeijer. op. cit. pp. 168,169.

19 1934. 'Rapport der Commissie, ingesteld door Burgemeester en Wethouders van Amsterdam, ter bestudeering van het vraagstuk van het bouwen al dan niet op opgehoogden grond.' I rely on Hooimeijer. op. cit. for an account of this report.

20 Amsterdam. 1934. *Algemeen Uitbreidingsplan van Amsterdam : Nota van Toelichting.* p. 159. [*Boezem* designates an outlet waterway at a higher level than the *polder*.]

level in spite of the future recurring cost of pumping the water up and out of the *polder*.[21] A further recommendation is also made: that water is an important visual element of the city and a tradition that should be perpetuated.[22] The technical report thus concludes that while the problem of managing water and raising land to build on is highly technical, its ultimate resolution must depend on a cultural and aesthetic judgment. This recommendation applies in particular to the choice of building at *polder* or *boezem* level, for urban transitions from one level to the other require an infrastructural zone including canal, dike, but also an area of ramp to transition/ connect from one level to another. Negotiating this complex infrastructural landscape in a way that produces a coherent, interconnected city is a technical problem that must be directed by social and cultural considerations. The AUP and the technical report on land-raising together establish the necessity of pairing technical knowledge and cultural/aesthetic considerations in the planning of Amsterdam. The AUP document replicates this duality, integrated data-visualization with design ideas in an early example of Dutch data-informed design.

Previous master plans for Amsterdam were delivered as plan drawings accompanied by a few illustrations or data. This is the case, notably, for Berlage's plan of Amsterdam Zuid of 1915, which relied on a handful of plans and bird's eye view renderings.[23] Van Eesteren and van Lohuizen's AUP, however, is accompanied by extensive data visualizations and a series of maps, each expressing a different layer of spatial data in a way that supports the urban form proposed in the master plan.(figs. 3-6) This mode of supporting an urban master plan took on significance beyond Amsterdam, via the CIAM 4 *Functional City* exhibit, for which the AUP drawings acted as examples.[24] The data-visualizations and maps of the AUP were the work of Theodoor van Lohuizen, a Dutch civil engineer, who developed over his career a well-defined and influential idea of how urban data should integrate with urban design.

Van Lohuizen ideas on the integration of urban data and urban design are reflected in his ideas on the roles of urban designer and what he calls the *urban surveyor* as articulated in his inaugural address of 1948 at TU Delft.[25] Van Lohuizen rejected the idea that quantitative urban surveying and design could be carried out by a single person and insisted instead that it can only be the result of several minds working together simultaneously- a designer, a researcher and various engineers.[26] Van Lohuizen focused instead on the nature of the cooperation between *onderzoeker* (surveyor) and designer.[27] He emphasizes that this cooperation is not linear, with the researcher handing off to the designer,

21 Hooimeijer. op. cit. p. 169. "The final advice is to take the building of the *polder* city outside the rail ring very seriously and to complete the boezem city within that ring so the ring can form a good border."..

22 Ibid. p.168. "The commission takes it even further and gives advice about the general expansion plan in the making. They consider water as a crucial element in the urban vista of Amsterdam; it is seen as a tradition that should be continued. This is, of course, a subjective opinion that is more difficult to defend..."

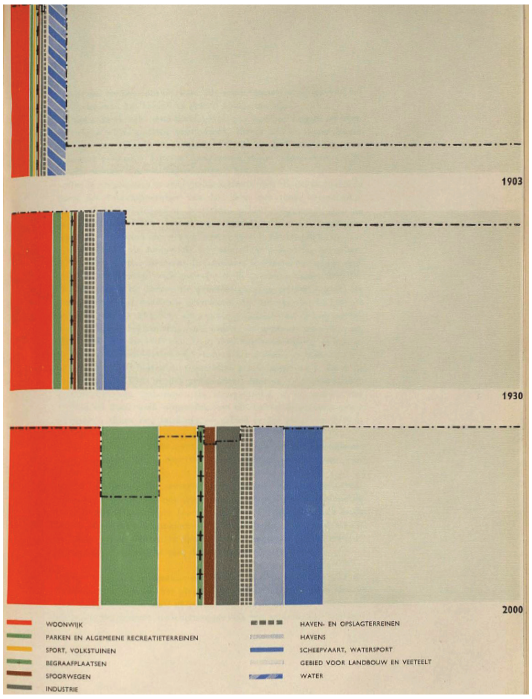
23 Interestingly, Berlage was aware of the more evidence-based approaches of Gustav Langen, and began to integrate these ideas at the end of his career though he maintained a strict separation of the artistic role of urban designer from the data-oriented work of the engineer. See Somer. 2007. *The Functional City.* p.133. "He [Berlage] could offer no more than a fleeting preview of a functional-scientific approach to planning; the principle of survey before plan had barely taken root at this stage, and besides, Berlage incorporated this new development effortlessly into his ideas about the division of labour between the civil engineer and the architect; the former supplied the factual material that satisfied all functional requirements, while the latter had the capacity to create space and mass that would enable it to be processed in a practical aesthetic whole. Science took the first step towards a 'grand composition', which could only be brought to fruition by art."

24 Somer. 2007. *The Functional City: CIAM and the Legacy of Van Eesteren.*

25 Van Lohuizen. 1948. *De Eenheid van het Stedebouwkundige Werk.* Lecture.

26 For these observations I rely on the translated transcript of Van Lohuizen's 1948 lecture op.cit. p.39-40.

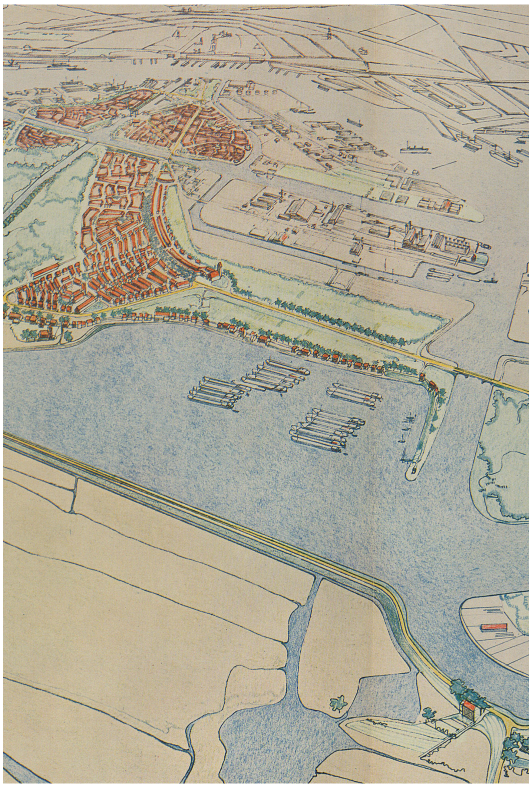
27 From my correspondence with Dr. H.D. van Bergeijk of T.U. Delft: "Van Lohuizen called his own work as survey work and referred to himself as a surveyor. In other words his research was based on empirical data that would be found through surveying."



3. Color-coded visualization of spatial uses in Amsterdam for 1900, 1930 and 2000 (projected). From Amsterdam General Expansion Plan 1934 (AUP).

4. Visualization of future inhabitation pattern of Amsterdam. Existing building in light grey. Black dots represent 100 housing units in the year 2000. Red dots represent 100 obsolete housing units in the year 2000. From Amsterdam General Expansion Plan 1934 (AUP).

5. Visualization of land elevation relative to the Amsterdam Stadspeil. Lowest polder areas shown in darker green. From Amsterdam General Expansion Plan 1934 (AUP).



6. Rendering of Amsterdam Noord and Buiksloterham area. Northern canal as shown was never constructed. From Amsterdam General Expansion Plan 1934 (AUP).

but is rather more complex with each by turn reflecting on the work of the other. He gives special consideration to the task of the surveyor, who he charges both with scientific objectivity, but also with an ability to communicate and advocate for a specific urban goal:

> "He uses the methods of science in full objectivity and with a profound sense of truth. Just like the pursuer of pure science he will not be satisfied until he has studied his problem in the minutest particulars, but for him the object of his research is always the applicability. He will no doubt fail if he merely collects data. He must take in consideration that for every application of social survey it is necessary that the material (statistics, results of public enquiries and censuses) should be elaborated into a form in which it is comprehensible to the users and if possible shows the direction in which the survey leads."[28]

Van Lohuizen's urban researcher is relevant to the idea of a data-driven city not only because he deploys data in the service of the design of the city, but also because of his active and skeptical role in the *creation* of data. The urban surveyor not only interprets official statistics, but actively collects new data, "het moeizaam verzamelen en verwerken van gegevens," and engaging in surveying of urban areas, "verkenning van de omgeving," in the interests of urban design.[29] The surveyor as van Lohuizen defined him is not a passive consumer of data, but instead critically evaluates urban data and has the ability to generate new data adequate to his questions. In the final section of this case study the roles associated with urban data collection and urban design will again be discussed in the context of the Buiksloterham Circular District and the quantification of *urban metabolism*.

3.2.7 Mega-infrastructure: *Afsluitdijk* and Deltaworks

In 1933, as the AUP was being completed, Amsterdam was definitively protected from storm surges by the 32km *Afsluitdijk*, the 'enclosure dike', which closed off the *Zuiderzee* from the North Sea. Formerly a tidally-active sea inlet, the *Zuiderzee* became a large shallow fresh-water lake with artificially controlled water level and was renamed the *IJsselmeer*. Massive new opportunities for land reclamation were produced with the construction of the *Afsluitdijk,* eventually leading to the creation of *Flevoland* and its capital *Lelystad*. *Lelystad* is named for the engineer, Cornelis Lely, who championed the idea of closing off the Zuiderzee in the 1890s. However, it wasn't until the *Zuiderzee flood* of 1916 that the plan was put into effect.[30] Significantly, 1916 was the last major flood to affect the Amsterdam area. Though the city itself escaped disaster, Buiksloot and other villages north of the IJ were devastated. These villages were incorporated into the city of Amsterdam during reconstruction efforts after 1916 when they were unable to fund their own dike repairs.

The massive infrastructure of the *Afsluitdijk* became a model for Dutch civil engineering. So, when a devastating flood struck the South-western delta of the Netherlands in 1953, the response of a government-assembled commission to study the problem was to propose massive new engineering

28 Ibid. p.41. Translation above is from ed. van Bergeijk. Dutch original: "Hij gebruikt de methoden der wetenschap, hij heeft daarvan de objectiviteit, de diepte, de waarheidszin; evenals de beoefenaar van de zuivere wetenschap zal hij 'niet bevredigd zijn voor hij zijn vraagstuk tot de bodem toe gepeild heeft, maar voor hem is het doel van zijn zoeken steeds de mogelijkheid van toepassing. Zeker zal hij tekort schieten, wanneer hij volstaat met de verzameling van gegevens. Hij moet er rekening mee houden, dat het voor iedere toepassing van sociaal onderzoek nodig is het materiaal: statistieken, resultaten van enquêtes en van tellingen, te verwerken, zo, dat het in een vorm komt waarin het begrijpelijk wordt voor de gebruikers en zo mogelijk de richtlijnen, waartoe het onderzoek voert, reeds aangeeft."

29 This description comes from the beginning of the speech where van Lohuizen describes the ideal activities required in urban design. The activities I highlight are ones requiring collection and processing of data, and thus help define the new role of the urban researcher.

30 Lonnquest, John, and Maurits Ertsen, eds. 2014. *Two Centuries of Experience in Water Resources Management: A Dutch-U.S. Retrospective*. p. 161.

projects in the same vein. The *Delta Commission*, as it was named, proposed the *Deltaworks*: pharaonic infrastructures designed to block storm surges before they reached vulnerable land, and yet also re-open to allow free navigation and passage of marine life. The *Oosterscheldekering* (completed 1986) and the *Maeslantkering* (completed 1997) storm surge barriers have become national icons, representing Dutch engineering ingenuity and audacity in the face of great risk. The photogenic Delta works, however, were not the only contribution of the Delta Commission. They also laid the foundation of a national flood preparedness program that used statistical analysis of risk and cost to allocate flood-prevention resources throughout the country.

3.2.8 Optimizing flood risk: David van Dantzig and the *dijkringen*

The Delta Commission's cost-benefit analysis, among the earliest applications of this technique, was developed by mathematician David van Dantzig who contributed a chapter to the commission's final report entitled, 'The Economic Decision problems concerning the security of the Netherlands against storm surges.'[31] He approached the problem of protecting the Netherlands from flooding as an optimization problem. Beginning with the assumption that it is economically impossible to provide perfect protection from flooding, he developed a method of finding a compromise between the cost of a potential flood and the cost of given height of dike. He proposed two graphs- a linear function L(x) representing the cost of building a dike depending on its height given by the variable x, and R(x) which represents the risk of losses incurred by flooding for a given height of dike.(fig. 7) Adding the two equations together results in a concave-up graph whose minimum represents the optimal dike height.

Taking this risk analysis calculation seriously requires making what van Dantzig calls 'imponderable' quantifications: the monetary value of human life and the cultural value of the Central Holland and its irreplaceable historical artifacts. Though he may have called them imponderable, Dantzig still offered up figures for each of these values and used them to propose appropriate spending on the dike protections of central Holland. To compartmentalize risk, and to allow for different cost-benefit calculations for different regions, van Dantzig proposed dividing up the country into a finite number of water-tight compartments each with an independent flood protection system.

The idea of a patchwork of water-tight compartments was ultimately incorporated into Dutch national policy as the dike rings (*dijkringen*), each with its own system of peripheral dikes built to a standard determined by the van Dantzig cost-benefit formula. The highest level of protection has been accorded to the *Randstad*, the semi-circular cluster of cities including Rotterdam, the Hague, Amsterdam, and Utrecht. This megalopolis, which accounts for the majority of the Netherlands's population and economic output, is today contained within dike ring 14 which is meant to be protected against a 1 in 10,000 year flood. This statistic does not mean that these floods appear regularly every 10,000 years, but that in any given year they are estimated to have a 0.01% chance of occurring. The agricultural river lands in the center of the country have the lowest level of protection adequate up to a 1 in 1,250 year flood, or 0.08% chance of occurring in a year. The difference in risk has been deemed acceptable given the economic value of each parcel of land and the cost of building the flood protection system.

31 van Dantzig, David & Kriens, J. 1961. "Het Economisch Beslissingsprobleem Inzake de Beveiliging van Nederland Tegen Stormvloeden." *Rapport Deltacommissie* Bijdrage II.2.

Amsterdam sits at the northern border of dike ring 14 (the Randstad dike ring) and the parts of the city sitting north of the IJ necessarily sit in a separate dike ring– number 13. The dikes not only split the city in two, but they also leave a swath of land along the banks of the IJ that falls into neither dike ring 13 or 14. While dike rings 13 and 14 are both accorded the highest level of flood protection, the river banks fall into dike ring 44 and are accorded the lowest level of protection.[32] What can account for this inconsistency? First and foremost, the city of Amsterdam historically sits to the south of the IJ river. The lands to the north of the IJ were only incorporated into the city in the 1920s and even then were not fully connected to the city until the A10 orbital motorway was completed in 1990. (Even today most inhabitants of Buiksloterham use a ferry to access the center of Amsterdam.) Second, until the end of the twentieth century the banks of the IJ river were devoted almost exclusively to industrial uses (ship-building, petroleum refining). Finally, the IJ represents a significant water drainage basin for north and central Holland: if flooding were to occur somewhere near Amsterdam, it would likely happen along the banks of the IJ. In the 1960s as the dike rings were first being imagined it was logical to conceive of the banks of the IJ as outside of Amsterdam, even more so as the existing infrastructure already dictated this separation.

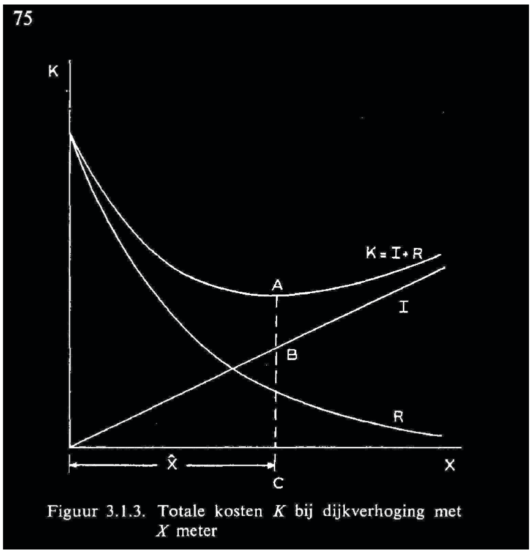
3.3 Reorientation: data-driven delta, public awareness and action

Since the 1980s Amsterdam has grown increasingly out onto the banks of the IJ, slowly completing the post-industrial reclamation of the waterfront.[33] With this growth much of the vibrant new activity in the city has moved across the dike walls, which are now difficult to discern in the urban landscape. This growth challenges the original cost-benefit calculations of the 1960s era Delta Commission and the form that these calculations gave to the dike rings. How risky is it for people to move from dike ring 14 to dike ring 44? After all, no major flood has occurred near Amsterdam since 1916. Throughout the Netherlands the distribution of property and population is shifting, Amsterdam is not even the most dramatic case. Though the infrastructure of the 20th century may provide good protection within its dike rings, it is not a flood protection strategy that can adapt to shifting patterns of inhabitation. Looking to the future, not only is the upkeep of the 20th century flood protection system necessary, but some means of adapting to changing ways of living is also necessary.

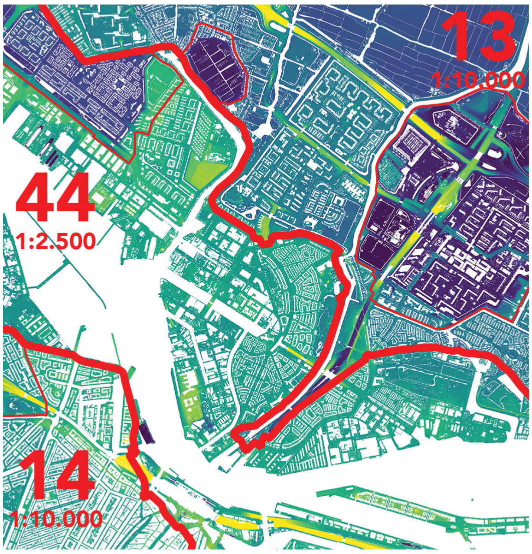
Risk of flooding has also evolved since the 1960s due to changes in global climate which are raising the water level of the North Sea. In response to the growing threat of climate change the Dutch government formed a new Delta Committee which published its report on the future of water management in the Netherlands in 2008. The title of this new report, *Working together with water: a living land builds for its future*, announced an *paradigm shift* from entirely controlling the water system to accommodating it as it evolves (perhaps unpredictably) alongside patterns of human land use.[34]

Data (alongside infrastructure) is a protagonist of the 2008 Delta committee report, making it possible to understand, manage and raise awareness about the complexity of the evolving water system. Climate change's impacts on the Netherlands will not be limited to a rise in the level of the North Sea; flows in the major rivers of the Netherlands, the Rhine and the Meuse will likely increase in the winter and decrease in the summer with the possibility of drought. Preparations need to be made for

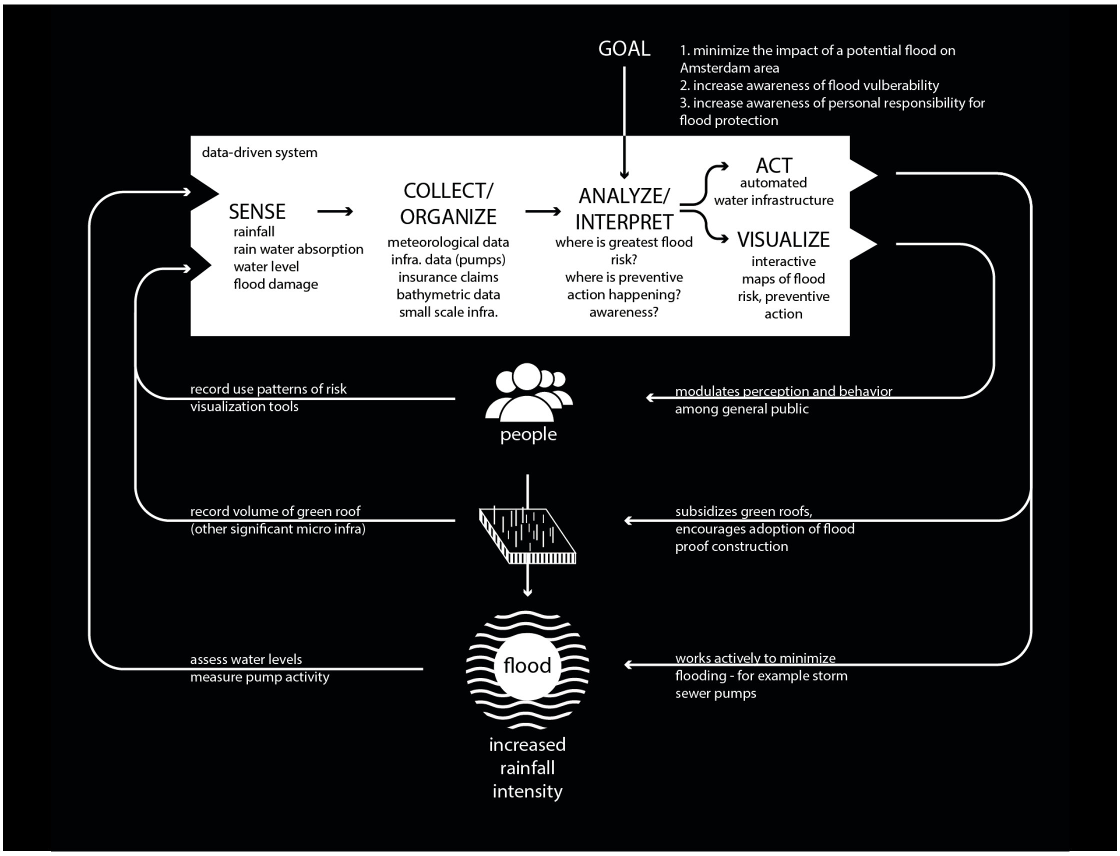
32 IJburg, a new area of reclaimed land to the east of Amsterdam sits in its own dike ring- 13a.
33 See for example: Christiaanse. 2003. "Housing in Harbours in Holland."
34 Meadows. 1997. *Leverage Points: Places to Intervene in a System.* See leverage point 1, "1. The mindset or paradigm out of which the goals, rules, feedback structure arise."



7. David van Dantzig's method of optimizing dike height. Cost of dike construction [I] is added to risk of flood [R] which results in graph [K] whose minimum represents optimal investment in the dike.



8. Central Amsterdam lies in dike ring 14, North Amsterdam is in dike ring 13, both have the highest level of flood protection. The banks of the IJ including Buiksloterham like in dike ring 44 and have the lowest level of protection.



9. Diagram of the Amsterdam feedback framework, with the built environment mediating between the matter of concern- flood waters- and concerned inhabitants.

discharging this water in the winter, and retaining it in the summer. Parallel to the Delta committee's preparations for climate change the Dutch government has also recently made significant updates to van Dantzig's 1960s calculations, returning for example to the hard problem of non-quantifiable values: "How can the value of reducing the number of victims be assessed in monetary terms?"[35] The recommendations of the Delta committee report includes a push for a new layer of digital infrastructure that both monitors the water system and interfaces with general population as an information sharing tool:

> 'Information and communication technology will come to offer new facilities for risk monitoring, allowing the population to be informed and brought to safety when disaster threatens.'[36]

This recommendation is part of a three layered approach to water management, which supplements the (1) dike ring infrastructure with (2) sustainable spatial planning that limits damage in the case of a flood, and (3) disaster management which seeks to prevent large numbers of casualties in the rare case of a catastrophic flood.[37] While there is a push to digitize the physical infrastructure of the dike rings, the main contribution of data-driven methods is to the other two layers where information sharing and evaluation are crucial.

The Delta Act came into effect in 2012, putting into action the recommendations of the 2008 Delta commission report. A Delta Commissioner, a Delta Fund and the Delta Program were created to manage, finance and implement the Delta report's goals in cooperation with the Rijkswaterstaat (the national water management agency) and local governments.

3.3.1 Flood risk and shelter: *Overstroom Ik?*

The data-assemblage that is rapidly accreting to the Dutch water infrastructure begins to interface with the city of Amsterdam and its architecture in spatial planning and disaster preparedness. The digital tools that I will examine next are prone to fast obsolescence; anyone reading this in the future will likely find that they are already defunct. Just as likely, however, is that new tools providing similar functionality will exist. Most important for my research is the analysis of the feedback loops that are developing between the representation of the city as data and the physical form of the city.

To distribute personalized information about flood risk the *Rijkswaterstaat* has created an online tool called *Overstroomik.nl*. The tool asks the user to enter the location of his home to answer the simple question 'Overstroom ik?' (Will I flood?).(fig. 10) Based on the entry, the site queries an online database of flood risk maps and shows the user an infographic of a home immersed in varying levels of water. If the user's location has a risk of flood the response to the initial question is shown in bold-face print "Yes, you flooded up to a maximum of 2.0 meters." It goes on to explain that there is a 10% risk of this flooding occurring in the user's lifetime and ending, "That could be tomorrow."(fig. 11)

35 Bos, Frits and Zwaneveld, Peter. 2017. "Cost-benefit Analysis for flood risk management and water governance in the Netherlands: An overview of one century." The Hague: CPB Netherlands Bureau for Economic Policy Analysis. p. 37 In the section, "A cost-benefit analysis for new safety norms," they explain that the value of statistical life was set at 7 million euro for purposes of updated water governance CBA.
36 Deltacommissie 2008. *Working Together with Water: A Living Land Builds for its Future.* (English translation) p. 94-95.
37 Ibid.

10. overstroomik.nl start page: The page prompts the user to enter her home address with the question, «Do you live in a risk area?»

11. overstroomik.nl: The page provides an estimate for how high flood waters may rise in a given area if dikes fail. This result is for an address in Buikslotermeer, a polder area in Amsterdam Noord.

12. overstroomik.nl start page: The page asks the user to explore two flood scenarios, evacuating or staying. For each scenario tips are provided.

13. overstroomik.nl: If the 'stay' option is selected, a map visualizes which buildings in the user's neighborhood will be viable flood shelters. Buildings shown in red are likely to be completely inundated.

14. overstroomik.nl: If the 'leave' option is selected, a map visualizes where the evacuation route may be disrupted by flood waters. In Buikslotermeer the ring road is depicted as blocked with a series of red crosses.

Overstroomik.nl has a further function called 'Wat kan ik doen?' (What can I do?), which prompts the user to make a plan to stay or to leave during a flood.(fig. 12) Two more interactive maps are provided to support this decision; the first, 'Dry places in your area,' queries the number of floors for each building within the user's search area and places a red dot on buildings completely submerged and a green dot on those with a dry floor which can provide refuge.(fig. 13) The second map, 'Water op de weg,' is meant to help the user develop an evacuation plan if he decides to leave. Roads that are likely to be flooded are marked with a red X.(fig. 14)

While the primary goal of *Overstroomik.nl* is to permit the inhabitants of the Netherlands to make a well-informed plan should flooding occur, the maps also have a secondary effect on the development of the city and its architecture. Users who discover that a particular site is prone to flooding may re-evaluate plans for living or building in that area. Indeed, this modification of behavior would meet the Delta program's goals for spatial adaptation which call for discouraging development in flood prone areas through awareness-building instead of an out-right ban. Furthermore, the 'Dry places in your area' map proposes re-purposing the city's buildings as a distributed infrastructure of mini flood-shelters. The re-purposing of underused resources by linking them in a distributed network to many possible users is one of the fundamental 'disruptive' potentials of the 'sharing economy'. Here the Dutch state is using the same technique that created the success of Uber and Airbnb, as part of the response to the risk of flooding.

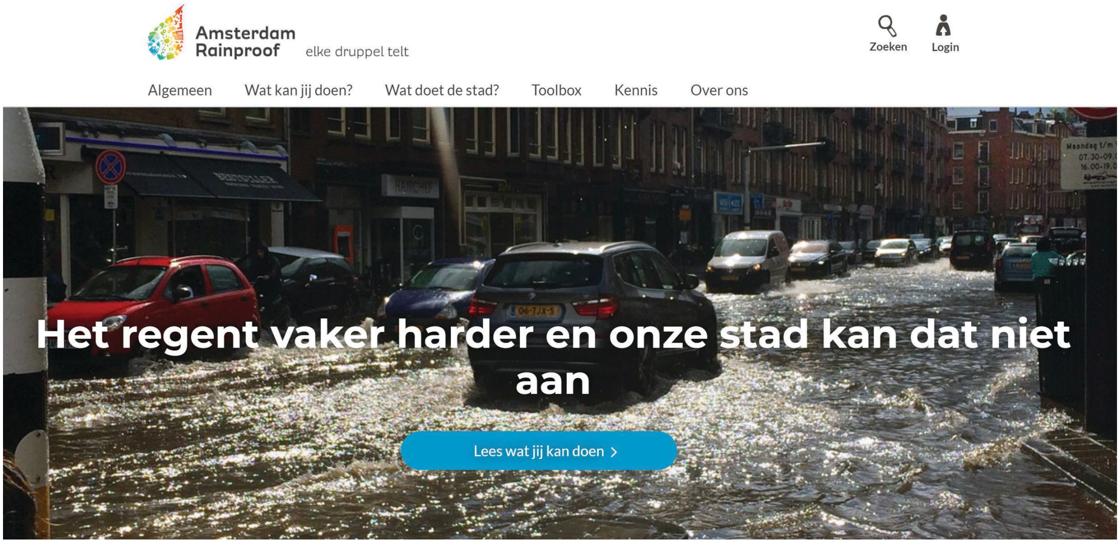
3.3.2 Public action on storm flooding: *Amsterdam Rainproof*

Amsterdam Rainproof, takes the next step toward incorporating architecture into a digitally networked water management infrastructure. This online portal, though an initiative of *Waternet* (the public water utility of Amsterdam, and offshoot of the AGV waterboard), follows in the wake of the 2008 Delta Report by encouraging adaptation to climate change. Instead of the threat of a dike breach, *Amsterdam Rainproof* takes on the less catastrophic but much more likely urban flooding due to increased or extreme rainfall. Climate change is expected to increase the intensity of rain storms in the Netherlands. In recent years Amsterdam has already experienced extreme rain events that have led to flooded streets and damaged buildings. The large percentage of impermeable surfaces in urban areas means that little rain water is retained in the soil and is instead channeled to the city's storm-sewer system which can be overwhelmed.

The city's storm sewers are currently built to handle a maximum precipitation of 20mm per hour.[38] Extreme rainfall, like that experienced in 2014 in Amsterdam, can drop as much as 90mm per hour. In parts of the city lying below the level of the canals, water in the storm sewers must be pumped up into the canal before being carried away. The uptake of rainfall is limited both by the diameter of the storm sewers lying beneath the roads of Amsterdam, but also at the pump stations moving water out of the streets into the canals.

Amsterdam Rainproof presents this dilemma in the most direct terms. "It's raining more often- and our city can't handle it," is the claim that greats a visitor to the website rainproof.nl. Prompting the user with a link, 'Wat kan ik doen?' (What can I do?), a catalogue of build-able interventions is presented,

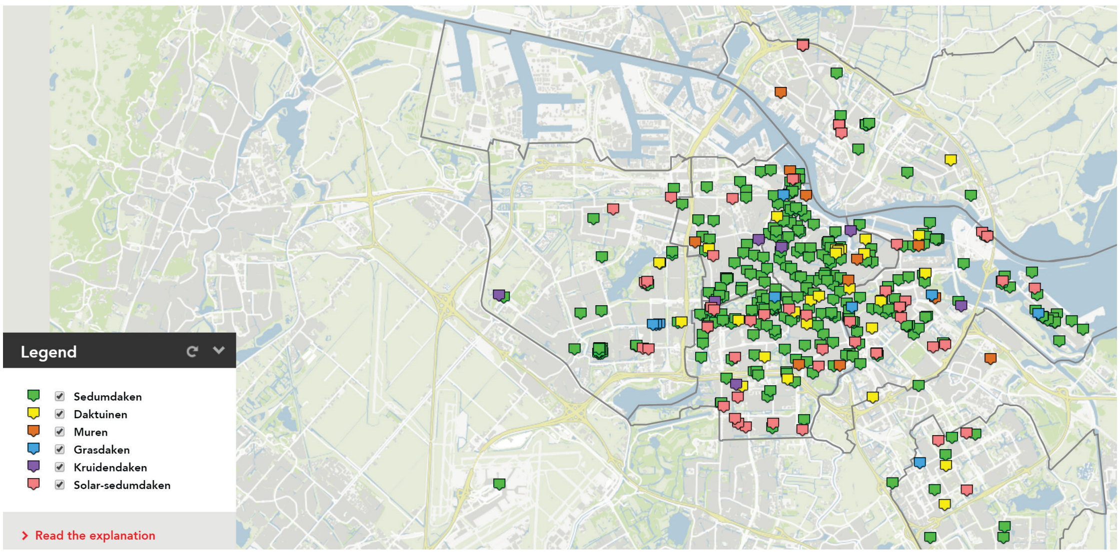
38 The figures cited in this paragraph are taken directly from *Amsterdam Rainproof*'s awareness campaign. See rainproof.nl.



15. Amsterdam Rainproof. translation: 'Its raining harder and our city can't take it.' (All images retrieved 2018.11.18)

16. Amsterdam Rainproof. Grid of rainproof interventions.

17. Amsterdam Rainproof. Green roof details.



18. City of Amsterdam. Map of green roof database. (2018.11.18)

with explanations of how they work and often a link to a supplier or contractor who can provide the product or carry out the construction. The site focuses on modifications to the built environment that may reduce damage to existing buildings when flooding does occur. Interventions that increase water retention from rain storms are also prominently featured. For some interventions, like green roof construction, a subsidy is available to defray the cost of construction, and a link is provided directly to the municipal government website.

While increasing the dimensions of the storm water system is one possible solution to increased rainfall, *Amsterdam Rainproof* presents interventions that increase the retention of rainwater and prevent it from reaching overwhelmed storm sewers in the first place. This strategy, decentralization, splits the burden of providing for water infrastructure between the city government and many private actors. The cost of flood prevention becomes a shared cost between the government's investment in storm sewers and private actors' voluntary investment in water retention. While the decentralized strategy may reduce public costs, it is unclear to what extent it can be depended on to increase flood prevention through rainwater retention or to reduce the damage of flooding.

Among the interventions that *Amsterdam Rainproof* proposes, the most directly architectural is the green roof, a mainstay of modernist architecture (*toit-jardin*) but a relatively rare feature among the traditional canal houses of the city. The green roof, while desirable to architects and homeowners for purely aesthetic reasons, is interesting to the city of Amsterdam for its ability to retain rain water during potentially flood-causing storms. While proposing a variety of methods for the construction of green roofs, and local installers with expertise in green roofs, Rainproof also directs visitors to the city of Amsterdam's subsidy for green roofs. When applying for the subsidy one must provide information on the dimensions and type of green roof being installed and then complete the installation within a given frame of time. This data in hand, the city is able to monitor the area of green roof constructed in Amsterdam, and thus to estimate the impact of green roof water retention on the reduction of urban flooding during intense rainfall.

The green roof subsidy gives the city a new spigot to turn in the water management system. If flooding caused by heavy rain becomes an increasing problem in years to come, the city can increase the subsidy and drive greater green roof creation and rain-water retention. Conversely, if rainfall does not become as severe as forecast the city can simply scale back or remove the subsidy. A distributed system of this kind permits gradual and responsive investment, as opposed to the one-off massive investments required for public works. The green roofs of the city of Amsterdam (an architectural element) have become a distributed public infrastructure, and the city only has to pay a fraction of the cost. The ability to organize, incentivize and monitor rain water retention through this sort of distributed system is accelerated with an automated and data-driven system.

3.3.3 Preventing flood damage via predictive analytics

Evaluating water management efforts presents a true big data challenge for the City of Amsterdam. *Rainproof Amsterdam* has implemented a data-mining approach to this challenge, collaborating with the insurance agency *Achmea* and the big-data analyst *Synerscope*.[39] This project, so far run only as a trial, pulls data sets from *Achmea*'s insurance claims, the Dutch meteorological agency, the national

39 Dekker, Gert. Et. Al. 2016. Van last naar les: Hoe publiek-private samenwerking de regenwateroverlast voor inwoners, woningeigenaren en klanten kan verlagen. *Amsterdam Rainproof* with Ambient, TU Delft, and Synerscope.

cadastral authorities, *3di*'s bathymetric flooding simulations, and Google's street photos. Using *Synerscope*'s proprietary multi-dimensional search algorithm, clusters of damage claims are associated with certain architectural features captured from Google's street view with machine vision. The results are fairly mundane: for example, basements with certain types of ventilation details are particularly susceptible to flooding from heavy rain.[40] Some types of damage also result from one-way attachments to sewer drains which cause connected washing machines or toilets to overflow when the storm sewers become overwhelmed in a heavy rain. The granularity of the study, which can automatically pull specific words from an insurance report and associate them with an image of a building and an ultra-precise simulation of the city's water system is, however, rather revolutionary. Not coincidentally, *Rainproof Amsterdam* now prominently links to one-way sewer connection valves, and shielding systems that prevent small floods from entering basement or street level doors and windows.[41]

A distributed system of private homes that as an aggregate provide a significant public infrastructure- monitored with a previously-unimaginable degree of granularity by machine-driven algorithm and coaxed into existence with a combination of modest public subsidies and internet-driven awareness campaigns: this is one vision of the architecture of the data-driven city. This feedback loop is an example of the new formal basis of architecture in the data-driven city: policy, data, finance, infrastructure incorporate the architectural artifact into a larger, software managed systems. At face value, there is little insidious to be found in the example of Amsterdam. Skeptics will rightly point out that this sort of private infrastructure cannot substitute for adequate public infrastructure. As a compliment, however, to an already excellent public infrastructure – as is the case in Amsterdam- extra measures that rely on a mix of public-private investment can only be a plus.

From the point of view of the architect, the criticism of the *feedback framework* is perhaps more compelling: treating the elements of the architectural artifact as pieces of a larger distributed system tends to encourage the ontological collapse of the work of architecture into an incoherent assembly of products, each functioning according to its own 'intelligence.' This Cassandra-esque scenario, however, seems disproportionate to the banality of a government subsidy for a green roof, even if it does happen to be digitally tracked. What is true is that the changes driven by the Delta Program will without question change the form and image of the Dutch city. How exactly these changes happen, however, will be determined by those intimately involved with the day-to-day creation of new urban spaces and forms- not least of whom are the Dutch architects.

3.4 Built form: Buiksloterham Circular District

With the evidence presented thus far, the data-assemblage model helps us to map out the growing complexity of water management in Amsterdam with its shifting matter of concern, constellation of public and private actors, databases and digital tools of measurement, visualization and social influence. Within the assemblage we also can discern the position and role of the built environment. So far our examples in Amsterdam show the built environment instrumentalized, working as a tool of public policy. Useful properties of architectural elements like green roofs are monitored – entered in public databases – but also actively promoted and managed as cloud-like distributed infrastructures.

40 Ibid. See p. 38, figure 12 which lists the number of insurance claims associated with leaks through basement windows or ventilation. 'via kelderlichtschachten of ingangen van de kelder'
See p. 32 figure 7 Which depicts automated analysis of Google street view searching for basement window details on building facades.
41 www.rainproof.nl/wat-kan-ik-doen/gebouw (accessed 21.04.2019)

This evidence supports the idea that the data-driven context does have a morphological impact on the built environment: for instance the propagation of a type of useful (and quantifiably predictable) water-retaining green roof.

Thus far the depiction of the built environment and its creators,however, has only been passive, and the question of if, or how the architect and architectural form might influence the development of the data-driven city has not been directly addressed. The passive depiction of architect and architecture is due in part to the method used to build up the history of the data-assemblage: tracing first the appearance of a communal matter of concern, then its practices of measurement and management and finally its recruitment of tools and new technologies. In this analysis we reach the built environment last, where it appears as if as a result of policy. In the following section, however, I reverse this method by looking closely at a series of architectural projects, asking how their creators aimed to make change, and considering if evidence suggests that their work has exerted wider systemic influence in the data-assemblage. Can built form change the way the city is quantified, monitored and algorithmically managed?

3.4.1 Buiksloterham Circular District

In 2015 a vision document was published for a heavily-polluted post-industrial district called Buiksloterham that sits north of the river IJ directly across from the historic center of Amsterdam. The document, *Transitioning Amsterdam to a Circular City: Circular Buiksloterham Vision & Ambition*, laid out a vision for a *circular* district where material resources would be indefinitely cycled, and energy would be generated on site from renewable sources.[42] The means of achieving this vision rested not solely on the willpower of its residents, but also in hopes for a new data-driven system of digital monitoring and management. Materials coming in and out of the district would be checked into a district database and tagged with a digital passport to monitor their use and eventual reuse.[43] Energy, produced on site, would be distributed through quasi-autarkic smart grids, shared between neighbors and passed on to the city-wide grid in instances of surplus.[44] Water, in particular, was to be a focus of this digitally mediated urban metabolism. Storm water was to be carefully managed in a system of green roofs, water retention basis, and bio-swales- making the installation of a storm sewers in the polluted soil of the post-industrial sites unnecessary.[45] Residential waste water was also to be subject to digital scrutiny. Divided into gray water and black water the two streams would be diverted to a new kind of water treatment plant where the biological nutrients in black water would be reclaimed as energy in a bio-reactor, and the less soiled gray water would be filtered and returned to the cycle as drinking water.[46] An overview of this circular metabolism was proposed to be made publicly visible in an online map, the *Circular Buiksloterham Interactive Metabolism Map*[47]. (fig. 20)

The initiators if the Circular Buiksloterham vision document included the City of Amsterdam's development office (*Ontwikkelingsbedrijf Gemeente Amsterdam*), a housing cooperative/developer

42 Gladek, Eva, Sandrine van Odijk, Pieter Theuws and Albert Herder [Metabolic,studioninedots & DELVA Landscape Architects.] 2015. 'Transitioning Amsterdam to a Circular City: Circular Buiksloterham Vision & Ambition.'
43 Ibid. p. 33.
44 Ibid. p. 167.
45 Ibid. p. 36,37.
46 Ibid. p.38, 127.
47 Ibid. p. 69.

with stakes in the area *de Alliantie*, and perhaps unsurprisingly *Waternet*, Amsterdam's water utility and a division of the *Amstel Gooi en Vecht* waterboard. The waterboard, the ancient institution responsible for managing the flood defenses of Amsterdam, was now helping initiate a new smart city in the post-industrial north of the city. *Waternet* first announced its interest in the district in April of 2014 at a public forum on water innovation, where it proposed Buiksloterham as a site for testing new and more sustainable ways of managing urban water.[48] As a post-industrial district, Buiksloterham had little of the water infrastructure that would be needed for a residential area. But its closeness to the historic center, combined with new mobility offers that reduced the time crossing the river, made the eventual development of large amounts of housing on the site seem inevitable. *Waternet* would be faced with the need to install new water infrastructure for the growing residential population. This prospect, however was looked on as an opportunity to reassess the sustainability of the existing water management system and to invest in innovative new systems of management and ways of living with water, in particular smart systems.[49]

3.4.2 NDSM and de Ceuvel: resettling a post-industrial district

In 2014, however, when *Waternet* turned its attention toward Buiksloterham the area was not a blank slate. Already in 2009 the city of Amsterdam had begun offering sustainability grants to motivated individuals to redevelop post-industrial sites in the area. The resulting projects were put forward by a quirky group of non-conformists attracted to the idea of sustainability, and the aesthetics and opportunities of a still raw post-industrial area. Most influential for the development of the Circular Buiksloterham vision was a project sited at a former shipyard *de Ceuvel Vlharding*. In 2010 a group of young architects won a competition for a ten year lease from the city of Amsterdam to build what they called a 'sustainable workplace.' The shipyard had been vacant since 2002 when the shipbuilder was cut off from the harbor by the construction of the *Ridderspoorweg* bridge and shut down his business. The site, like much of Buiksloterham, was heavily polluted. In order to build on the site a protective layer of clean earth up to a meter thick would need to be placed on top of the site. Lacking the time or resources for such an extreme intervention the young designers needed to develop a cheaper and temporary solution to occupying the site.

Steven Delva of *DELVA* landscape architects, proposed a phytoremediative garden- with a variety of plants that would help clean the site's soil over time. *Space&matter*, a group of three architects, proposed a clustering of small structures that would sit on top of the polluted soil without disturbing it- an important consideration for the environmental review of the project. The idea of these small pavilions evolved into a series of reclaimed houseboats, purchased for next to nothing, refurbished and lifted and placed onto the site by a crane. *Space&matter* also proposed a sinuous boardwalk that would connect the houseboats together and allows visitors to walk above the 'forbidden garden' and polluted soil. Tying the project together was a sustainability concept developed by a third contributor, *Metabolic*. Proposing on site food production, energy creation, composting toilets and biofiltration of waste water, *Metabolic* aspired to making *de Ceuvel* a closed system capable of sustaining itself independently of other urban material and energy flows. The *de Ceuvel* development was nurtured

48 Ibid. p. 25. "On April 11th, 2014, an event on water-related innovation in the city was hosted by Waternet at the Pakhuis de Zwijger, a Amsterdam-based podium for citizen participation. At this event, Buiksloterham was proposed as a key innovation zone for circular urban development in the city."
49 van Assenbergh, Evelien (Waternet). 2016. Gemeentelijk Rioleringplan Amsterdam 2016-2021. pp. 29,31.

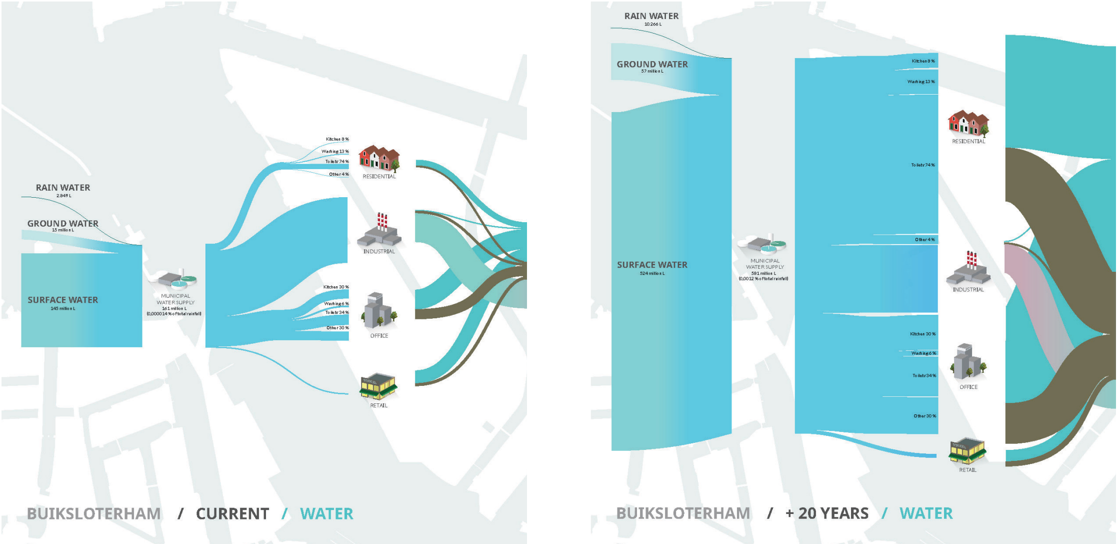
during its creation by Eva de Klerk who had spear-headed the reuse of the nearby NDSM dockyards in the early 2000s and the creation of the NDSM Kunststad in 2007. *Metabolic* was incubated in a trailer on the NDSM site and mentored by de Klerk, and the initial retrofitting of the *de Ceuvel* houseboats took place at the NDSM wharf. By 2012 the house boats had been lifted onto the *de Ceuvel* site, and the young designers responsible were gaining notoriety at home and internationally for their boot-strap approach to sustainable design. As the *de Ceuvel* team explained it, they were able to take waste land and waste material and create new value.

When *Waternet* proposed taking on Buiksloterham as an urban lab for water innovation in 2014 they turned to *DELVA* and *Metabolic* as natural partners. Bringing *de Alliantie* and the City of Amsterdam on board they also recruited a new office of architects *studioninedots*. Together they produced the Circular Buiksloterham vision document which was released the next year. Building on the non-conformist individualism of *de Ceuvel*, the vision document emphasized a communal and pluralistic approach to the founding of a smart district. Stakeholder discussions were diligently convened and produced a list of many hundreds of possible sustainable interventions throughout the site.[50]
In parallel *Metabolic* conducted a detailed urban metabolism analysis which gathered data on current material and energy use in the district and constructed a business-as-usual prediction for the needs in twenty years.(fig. 19) They also generated an aspirational scenario for a circular metabolism diagrammed as a timeline, demonstrating the extent to which material and energy flows could be made sustainable in the next two decades.[51]

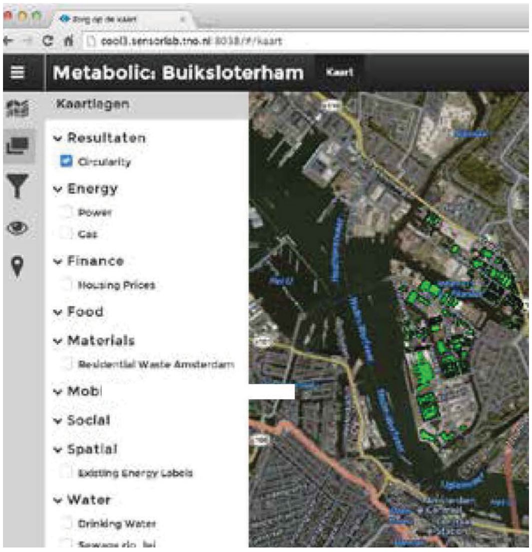
3.4.3 Cityplot Buiksloterham

In parallel to the vision document *de Alliantie* also had begun its own plans for a (~3 ha) development in Buiksloterham with *studioninedots* and *DELVA* as designers of the masterplan. The development is named *Cityplot* in reference to an urban master planning concept developed by *studioninedots* in 2012. Originally shown in an exhibit at the ARCAM gallery, the *Cityplot* concept breaks down the Amsterdam urban block into multiple parcels of differencing scales.[52] Within this framework large institutions as well as individuals can invest in and build on the land. The varied subdivision of the block also produces an intimate public space at its center where interactions between the residents of the block could take place. Key to the concept is the presence of an *urban activator;* a locally owned self-built, self-managed work space that serves as the social and economic core of the *Cityplot* block. In the case of the Buiksloterham *Cityplot* development, these ideas are imported directly on the site. The small self-build plots allow for the individualistic character of the Buiksloterham district to be extended, while the adjacent larger plots provide viable investment basis for the large developer *de Alliantie*. Several sites for urban activators are included on the site. As they are put up for auction, these sites also come with a required statement of intent which explains the buyers plans to create an economically dynamic and sustainability oriented workspace. The urban activators, hope to revive or

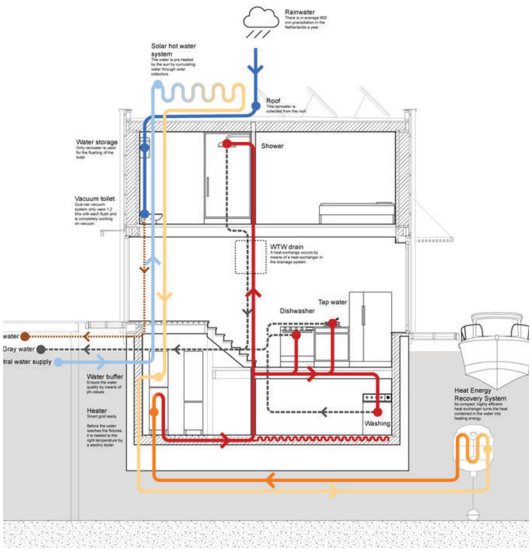
50 Gladek et al. 2015. 'Transitioning Amsterdam to a Circular City: Circular Buiksloterham Vision & Ambition.' pp. 109, 110. "Stakeholders are those who have a direct stake in the development of Buiksloterham as a result of their power, those who are subjected to the power of decision-makers or those that have in some way a stake in the development of the area" They are engaged via 'digital survey' or 'joint work-shops'.
51 Ibid. Present day and +20 years business as usual scenarios are presented via Sankey diagrams (for water see pages 136 and 137 with explanation on pp. 128-129). Key measures to achieve a circular economy are shown using a timeline (for water see timeline p.61 and expla-nation p.60).
52 ARCAM. *The city of the future.* Exhibition Nieuwe Oogst. 13 Oct 2012- 24 Nov 2012



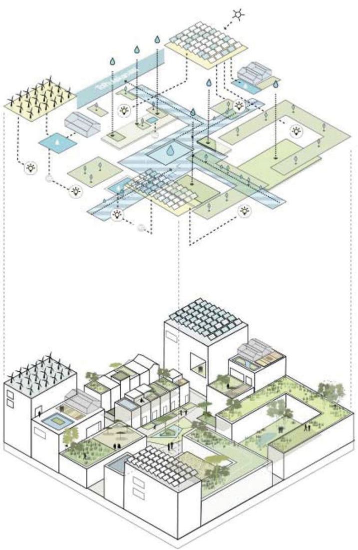
19. Circulair Buiksloterham. 2015. Sankey Diagram of current and future water use in district.



20. Circulair Buiksloterham. Proposed map of circularity rating.



21. Schoonschip. 'Circular' water heat and waste system.



22. Cityplot Buiksloterham. Water retention strategy.

23. Cityplot Buiksloterham. Rendering of flooding street.

propagate the success of *de Ceuvel*, creating pockets of creative activity within the block and in theory producing the sustainable economy innovations necessary to achieve the ultimate goal of a Circular Buiksloterham.

Water management defines much of the physical form of *Cityplot* Buiksloterham. The architectural agenda promoted by *Waterproof Amsterdam* and *Waternet* in the city of Amsterdam finds clear expression here in the physical features of the masterplan. The roofscape of the development consists mainly of flat roofs which, along with ground level public space, are organized into four separate levels of water management.(fig. 22) At the highest level the flat roofs are used to collect solar energy. Rainwater is collected at this level and discharged to the second level where it is retained in green roofs and in some instances used as gray water to flush toilets. At a third level rainwater is passed on to collective gardens, which may be on roofs or at ground level, and finally in a fourth level it is passed on to open public spaces at ground level where it is retained in planted areas or pools. The retention pools of the open public spaces in turn link to the car-accessible streets which drain downhill to the *Tollhuis* Canal. The street-section proposed by the designers is concave (instead of the typical convex) so that, as is shown in the renderings (fig. 23), the street center will flood in heavy rain and act as a large gutter leading storm flood water to the canal. The masterplan document describes this flooding as a 'characteristic visual element' in the development.[53]
Draining water to the *Tollhuis Canal* at *Cityplot* Buiksloterham would be made possible by the profile of landfill added to the site. A layer of topsoil of approximately 75cm must be added to the site; in the masterplan document this is described as necessary to reduce the risk of flooding. While rainwater management is a one motivation for the addition of this soil, remediation documents filed with the city of Amsterdam make clear that this layer is also necessary to protect future residents from the polluted soil that currently exists on site.[54] The designers propose sloping this soil up from the main street serving the site (Distelweg) to a maximum thickness of about a meter and then down again toward the *Tollhuis Canal* on the other side of the site. (Ground water on site is kept rather low by a layer of impermeable dredge which dates to the period when the land was created.) The potentially polluted nature of storm-water run-off from the site is highlighted by the designer's proposal of remediation gardens floating in the canal which would filter run-off water before discharging it into the canal.

Anticipating the presence of the densely inhabited *Cityplot* site in Buiksloterham (along with other new residential buildings) *Waternet* has begun an initiative to develop a new kind of water treatment plant to the north of the *Cityplot* site. Beginning from the circular concepts tested by *Metabolic* at *de Ceuvel* and enumerated in the Circular Buiksloterham vision document, the *Waternet* facility plans to redirect waste water from surrounding areas into two separate streams. *Black water* collected from toilets will be diverted to a bio-reactor where it will generate biogas which can be used to produce electricity through combustion and hot water through heat transfer. A second stream of *gray water* is treated separately. It is first stripped of any heat through heat transfer, with heat from this process and from the black water heat exchange is then used to heat local residences. The gray water then undergoes a process of purification and filtration after which it is returned to the clean water system. This pilot project is pitched as a heavily monitored case study, where data will be carefully and

53 Zo wordt het gebied ontwaterd, het rioolstelsel ontzien van (piek)belastingen en wordt water een kenmerkend zichtbaar onderdeel van Buiksloterham. P. 8 Uitgangspunten *Cityplot* Buiksloterham

54 Traast, Steven & Jeroen Geerdink [Search *Ingenieursbureau* B.V.]. *Saneringsplan.* Locatie: Distelweg 99 t/m 104 en Asterweg 49 te Amsterdam. Opdrachtgever: De Alliantie Ontwikkeling.Projectnummer: 25.14.00232.1 See p. 11 fig. 3 'Dwarsprofiel'

extensively gathered and used to evaluate the future viability of these sustainable 'circular' processes. As a flagship project for *Waternet*, this data is also expected to be made public as part of the open-data position of Circular Buiksloterham and in an effort to inspire future innovative water management techniques elsewhere in the world.

Cityplot Buiksloterham's masterplan was completed in early 2015 and began selling its plots by the end of the year. This frenetic pace, however, has since stalled as official approval of the remediation plan for the site's polluted soil has been withheld. Optimistic projections on the part of the developer and the city forecast the beginning of the some construction in coming years, but it is undeniable that the severely polluted nature of Buiksloterham's soil is proving more of a challenge than initially anticipated. Other housing projects within the district, however, have sought to entirely avoid the soil; a strategy which may ultimately be more successful and has produced a very different physical form and mode of life than that put forward at *Cityplot*.

3.4.4 Schoonschip: *space&matter*

Near the *Cityplot* site, along the Hasseltkanaal the architects of *space&matter*, the authors of the *de Ceuvel* project, have proposed a new housing collective not on the polluted post-industrial land, but floating in the canal. The initiator of the project is Marjan de Blok, another Eva de Clerk protégé, who in 2008 created an *autarkic geWoonboot* which was moored outside the NDSM shipyard. The *geWoonboot* ,which in English translate roughly to communeBoat, is an entirely self-sufficient home floating in the IJ on a concrete buoyancy tank. The autarkic (self-sufficient) elements included rain water capture, PV panels and a garden-like purification system that floated next to the home and processed all its liquid waste. De Blok became convinced that the autarkic houseboat had potential not just as a one-off green icon but could be implemented in greater numbers in an autarkic floating community.

In 2010 de Blok settled on the *Hasseltkanal* in Buiksloterham as the site for the community, and in 2011 she brought architects *space&matter* onto the team, along with the environmental consultants *Metabolic* to create a feasibility study. Slowly the vision of an autarkic community of house boats emerged. It was not until 2016 that a plan was formally submitted for approval to the City of Amsterdam. While each houseboat would have many of the self-sufficient features of the original *geWoonboot* they would also be able to work together in a common framework to create a more resilient whole. The physical framework permitting this cooperation and resilience was conceptualized by the design team as a branching network of piers that would provide physical mooring for each houseboat, but also contain an infrastructure bundle.(fig.21) While visually recalling the network/node interfaces of 1960s avant-garde architecture like Archigram's plug-in city, the Schoonschip pier would not just be an umbilical cord delivering resources to hungry nodes, but a smart network allowing the houseboats to autonomously exchange information and negotiate the sharing of energy via a 'smart grid'.

3.5 Conclusions: post-industrial pioneers

In Buiksloterham district there is evidence of a complicated inter-mixture of incipient urban data-assemblage and an architectural/ social movement, raising the question of reciprocity and co-production central to this thesis. Can the implementation of data-driven urban systems produce change- in civic practice or sustainability- or will it act to entrench existing hierarchies?[55] This is the question we direct toward the architectural artifact and the architect, as active components of the urban data-assemblage. How has architecture contributed to the hardening of existing hierarchies and practices in the constitution of the data-driven city, or conversely how has architecture acted to introduce innovation and destabilize urban hierarchies? In the case-study of Buiksloterham we can interrogate the agency of architecture at two levels: that of data-driven resource management (here our matter of concern is water) and secondly at the level of data-driven civic control and/or participation.

In the Amsterdam case study we can see that architectural projects have the ability to act as stabilizers within the data-driven city: absorbing new practices and technologies into familiar forms and systems of life, this I would argue is the case of Studioninedots' *Cityplot* proposal. In *Cityplot* the architectural artifact acts to stabilize the data-driven city in terms of familiar signifiers, spaces, and ways of living. On the other end of the spectrum are the works of *space&matter* like *de Ceuvel* and the *Schoonschip* project. These constructions are transient, or potentially kinetic. They employ technologies in autarkic networks instead of in centralized hierarchies, and they encourage a culture of self-build, self-sufficiency, and self-determination, and the intense collaboration of small groups based on shared values and aspirations.[56] These architectural propositions use the creation of the data-driven city to break down existing strata of hierarchy, bureaucracy and technological process. They tend toward an ideal of techno-nomadism, and also toward the formlessness of found solutions like re-purposed houseboats, or the frameworks of the *de Ceuvel* boardwalk or the *Schoonschip* infrastructural pier.

In Buiksloterham, the data-driven city did not precede an architectural movement, but rather arose in reciprocity with it. *Cityplot* Buiksloterham and *Schoonschip*, though initiated by non-designers, were created from models that young designers had already put forward as models for future urbanisms. The combination of young architectural thought leaders creating experimental projects, and the water authority's interest in testing new sustainable technologies coalesced into the idea of a *circular* city where the urban metabolism would be tracked and shaped into a new kind of urbanism. In this mix the architectural form, in the case of *de Ceuvel*, provided the physical framework for experimentation and ultimately the physical proof of its success, becoming a totemic figure in attracting interest and confidence in the experiment and accelerating its development. As the data-driven circular city of Buiksloterham develops, however, its architecture suggests two potential destinies for the data-driven

55 This is the question Anthony Townsend asks repeatedly in, "Smart Cities." In the section 'Slow Data' (p.316-320) he reflects on the rebound effect of greater efficiency and speculates that smart technology may simply lead to accelerated consumption. His response is that the city needs 'slow data,' to produce 'behavior change.' Earlier he cites the example of the digitized land ownership database in the state of Karnataka, India. In this case he assess that 'centralizing records merely centralized corruption,' an instance of a data-driven system that reinforces corrupt hierarchies instead of breaking them down. (See p.13)

56 Admittedly the Cityplot project also includes self-build plots as part of its dynamic master-plan. A black/white contrast between the two projects can not be made, and should not be forced: neither is meant to be portrayed as 'good' or 'bad.' My observation is that in creating the architecture of the data-driven city the designer has the ability to produce a more conservative product which reinforces commonly held ideas about what a city is or conversely to leverage the technological change to destabilize ideas of what the city, the building should be. Given these two examples one seems to illustrate the act of stabilizing hierarchies, and the other de-stabilizing hierarchies.

city: the semi-autarkic or nomadic formalization proposed by *de Ceuvel*, *Schoonschip* and their spiritual predecessor- the *NDSM kunststad*, and the stabilized, hierarchic formalization of *Cityplot* where large developer and large city authority provide the initiative.

The case study of Buiksloterham also suggests that the nature of design process and practice may be bifurcating due to the demands of new data-driven tools. The partnership between designers of Buiksloterham and data-driven sustainability consultants *Metabolic* offers a sequel to the Dutch practice of data-informed design. Like van Lohuizen and van Eesteren, the designers of *de Ceuvel*/ Cityplot, Schoonschip have favored a practice model where data supporting urban design is created by a specialist (in this case the specialist is in urban metabolism). This is a contrast to the datascape model where the architect immersed himself in data to produce design. The result is design that is not 'over-determined' by data- to quote William Rankin's description of the datascape- but instead uses data to propose a pragmatic vision of a radically different future. In comparison with the role imagined by Van Lohuizen, in Buiksloterham the urban researcher/surveyor is no longer a generalist but a deep specialist in urban metabolism and sustainable urban systems with an ability to recruit the enthusiasm of key stakeholders.

The emergence of new, innovative models of data-driven practice in Buiksloterham are evidence that a very old data-assemblage can avoid obduracy, or at least spin-off smaller offspring which move in new directions. The split geography of Amsterdam, along with the spatial effects of post-industrialization must be recognized as creating a new and separate conditions that forced the existing data-assemblage to reset and try something new. Dutch pragmatism no doubt is also responsible for this reorientation, for recognizing the challenging new conditions in the post-industrial north as an opportunity for experimentation. Embeddedness and obduracy of cultural-technological systems is not necessarily one-directional, as this case shows, new conditions can provoke hopeful new developments.

The history of Amsterdam's water management data-assemblage sketched out in the beginning of this chapter suggested that the built-environment must be instrumentalized in the data-driven context, and even dissolved into distributed clouds of architectural elements. Instead of looking at singular works of architecture as an artifact, in the tradition of Rossi or Eisenman, the data-driven city has encouraged us to look at distributed networks of architectural elements as emergent urban infrastructures. The fragmentation of the architectural artifact does not necessarily mean a sidelining of the architect, but an evolution in the role of the designer in the city.

The catalogue of flood-proof or flood-adaptive architectural interventions proposed by *Amsterdam Rainproof* that we considered earlier is matched by a similar catalogue promoted by the Delta Commission for all of the Netherlands. The *Groen Blauwe Netwerken* design tool, was developed by an office of architects and designers, *Atelier Groen Blauwe*, led by the architect Hiltrud Potz.[57] Though all instances of these interventions will not be authored and executed by Potz, her cumulative impact on the form of architecture in the Netherlands may be ultimately larger than that of a traditional architect creating singular works of architecture. The impact of this design work extends beyond the enclave of capital-A Architecture, and into the wider world of urban form and anonymous 'building.' Design in the data-driven city may thus have a broader horizon of impact even if its product is more nebulous than the master works of 20th century modern architecture.

57 https://nl.urbangreenbluegrids.com

While the Buiksloterham projects do not break the architectural artifact down as radically, they do however, seem to desire to take on the role of prototype. Projects like *space&matter*'s *de Ceuvel* or *Schoonschip* take on a procedural, exemplary logic that is presented as a model for wider application. The prototypical nature of these projects is enforced by the systems logic *Metabolic* has built into their design. Metabolic is beginning to apply circular metabolism concepts at a city-wide scale in Amsterdam via development regulations.[58] We are left to wonder if the architectural works of *space&matter* will also achieve broader influence in the city as prototypes for building and giving meaning to a data-driven circular city.

58 I expand on this in section 5.2.2. See: Gladek, Eva. 2018. "Sustainable Urban Systems and Circular Cities of the Future." Lecture, Center for Livable Cities. Singapore. September 6, 2018. Available online at https://youtu.be/7o0qpe0vDwk (accessed 08 April 2019).

References:

Books and Journal Articles:

Bos, Frits and Peter Zwaneveld. 2017. "Cost-benefit Analysis for flood risk management and water governance in the Netherlands: An overview of one century." The Hague: CPB Netherlands Bureau for Economic Policy Analysis.

Burke, Gerald. 1956. *The Making of Dutch Towns: A Study in Urban Development from the Tenth to the Seventeenth Centuries*. London: Cleaver-Hume Press.

Christiaanse, Kees. 2003. "Housing in Harbours in Holland." *The Planning Review* 39 (154) 4–10.

De Waal, Martijn. 2014. *The City as Interface : How New Media Are Changing the City.* Vol. 10. Rotterdam: NAI.

De Waal, Martijn, Michiel De Lange, and Matthijs Bouw. 2017. "The Hackable City: Citymaking in a Platform Society." *Architectural Design* 87.1 pp. 50-57.

De Waal, Martijn, and Marloes Dignum. 2017. "The Citizen in the Smart City. How the Smart City Could Transform Citizenship." It- Information Technology 59.6: 263-73.

Delva Landscape Architects, et al. 2016."Hackable Cityplot." In *IABR 2016 - the next Economy.* Brugmans, George, et al. Rotterdam: International Architecture Biennale Rotterdam(IABR)

Fainstein, Susan S. 2008. "Mega-projects in New York, London and Amsterdam" 32 (4): 768–85.

Ferguson, Francesca, and Berlin. 2014. *Senatsverwaltung fur Stadtentwicklung. Make_Shift City : Renegotiating the Urban Commons : Die Neuverhandlung Des Urbanen*. Berlin : Jovis Berlin.

Gerritsen, Herman. 2005. "What Happened in 1953? The Big Flood in the Netherlands in Retrospect." *Philosophical Transactions. Series A, Mathematical, Physical, and Engineering Sciences* 363.1831 pp. 1271-91.

Graafland, Arie. 1999. "Of Rhizomes, Trees, and the IJ-Oevers, Amsterdam," *Assemblage*. no. 38: 29–41.

Graafland, Arie. 2000. *The Socius of Architecture : Amsterdam, Tokyo, New York.* Rotterdam : 010 Publishers.

Hooimeijer, Fransje. 2014. *The Making of Polder Cities: A Fine Dutch Tradition.* Heijningen: JAP SAM Books.

Hommels, Anique. 2005. *Unbuilding Cities: Obduracy in Sociotechnical Change.* Cambridge, MA: MIT Press.

Ihde J., Augath W. 2002. “The European Vertical Reference System (EVRS), Its relation to a World Height System and to the ITRS.” In: Ádám J., Schwarz KP. (eds) *Vistas for Geodesy in the New Millennium.* International Association of Geodesy Symposia, vol 125. Springer, Berlin, Heidelberg.

Kind, J.M. 2014. “Economically Efficient Flood Protection Standards for the Netherlands.” In J*ournal of Flood Risk Management*. 7. pp. 103-117.

LOLA Landscape Architects. 2014. *Dutch Dikes.* Rotterdam: nai010 publishers.

Lonnquest, John, and Maurits Ertsen, eds. [US Army Corps of Engineers and Rijkswaterstaat] 2014. *Two Centuries of Experience in Water Resources Management: A Dutch-U.S. Retrospective.* Alexandria, Virginia: Department of Defense (DOD).

Lootsma, Baart. 2003. “What is (really) to be Done? The theoretical concepts of MVRDV.” In *Reading MVRDV.* Patteeuw, Veronique, et al. Rotterdam : NAi Publishers.

Masboungi, Ariella. Ed. 2016. *Le Génie d’Amsterdam: Opportunité, agilité, inventivité.* Paris : Editions Parentheses. (Ministère du Logement et de l’Habitat Durable.)

Molema, Jan, and Casciato, Maristella. 1996. *The New Movement in the Netherlands 1924-1936*. Rotterdam: 010 publishers.

Rieniets, Tim. 2009. *Open City : Designing Coexistence.* Amsterdam: SUN.

Salewski, Christian. 2012. *Dutch New Worlds : Scenarios in Physical Planning and Design in the Netherlands, 1970-2000.* Rotterdam: nai010 publishers.

Schot, Johan. 2010. *Technology and the Making of the Netherlands : The Age of Contested Modernization, 1890-1970.* Zutphen: Walburg Pers.

Somer, Kees. 2007. *The Functional City : The CIAM and Cornelis Van Eesteren, 1928-1960.* Rotterdam: NAi publishers.

Taverne, Ed. 1993. S*tedebouw : De Geschiedenis van de Stad in de Nederlanden van 1500 Tot Heden.* Nijmegen : Uitgeverij SUN.

Townsend, Anthony M. 2013. *Smart Cities : Big Data, Civic Hackers, and the Quest for a New Utopia.* New York: New York : W.W. Norton.

Van Bergeijk, Herman. Ed. 2015. *Van Lohuizen and Van Eesteren: Partners in Planning and Education at TH Delft.* Issue 1: Inaugural Speeches in the Built Environment: Global and Contextualized. Delft: TU Delft Open.

Van Dantzig, D. 1956. "Economic decision problems for flood prevention". In *Econometrica*, 24. pp. 276–287.

Van Lohuizen. 1948. *De Eenheid van het Stedebouwkundige Werk.* Lecture transcript. TU Delft. Available online: https://efl-stichting.nl/ Accessed 9 Nov. 2018.

Wagenaar, Cor. 2015. *Town Planning in the Netherlands since 1800 : Responses to Enlightenment Ideas and Geopolitical Realities.* Second edition, Rotterdam : nai010 publishers.

Wit, Saskia De. 2009. *Dutch Lowlands : Morphogenesis of a Cultural Landscape.* Amsterdam: Uitgeverij SUN.

Government and Institutional Documents:

Amsterdam. 1934. *Algemeen Uitbreidingsplan van Amsterdam : Nota van Toelichting.* Amsterdam : Dienst der Publieke Werken.

Bos, Frits and Zwaneveld, Peter. 2017. *Cost-benefit Analysis for flood risk management and water governance in the Netherlands: An overview of one century.* The Hague: CPB Nethelands Bureau for Economic Policy Analysis.

Dekker, Gert. Et. Al. 2016. *Van last naar les: Hoe publiek-private samenwerking de regenwateroverlast voor inwoners, woningeigenaren en klanten kan verlagen.* Amsterdam Rainproof with Ambient, TU Delft, and Synerscope. Available online:

Deltacommissie 2008. *Working Together with Water: A Living Land Builds for its Future.* Ed. Secretariat Delta Committee. Nov. 2008 (translation: Priestnall, I & van Otterloo, S.)

Gladek, Eva, Sandrine van Odijk, Pieter Theuws and Albert Herder [Metabolic,studioninedots & DELVA Landscape Architects.] 2015. '*Transitioning Amsterdam to a Circular City: Circular Buiksloterham Vision & Ambition.'* Online: Gemeente Amsterdam. "Buiksloterham: circulaire stadswijk." Amsterdam.nl, https://www.amsterdam.nl/projecten/buiksloterham/circulair/. Accessed 9 Nov. 2018.

Traast, Steven & Jeroen Geerdink [Search Ingenieursbureau]. 2015. *Saneringsplan.* Locatie: Distelweg 99 t/m 104 en Asterweg 49 te Amsterdam. Opdrachtgever: De Alliantie Ontwikkeling. Projectnummer: 25.14.00232.1

van Assenbergh, Evelien (Waternet). 2016. *Gemeentelijk Rioleringplan Amsterdam 2016-2021*. Amsterdam: gemeente Amsterdam. https://www.waternet.nl/siteassets/ons-water/gemeentelijk-rioleringsplan-amsterdam-2016-2021.pdf. Accessed 21 April 2019.

van Dantzig, David & Kriens, J. 1961. *Het Economisch Beslissingsprobleem Inzake de Beveiliging van Nederland Tegen Stormvloeden.* (The Economic Decision Problems Concerning the Security of the Netherlands Against Storm Surges.) Rapport Deltacommissie (Delta Commission Report) Bijdrage II.2. 1961

van Drimmelen, C., Koeze, R., & Monchen, E. 2013. *Waterproof Amsterdam: Working Towards Water Resilient Urban Design*. PLAN|Amsterdam.

Wallbrink, H and T Brandsma. [KNMI] 2008. “DIGISTAD: Disclosure of the hourly meteorological observations of the Amsterdam City Water Office 1784-1963.” *Hisklim* 9, 4. pp.26.

Websites:

Amsterdam Rainproof. https://www.rainproof.nl/ (accessed 06 September 2018).

Digital Delta. http://www.digitaldelta.nu/en/ (accessed 06 September 2018).

Kennisportaal Ruimtelijke Adaptatie (Spatial Adaptation – Delta Commission). https://ruimtelijkeadaptatie.nl/ (accessed 06 September 2018).

Overstrom Ik? http://www.overstroomik.nl/ (accessed 06 September 2018).

Urban Green Blue Grid (atelier GROENBLAUW) https://nl.urbangreenbluegrids.com/ (accessed 06 September 2018).

Waterschap Amstel Gooi en Vecht (AGV) | *Legger*. https://www.agv.nl/onze-taken/legger/. (accessed April 24, 2019).

Atrium of WOHA Architects ‘Dawson Skyville.’ (author’s photograph)

4 Data-driven Density: Singapore's Public Housing

4.1 Introduction: Singapore's HDB, optimizing density and sharing space

'Deplorable over-crowdedness,'[1] 'one of the most crowded slums in the world,'[2] 'appalling conditions [...] densities up to 1,000 or more to the acre,'[3]: these words from the early leaders of Singapore's public housing agency, the Housing Development Board (HDB), describe the conditions of their city-state's central area as inherited from the British in 1960. These descriptions define over-crowding as a primary matter of concern for land-poor Singapore and announce the metric of persons per land area that came to define the working methods of the HDB as they urbanized the nation on a high-density high-rise model.

In the post-war years the densely populated rowhouses of Singapore's central area and the informal settlements of wooden huts in the periphery offered density in a pernicious form: congestion impeded movement, lack of sewage raised public health concerns, deadly fires spread quickly. Yet, Singapore's density also represented its greatest resource: the bodies and minds of people whose hard work, resourcefulness, and social bonds would produce the wealth and strength of a new nation.

To replace the pernicious density of the post-war slums with a livable density the HDB developed an extensive data-gathering apparatus beginning from simple person to land ratios, and evolving toward more sophisticated social and ecological indicators of healthy urban density. This case study describes

1 Liu Thai Ker. 1985. 'Overview.' In *Housing a Nation.* p.10
2 Teh Cheang Wan. 1975. 'An Overview.' in *Public Housing in Singapore.* p.2-3
3 Ibid. p. 2 and p.4

how HDB's data-gathering apparatus evolved in tandem with its architectural and planning work, each influencing the other as the sophistication of the institution grew, and its goals evolved.

Some important actors will emerge in the history of HDB's data-assemblage. Architect, Liu Thai Ker led efforts in the 1970s to formalize architectural response to HDB's institutional goal of optimizing use of Singapore's scarce land. Sociologist Stephen Yeh in the 1960s pioneered survey tools which allowed HDB to assess the social success of its building project, and make judicious adjustments. More recently landscape architect Ong Boon Lay (while working with HDB) created a new metric accounting for urban density and ecological productivity simultaneously. WOHA architects have built off this new direction in recent years designing some of the densest and most innovative housing ever produced by HDB. Today the problem of density remains contentious in Singapore with its now aging population. In this changing context the HDB continues to modulate its approach to high-rise high-density urbanism, integrating new ecological metrics, and novel automated tools into its design processes and estate management.

4.2 The data-assemblage: measuring and managing density in Singapore

4.2.1 Before HDB: the colonial era

Housing in Singapore was long been described as an emergency. Waves of immigration during the 19th century combined with minimal government oversight of building resulted in the growth of dense slums in the Singaporean Central Area and wooden squatter structures ringing its periphery. Though the British colonial government had recognized the housing emergency they had not been able to effect large scale change. In 1918 a colonial Housing Commission made a report on housing conditions and recommended the formation of an institution enabled to improve the housing conditions in Singapore. As a result HDB's colonial predecessor was created: the Singapore Improvement Trust (SIT) which began work in 1927.[4] In its early years SIT had limited ability to create new housing, and only in 1932 did it begin to produce new housing estates.[5]

The Second World War exacerbated the housing crisis in Singapore. When the British colonial government returned after the Japanese occupation SIT was reorganized to focus primarily on supplying new modern housing. They produced several low-rise housing estates in the 1940s (Kampong Bahru, Princess Estate) and in the 50s began to build high-rise housing blocks.[6]

SIT's new high-rises, like the fourteen story Forfar House of 1955, were strikingly foreign at this time in Singapore. There was popular concern about the impact these buildings had on their residents. Sensationalized reporting on suicides from the corridors of these highrises, led one early SIT highrise in Upper Pickering to be labeled the 'suicide flats.'[7](fig. 1) These reports reflect the social challenge of modern architecture's solution to managing density by building upwards- a challenge that would preoccupy HDB in coming decades.

SIT made a new effort to survey the housing problem in the 1950s with results gathered in the *Report*

4 HDB. 1975. *Public Housing in Singapore* p.3 A 1907 report on sanitation predates the 1918 report and linked unhygienic living conditions to unacceptable density of housing in the central area.
5 Ibid. p.4
6 Seng, Eunice. 2017. 'Architecture of Improvement and Aspirations of Communality.' in *Singapore's Vanished Housing Estates* p.11
7 Ibid.

of the Housing Committee 1956. This report's emphasis on the gathering of urban data, and using it to shape public housing policy is an important precursor to the HDB's data assemblage. The 1956 report describes densities above 1000 persons per acre in the central area, and notes with alarm the growth of informal squatter settlements in the periphery of Singapore where fire and disease posed threats to the residents.[8] In this report for the first time we find the goal of building 10,000 units per year to meet Singapore's housing needs. This was taken up as the goal of the Housing Development Board's first five-year plan upon its founding in 1960: 50,000 units in five years.

4.2.2 The emergency era: HDB's first five years.

HDB was created in 1960, shortly after Singapore became self-governing, to address the housing crisis by building public housing. In response to the perceived lack of power and political will at SIT, HDB was founded with a great deal of power. The Housing and Development Act of 1959, the Land Acquisition Act of 1966, and the Central Provident Fund Amendment Act of 1968 provided the legal framework for HDB able reclaim land, build quickly, with funding assured by the Central Provident Fund.[9]

The first five years of the 1960s was a period of great change for Singapore.[10] Fires destroyed large areas of informal housing near the city's central area, and many early HDB projects were designed to hold people displaced by the fires. The Bukit Ho Swee fire of 1961 is frequently cited in the HDB's histories as an early test of the institution. The fire displaced some 16,000 people, and led Prime Minister Lee Kwan Yew to make a public pledge to rehouse the victims in modern housing in one year on the site of the fire.[11] In recognition of the circumstances in which they were built, the first generation of housing blocks designed by the HDB are commonly referred to as the 'emergency' plans.[12](fig.4) These blocks were built in great haste, with an emphasis on cheapness and speed of construction. HDB architect Alan Choe recalls this about the early flats:

> "… in the first generation of Housing Board flats, we have a lot of what is known as one-room apartments. One-room apartments in those days were really basic. [...] But that is how we started the public housing to achieve the target numbers. Because in those days target numbers were a more important priority than niceties that we can afford today, like the environment, greening of the area, playground, carpark. Those were not there. Just to put a roof over their head.'[13]

At this point in its history, the working method of the HDB was essentially linear: housing was produced as quickly as possible as cheaply as possible with the goal of rehousing displaced peoples and meeting the ambitious initial goal of 50,000 new units in five years. The first generation of HDB housing was not standardized, for example some blocks were built with flats that shared toilets and kitchens, while others were built with individual toilets and kitchens within the flats.[14] Referred to as

8 Singapore Improvement Trust. 1956. *Master plan reports*. "In the Central Area (Redevelopment) existing net residential densities of over 1,000 persons per acre have been found in certain blocks, where people are living on less than 25 square feet of floor." [p.20]
"The most densely populated attap areas are near the City at Tiong Bahru, Bukit Ho Swee, Kampong Soopoo and parts of the Kallang Basin. Living conditions in these areas are very bad, and it is considered that they can only be rendered healthy by a planned programme of clearance and rebuilding." [p. 19]
9 See Liu Thai Ker. 1985. 'Overview.' In *Housing a Nation.* p.24-26
10 During this period Singapore merged with Malaysia, experienced conflict with Indonesia (the *konfrontasi)* and eventually in 1965 left Malaysia to become an independent city-state.
11 Our Homes. P 41
12 HDB. 1985. *Housing a Nation.* p. 72- see illustrations
13 Alan Choe Fook Cheong. Oral History. Reel 7 Accn No. 001891. Singapore National Archives.
14 Fernandez, Warren. 2011. *Our Homes : 50 Years of Housing a Nation.*, p. 46

a period of experimentation, anecdotal evidence seems to have convinced the architects that shared facilities should no longer be included in HDB's housing blocks.[15] In his oral history, Alan Choe reflects on the difficulty of sharing kitchens between hallal and non-hallal residents in early HDB housing. These forced encounters in the communal space of the early HDB blocks were contemporaneous with the race riots of 1964, which contributed to the separation of Singapore from Malaysia. It can be inferred, even without the testimony of Alan Cho, that the shared use of these spaces would have been tense.

HDB began to methodically collect data and adapts its designs to that data during the transition out of the emergency period. A new set of flat plans was introduced in the second five year plan which made incremental improvements on the emergency flats- with larger areas and in-flat kitchen and toilet. The layout of HDB's block design was significantly changed at this time as well, with the double-loaded corridor abandoned and replaced predominantly with single loaded corridor blocks which had better cross ventilation in the tropical climate. With the emergency era at an end, and the second five year plan under way the reflexive working method of HDB began to be developed with greater sophistication.

4.2.3 HDB's feedback framework

The reflexive nature of HDB's working method was built into its organizational structure. HDB was created with a group of departments that would control different aspects of the public housing process. The basic function was linear, producing public housing like an assembly line. The *Secretariat* established the overall agenda for the HDB, the *Estates Department* would acquire land, the *Resettlement Department* would clear the site and resettle its former inhabitants, and finally the *Building Department* would design and build new housing. The government remained the landlord of the housing estates after their creation. Completed HDB housing was then handed over from the *Building Department* back to the *Estates Department* which would manage it in perpetuity.

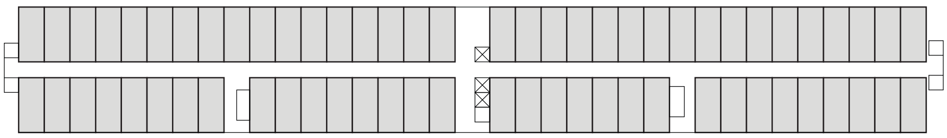
A *Statistics and Research Department* was tasked with serving as a *'data bank'* for the HDB, in parallel to the primary work of produced and managed public housing. It gathered information on the functioning of the buildings as they were lived in, conducting research and providing *'feedback and benchmark information*' to the Secretariat.[16] This data-gathering included the collection of metrics of resident satisfaction through surveys, and the transformation of this data into actionable information.

Stephen Yeh's surveys of HDB resident satisfaction in 1968 and 1973 represent a first significant step toward creating the HDB's *data-bank*, and system of *feedback* and *benchmarking.* Second, the appointment of Liu Thai Ker in 1969 to the newly created position of head of Design and Research in the HDB Building Department, represented the creation of a new reflexive design function within the organization. Together these steps represent the emergence of a functioning data-assemblage at HDB: a group of institutions and practices for collecting and acting on data.

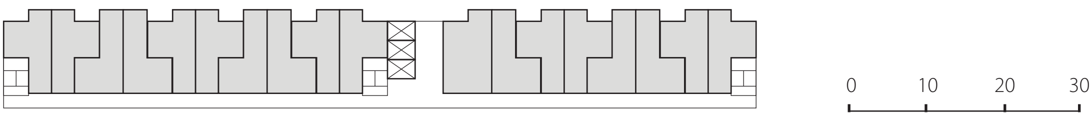
15 Ibid.
16 HDB. 1975. *Public Housing in Singapore.* p.7

1. SIT Upper Pickering Housing. 1952-1953

2. HDB. 1961 Bukit Ho Swee Blocks under construction.



3. HDB. Emergency-era (circa 1960-65) block of 1-room flats. Redrawn from, ‘Housing A Nation.’ 1985. p. 72.



4. HDB. Circa 1965-1970 block of ‘standard’ 2-room flats. Redrawn from, ‘Housing A Nation.’ 1985. p. 72.

4.2.3 An architect studies density: Lui Thai Ker and the HDB Design Research Group

Liu Thai Ker was a prize-winning young architect in the New York office of I.M. Pei when he was recruited back to Singapore in 1969 by HDB CEO Teh Cheang Wan. Teh lured Liu back with the prospect of leading a new division of HDB's building department: the *Design and Research Unit*.[17] The establishment of the *Design and Research Unit*, represents the appearance of an important new strand in the reflexive working methodology of the HDB. In setting up the Design and Research Unit Liu Thai Ker established practices of quantifiable optimization and of data-informed scenario planning. Both techniques, still in practice today, were applied to managing density.

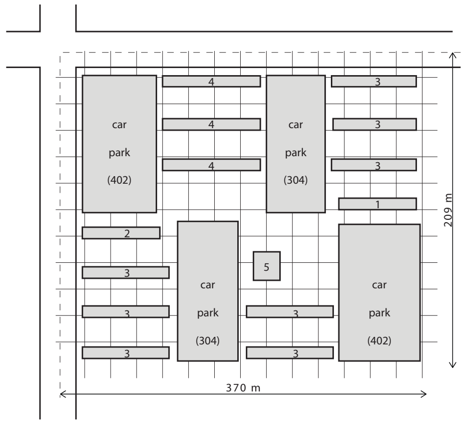
Maximizing residential density on scarce land is the fundamental challenge that has faced HDB since its founding. Liu Thai Ker wrote in 1975 that, 'Every piece of land must utilized to the fullest extent.' And that, 'By trial and error and feedback, the highest possible residential density will have to be formulated for all the public housing areas.'[18] Through a form of scenario planning Liu Thai Ker defined a range of possible densities, the trade-offs between them, and based on the results of these scenarios he can formulate a hypothesis about what density may work best for Singapore.

Comparing high density urban scenarios to a low density scenarios, Liu used quantitative measure of density and simple spatial planning techniques to legitimize HDB's high-density high-rise mode of urbanism. This 1971 test compared a site plan with 2000 housing units for multiple scenarios. A high density scenario included housing blocks 12 stories tall and point blocks 24 stories tall.(fig.5, bottom) In a low density scenario the blocks were held to a maximum of four stories- a walk-up type without elevators.(fig. 5, top) All blocks were oriented north-south, 'to minimize the effect of the tropical sun.'[19] For each scenario additional areas of open space, road, car park and apron were drafted in according to standardized guidelines, for example the number of cars anticipated per unit of each type of housing. In the high-rise scenario, one plan was drawn as example, and three additional options are considered in tabulated data.[20] The densest scenario included 2000 units on 10 hectares, which corresponds to about 10,000 people (density of 1000persons/hectare). The low-density scenario housed the same number of people on about 17 hectares (a density of about 120 units per hectare or slightly under 600persons/hectare.)

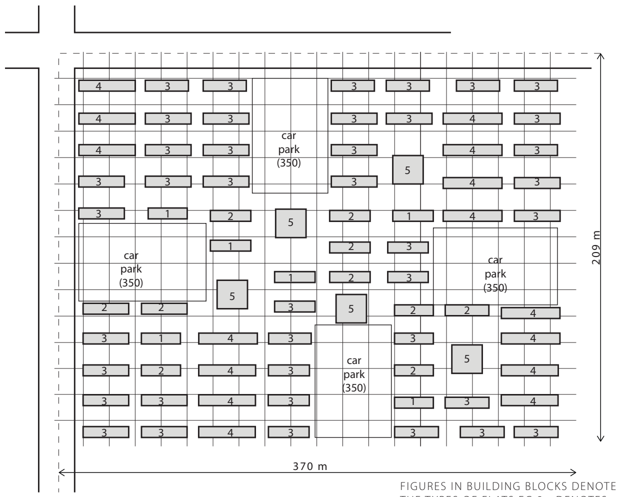
Liu Thai Ker concluded that the difference between the high-rise and low-rise is 'thought to be too big, involving too much extra land, for the general application of low-rise development in Singapore.'[21] He concedes that the 'merits and de-merits' of walk up development 'require more research,' and that the lower density is, 'more in keeping with the human scale.'[22] A table of densities of contemporaneous HDB estates includes densities that range from 211 to almost 260 units per hectare (1300 persons/hectare), similar but slightly higher than the ideal density scenario.[23]

Liu suggests that higher residential densities may become workable in the future as people become accustomed to high-rise living and, 'as we become able to build needed open spaces into buildings at upper levels,' quoting Kevin Lynch.[24] This aspiration to create artificial open space at upper level

17 Liu Thai Ker. Oral History ACCN. N. 001732/29 Reel 12. Singapore National Archives. transcript p. 103
18 Liu Thai Ker. 1975. 'Design for Better Living Conditions.' In *Public Housing in Singapore.* p.123.
19 Ibid. p. 147.
20 Ibid. p. 148.
21 Ibid. p.147
22 Ibid.
23 Ibid. p.150.
24 Ibid. p 147 Liu quotes from Lynch. 1956. *Site Planning.*



High rise residential development

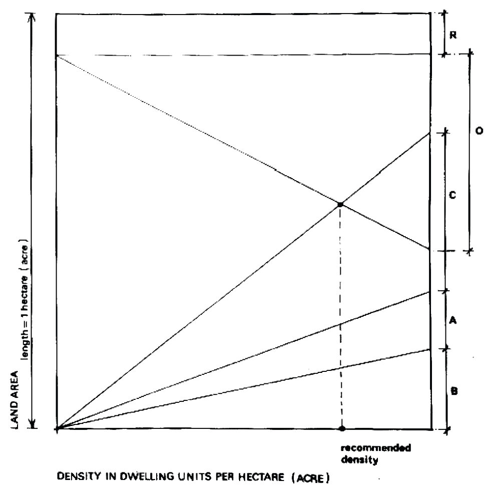


Low rise residential development

FIGURES IN BUILDING BLOCKS DENOTE THE TYPES OF FLATS EG 3 - DENOTES 3 - ROOM FLATS

0 50 100 150m

5. HDB. comparison study of land needed for high-rise and low rise development (redrawn from, 'Public Housing In Singapore.' 1975. p. 148



6. HDB. Method for calculating optimal density. from, 'Public Housing In Singapore.' 1975.

of buildings recurs throughout the history of the HDB. While Liu's density scenarios are useful in legitimizing a high-density high-rise urbanism against a low-rise alternative, they fail to fully address the problem of density by tackling the question of how many people *should* inhabit an area of land. HDB's mandate is to, 'achieve as high a residential density as possible,'[25] which Liu addresses as a problem of optimization.

Lui Thai Ker abstracts the problem of maximizing residential density with a simple system of linear equations which can be solved for an optimum.(fig. 6) On an x and y axis representing density of dwelling units vs. land area respectively, Liu plots land areas needed for building footprint(B), a building apron area (A), and carpark area (C).[26] These areas increase along the x axis as density increases. At the top of the graph space a strip of area is reserved for road area (R) which is held constant regardless of density. Finally, the area of open space (O) required for a given number of occupants is inserted at the top of the graph. This quantity grows as the density on the site increases, but is graphed from the top down so that the increase in required open space can intercept required building space.

The intercept point of this graph represents the density of inhabitation at which the sum of built area and required open space exceed the limitations of one hectare of land- and therefore (within the constraints of this system) represent the optimal density. While this technique of land use optimization does provide a system for consistently ensuring a similar high-density use of land in HDB developments, Liu does not yet move on from the question of residential density and land use. In a subsequent section of the same document he returned to the question of whether high-density high-rise development provide adequate or 'decent' living conditions for the people of Singapore.[27]

To study living conditions in HDB high-density estates, Liu developed a matrix of criteria, which he refers to as the *Crowdedness Index,* to comparatively evaluate quality of life in HDB housing.(fig. 8) He writes that he finds contemporary standards for evaluating urban living conditions lacking and that he intends to develop, 'a comprehensive set of criteria covering most if not all of the planning and design considerations in relation to some notions of minimum standards of living conditions,' that would be a, 'useful common framework of reference for residential developments.'[28]

Liu bases his investigation of living conditions on the research of engineer Richard Meier, who developed a method of calculating a minimum adequate standard of living for human needs like food, fuel, minerals and, living space.[29] Meier's research builds from physical first principles and biological needs to define minimum adequate standards. Meier references several possible figures for minimum living space: soviet workers housing at 3-4 m^2 is dismissed as having 'long-run dis-economies,' 20 m^2 per person is cited as the overly liberal minimum standard used by, 'the designers of new housing.' Meier eventually advocates 6 m^2 per person as a sufficient population average.[30] Meier calculates elsewhere that Earth may support, 'upwards of fifty billions of persons,' based on the resources of the Earth and the appropriate assignment of a minimum standard of living.[31]

25 Ibid. p.145.
26 Ibid. p. 182-184
27 Ibid. p.159-168.
28 Ibid.p.169
29 Meier. 1956. *Science and Economic Development: New Patterns of Living.*
30 Ibid. "The logical economic approach, from the point of view of those responsible for economic development, would be to provide just enough more living space, suitably equipped, to permit the adults to become dependable industrial workers. The Russians have shown that this aim can be achieved with roughly 3 to 4 square meters per capita, or three persons to a room, even in a harsh climate that prevents much living out of doors. The disadvantages and long-run diseconomies of this level of crowding are, however, readily apparent to their planners, and so the promise is made that the present overcrowding is a temporary condition which will be overcome in time." [p.160, 164] See p. 164 for additional quotes and figures.
31 Ibid. p.236.

In contrast to Meier, Liu does not attempt to demonstrate biologically what conditions are necessary for minimum living conditions, but instead develops a comparative ‘yardstick’- the *Crowdedness Index* - to give a sense of progress and position relative to peers. Though this study is highly quantitative, and depends on the creation of new metrics like *livable space*, it is also seeks support from other forms of knowledge; written description, architectural plans and value judgments about how it is best to live.

The primary tool of Liu’s investigation into living conditions is the *Crowdedness Index*: a matrix of metrics (building coverage, plot ratio, density, floor space per person, open space per person and livable space per person) that are applied to HDB developments, private developments in Singapore, and examples of informal or vernacular housing in Singapore.(fig. 8) Of the metrics, the final value *livable space per person* is novel and, as the sum of residential floor space per person and open space per person, represents the cumulative benefit of exterior open space and personal residential space to each individual. *Livable space per person* reflects the common sense idea that one of the mitigating factors of high density living is accessible open space.

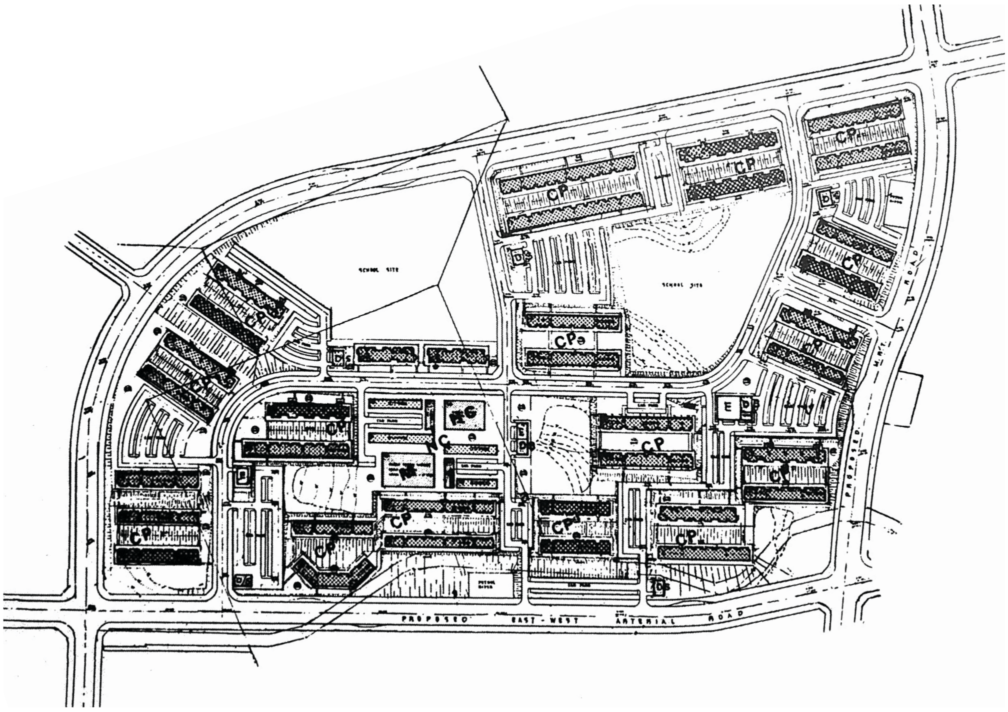
To supplement the *Crowdedness Index* with data from non-HDB residential areas, Liu includes five vernacular/informal study areas. These areas are relevant not only for the levels of density they represent but also for their architectural typologies and (as we will see) their implied family structures. The first two study areas, *Sago Lane* and *Kreta Ayer* (fig. 9), are historical areas from the center of Singapore mostly built as shop houses- a form of row house.(fig. 11) Liu refers to these as, ‘some of the worst urban slum areas in Singapore.’[32] Another case study is of *Redhill*, a ‘squatter area around the urban fringe,’ which had been built of ‘buildings in timber boards and zinc and attap roofing.’[33] By 1972 this site had already been cleared. The two final sites are in Woodlands, 25 kilometers from the center of Singapore: semi-rural or agricultural sites with wooden vernacular housing.(figs. 10,12)

In the ‘crowdedness’ matrix the HDB housing is demonstrably better than any of the study areas in providing <u>residential floor area</u>. *Sago Lane* offers the least space at about 4.5 m^2 per person, and Woodlands is best with nearly 9 m^2 per person. HDB housing, however, starts at 9.9 m^2 for a one-room apartment, and goes up to 20 m^2 per person for a 5-room apartment (3bedroom). Singaporean vernacular housing simply did not provide much space per individual.

Livable space per person (the metric that Liu created) tells a slightly different story. While HDB flats provide more livable space than vernacular housing in Singapore’s center at *Sago Lane* or *Kreta Ayer*, housing in the periphery at *Redhill* or *Woodlands* provides more livable space per person. (342 m2 at Woodlands vs 16 m2 in HDB 1 room flat)

In response to the lack of access to open space in HDB flats compared to semi-rural vernacular settlements, Liu argued for contextualizing the *livable space per person* measurements. *Woodlands*, he argued, though it benefited from large amounts of green open space, was remote from central Singapore and provided little access to transport or sewerage. In Redhill, already demolished by 1975, a higher amount of open space per person was offset by the fact that this space also worked as a sewage system. Liu writes, ‘human and animal wastes could be detected in open earth drains flowing in between the huts.’[34] Access and hygiene, it would seem from Liu’s statements, are essential for fully accounting for quality of living conditions – beyond measures of density.

32 Liu Thai Ker. 1975. ‘Design for Better Living Conditions.’ In *Public Housing in Singapore* p.163 Today some of the original housing stock of these areas remains, although populated at much lower densities.
33 Ibid.
34 Ibid. p. 178.

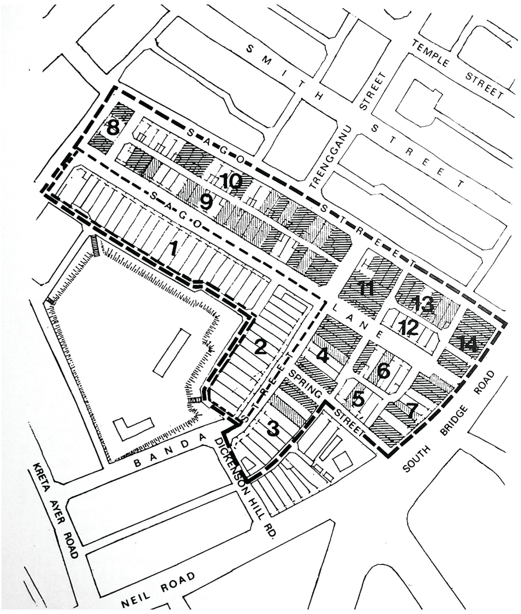


7. HDB. 1975. Ang Mo Kio New Town Neighorhood II. (PHIS p.151)

HDB Crowdedness Indices of Study Areas (1975)

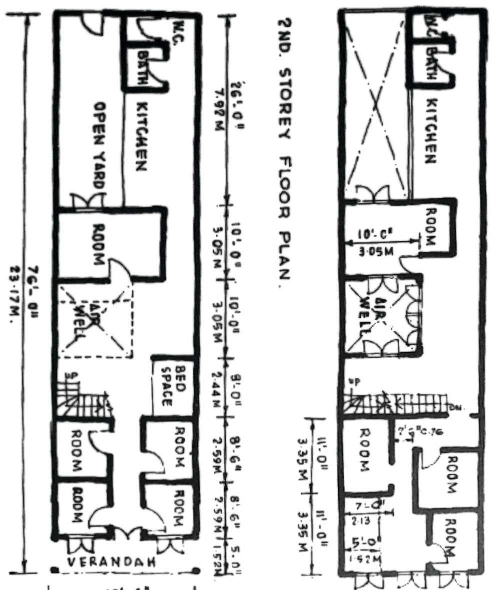
	Building Coverage (per cent)	Plot Ratio	Density (persons/ha)	Residential Floor space/ Person (m2/person)	Open Space/ Person (m2/person)	Livable Space/ Person (m2/person)
Sago Lane	51.9	1.19	2324	4.54	2.07	6.61
Kreta Ayer	46.6	1.17	1672	5.35	3.19	8.54
Redhill/Henderson	26.5	0.26	370	7.15	19.88	27.04
Woodlands Lot 155	19.1	0.19	215	8.90	37.73	46.63
Woodlands	2.5	0.03	29	8.68	333.70	342.33
HDB Flats: 1-Room	12.7	1.38	1394	9.90	6.26	16.16
2-Room (Improved)	12.6	1.43	1338	10.65	6.53	17.18
3-Room (New)	14.9	1.71	1168	14.67	7.29	21.96
4-Room (New)	17.8	1.91	1156	16.54	7.11	23.65
5-Room	19.0	2.41	1156	20.83	7.01	27.84
5-Room (Point Block)	9.0	2.39	1156	20.66	7.87	28.53
Private Terrace Housing	19.3	0.39	107	21.70		
Private Flats	9.5	1.5	450	27.90		

8. HDB. 1975. *Crowdedness Index* developed by Liu Thai Ker as part of the work of the *Building Research Unit.* Liu Thai Ker. 1975. 'Design for Better Living Conditions.' In *Public Housing in Singapore* p. 174 Table. 14.

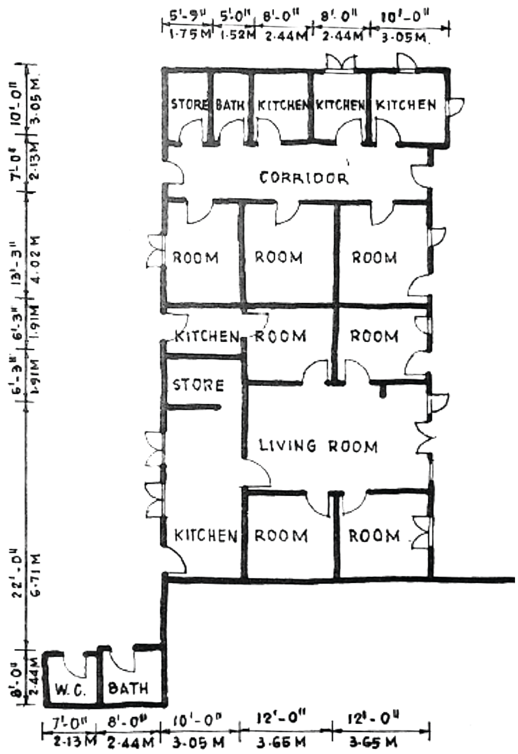


9. HDB. 1975. Kreta Ayer study area site plan (PHIS p.164)

10. HDB. 1975. Woodlands study area site plan. (PHIS p.167)



11. Kreta Ayer 'Slum Building' - *Shop House* type.
(PHIS p.170)



12. Woodlands' Squatter Hut' - Vernacular South-east Asian wood construction. (PHIS p.171)

Typology of architecture was also raised as part of Liu's comparison of living conditions in Singapore. He wrote, 'The layout of the settler huts, and to a lesser extent of the tenement houses may be said optimistically to be conducive to a communal and extended family type of living pattern, whereas the public housing flats do not led themselves to this way of life easily.'[35] In this statement Liu recognizes that the unit types created by HDB were progressively carving up the traditional Chinese and Malay multi-generational family. Density metrics alone cannot express this significant social transition between vernacular and modern housing, but it is illustrated with great clarity by the floor plans that Liu includes with his analysis of living conditions. A 'squatter hut' in Woodlands housing 18 persons includes seven bedrooms – each presumably for the several members of one branch of the extended family – four kitchens, one shared room and one large verandah.(fig. 10) The residents of one bedroom of the vernacular house would have an entire HDB flat to themselves, dividing up the multi-generational family. Liu is unsentimental about this change: HDB residents would have more residential space per person, greater privacy, modern bathrooms, and better access to public transport and shared facilities.

Though his analysis does reveal short-comings of HDB housing, Liu is pragmatic in arguing that many would eventually be overcome through design or management. Though vernacular housing, 'may at any time be extended to suit the changing needs of the family,' the same need could be met by, 'providing a certain number of rentable flats within the building block.'[36] Similarly, the lack of open space or direct access to play areas could be compensated by, 'making access balconies to the flats attractive enough to function as playgrounds in the sky.'[37] The hope of creating 'playgrounds in the sky' to compensate for density remains a goal of HDB's even today.

Liu acknowledges that at this stage HDB's work is experimental: 'The architects and planners are eager to know the long term effects of this high-rise, high density mode of public housing development on the people.'[38] 'The task ahead, besides the sheer effort to keep up the housing output, should be something no less ambitious than to make high-rise development a viable way of life, since there apparently is no alternative for Singapore.' [39] Quantitative measurements made it possible for Liu to evaluate HDB's efforts, chart them against pre-existing options and track their development over time. Liu's use of density metrics, even the ones he has personally developed, however relies extensively on supplementary information in the form of written explanations and urban and architectural plans. Liu's working methods, lend credence to the claim that urban data must be interpreted in a wider context to provide a full picture of human living conditions. Contemporary with Liu Thai Ker's design research, the sociologist Stephen Yeh was developing protocols for HDB to assess the social quality of life in its estates.

35 Ibid. p. 178.
36 Ibid. p. 180.
37 Ibid. p. 180.
38 Ibid. p. 180.
39 Ibid. p. 181.

4.2.4 A sociologist studies density: Stephen Yeh's social metrics

In 1968 sociologist Stephen Yeh made the first broad survey of resident satisfaction in HDB units.[40] Analysis of this survey (along with analysis of second survey in 1973) were published in Ekistics in 1972 and 1974 and in HDB's comprehensive *Public Housing in Singapore* of 1975.[41] These surveys represent the first broad and well-documented case of data-informed design iteration within the HDB. As we will see the survey was written with the physical parameters of the housing system so that the form of the units, blocks and estates could be adapted in response to the survey results.

The surveys interrogated resident satisfaction at four environmental scales: the flat, the floor, the block and the estate. At each level we see the definition of parameters of interest. At the level of the flat, residents were asked what changes they themselves had made to the flat, and allowed to choose from a predefined list (removal of wall between kitchen and balcony, removal of dapor (a kind of stove), installation of window railings, use of tinted glass for windows, fixing of built-in cupboards and shelves to the kitchen). Residents were then asked to rank the most important change made to the flat.[42] Preference for certain predefined adjustments (like a larger kitchen) was also solicited. (fig. 16)

In discussing of a possible increase in kitchen area, Yeh reveals the method and mindset behind the parametrization of the HDB flat in the household surveys. An increase in kitchen area could not be permitted to increase the overall area of the unit due to budget limitations, thus this area would need to be subtracted from some other space. The HDB, however, would not consider reducing the size of bedrooms below the United Nations recommended minimum size (a fixed parameter). This made the choice of a larger kitchen a trade-off between living space (a flexible parameter) and kitchen area. (figs. 13-15) The survey thus needed not only to learn if residents wanted a larger kitchen, but to ascertain if they would willingly trade living space for kitchen space.

With the establishment of these parameters, kitchen size could be modified in future buildings based on the results of the survey. The parametrization of the HDB flat seems to have strongly influenced certain design decisions for subsequent generations of flats. Yeh cites, or example, a strong preference for separate bath and toilet in the 1968 survey as the justification for the incorporation of this feature in all new units thereafter.[43]

At the level of the floor and the block a more limited form of parametrization was enacted in the survey. Residents were asked the highest floor level they would be willing to live on and the level of floor they would prefer to live on. This seems to have been an attempt to understand both the social impacts of high-rise living (an issue of concern since SIT's 'suicide-block' of the 1950s, see 4.2.1) as well as to provide a resident driven response to the question of the limits of density. As we have seen the problem of ideal density was being simultaneously studied by Liu Thai Ker in the Building Department's *Building Research Unit*. Responses to these questions led Yeh to the conclusion that, based on available data, 'it is clear that the majority of people was not keen living in high-rise blocks taller than

40 Yeh had already worked on the Singapore Sample Household Survey in 1966, in association with the Department of Sociology, National University of Singapore.

41 Yeh, Stephen and Tan Soo Lee. 1975. 'Satisfaction with Living Conditions.' In *Public Housing in Singapore.* p. 214 For Ekistics articles see references section at the end of this chapter.

42 Ibid. p.216 Only the most important change was coded into the database, a limitation of early computational systems to comprehend larger or varied datasets.

43 Ibid. p. 217

eleven stories.'[44] To what extent this study of resident-led density preference led to an impact on HDB designs is not clear- future HDB publications do reference a limitation for slabs block to 'around twelve storeys.'[45] That these data informed future generations of HDB design seems clear, defining an evolving formal basis for the production of Singapore's public housing.

Beyond providing feedback on the ideal parameters of HDB housing, Yeh went further to conduct predictive analysis based on his survey data.(fig. 17) He used these predictions to suggest levers for future policy decisions. Yeh carried a multiple regression analysis of the twenty-one variables of satisfaction from the dataset- in this analysis he chooses to hold four variables as dependent: Satisfaction with Estate, Block, Floor, and Flat. Social environment variables, like 'cleanliness of building' and 'control of gangsterism' are left as independent variables. This statistical set up treats satisfaction with the built environment as the result of the social environment, and asks which social variables are most impactful and to what extent.[46] For each dependent variable Yeh outputs three or four most significant independent variables. In the case of 'satisfaction with flat', for example, the associated independent variables are Amount of Noise, Cleanliness of Building, Social Visiting Frequency, and Control of Gangsterism.(fig. 17) Yeh notes that cleanliness of the building, 'on average increases the satisfaction with the flat by 0.041.' Satisfaction with noise increases satisfaction with the flat by 0.040, satisfaction with control of gangsterism leads to an increase of 0.027.[47]

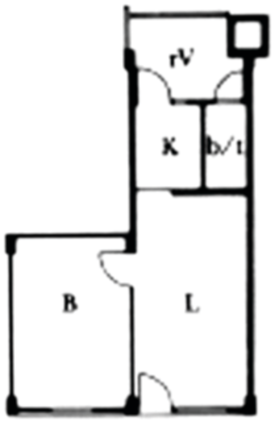
Yeh's analysis of the satisfaction data represented it as predictive and actionable information. His analysis offers variables that can be acted upon (i.e. Amount of Noise), and gives an estimate of what the result of acting on the variable may be on residents perception of their built environment (4% greater satisfaction with flat). As such these variables would likely have been seen as levers for policy makers, i.e. 'If you want to increase satisfaction with the HDB flats then institute a program to make sure the blocks are clean.' The fraction of 'satisfaction with flat' obtained by ensuring satisfaction with cleanliness seems quite small – 0.041- but in terms of the population housed by HDB at the time (some one million individuals) it represents 40,000 individuals.[48]

Stephen Yeh saw his surveys of resident satisfaction as providing a distinctly different form of feedback on the success of public housing in Singapore: a valuable contrast to the expertise of the architect.

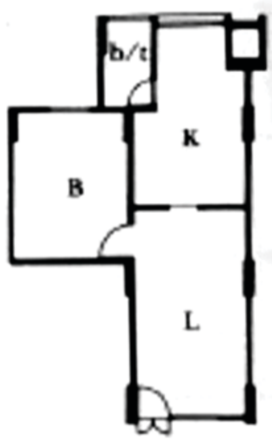
> 'The evaluation of the impact of public housing must include two complementary perspectives. The first is "looking in from the outside", i.e. analysis of objective or quantitative data from the position of the planner or interested layman. The second is 'looking out from the inside', i.e., the views of those residing in the public housing units since they are the consumers of HDB's products.'[49]

44 Ibid. p. 220.
45 Wong, Aline. et al. 1985. *Housing a Nation : 25 Years of Public Housing in Singapore.* p.88. HDB's point blocks were always much higher- around 25 stories.
46 It would have been possible to set the multiple regression analysis up in the opposite way with social variables made dependent and asking to what extent satisfaction with built environment impacts these results. Yeh, however, did not address in this inverted question, perhaps betraying a bias for the social engineering he advocates elsewhere. See Yeh, Stephen and Tan Soo Lee. 1975. 'Satisfaction with Living Conditions.' In Public Housing in Singapore. p.351
47 Increase in satisfaction here is measured within an 'index of satisfaction' that maxes out at 1.0. So 0.041 could also be stated as 4.1 percent.
48 Lee Hee Seng. 1975. 'Foreword' in *Public Housing in Singapore.* p. v.
49 Yeh, Stephen H.K. 'Satisfaction with Living Conditions' in *Public Housing in Singapore.* p. 214.

13. HDB 2-room 'emergency' unit early 1960s [37 m[2]]



14. HDB 2-room 'standard' unit circa 1965 [41 m[2]]



15. HDB 2-room 'improved' unit circa 1970 [45 m[2]] (larger kitchen)

Number of Rooms	Preference For Size of Kitchen (from 1973 HDB Sample Household Survey)			
	Bigger Kitchen	Smaller Kitchen	Undecided	Total
Rented Units:				
Two	43.4	27.9	28.7	100.0
Three	37.8	38.1	24.1	100.0
Four to Five	62.5	27.1	10.4	100.0
All Units	42.4	31.3	26.3	100.0
Purchased Units:				
Two	50.9	25.4	23.7	100.0
Three	55.9	29.9	14.2	100.0
Four to Five	58.4	22.2	19.4	100.0
All Units	55.7	29.3	15.0	100.0

16. HDB. 1973 Sample Household Survey: Kitchen size preference survey results.

Regression	Dependent Variables	Independent Variables	Coefficient of Multiple Regressions	Standard Errors of Estimate	F Ratio	T Value	Multiple Regression Equation
1	Satisfaction with Estate (X_{17})	Cleanliness of Building (X_{14})	0.241	0.148	19.221	4.673	$X_{17} = 0.838 + 0.054\,X_{14} + 0.036\,X_{16} + 0.051\,X_{11} + 0.028\,X_{12}$
		Amount of Noise (X_{16})				3.591	
		Goods in Nearby Markets and Shops (X_{11})				3.041	
		Control of Gangsterism (X_{12})				2.978	
2	Satisfaction with Block (X_{18})	Amount of Noise (X_{16})	0.285	0.196	35.620	7.204	$X_{18} = 0.825 + 0.095\,X_{16} + 0.079\,X_{14} - 0.050\,X_5$
		Cleanliness of Building (X_{14})				5.230	
		Dissatisfied with Flat Allotted (X_5)				−2.174	
3	Satisfaction with Floor (X_{19})	Amount of Noise (X_{16})	0.221	0.215	15.546	4.224	$X_{19} = 0.795 + 0.061\,X_{16} + 0.068\,X_{14} + 0.051\,X_{10} + 0.029\,X_2$
		Cleanliness of Building (X_{14})				4.099	
		Hawkers' Service (X_{10})				2.705	
		Type of Flat (X_2)				2.129	
4	Satisfaction with Flat (X_{20})	Amount of Noise (X_{16})	0.165	0.196	8.898	2.994	$X_{20} = 0.083 + 0.040\,X_{16} + 0.041\,X_{14} - 0.032\,X_{21} + 0.027\,X_{12}$
		Cleanliness of Building (X_{14})				2.671	
		Social Visiting Frequency (X_{21})				−2.203	
		Control of Gangsterism (X_{12})				2.144	

Note: Acceptance of the above regression relationship is based on the following riteria at 95% level of significance: (a) T Value, 1.96, (b) F Ratio, 8.84.
Source: 1973 HDB Sample Household Survey.

17. HDB. 1973 Sample Household Survey. Satisfaction survey: results of stepwise regression analysis.

Yeh saw his work specifically as advocating for the residents of public housing, but also as counter-balancing the 'outside' view of the planner and architect. Yeh's emphasis on the importance of social environment to the success of public housing has been supported by contemporary scholars like Belinda Yuen who has cited the importance of social environment in maintaining viable public housing over the long-term.[50] The Sample Household Survey, which Yeh first created in the late 1960s, remains an ongoing HDB tradition, completed every five-years (with a change format) and a testament to the degree that this sociological data is valued by the institution.[51]

4.3 Reorientation: rising standards of living, a complexifying understanding of density

4.3.1 Amenity, place-making and neighborliness

Over-crowded housing was no longer an emergency in Singapore of the 1980s. In 1975 a million Singaporeans were living in HDB flats, and by 1985 that number had doubled to two million or 81 percent of Singapore's population at the time.[52] The population of Singaporeans living in slums or squatting, by HDB's account, had fallen from 560,000 in the mid 1960s to 130,000 in 1985.

During the same period there was a profound shift in the types of flats that were in demand: in the 1960s HDB had built its first New Town *Toa Payoh* with 30 percent one-bedroom units. By the 70s one-bedroom flats were only 5 percent of the mix (in *Ang Mo Kio*) and by the mid-80s one-room flats were one-tenth of one percent of the total mix. The most popular flat type in the 1960s was the 3-room, which was replaced by 4-room unit as most popular in the early 1980s with the 5-room unit in second place.[53] Alongside the increasing preference for larger units (driven in part by the growing affluence of the Singaporean populations) the average family size was decreasing from 6.2 persons per household in the 1960s to 4.4 in the early 1980s.[54] The result was that, even as HDB built more, the density of its New Towns was falling.[55]

The net population density in HDB estates at 1000 persons/hectare in 1981, had dropped to 880 persons/hectare by 1985. Liu Thai Ker had anticipated this situation in the mid 1970s when he wrote:

> 'It is difficult to see how an absolute minimum standard of living can be maintained forever [...]. Therefore, more and more people are expected to apply for larger and better housing units. At the same time, the demands for amenities and facilities multiply in number as well as in types.'[56]

In this passage Liu anticipated the challenges that rising aspirations will bring for HDB. While he

50 Yuen, Belinda. 2006. 'High-rise Living in Singapore Public Housing.' 'In addition, more than the specifics of the dwelling unit, it appears that satisfaction with high-rise living also draws on a considered balance of the wider residential environment. In considering the livability of the high-rise, concern seems to be prioritised on the availability of neigh- bourhood facilities, lift efficiency and safety and one's neighbors.'

51 See for example: Housing & Development Board. PUBLIC HOUSING IN SINGAPORE: Residents' Profile, Housing Satisfaction and Prefer-ences. HDB Sample Household Survey 2013. Singapore, Dec. 2014.

52 Wong, Aline. Et al. 1985. *Housing a Nation : 25 Years of Public Housing in Singapore.* p 498 & 500

53 Ibid. Table 5. p. 81.

54 Ibid. Table 6 p..82..

55 "Another important factor we considered was the rising demand for larger flats – the bigger their sizes the lower their densities. [...] The increasing demand for larger flats is expected to continue. [...] Conversely, the household size will continue to decline. It dropped from 6.2 persons in 1968 to 4.4 persons in 1984 and is projected to be 4 persons in 1990 and even lower in the future. In order to achieve a combined net residential density of 200 du/ha, we have to increase the densities for all the individual types of flats as shown in Table 4 by about 15 percent." [p.81-82 Housing a Nation]

56 Liu Thai Ker. 1975. 'Design for Better Living Conditions.' In *Public Housing in Singapore.* p. 123.

acknowledged that Singaporeans cannot be expected to be happy forever with the 'minimum standard of living,' he seems to interpret his mandate at HDB as requiring him to search for the optimal use of resources and density, even if it means pushing back against the rising aspirations of the Singaporean people.

Faced with falling net density in its estates in the early eighties HDB actively intervened to maintain higher density. Instead of reducing the size of units, a move that would have been unpopular with residents, the HDB considered two possible solutions- increasing building heights or reducing the spacing between buildings. In the end HDB decided against building higher and began moving its blocks closer together- decreasing the required spacing between blocks by 15 percent in 1982.[57] Moving blocks closer together could not compensate for another fundamental shift in Singapore's population- demand for public housing began to drop steeply in the late 1970s.

In 1977 the waiting list for HDB flats fell abruptly, signaling the declining urgency of HDB's initial mission to provide basic housing to Singapore's population and the need to shift the HDB's housing in new directions.[58] Lui Thai Ker described this as a 'turning point' for the HDB: "[The waiting list trough] led the Board to believe that [...] it was time to pay more attention to qualitative improvements in the housing estates."[59] [italics added] The transition was not just from quantities to qualities but from, "flat builder to new town developer,"[60] in Liu's words. HDB from now on would be looking to create not just flats, but towns, with all the complex social implications of that word.

Even as he announced this evolution in HDB's mission, Liu Thai Ker (now HDB Chief Executive Officer) firmly stated in a 1985 *Overview* of HDB's work that high-density high-rise living remained the only choice for HDB and Singapore in general. To support this position he described a design scenario carried out in 1984 by HDB planners for an estate in which residential buildings were held to 4-stories: "The resultant space between buildings was 2.23 m [...] leaving barely enough space for rainwater to filter down. Obviously, low-rise high-density residential development is not a viable alternative in the context of Singapore."[61] He disputed the 'common belief' that high density is synonymous with crowding and lower standards of living. Crowdedness, he argues, "should be assessed from multiple number of indices," like the "size of flat, the number of persons per housing unit, the internal floor area per person, the outdoor usable area."[62] Together these quantifiable factors, along with the skill of the designer in configuring 'building heights and spaces' produce the, 'perception' of crowdedness.[63] Liu Thai Ker emphasizes that crowdedness is not an existing physical property of space, but a perception of a social/spatial condition: "Rich people in major cities are willing to pay extremely high prices to buy quality – but high-rise – apartments."[64]

57 Tan Keng Joo, Tony. et al. 1985. "Physical Planning and Design." in *Housing a Nation : 25 Years of Public Housing in Singapore*. p. 84. "In 1982 , these guidelines [for building spacing] were revised because of two factors. [The first is a water catchment scheme limiting new town development.] The second was the increased demand for larger flats mentioned earlier. To counter these two factors, we have to either build higher or reduce the building spacing in order to increase the densities by about 15 percent. [...] An evaluation of the two alternatives favoured the reduction of minimum building spacing. This took into account the lift-ratio, car parking requirements, outdoor open space, human scale and most importantly the continuous decline in average household size, leading to a drop in net population density, as outlined in the previous section. All things considered, we decided to reduce the site of guidelines for minimum building spacing by about 15 percent."

58 Liu Thai Ker. 1985. 'Overview.' In. *Housing a Nation : 25 Years of Public Housing in Singapore* p.13

59 Ibid.

60 Ibid.

61 Ibid. p. 9.

62 Ibid.

63 Ibid.

64 Ibid.

Isolation, perhaps paradoxically after concern over crowdedness, is the next concern for high-density high-rise housing that Liu addressed in his 1985 *Overview*. Referring to the need to use a lift to reach one's unit in a high-rise building, Liu wrote: "Some sociologists believe that this [reliance on lifts] could lead to a sense of isolation." Indeed, it was exactly the problem of high-rise isolation that had been addressed by HDB's Chang Chen-Tung, who had written ten years earlier that, "to a certain degree the relatively low level of neighborliness [evidenced by the HDB 1973 Sample Household Survey] represents a behavioural response to high-density living more characteristic of public housing estates than of other types of neighbourhood."[65] Chang described this as a possible manifestation of the *autonomy-withdrawal syndrome*, and suggested that one effect of urbanization is the, 'desire to be left alone.' He emphasizes the 'group-preserving' value privacy, and challenged planners to promote positive aspects of 'neighborliness and privacy at the same time.'[66]

Liu dismissed categorically concern over isolation and using the Sample Household satisfaction surveys to support his position: "While in 1973 only 13 percent of the HDB residents preferred to live above the tenth storey, in 1981, 32 per cent were so willing [...]. The adjustment of the Singaporean people to high-rise housing blocks has not been a problem."[67] Though Liu dismissed the concerns of 'some sociologists,' over isolation, a new generation of designers like Tony Tan Keng Joo, Chief Architect of the HDB from 1982 to 2002, were taking on the potential social problems of high-density high-rise urbanism like isolation with new design ideas.

Qualitative improvements to the design of HDB estates, meant not only adding amenities like cinemas, but more fundamentally reconsidering how families, apartments, housing blocks and open space were aggregated to produce a neighborly form of high-density high-rise living. This meant re-considering the habitat not just in terms of person to land-area ratios which dominate the first twenty years of HDB's practice, but also in person to place ratios at socially-appropriate scale. Simply put, designers at HDB in the 1980s were devoting more attention to the question of what is the best size/shape relationship for a high-rise neighborhood. From this work a new planning/ urban design concept of *precinct* was developed to be more appropriate to social neighborhood formation.

4.3.2 HDB's precinct: spatial and quantitative definitions of neighborhood

Neighborhood size for HDB New Towns had been initially determined relative to the number of people necessary to sustain a commercial center. This in an early new town like *Ang Mo Kio* where neighborhood size was 6,700 flats, or about 26,000 people.[68] In 1985, Tony Tan Keng Joo acknowledged that a socially-oriented neighborhood, what they call a 'neighborhood of community,' would likely have a smaller number of people.[69] To design a physical space closer in size to a 'neighborhood of community', they proposed a significant modification to a planning element in HDB new towns called the *precinct*.

The HDB precinct is defined by relations of orientation to a central space, 'An ideal precinct [...] is probably one where all blocks orientate towards a central open space.'[70] With this criterion the

65 Chang Chen-Tung. 1975. "A Sociological Study of Neighborliness." In *Public Housing in Singapore.* p 299
66 Ibid. p 300, 301
67 Liu Thai Ker. 1985. 'Overview.' In *Housing a Nation : 25 Years of Public Housing in Singapore.* p9-10
68 Tan Keng Joo, Tony. et al. 1985. "Physical Planning and Design." in *Housing a Nation* p.90
69 Ibid..
70 Ibid.


18. Ang Mo Kio HDB New Town Neighorhood 2xx. Blocks 201-235 highlighted. circa 1970-1978. See also fig. 7. (Google)


19. Bukit Batok Neighborhood 2xx. Blocks 231-241 highlighted. circa 1979-85. (Google)


20. Bishan Neighborhood 1xx. Blocks 168-197 highlighted. circa 1982-88. (Google)

authors cite contemporary precinct sizes in 1985 between 1,000 to 1,200 flats. Although with some blocks in these precincts facing outwards the result is a 'less than optimal level of visual identification with the precinct.' If all blocks have unimpeded inward views to the central space, the authors suggest the size would be between 400 and 800 flats. While the architectural framework of housing blocks and apartment orientations is the basis for these numbers, the result they are targeting is not formal but rather the, 'visual identification' between resident, central space and social grouping. The phenomenon of visual identification of the precinct, they suggest, may be strengthened through clearer marking of the boundaries of the precinct via, 'gateways and archways to create a stronger sense of entry.'[71]

The precinct concept was, like other HDB innovations, tested by empirical research. The primary source of empirical support comes from the HDB household surveys: 'Interviews revealed more positive responses to some aspects of community sentiments from residents of two precincts, compared to residents of a non-precinct area of the same age.'[72] An additional empirical test is deployed on the precinct: "Observation of the patters of movement across the sites identifies the important role of building and road layout in *channeling* people. It seems very likely that a high degree of channeling led to the higher levels of neighbor recognition reported by residents of the precinct areas."[73]

Empirical observation of pedestrian flow represented a new level of sophistication in the measurement of density at HDB. By tracking the spatial intensity of movements and correlating it to social metrics of identity, quantitative technique began to reflect some of the complexity of social phenomena in urban space. Not coincidentally the authors cite Hiller and Hanson's *The Social Logic of Space* as an inspiration for their observation of pedestrians in HDB precincts.[74] The emergence of the network idea of the city and accessible geo-spatial computational tools in the mid 1980s was revolutionizing the understanding of the city and HDB was at the forefront of adapting their design concepts and methods to these developments.

4.3.3 Longitudinal social studies and relational measurement of density

HDB began the 1970s to carry out longitudinal surveys of its residents, as part of its shift in orientation from quantities to qualities. Based on interviews with residents, the longitudinal study provided personal viewpoints on HDB's what it was like to live in an HDB estate. A longitudinal survey led by Chua Beng Huat of HDB's *Systems and Research Department* published in 1985 gave an overview of this new methodology, which offered new means of understanding density not just as a simple ratio of people per area, but as an intensity of relations between people and places. Chua's survey followed people over three years as they were resettled from a semi-rural village called *Soon Hock* to *Ang Mo Kio*, a second generation New Town. (See figs. 7, 18.)

The methodology of the *Soon Hock* longitudinal study differed markedly from earlier sociological studies at HDB. The authors highlighted that their *conversation-interview methodology* was

71 Ibid.
72 Ibid. p. 91
73 Ibid.
74 Ibid.

deliberately 'adopted in contrast to the survey method used in most existing studies' at HDB.[75] The conversation method allowed them to gather information defined not by the concerns of the interviewer (as is the case with a survey) but instead following the concerns of the interviewee. The recorded conversations were supplemented by, 'time budget records, layout plans of each dwelling and business premise, observation records of casual village activities and organized community activities. In the second and third stages, respondents were also asked to draw perceptual maps of their surroundings to gauge their familiarity with their new environment.'[76] These additional documents added spatial and temporal information produced by the interviewers and the interviewees to the study. The result was a richer image of the results of the resettlement process and HDB life than what had previously been depicted by architectural studies or social surveys. The longitudinal survey not only incorporated new points of view from the residents but also better described temporal and spatial effects, contributing to understanding of the evolution of social fabric in response to change in the physical environment.

The break-up of the traditional multi-generational family into several nuclear families was the primary social result of the resettlement from village to HDB high-rise public housing. In village housing, the home was constructed so that, "each branch of the multi-family had one bedroom to themselves."[77] In HDB housing each of these nuclear families would have their own apartment. Splitting the family had the effect of elevating younger women, who had felt, "oppressed by the control [...] exerted by the patriarch/matriarch of the household,"[78] in traditional housing. Younger women were noted to be more enthusiastic about the move to HDB housing than elderly women. The elderly, in particular elderly women, anticipated social isolation upon resettlement and breakup of the multi-generational family, and understandably had misgivings about the transition.[79]

Returning to the same interviewees two years after their resettlement Chua Beng Huat and his co-authors found that when family members were located to adjacent units, the elderly seemed happier. "Strong negative sentiment tended to disappear among some immediately following resettlement although it persisted in others; the differentiating factor was whether the families opted to live entirely separate from each other or to continue living as neighbors under the joint-balloting scheme."[80] Joint balloting was an HDB initiative permitting related families to be, "allocated adjoining flats or flats within the same estate."[81] At the same time new social relations were also formed: an elderly woman who had complained of heartbreak over resettlement was found two years later to be engaged in a new social group which met regularly in the HDB block *void deck* an area at ground floor kept open for social gatherings.

HDB relocation also led to changed financial circumstances. Two years after resettlement young men appeared to have the most difficulty rebuilding a social life. Taking on the HDB flat was a financial burden to many families and the brunt of that burden was carried by working-age men. The authors note that, 'These men have not been able to regain the same level of interaction with their village

75 Chua Beng Huat and Julie Sim. 1985. 'Resettling Soon Hock Village: A Longitudinal Study.' In *Housing a Nation : 25 Years of Public Housing in Singapore.* p. 337.
76 Ibid. p. 338.
77 Ibid. p. 349.
78 Ibid.
79 Ibid.
80 Ibid. p. 357.
81 Ibid.

friends even after two years. Nor have then been able to make new friends among their neighbours[…] Social life for them has become drastically reduced to nominal exchanges with immediate families and relatives.” The void deck was ‘unsuitable’ for to these young men because of, ‘“ear of police checks and being branded as ‘bad-hats.’”[82] “Young men who were used to casual […] nightly gatherings […] complained about social isolation.” The ability of HDB’s architecture to substitute for traditional social spaces did have some limitations for specific groups of people, in particular young men.

The longitudinal survey also vividly revealed the profound differences between the spatial characteristics of the traditional village – or kampung – and the HDB block. The isomorphism of the village’s physical layout and its residents relationships is emphasized. “Unpaved, dirt tracks […] subdivided the village into various pockets,” so that the, ‘social network of the village-bound residents were formed mostly within the lane or section where they lived.’[83] The ‘openness or permeability of their village houses […] enabled them to catch sight of each other and to meet easily.’ Spaces were easily distinguished from each other, appropriated and modified by their residents. Each lane was, ‘‘highly differentiated. Each lane had its own features and focal points. Within each lane, every house had its own character, even among the newer, more standardized dwellings.”

Appropriation and place-identification at HDB were also identified as challenges by the authors of the longitudinal survey. Upon resettlement within an HDB flat the new residents devoted a great deal of effort and money to decorating and redesigning the interior of the flat which as a rule at HDB are delivered unfinished and unfurnished. Furnishing and decorating was a significant act of appropriation for the new residents, and the authors note that it was associated with a sense of satisfaction with the flat.[84] Appropriation and identification with place at HDB, however, seemed to stop at the level of the flat, with the surveyors noting that residents learned to identify their neighborhood via the system of numbering: “All the respondents *identified their neighborhood by the first digit of the block numbers*. […] Likewise, they were aware of other neighborhoods in the new town, even if only to the extent that these were also *areas with blocks starting with the same digit*.”[85] Placemaking of the sort advocated by designers in the 1980s had not been present in the planning and design of Ang Mo Kio in the early 1970s.

While measuring density in its crudest form requires only metrics of people per area, managing and building for density require a more complex understanding of how people might live together. The longitudinal survey of *Soon Hock Village* resettlement revealed the complexity and richness of the social impacts of HDB resettlement. This type of survey for the first time raised the voices of a few residents up to the same level of authority as building statistics and satisfaction surveys. However, just as these individual voices were being highlighted, HDB was also struggling to communicate with its more than two million tenants- four fifths of the population of Singapore. The difficulty of organizing the many prosaic communications with this massive quantity of tenants motivated the first digitization and automation of HDB’s estate management.

4.3.4 Managing density: digitizing communications and records for two million tenants

Managing high-rise high-density housing is at least as complex as building it in the first place, even if the details are more prosaic. Lifts, water-tanks, and electricity, are all critical to living in high-

82 Ibid. p. 364.
83 Ibid. p. 339 and 344.
84 Ibid. p. 355 “On the whole, the resettled were satisfied with the flat itself after spending the money to ‘beautify’ it.”
85 Ibid.

rise buildings and all are require regular maintenance and are subject to periodic unforeseeable breakdowns as they age. Tenant complaints need to be filed and responded to promptly, and tenants trapped in elevators need to be rescued immediately even if it happens at two o'clock in the morning.

By 1985 HDB was managing housing for some two million residential tenants (not to mention its commercial and industrial premises and supporting facilities.) For these two-million tenants it managed 7,345 lifts.[86] The housing and its systems had been built over the last twenty-five years, and it was almost entirely high-density high-rise housing twelve stories or taller. Digital communication and control systems became central to managing the growing complexity of the existing housing estates in the mid-eighties as tenancy spiked and buildings systems started to approach the ends of their functional life-spans.

Lifts are crucial to HDB's high-rise high-density urbanism and in the late 1970s and 1980s they became the introduction point for the first systems of digital sensing and control. According to contemporaneous surveys of the tenants, the lifts were perceived to be the most unsafe place in the HDB estate.[87] HDB's estate management services needed better tools to ensure the proper and safe function of their lifts. In the early 1970s the HDB introduced a Essential Maintenance and Service Unit (EMSU) whose control room would take calls twenty-four hours a day and maintained radio contact with remote service teams who would be dispatched to make emergency repairs on critical building systems (and rescue tenants trapped in elevators.) The EMSU in 1973 began offering 'round-the-clock' lift rescue services due to, "lift companies' inability to provide efficient rescue services.'

In 1978 the HDB began its first experiments with closed circuit surveillance of lifts. The CCTV footage from the lift was fed live via a central antenna to the home televisions of the block residents, and to a monitor in the ground floor lift lobby.[88] Beginning in 1981 HDB introduced a *telemonitoring system* for all its lifts enabling, 'direct monitoring of lift operations and automatically detect[ing] faults and breakdowns for prompt attention."[89] A 'lift monitoring device' or sensor were connected to an *Area Receiving Station* at the HDB area office, and then linked to a 'master computer' at an *Emergency Maintenance and Service Center*. A 'crime-related' signal would send an SOS message to the service center and set off an alarm, and the police would be contacted.[90] The project was successfully tested in 1981 in *Ang Mo Kio West*, expanded in 1982 with 1,559 elevator sensors in place by 1985. Variations of both systems, CCTV and lift-sensor network remain in place today.

In 1983 Singapore experienced an island-wide power outage, an *Automatic Rescue Device* allowed 98 percent of residents to escape the lifts they were trapped in. This device, battery operated, is activated when power goes out and autonomously returns the lift to the closest floor level allowing any occupants to exit.[91] This autonomous system, installed in 1979, proved to be a necessity for an institution managing so many high-rise homes.

Digital systems were an integral part of HDB's management of their housing estates by the mid 1980s. As the population living in HDB housing continued to grow over the following decades the role of digital technologies in mediating between the central agency and its millions of tenants expanded

86 Yao Chee Liew. 1985. 'Infrastructure.' In *Housing a Nation : 25 Years of Public Housing in Singapore.* p. 141 Table 6.
87 Ibid. p. 141 Table 7.
88 Ibid. p. 142.
89 Ibid. p. 143.
90 Ibid.
91 Ibid. p. 141-142

at an accelerating clip. While the creation of Town Councils in 1986 did allow HDB to devolve some of its maintenance and oversight responsibilities to local citizen-run organizations, the management responsibilities of the HDB remain vast today. In the last two decades digital systems have expanded their roles in the institution, changing the way HDB measures and designs for density (4.4.1), and even supplementing the social networks of families and neighbors within HDB estates (4.4.2).

4.4 Built form: HDB's pursuit of livable density in the smart era

Perceptions of density have continued to evolve over the last two decades in Singapore, conditioning and motivating the introduction of smart technologies at the HDB and the advent of a data-driven urbanism. Demographics in the 21st century again drive concern over how HDB manages density but, in contrast to the over-crowding of the 1960s, now a demographic shift to an older and possibly shrinking population of citizens is driving concern.

Population in Singapore is projected to continue to rise till 2030 and beyond, with the overall population density in Singapore increasing from 11,000 persons per kilometer square to 13,700 in the next ten years.[92] Implied is an increase to a population size of about 7 million. This projected increase in density would seem to be a familiar challenge for HDB, but hidden within the ratio of persons per land area are new difficulties.

The demographics of Singapore are changing dramatically due to a declining birth rate and an aging population. The fertility rate in Singapore has been below replacement level since the late in 1970s, and even though its citizens are living longer, the ratio of young to old has dramatically shifted with the elderly projected to make up a quarter of Singapore's population by 2030.[93] If the fertility rates continues unchanged in the future (and is not supplemented by immigration) the population of Singaporean citizens will peak in the 2030s at around 3.4 million and fall thereafter to about 2.6 million by 2060.[94] The result of this demographic change would be reflected in smaller families and more elderly living on their own. A further, politically-sensitive implication is that if Singapore wishes to rebalance the demographic pyramid it would need to import young people from other countries.[95] This possible influx of new citizens would represent a new challenge to HDB's policy and practices of ethnic distribution meant to foster the integration of a diverse population into a coherent nation.[96]

Liu Thai Ker (retired from HDB and URA since the 1990s) called publicly in 2013[97] for Singapore's planners to anticipate a population of 10 million by 2100, stirring up controversy among some in Singapore who feel that the city is already too congested with too much population growth coming from 'overseas'.[98] Should this figure be attained without the landmass of Singapore changing

92 Cheong, Koon Kean. 2018. "Lecture II: Anticipating our urban future, trends, threats and transformation." Lecture, IPS-Nathan Lecture Series, National University of Singapore. 10 April 2018. p.18
93 Ibid.
94 National Population and Talent Division, Prime Minister's Office. 2013. «A Sustainable Population for a Dynamic Singapore: Population White Paper." Singapore, Oxford Graphic Printers Pte Ltd. As a caveat, a new *Population in Brief (PIB) 2018* has been released by the minister's office since this writing that I have not yet had the occasion to review.
95 Cheong, Koon Kean. 2018. "Lecture II: Anticipating our urban future, trends, threats and transformation." Cheong refers to this possible immigration as the 'introduction of new citizens.' See p. 4
96 HDB has an ethnic integration policy which precludes buildings or neighborhoods from becoming exclusively populated by a single ethnic group. See: Ooi, Giok Ling. 1993. *The Management of Ethnic Relations in Public Housing Estates.* Singapore : Institute of Policy Studies : Times Academic Press.
97 Heng, Janice. "Look Ahead to 10 Million People by 2100?" The Straits Times, April 28, 2013. "Former chief planner says a better living environment is possible even with high density"
98 "On the Record: Liu Thai Ker, Architect and Former Master Planner of Singapore." Channel NewsAsia. Accessed February 7, 2019. https://www.channelnewsasia.com/news/singapore/on-the-record-liu-thai-ker-architect-and-former-master-planner-9285942.

dramatically, the current overall density of the country would be nearly doubled to 19,000 persons per square kilometer. Furthermore, in this scenario the additional population would likely be primarily foreign-born. The burden of negotiating the spatial distribution of these new residents would fall largely on the HDB, with the associated demands of ethnic and national integration.

Looking forward from today, the HDB can envision two radically different density scenarios. In the first extreme scenario, immigration does not replace population loss and overall population will decline. Singapore will become less dense, and increasingly a country of elderly with fewer young people to assist them. In the second extreme scenario, Liu Thai Ker's 10 million scenario, Singapore will almost double in density and become a much more diverse country. Current HDB CEO Cheong Koon Hean has advocated for planning for the highest density scenario, simply because it is better to be prepared for the large population and then be left with additional resources put aside when it fails to materialize than vice versa.[99] At the same time as Cheong advocates for planning for high density scenarios, much contemporary work at the HDB is focused on how new building will accommodate the growing elderly population. It is with these demographic concerns in the background that HDB is integrating new smart technologies that promise to make possible the data-driven management of Singapore's future density.

The term *livable density* is used by Cheong to describe current HDB approach to density, which prioritizes human centric mitigation of the possible downsides of high-density high rise-living. The tenets of livable density (polycentric developments which limit stress on the central area, landscape areas providing relief from high density residences, contrasting building heights, well-located facilities and shops) adhere closely to previous HDB efforts to make high-rise living more pleasant. However, there are notable differences compared to the past in HDB's contemporary tools of measuring density and its the data-driven design tools used to overcome its undesirable effects.

4.4.1 The Integrated Environmental Modeler: simulating livable density

An important secondary effect of the high-rise high-density urbanism created by HDB has been increased prevalence of the urban heat island effect. As part of its efforts to mitigate the urban heat island effect, HDB has promoted its use of a new software tool called the *Integrated Environmental Modeler* (IEM) (previously UM_MIST (Urban Microclimate Multi-physics Integrated Simulation Tool)) as a smart planning tool within its Smart HDB Town Framework. The creators of the IEM tool at the *Singapore Institute for High Performance Computing* (IHPC) link its development back to concerns for problems arising from high-density high rise residential districts. They describe how urban heat island is a direct result of densely constructed urban environments with limited or inadequate planted green space, and note that a difference of 4 degrees Celsius is observed between Singapore's dense central business district and 'well-planted areas.'[100] Noise, also simulated by IEM, increases in proportion to density of population and use of transportation, and can be propagated in unexpected ways by urban form via for example the 'street canyon effect.'[101]

The purpose of the IEM tool, according to is creators at IHPC, is to 'enable urban planners to visualize

99 See CHEONG KOON HEAN lecture II. P. 12. "Regardless of public sentiments, it is wise to plan for scenarios with varying population sizes, as it would help planners to anticipate the types of infrastructure that will be needed, the appropriate densities to build on available land, and to work through the many difficult trade-offs in allocating land amongst competing uses. If the population growth does not materialise, we would have a happy situation of having more land buffer set aside and more choices in the use of land."

100 Pho, Hee Joo and Liu, Enxiao (Institute of High Performance Computing). 2016. "Modeling of Urban Heat Island and Noise Propagation in Singapore." In Powering Discoveries! vol.9 no.2 Singapore, ASTAR.

101 Ibid.

the effects of their designs on different environmental parameters, hence optimizing the planning and design of our living environment.'[102] Furthermore it should, 'intuitively look into the impact of master planning and urban design on environmental issues, perform proof of concept and what-if studies, and devise and experiment with mitigation measures and plans.' It would be a, 'common platform for planning, visualization and environmental processes.'

The tool works by integrating local meteorological data and traffic data with a digital three-dimensional model of a district. In parallel it simulates solar irradiance, windflow and temperature and urban noise. The results are output as separate GIS layer heatmaps. In a final step its creators are working to test the simulation results against data derived from the site.

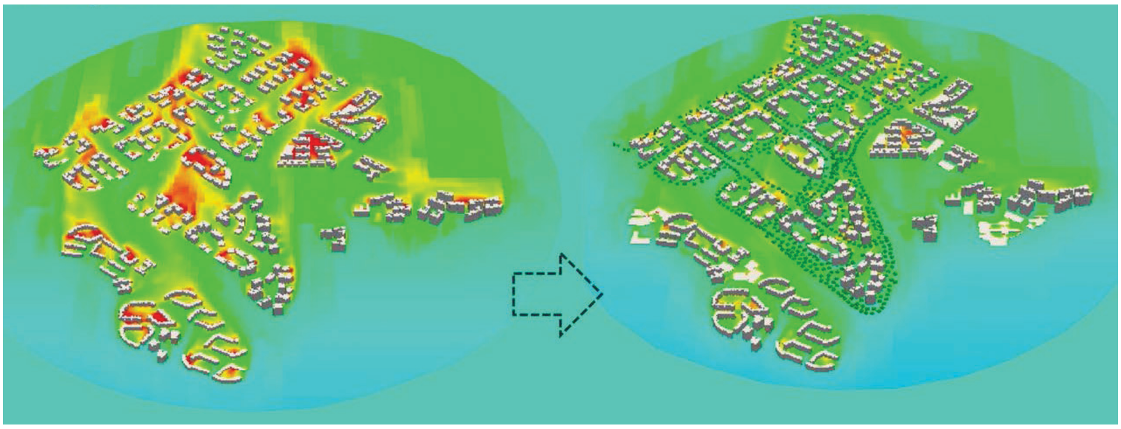
The HDB and IHPC have released limited information about how the IEM tool has been used in their urban design process, and often the information that is released comes in the form of press-releases or brochures. Released images include solar irradiance, temperature, wind and noise maps, mostly depicted as green-to-red heatmaps. In some images an urban heat island hot-spot is identified, and in a subsequent image it is solved or cooled down through the introduction of dense plantings on or near to the spot.(fig. 21) The success of the intervention is attested to by the heatmap- no longer red but instead approach a more mellow orange or even blue color. Beyond driving the decision to add extra plantings in planned urban open space, however, little evidence is available attesting to the use of the tool to make decisions about the distribution of urban density. Where housing is placed, and how tall the slab or tower should be, given available evidence, seem to be decisions that happen before the use of the IEM tool. Little of the hoped-for scenario testing described in the IHPC papers can be seen in the documents released by the HDB. This does not mean that this simulation-driven testing and iteration has not happened, but simply that it has not been released to the general public.

Ideally the IEM would be a more precise and sensitive update to the density optimizing techniques developed by Liu Thai Ker in the 1970s. The IEM could permit designers to ensure minimum levels of noise and urban heat island mitigation by distributing buildings relative to site topography, wind, and noise sources. Perhaps greater densities could be achieved while still maintaining the minimum standards for noise and UHI? Conversely, given a density goal, the IEM could help the designer to distribute slabs and towers in a way that would minimize impacts of UHI and noise. This would be an objective advance over the reductive density calculations of the 1970s and would also produce designs more intimately linked to the specificities of their sites. To function in this respect the tool would likely need to transition from being just an environmental simulator, to becoming more actively a design tool.

4.4.2 The Elderly Monitoring Tool: data-driven management of social density

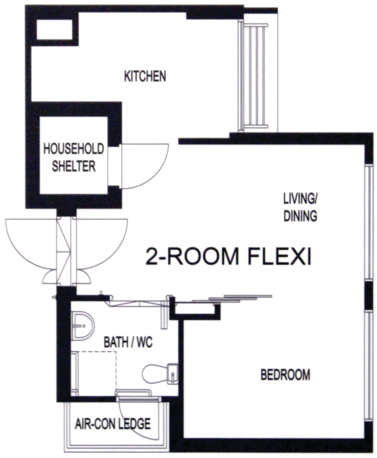
The problem of density is not just spatial, but also social – a complication that HDB has acknowledged and worked with since Stephen Yeh's early social surveys in the 1960s. And, while in the past architecture over-determined the composition of social relations by prescribing who would live next to whom, virtual social relations now challenge the power of architecture to determine who we come in contact with, under what circumstances and when. Seeking to harness the power of these virtual communities HDB has expanded its mandate to the creation of software applications which track, map, assist and manage residents' use of public housing.

102 Ibid. p.5

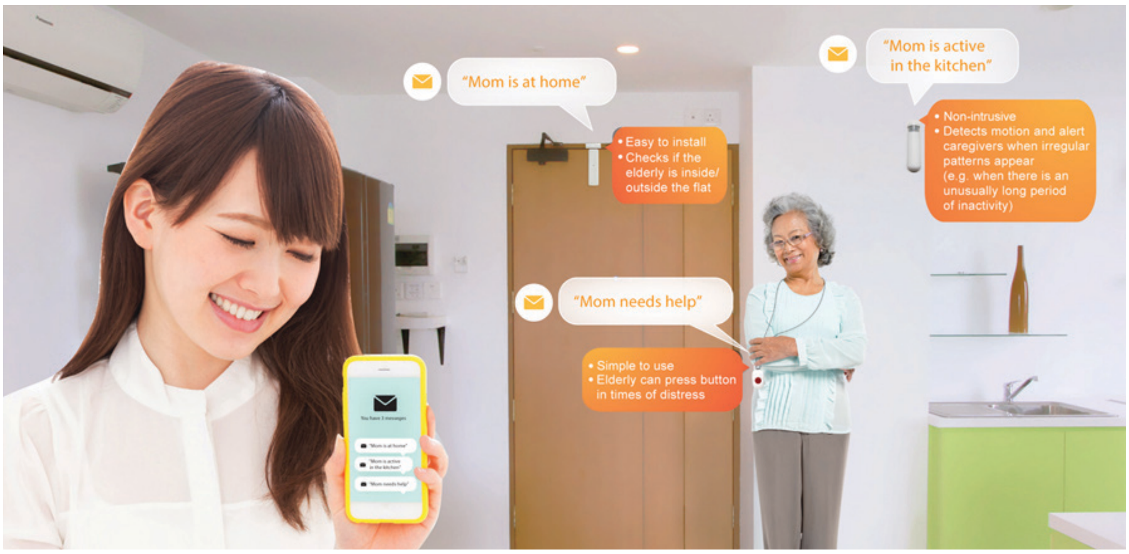


21. UM/MIST (IEM) tool applied to HDB's Tengah New Town. Simulated heat island effect mitigated by plantings.

22. HDB 2-Room Flexi Unit at Kampung Admiralty.



23. HDB 2-Room Flexi Unit standard plan.



24. HDB's implementation of the Elderly Monitoring System

The *Elderly Monitoring Tool* (EMT) addresses the problems of the elderly living alone in HDB units and is perhaps most prominent among HDB's proposed software tools. The tool tracks the daily movement of an elderly person within a dwelling unit using motion sensors, and builds a statistical model describing this person's routine. On a typical day the software provides assurance to the children or care-givers of the elderly person with messages like, 'Mom is OK,' and, 'Mom is active in the kitchen.' However, should this elderly person diverge from their accustomed routine in a manner that may indicate a medical emergency the software triggers a notification of this person's next of kin: 'Mom needs help.'[103] (fig. 24)

The *Elderly Monitoring Tool* augments or substitutes for the work of a care-giver with an automated tracking system, anticipating the demographic shift to an elderly population supported by a smaller youth population. Illustrations of the Elderly Monitoring Tool show a young women in the foreground receiving a notification on her smart phone about her mother who is shown standing in her flat in the background.[104] The tool permits the young woman to preserve at least in part her role as care-giver for her mother, while also presumably permitting her to be active and productive outside that role.

Software targeting HDB's aging population like the *Elderly Monitoring Tool* is complimented by new types of units that the HDB has offered in recent years for the elderly living alone. The *short-lease 2-room flexi flat* is the smallest unit that HDB currently offers, providing enough space only for a single individual or couple.[105](figs. 22, 23) The unit is designed to be configured for the elderly, with grab bars, lower kitchen counter height, and wheelchair space beneath sinks. The short-term lease associated with the unit, for 15 years or 40 years, is also specifically geared to the elderly who will not want to devote economic resources to purchasing a flat they may only need for a few years. The small and affordable *flexi-flat* offers a self-sufficient life-style for the elderly with the possibility of support as needed from care givers via the *Elderly Monitoring Tool*. The result is a hybrid condition where traditional relationships of care-giver and elderly are digitally mediated and the architectural environment supports an extended period of independence. While elderly parent and grown child may no longer physically live together as was the case in a traditional family, the HDB has sought to mitigate this physical distancing through the digital tools and an adapted built environment.

One of the first instance of the construction of the *2-room flexi-flat* in Singapore has been at *Kampung Admiralty*, a multi-use complex combing elderly housing developed by HDB, a medical center, child-care center and a hawker market.(figs. 27, 28) The project sits directly at a public transport rail line MRT station. The building was developed with the input of multiple agencies including the Ministry of Health (MOH) and was designed not by HDB but by WOHA architects. The project itself is not especially dense in terms of inhabitants: it contains only 100 flats in 8 stories on its site of about 0.8 hectares. In terms of diverse adjacent uses, green space, open public space and circulation, however, the projects displays an intensity and diversity of use that is not normally associated with an HDB project. A new logic of spatial intensity is at play in *Kampung Admiralty* that exceeds the density calculations that drove early spatial planning at HDB. This evolution of the desired nature of density toward a greater number of variables and complexity of relations has not however meant an

103 See promotional materials distributed by HDB: HDB, My Smart HDB Home@Yuhua. https://www.hdb.gov.sg/cs/infoweb/about-us/our-role/smart-and-sustainable-living/smart-hdb-town-page/hdb-smart-home-exhibition

104 Ibid.

105 Based on a visit to HDB's 'My Nice Home Gallery' in Toa Payoh on 30.04.2018. At 36 m^2 it is smaller even than the 2-room emergency flats built by HDB in the 1960s. (Although the 2-room units at that time housed four or more people, and not just two retirees.)

abandonment of the quantitative techniques of measuring and managing density. On the contrary, new HDB designs at *Kampung Admiralty* (as well as the *Skyville* project at Dawson) by WOHA grow from the quantitative approach fostered at HDB in previous decades and use these quantitative tools as stepping stones toward a new aesthetics of density.

4.4.3 Green Plot Ratio, Ong Boon Lay and WOHA: ecological density

WOHA, designers of HDB's *Kampung Admiralty,* frame their approach to designing urban architecture in terms of density: "Urban density will continue to increase, it cannot be stopped."[106] While we have seen this is not necessarily the case for Singapore with its declining fertility rate, their argument is framed more widely and takes into account tropical megacities like Manila, Bangladesh and Bangkok. As a result of growth in these cities they highlight the diminishing ratio of ground level 'amenity' per person as a fundamental challenge that they address as designers. While this ratio is similar to the *livable space per person* considered by Liu Thai Ker in the mid 1970s, it differs in that WOHA seek to be more sensitive to different the ecological and social uses of this ground-level space. The solution they propose to the problem of diminishing ground space per person is to use architecture as a means to multiply the ground: "Significant amenity can only feasibly be provided above ground level, by using Multiple Ground Levels to incorporate extensive gardens, parks and communal space."[107]

WOHA recognize that the solution to the dwindling ratio of urban open per person is not as simple as just providing open horizontal space at upper levels, but ensuring that it effectively replicates the social functions of traditional public/communal spaces. WOHA highlight in their writings the importance of horizontal connectivity in upper-level open space, as well as accessibility, navigability and familiarity of experience.[108] They also emphasize the ecological and public health benefits of gardens in upper-level open space.

In the tradition of HDB's efforts to quantify and track the density of their construction, WOHA have implemented a set of metrics to track the creation of upper-level social and ecological space. WOHA's rating system, like Liu Thai Ker's *Crowdedness Indices* of 1975, provides an alternate index for assessing buildings, 'in terms of their contribution to social and environmental sustainability, as well as their economic vitality.' [109]They have developed five metrics: *Green Plot Ratio, Community Plot Ratio, Civic Generosity Index, Ecosystem Contribution Index,* and *Self-Sufficiency Index*. Of these five metrics, the first two, Green Plot and Community Plot Ratio, are measures of amenity versus plot area, and thus represent a variation of the traditional density measurements like people per land area, units per land area, and built area to land area ratio (floor area ratio (FAR) or Gross Plot Ratio (GPR)). More specifically, Green Plot Ratio and the Community Plot Ratio directly address the problem of socially and ecologically functional open space for high rise high density residential building. Together they represent a sequel to the effort to define, measure and design for optimal density begun by HDB in the 1960s. After reviewing specifically how these metrics work, an overview of two HDB projects completed by WOHA using these metrics will help explain how they have contributed to the evolution of the architectural notion of density within the work completed by the agency.

106 Bingham-Hall and WOHA. 2016. *Garden City Mega City : Rethinking Cities for the Age of Global Warming*. p. 46.
107 Ibid.
108 Ibid. See points 4 and 6.
109 Ibid. See pp. 194-195.

Green plot ratio was not invented by WOHA, but was first proposed by Singaporean architect and academic Ong Boon Lay in 2002. Ong developed the idea of Green Plot Ratio while working on a competition entry for a new residential development in China with ArchUrban Architects and HDB subsidiary CESMA in 1998. The residential buildings of this competition entry used the void deck, a standard typological feature in HDB's residential slabs, as a landscape component, and introduced planted void decks at upper levels, calling them *skygardens*.[110] Ong felt that including additional green space within the built environment would contribute to the ecological impact of the overall urban plan, and he wanted to quantitatively track how much of an ecological difference this green space was making using the Leaf Area Index (LAI); a desire which led to the creation of the *Green Plot Ratio* metric.

Ong defined Green Plot Ratio (GnPR) as the ratio the Leaf Area Index (LAI) to the site area.[111] LAI depends on the density of leaf area in a given area of the site; so while a grassy lawn may have a Green Plot Ratio of one (ratio of leaf area to ground area is 1:1), a site with dense tree canopy as well as ground plantings would have a GnPR greater than one as the total area of leaves would exceed the ground area. Based on its use in botanical science, LAI is significant as a biological and ecological index: it reflects the metabolic potential of the vegetation including its ability to convert carbon dioxide to oxygen. Green Plot Ratio was developed by Ong specifically for transdisciplinary work, as it retained its validity in urban planning and scientific/ecological disciplines.

Green Plot Ratio was adopted as a policy tool in Singaporean urban planning in the years following Ong's proposal. After Ong submitted a competition entry to Jurong Town Corporation (JTC) for the area now known as One-North, JTC adopted the idea of GnPR for future design entries for the area.[112] In 2005 Singapore's Building Control Authority included GnPR as part of the GreenMark incentive program for sustainable buildings.[113] Starting in 2009 Singapore's Urban Redevelopment Authority (URA) introduced it's LUSH program which required new buildings in strategic areas to build new green space with GnPR equivalent to or greater than their site area. The URA also added incentives to the LUSH program by which a developer would receive Gross Floor Area exemptions or bonuses for communal sky terraces, communal ground gardens, and communal planter boxes. While the computation of landscape replacement areas depends on LAI calculation as its basis, the GFA exemptions and bonuses are calculated on the basis of surface area only using predetermined LAI factors for each vegetation type.

In their *Green Ratio*, WOHA have defined the metric differently, orienting it more to human use than ecological function. Instead of counting leaf area via LAI as Ong proposed, WOHA counts all surface area where landscapes coverage is at least 50% as contributing to the *GnPR*, thus including the

110 Ong. 2002. "Green Plot Ratio: An Ecological Measure for Architecture and Urban Planning." P.208. "4.2.1. Liuxiancun ecocity, Shenzhen, China [...] A key strategy was to incorporate skygardens—gardens incorporated into high-rise buildings above ground level. In the prototypical high-rise housing design (Fig. 4) that was proposed, the first level of accommodation was raised 3 storeys above the ground to enable light penetration into the entire ground floor. This allowed the ground floor or void deck under the building to be extensively landscaped. [...] The individual buildings achieved a GPR of about 2:1."

111 Ibid. p. 197: "Green plot ratio (GPR), is based on a common biological parameter called the leaf area index (LAI),and is defined as the single-side leaf area per unit ground area. The green plot ratio is simply the average LAI of the greenery on site and is presented as a ratio that is similar to the building plot ratio (BPR) currently in use in many cities to control maximum allowable built-up floor area in a building development."

112 Ibid. p.210.

113 Ong. 2012. "Green Plot Ratio- Past, Present & Future." p 3. "When the GreenMark was launched by the Building Control Authority in 2005, GnPR was included as part of the incentive to promote greenery in sustainable buildings (Figure 3). Points were allocated depending on the building typology and the amount of GnPR achieved."

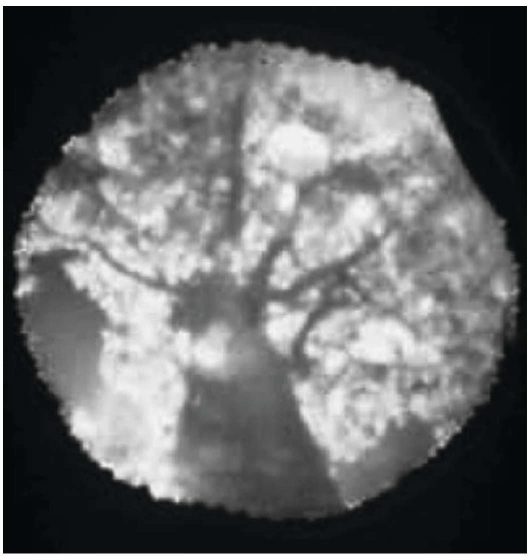
hardscape areas necessary for people to access the garden but which do not contribute to ecological function.[114] WOHA also includes water areas in their *Green Ratio* calculation, which, like hardscape areas, do not contribute to ecological function in the way leaf area does. While it diverges from the original ecological use of Ong's *Green Plot Ratio*, WOHA's *Green Ratio* produces a measurement that is reflective of the human experience of exterior landscape space on the site.

WOHA uses the *Green Ratio* not only to quantify the green open space provided in single projects but to track the trajectory of their practice as they push the limits of how much green space can be layered onto a single plot. They chart an exponentially increasing curve from the 130% Green Ratio of their Newton Suites apartment building (2007 completion), to 240% at Royal Pickering Hotel (2013 completion), to 1100% at the Oasia downtown tower.[115] While the trajectory achieved with building upper level green space in these private projects is impressive, their work with the HDB provides evidence that these spaces can also be built at levels of budget possible for public housing.

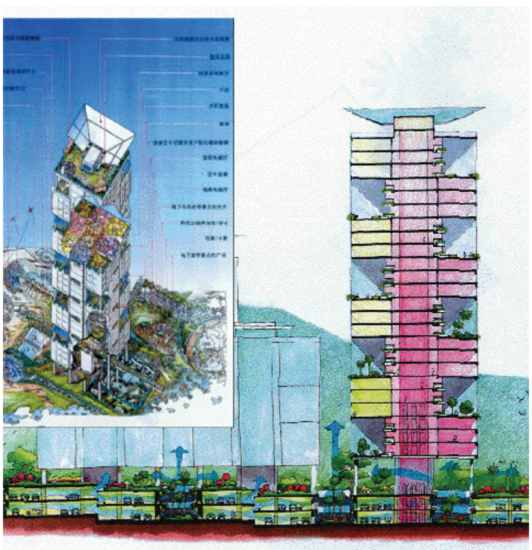
In an HDB housing development, *Dawson Skyville*, designed by WOHA in 2007 (completion 2015) the Green Ratio is 110% with planted sky gardens every eleven stories (floors 3,14,25,36 and a roof garden at level 47).(figs. 29,30 and Chapter 4 title page image) At *Kampung Admiralty* WOHA has calculated a Green Ratio of 110% as well; here distributed over upper level terraced gardens.(figs. 27,28) Green space, however, only accounts for a portion of what WOHA hopes to achieve to mitigate urban density in the tropical environment and they have developed other metrics to highlight other important density-mitigating features.

To account for upper level social space WOHA has developed the *Community Plot Ratio*, which functions like the *Green Plot Ratio* but measures instead the ratio of 'fully public areas, semi-private communal spaces, care centers, libraries, restaurants, cafes, and community centers,' to the building site.[116] While this metric is currently only used by WOHA, it would be unsurprising if a similar metric did enter Singapore planning in coming years as it does reflect the need for mitigating lost ground-level communal space.

114 Bingham-Hall and WOHA. 2016. *Garden City Mega City : Rethinking Cities for the Age of Global Warming*. p. 196
115 Ibid. p. 16
116 Ibid. p. 198



25. Hemispheric photograph used to calcuate LAI for a tree. From Ong, 2002.



26. Proposal for housing with planted skygardens, Liucian-cun Ecocity. From Ong, 2002.

Community Plot Ratio, however, is arguably over-reductive: it may encourage inaccurate comparisons between communal spaces that have subtle degrees of public and private, sharing and segregation. There is an inherent difference between upper level public space in a luxury hotel project like WOHA's *Royal Pickering,* accessible only to its clients, and that of a public housing project like *Dawson Skyville* which anyone may access. Furthermore there is, at least today, a difference between ground level open space which pedestrians may serendipitously wander into, and upper level open space like that of the *Dawson Skyville*, which may only be accessed by the more deliberate act of summoning an elevator. The metabolic function of green space, reflected in Ong's Green Plot Ratio, is valid regardless of accessibility (though there are concerns about accessibility for pollinators for example) whereas Community Plot Ratio is not a universal metric but rather a relative metric.[117] For the moment Community Plot Ratio must be understood within the context of each individual project, its program, place in the city, etc. Measures of accessibility, like urban network analysis, may in the future provide a better reflection on WOHA's stated desire to build to the city as an integrated three-dimensional matrix.[118]

WOHA, however, are sensitive to the complexity of public space and articulate about the need to do more than just reserve open floor area within high-rise housing. They raise concern about the potential isolation of high-rise living: "Due to the absence of shared community space, and the constraints of vertical circulation routes, apartment dwellers rarely even lay eyes on their neighbors." WOHA describe their designs as not only providing community spaces within the high rise, but also providing for visual and aural connections across multiple levels. While the Dawson Skyville project may provide a Community Plot Ratio of 120%, it also rotates the housing slab into a zig-zag configuration, framing a large void above each skygarden and fostering the sight lines and aural connections characteristic of a more familiar ground-level streetscape.

Thanks to the architect's thoughtful configuration of the *Skyville* building, the communal benefit of the skygarden space accrues indirectly to non-contiguous spaces via vectors of sight and sound. While the metric of *Community Plot Ratio* does act as an *indicator* of the presence of communal space in the Skyville project, it is too crude a measurement to articulate to full value (the qualities) of a coherent three-dimensional architectural design in creating upper-level community space. What if another architect with an inferior design were to offer a higher *Community Plot Ratio* at lower total cost? There is a chance that self-imposing a too-crude *key performance indicator* (KPI) sets up a process that overvalues trivial or less-important quantities while drawing attention away from the qualities of thoughtful design.

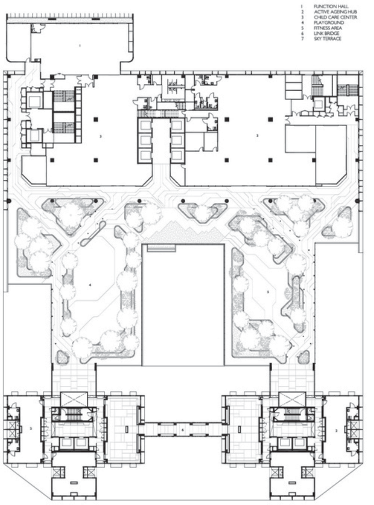
In spite of the reductivism of the individual *KPI*s they have created, WOHA's architectural approach is self-described as a holistic social/ecological/constructional effort. They describe their work as leveraging, 'aesthetics of the architecture, and the spatial usage, configuration and orientation of buildings, [...] to encourage unexpected sensory delight and spontaneous interaction within generous and overtly sociable public spaces.'[119] Metrics like green plot ratio and community plot ratio for each project are not in themselves adequate assessments or drivers for a design, but taken together

117 The Green Plot Ratio, however, has its own problems as the ecological function of 'green space' at upper levels will only persist with careful (and expensive) maintenance. Ong worries in his writings that urban plantings may be neglected without periodic inspections. See Ong. 2012. Green Plot Ratio- Past, Present & Future. p. 4.

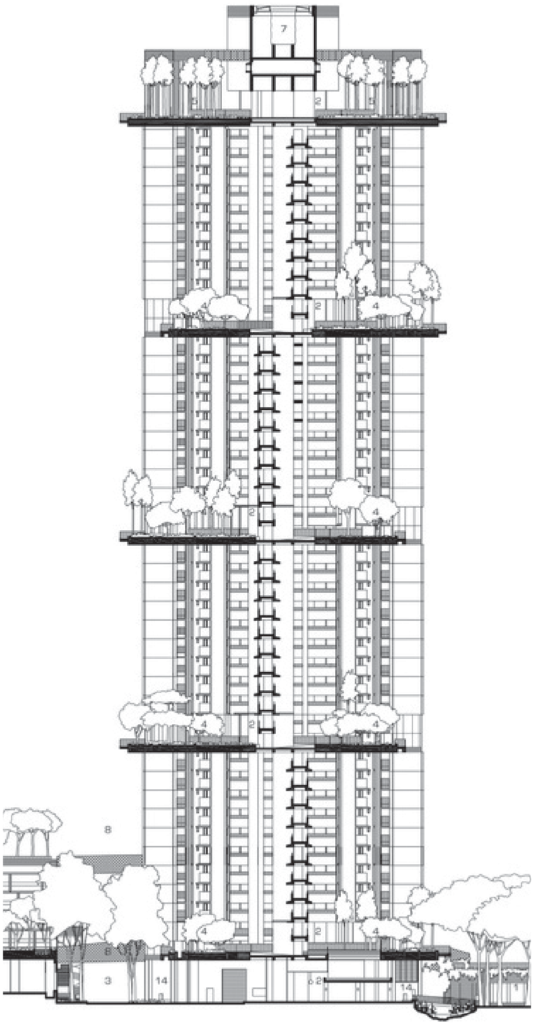
118 Bingham-Hall and WOHA. 2016. p. 292

119 Ibid. p. 46.

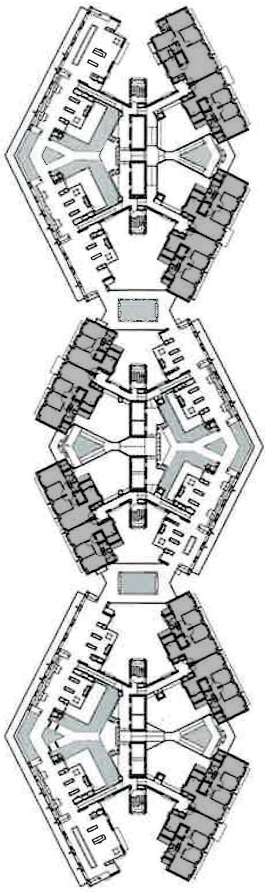
27. Kampung Admiralty aerial photograph. [WOHA]



28. Kampung Admiralty. Plan, 6th story. [WOHA]



29. Skyville. Section. [WOHA]



30. Skyville. Plan, 16th- 24th stories. [WOHA]

they offer an indication of an organically designed artifact that has both higher functions and higher aspirations. More important that the individual assessment of one building, however, is that the group of metrics makes it possible to chart continuities between projects, and conceptualize the contribution of the architectural artifacts to a larger urban whole: WOHA's *garden city mega cit*y or *lattice city*.

Singapore's URA (Urban Redevelopment Agency) already uses GnPR to track and manage the ecological contribution of green space in high-rise buildings via a regulatory program the have called LUSH (Landscaping for Urban Spaces and High-rise.) Aggregate GnPR reported for various plots in a district provides an index of its re-greening and ecological contribution. This practice has the potential to be built into an urban feedback loop: GnPR compared with metrics like air quality can to assess the benefits of urban re-greening and indicate whether to pursue higher or lower values in specific areas of the city. In this sense, the URA's map of *Green Plot Ratio* is not just an index but a planning tool for leveraging the aggregate potential of architectural elements to produce citywide ecological outcomes capable of offsetting some of the deleterious secondary effects of density.

WOHA affirms an overall vision of the city as a social/ecological system and describe their architectural designs as *prototypologies* designed to plug-in to this larger whole.[120] Their design strategy discretizes functional elements within large design assemblies which achieve specific quantitative goals for not just the building but for the larger urban system. In an architecture composed of aggregated functional elements, it is possible to achieve a higher GnPR by simply reconfiguring an existing design to include more *skygardens*. A project like the Oasia Tower with a GnPR of 1110% will make a significant impact on its district's GnPR. By employing metrics of *GnPR* and *Community Plot Ratio* as part of their design strategies, WOHA are preparing each project to function as a *prototypology* to be plugged into a larger urban system, with the potential to also be modified and plugged-in somewhere else. In the *prototypology* concept WOHA has found a connection between urban data, urban systems and architectural elements that drives their process of form-creation and impacts their aesthetic decisions.

The *prototypology* concept as developed by WOHA is inconceivable outside of the dense and land-scarce Singaporean context. Furthermore, it is strongly aligned with Singaporean quantitative planning practice as it has developed through the influence of HDB since the 1960s, with its self-reflective studies of how to configure and optimize human density. WOHA's most pragmatically persuasive prototypes emerge from collaborations with HDB, like *Dawson Skyville* and *Admiralty Kampung*, where public program, budget constraint, and civic importance have permitted the creation of buildings that are more socially and ecologically engaged that what a private developer would produce.

120 Ibid. p. 194-195. 'The strategies proposed by WOHA must be assessed within a very big picture. There is only one priority, and that is the holistic planning of the city. An individual innovation can only be deemed successful if it serves as a fundamental component of a *system* that performs better than ever before. [...] 20th century cities were planned as collections of segregated components, which were measured in terms of their economic productivity. [...] rather than their overall contribution to the city as components within a self-sufficient system. [...] In order to redirect th priorities of 20th century rationalist (de-personalized) planning, and to emphatically reinstall the notions of the 'greater good.' WOHA have created a social and ecological rating system for all city developments.'

4.5 Conclusions: density and the data assemblage

4.5.1 Evolution of HDB's management of density

A historical overview of density measurement and management at Singapore's HDB, like a time-lapse film of a growing plant, provides an image of an evolving urban system – an assemblage of many pieces- in which architecture is leveraged as a privileged instrument in breaking down and rebuilding spatial and social densities. While in recent decades this system has integrated digital tools into its processes, our time-lapse view shows us that the tools, practices, and mindset for measuring density, for building high-rise high-density estates, was firmly established in a pre-digital era by architects, planners and social scientists in an attempt to build an institution with an ability of self-reflection and self-improvement. Tools and practices for collecting data on density, and the empirical frame of mind that values their use persist today as the basis of HDB's practice. While we note that digital tools of data-driven automation are increasingly available to the planners and architects of HDB, these tools are encapsulated within a larger assemblage that, instead of surrendering agency to machinic efficiency, today more than at any time in the past values the synthetic (and difficult to quantify) contributions of innovative human designers like WOHA.

I would argue that the high-rise slab is the first and foundational element in HDB's density-management data assemblage. My time-lapse of HDB's system of density management would not begin until after 1965. True, colonial-era work like the *Singapore Improvement Ordinanc*e diagnostic survey of 1952-55 did use density measurements to assess the crowdedness of central areas slums. If we were to date the data-assemblage to this period its central matter of concern would be slum clearance and hygiene. It was not until the late sixties that Stephen Yeh and Liu Thai Ker joined HDB and began to develop reflexive tools to measure and evaluate HDB's effort to construct high-rise high-density estates. Their concern was not so much the problem of slums, but the concern of making high-rise high-density housing livable. Also, though measurements of density were taken before this time, they were not explicitly part of an iterative system of action, observation, reaction. With Liu and Yeh, data-collection is explicitly linked to responses in the modification of the built environment. In my timeline, the architectural type – the residential highrise, would exist as the initial component in the data-assemblage, and the tools and techniques of measurement and management would accrue to it.(Illustrations of this timeline can be found in Chapter 5, figs. 6,7)

A second argument for dating the beginning of the data-assemblage to 1965 is that the definitive separation from Malaysia in that year creates Singapore as *a nation without hinterland*, in which land is a precious commodity. The extreme condition of land scarcity, present in Singapore as in few other places on earth, enforces the precept that Singapore must be built at the highest possible density, a foundational paradigm for the HDB's data-assemblage. This theme is repeatedly announced in HDB's public statements of purpose. Here is Liu Thai Ker in 1975, 'To conserve scarce land resources in Singapore, HDB has been given the task of achieving as high a residential density as possible, within the limits of social acceptability, environmental amenability, and economical constraint.'[121] The work of HDB over the following 45 years could be summarized this way: maximize built density within quantitatively defined social, environmental and economic constraints.

121 Liu Thai Ker. 1975. 'Design for Better Living Conditions.' In *Public Housing in Singapore.* p. 145.

Pragmatic reductivism characterizes an initial period of the HDB data-assemblage from 1965 to around 1977. Land use is measured by land coverage, plot ratio, and density ratios like people per hectare of land, residential space per person, open space per person. Occasionally a new metric like *livable space per person* was created to better address a specific goal or concern; in this case the mitigating effect of open space on high-density living. Social datapoints were gathered via surveys of residents, to understand levels of satisfaction with elements of the physical environment. Simple pragmatic parameters were defined by the creators of these surveys to understand if residents would prefer bigger kitchens, individual bathrooms, or if they felt their neighbors were too noisy.

The result of the 1965-1977 regime of data collection and construction was a machinic architecture, pragmatically fulfilling essential biological needs at minimal cost. Designers like Liu Thai Ker, even as they systems of empirical evaluation and optimization, recognized in some way the limitations of these systems and supplemented their research with epistemically diverse material like studies of vernacular typologies. Also, in spite of HDB's emphasis on optimization of floor area and land, a handful of significant innovations emerged at this time that sacrificed efficiency to produce seemingly superfluous spaces. One such innovation was the *void deck*, an open floor at ground level used as social and commercial space, which was recognized as a valuable open/social space and achieved ubiquity in HDB housing starting in the 1970s. Unprogrammed open space like the void deck, inefficient in calculations of residential space per person, could be validated by alternative metrics like *livable space per person*.

A shift from 'quantities to qualities,' marks a second era in HDB's data-assemblage and can be dated to 1977, when the waiting list for HDB flats dropped for the first time, marking the end of the housing crisis. After this point, while metrics of land-optimization and resident satisfaction were retained as the empirical foundation of HDB's work, new concerns and empirical techniques were layered on top of this foundation to provide a higher resolution view of complex social life in HDB estates. These new empiric techniques were accompanied by a more highly differentiated and contextually-responsive architectural product. Neighborhoods were reconsidered as social groupings and not simply commercial catchment areas, a change in the system of thought which was accompanied by observation of patterns of human movement in estates, and design scenarios which produced visual orientations toward spatial centers. At the same time social life was re-examined not by as a set of clinical snap shots provided by cross-sectional surveys, but via longitudinal surveys which followed individuals over a period of time, tracing their responses to the HDB environment and allowing them to tell their own stories. In this era the data-assemblage can be seen as expanding, with new layers of practices, metrics, and systems of thought adding onto earlier layers.

Management also became an over-riding concern in the 1980s, with the population living in HDB estates exceeding two million in 1984. Managing these dense estates motivated the introduction of the first digital sensors and automated control systems for prosaic but essential services like lifts. The populations managed by HDB grew so large in this period that it became desirable from several perspectives that they split off from the agency. In 1986 Town Councils run by groups of local residents began to take over aspects of estate management from HDB.

Digitally automated systems of data-collection and response appear in this era associated with the necessity of managing very large quantities of critical communications with people and machines: these communications exceeded the abilities of human beings to manage unaided. Significantly, the process of devolving some management tasks to digital automation was paralleled by devolving some managerial authority to grass-roots committees of self-determining tenants in the Town Councils. In this case, digital automation and citizen self-determination were not oppositional processes, but rather domain specific processes each expanding to function within their own spheres.

Environmental constraints drive many recent developments at the HDB – with densities allowed to expand to much higher levels when mitigated by new environmental supports like *sky-gardens*. Data-driven simulation tools like the *UM-MIST/IEM tool* have been integrated into HDB design process and metrics like *Green Plot Ratio* have provided a more complete understanding of systemic ecological constraint and potentials. Similarly, demographic shifts toward an aging population have inspired both a typological/administrative and a social/empirical shift at HDB with new units being developed for those aging alone, and HDB-developed applications allowing care-takers to survey and care for the elderly even when they can not always be physically present. Within the expanding complexity of social and ecological concern over high-rise high-density living, the synthetic abilities of architects like WOHA to build for *livable density* has become increasingly valuable to HDB.

4.5.2 Flexibility of HDB's data-assemblage

Throughout its history HDB has remained remarkably flexible, adapting to changing demographic, social and cultural context. This flexibility is interesting from the perspective of architects because changes at HDB were often led by designers within or associated with the institution. HDB's flexibility is also relevant to the theory of *embeddedness* of social-technical ensembles. Prominent theories explored in the introduction to this thesis depict the *embeddedness* of a social-technical system accruing over time, adding increasing number of elements. The increasing in the number of elements leads, in theory, to obduracy of the social-technical ensemble, as any change impacts larger and larger numbers of elements.[122] A common example is a subway system, which once built following one system of train cars, rail gauge, tunnel width is very difficult to convert or connect to another system.

To treat the question of embeddedness first, while housing estates in general have some characteristics which make them less prone to obduracy than a subway system, it seems that there are some specific characteristics of *HDB as an institution and as a socio-technical assemblage* that have permitted it to remain flexible. A subway system must be homogeneous and continuous to function optimally: trains and people should be able to move from node to node without significant ruptures.[123] HDB's new towns, estates, buildings, and even flats, however, have been conceived not as continuous and homogeneous, but as discontinuous and heterogeneous. They form a *patchwork* urban environment.

122 Hommels. 2005. *Unbuilding Cities : Obduracy in Urban Socio-Technical Change.* p.27. "The actor-network theorists Michel Callon, Bruno Latour, Madeleine Akrich, John Law, and Annemarie Mol describe technological development as a process in which more and more social and material elements become linked in a network. They investigate attempts by actors to stabilize that network. But the larger and more intricate a network becomes, the more difficult it will be to reverse its reality. In this way, a slowly evolving order becomes irreversible.'

123 Ibid. "Latour gives a clear example of how a network become more obdurate and less reversible. He describes the late-nineteenth-century controversy between the city of Paris and a number of major private railroad companies concerning subway construction. The socialist city government was looking for a way to guarantee that the railroad companies could not take command of the subway system if a right-wing party were to win the city elections in the future. It found a solution in having subway tunnels built that were narrower than the railway companies smallest coaches. As the subway network expanded its design became less and less reversible. Th obduracy of the subway network became obvious when after 70 years the railroad companies and the subway companies wanted to link their networks. The engineers who were hired to enlarge a number of tunnels were essentially asked to undo what had been decided earlier.'

High-rise housing blocks, built of steel and concrete, are for obvious reasons relatively obdurate. They are expensive and slow to build, and expensive and slow to demolish. However, HDB blocks are continuously adapted over time and complete demolition is relatively rare. With continuous small upgrades over time (new paint jobs, new entry porticos, new lifts) it can be difficult to visually identify the precise build date of an HDB block. Within blocks, one bedrooms flats have been combined to create larger flats when market forces pointed in that direction. This is without mentioning the extensive modifications that residents make within their own units. Historic HDB buildings are themselves patchworks of interchanged or modified elements.

HDB New Towns and Estates, even more than HDB buildings, are built as patchworks. Part of this is the checkerboard principle of HDB urban design, which juxtaposes different types of development on alternate parcels: point blocks, juxtaposed with slabs, juxtaposed with sports facilities, etc. Adding to the sense of patchwork urbanism is the periodic replacement of older blocks through HDB programs like Selective En-Block Replacement Scheme (SERS). HDB also deliberately holds some plots of land in reserve, deliberately unbuilt, as a resource to meet un-anticipated future needs. The result is a patchwork fabric, where new and old exist side by side and are sometimes difficult to distinguish form one another. What is lost in homogeneity, is compensated for in flexibility – there is no reason that a new generation HDB block can not exist side by side with an older generation block or function just as well.

The most significant contribution to the flexibility of HDB's work, however, has been its iterative and self-reflexive methodology. Even when there was a great push for standardization of unit types and construction technique, HDB units, blocks, neighborhoods, estates and new towns have been grouped generationally, with each subsequent generation expected to change and improve relative to its predecessors. Though iterative evolution makes flexibility possible, the HDB's history suggests that the leadership and innovation of a few individuals (often designers) at key turning points was crucial in making meaningful change .

Significant instances that we have described in this study include Liu Thai Ker's reorientation of HDB from 'quantities to qualities' after 1977 which made room for efforts by Chief Architect Tony Tan Keng Joo and his colleagues to push for *neighborhoods of community* and *placemaking*. This reorientation also made possible the sociological work of Chua Beng Huat exploring the stories of resettled HDB residents. Recently CEO Cheong Koon Hean has focused on demographic change to re-orient HDB, a change which has brought to the fore innovations by the architects at WOHA on *Kampung Admiralty* and *Dawson Skyville*.

Contemporary innovations at HDB have tended to promote higher and denser residential developments like Dawson Skyville. For this reason, one might ask if a reorientation of the data-assemblage has really happened or if a high-density high-rise paradigm has only been reinforced, essentially demonstrating an obdurate system of thought and practice creating more extreme adaptations of the same residential high-rise concept. This interpretation, however, would be problematized by much of the design work taken on HDB in the late 1980s and 1990s when deliberately smaller scale developments were introduced at the center of precincts to aid with visual identification and produce human scale developments. The cluster of four-story town houses at the center of Potong Pasir, visually connected to the larger housing blocks by their dramatically sloping roofs provide an instance of density experimentation at the service of place-making very different from what was produced in the 1960s at Toa Payoh or has been built in recent years at Punggol.

HDB's public housing, in spite of being a very large social-technical assemblage, has retained a degree of flexibility largely due to institutional process of iteratively-improved design practice, patchwork urbanism, and built form based on aggregation of discrete elements open to modification or replacement.

4.5.3 Built Form: data and typological change

Data-collection and built form have evolved in tandem at HDB since the 1960s. This process has been a collaboration between designers like Liu Thai Ker and social scientists like Stephen Yeh. Together they have created a system of built form that is heavily standardized (all 2-room units have the same square footage) and thus amenable to quantitative survey. More importantly they have collaborated to create parametrized form, and surveys that directly interrogate these parameters. The alignment of formal parameters and survey data-points has allowed built form to respond systematically to survey results. Iterations of new built form and surveys have provided a means of assessing the success of a given formal change. Standardization and parametrization represent the two most significant hand-holds of the data-assemblage in HDB's built form.

The reality of HDB's parametrized built form is pragmatic and prosaic. Some of the clearest examples of formal change driven by empirical results have been the separation of bath and toilet rooms and the expansion of the kitchen in HDB apartments of the late 1960s. More recently, the relationship between Singapore's demographic shift to an aging population and the creation of the new 2-Room Flexi Unit represents a looser form of alignment between social data and architectural form.

Standardization and parametrization occur at all scales of HDB's urbanism. Stephen Yeh's *Sample Household Surveys* starting in the late sixties interrogated block height, and contributed to a standardization of the 12 story building height for HDB housing blocks. (Excluding point blocks.) The evolution of HDB's corridor spaces was equally standardized and interrogated for its social impacts (as well as cross ventilation.) Liu Thai Ker often cites the *segmented* corridor as one of his major innovations at HDB, where groupings of four to eight families around a corridor segment would give children a safer place to play and foster intimacy among neighbors.[124]

The precinct, at a scale between neighborhood and town, is another HDB creation where we have seen co-evolution between built form and data-gathering practices. In its earliest iterations in the 1970s the precinct was sized to match the required catchment area of a commercial center and was very large (6,700 apartments). In the 1980s this concept was refined with studies of visual connection to a central space, pedestrian *channeling*, and *placemaking* via distinctive architectural elements like gates. In the precinct we see an idea initially controlled by a single quantitative criterion, which is then reworked with more careful thought about social use and more sensitive metrics (like flow.) The result of these changes in mindset and measurement practices is most dramatically reflected in the 1985 proposal to decrease the size of the HDB precinct to between 400 and 800 apartments.[125]

124 Liu describes the groupings of four to eight families along a corridor segment (as opposed to twenty or thirty) as, 'small villages [...] in the sky.' See Liu Thai Ker. Oral History. 001732/29/17

125 Tan Keng Joo, Tony. et al. 1985. "Physical Planning and Design." in *Housing a Nation* p. 91.

Though HDB's designs are heavily standardized in terms of unit types, construction technique, block height, and precinct size, at certain scales of architectural form a degree of freedom was carved out for designers to work more creatively with(in) these standards. The layout of the linear housing block, in particular, became the site of much creativity in the 1980s. Though HDB blocks of the 1960s were laid out exclusively according to solar orientation, by the 1980s this stringent orientation was deemed inefficient and not conducive to *placemaking*. In the estates of the 1980s we see the block wrapped around central spaces or following site contours.(See figs. 18-20) With these more freely deployed blocks we see architectural artifacts that act as *frameworks*, gathering together standardized units and equipment (like lifts and waters tanks) and working interpretatively between groupings of these elements and the constraints of the site to create architectural wholes. These *frameworks* sometimes recall the work of Structuralist or Metabolist architects of the 1960s and 1970s. The relationship to megastructure is made explicit in the present day with the mega HDB projects of WOHA (*Skyville* and *Kampung Admiralty*), who refer to their projects as *domesticated megastructures*.[126] (figs. 27-30)

126 Bingham-Hall and WOHA. 2016. p. 76

References

Books and Journal Articles:

"EDITORIAL." Ekistics, vol. 7, no. 41, 1959, pp. 205–206.

"SPECIAL ARTICLES: Singapore Improvement Trust. Master Plan Reports." Tropical Housing & Planning Monthly Bulletin, vol. 1, no. 8, 1956, pp. 16–27.

Bingham-Hall, Patrick and WOHA. 2016. *Garden City Mega City : Rethinking Cities for the Age of Global Warming.* First edition. Singapore Pesaro Publishing.

Campbell, William. "SINGAPORE PREPARES FOR A POPULATION OF 3.5 MILLION." Ekistics, vol. 30, no. 176, 1970, pp. 49–53.

Cheong, Koon Kean. 2018. "Nation-building, Singapore-style: Better Living Through Density." In Council on Tall Buildings and Urban Habitat Journal. No. 1. Chicago, IL. pp.54-56

Chua, Beng Huat. Political Legitimacy and Housing : Stakeholding in Singapore. London ; New York: Routledge, 1997.

Fraser, J. M. "THE WORK OF THE SINGAPORE IMPROVEMENT TRUST." Ekistics, vol. 4, no. 25, 1957, pp. 37–38.

Fernandez, Warren. 2011. *Our Homes : 50 Years of Housing a Nation.* Singapore : Published for the Housing and Development Board by Straits Times Press.

Great Britain, Department of Scientific and Industrial Research. "HOUSING AND PLANNING IN SINGAPORE, 1957." Ekistics, vol. 7, no. 41, 1959, pp. 212–217.

Hassan, Riaz. "Social Status and Bureaucratic Relationships among the Public Housing Tenants in Singapore." Ekistics, vol. 33, no. 196, 1972, pp. 178–181.

Hassan, Riaz. "Social and Psychological Implications of High Density in Hong Kong and Singapore." Ekistics, vol. 39, no. 235, 1975, pp. 382–386.

Hillier, Bill, and Julienne Hanson. 1984. *The Social Logic of Space.* Repr. Cambridge: Cambridge : Cambridge University Press.

Hommels, Anique. 2005. *Unbuilding Cities : Obduracy in Urban Socio-Technical Change.* Cambridge, Massachusetts: MIT Press.

Ker, Liu Thai. 1975. "Design for Better Living Conditions in Singapore Flats." *Ekistics*, vol. 40, no. 238, pp. 199–204.

Ker, Liu Thai. "Reflections on Problems and Prospects in the Second Decade of Singapore's Public Housing." Ekistics, vol. 38, no. 224, 1974, pp. 42–46.

Koh, Kim Chay, Ong, Eugene, Tay, Eddie, Seng, Eunice, and Balasingamchow, Yu-Mei. *Singapore's Vanished Public Housing Estates.* Second ed. 2017.

Koolhaas, Rem. “Singapore Songlines: Portrait of a Potemkin Metropolis … or Thirty Years of Tabula Rasa.” In S,M,L,XL : Small, Medium, Large, Extra-large. Ed. Koolhaas, Rem, and Mau, Bruce. New York: Monacelli, 1995. p.1008-1087

Lee, Christopher Chee Meng. “Dominant Type and the Developmental City State.” In The Fourth Typology; Dominant Type and the Idea of the City. Lee, Christopher. Doctoral Disseration, TU Delft. 2012.

Lim, William. “Shopping Centers, Singapore.” Ekistics, vol. 37, no. 219, 1974, pp. 114–115.

Lim, William S.W. “Tall Buildings for Urban Centers in Third World Countries.” Ekistics, vol. 40, no. 238, 1975, pp. 196–198.

Lim, William Siew Wai. “Public Housing and Community Development in Singapore.” Ekistics, vol. 51, no. 307, 1984, pp. 319–327.

Loh, Kah Seng. Squatters into Citizens : The 1961 Bukit Ho Swee Fire and the Making of Modern Singapore. 2013. Southeast Asia Publications Ser.

Lynch, Kevin. 1962. *Site Planning*. Cambridge- Mass: Cambridge- Mass. : M.I.T. Press.

Meier, Richard L. 1956. *Science and Economic Development : New Patterns of Living.* New York: New York : Wiley.

Ooi, Giok Ling. 1992. “Managing Change and Continuity in the Public Housing Process in Singapore.” Ekistics, vol. 59, no. 354/355. pp. 170–179.

Ooi, Giok Ling., Siddique, Sharon, and Soh, Kay Cheng. 1993. *The Management of Ethnic Relations in Public Housing Estates.* Singapore: Institute of Policy Studies : Times Academic.

Ooi, Giok Ling., Kwok, Kenson, and Institute of Policy Studies. 1997. *City & the State : Singapore’s Built Environment Revisited.* Singapore : Melbourne [Australia] : New Zealand: Institute of Policy Studies ; Oxford UP.

Ong, Boon Lay. 2002. “Green Plot Ratio: An Ecological Measure for Architecture and Urban Planning.” Landscape and Urban Planning 63 (4): 197–211.

Ong, Boon, A Ho, and Kim Ho. 2012. “Green Plot Ratio- Past, Present & Future.” In Tropics 2050. Singapore: National University Singapore.

Siew Eng, Teo, and Lily Kong. “Public Housing in Singapore: Interpreting ‘Quality’ in the 1990s.” Urban Studies 34.3 (1997): 441-52.

The Singapore Housing and Development Board. “HOMES FOR THE PEOPLE: A REVIEW OF PUBLIC HOUSING IN SINGAPORE.” Ekistics, vol. 21, no. 124, 1966, pp. 201–207.

Wong, Aline K., Yeh, Stephen H. K, and Singapore. Housing Development Board. Housing a Nation : 25 Years of Public Housing in Singapore. Singapore]: Published by Maruzen Asia for Housing & Development Board, 1985.

Yeh, Stephen H. K. “Some Trends and Prospects in Singapore’s Public Housing.” Ekistics, vol. 33, no. 196, 1972, pp. 182–185.

Yeh, Stephen H.K., and Statistics and Research Department, Housing and Development Board. “Homes for the People.” Ekistics, vol. 38, no. 224, 1974, pp. 35–41.

Yeh, S. H. K. *Public Housing in Singapore - a Multi-Disciplinary Study.* Singapore: Singapore UP, 1975.

Yuen, Belinda, et al. “High-Rise Living in Singapore Public Housing.” *Urban Studies*, vol. 43, no. 3, 2006, pp. 583–600.

Government/ Institutional Documents:

Govtech. Leading Digital Government Transformation: Annual Report 2017/2018. Singapore, 2018.

Govtech. Smart Nation: Improving Lives, Supporting Businesses. Annual Report 2016/17. Singapore, 2017.

Housing & Development Board. HDB Annual Report 1988/1989. Singapore, Dec. 1989.

Housing & Development Board. HDB Annual Report 1992/1993. Singapore, Dec. 1993.

Housing & Development Board. HDB Annual Report 1993/1994. Singapore, Dec. 1994.

Housing & Development Board. HDB Annual Report 1994/1995. Singapore, Dec. 1995.

Housing & Development Board. HDB Annual Report 2012/2013. Singapore, Sep. 2013.

Housing & Development Board. 2014. HDB Annual Report 2013/2014. Singapore, Oct. 2014.

Housing & Development Board. 2014. “Smart HDB Town Framework.” Press Release. 11 Sep 2014. Singapore. Available online https://www20.hdb.gov.sg/ fi10/fi10296p.nsf/PressReleases/ F93B15F80588397748257D500009CE6C (accessed 10 April 2019)

Housing & Development Board. PUBLIC HOUSING IN SINGAPORE: Residents’ Profile, Housing Satisfaction and Preferences. HDB Sample Household Survey 2013. Singapore, Dec. 2014.

Housing & Development Board. Public Housing in Singapore: Social Well-Being of HDB Communities HDB Sample Household Survey 2013. Singapore, Dec. 2014.

Infocomm Development Authority. Shaping a Smart Nation: Annual Report of the Infocomm Development Authority of Singapore 2013/2014. Singapore, Sept. 2014.

Infocomm Development Authority. Towards A Smart Nation: We Build, We Govern, We Deliver. Annual Report 2014/15. Singapore, 2015.

Infocomm Development Authority. Better Lives, More Opportunities, Stronger Communities: A Smart Nation Together. Annual Report 2015/16. Singapore, 2016.

Institute of High Performance Computing. 2016. “Modeling of Urban Heat Island and Noise Propagation in Singapore.” In Powering Discoveries! vol.9 no.2 Singapore, ASTAR.

National Population and Talent Division, Prime Minister's Office. 2013. «A Sustainable Population for a Dynamic Singapore: Population White Paper." Singapore, Oxford Graphic Printers Pte Ltd.

Urban Redevelopment Authority. 2017. An Overview of the Lush Programme: Annex A. Singapore, URA Circular No : URA/PB/2017/06-DCG.

Popular Press:

Heng, Janice. "Look Ahead to 10 Million People by 2100?" *The Straits Times*, April 28, 2013.

"On the Record: Liu Thai Ker, Architect and Former Master Planner of Singapore." Channel NewsAsia. Online. https://www.channelnewsasia.com/news/singapore/on-the-record-liu-thai-ker-architect-and-former-master-planner-9285942. (accessed 7 February 2019.)

Websites:

HDB, My Smart HDB Home@Yuhua. https://www.hdb.gov.sg/cs/infoweb/about-us/our-role/smart-and-sustainable-living/smart-hdb-town-page/hdb-smart-home-exhibition

Lectures/Oral Histories:

Cheong, Koon Kean. 2018. "Lecture I: What Makes A City Successful? Lessons from Inspiring Cities." Lecture, IPS-Nathan Lecture Series, National University of Singapore. 10 April 2018. In Cheong, Koon Hean. 2018. Seeking a Better Urban Future. IPS-Nathan Lecture Series. WORLD SCIENTIFIC. https://doi.org/10.1142/11246.

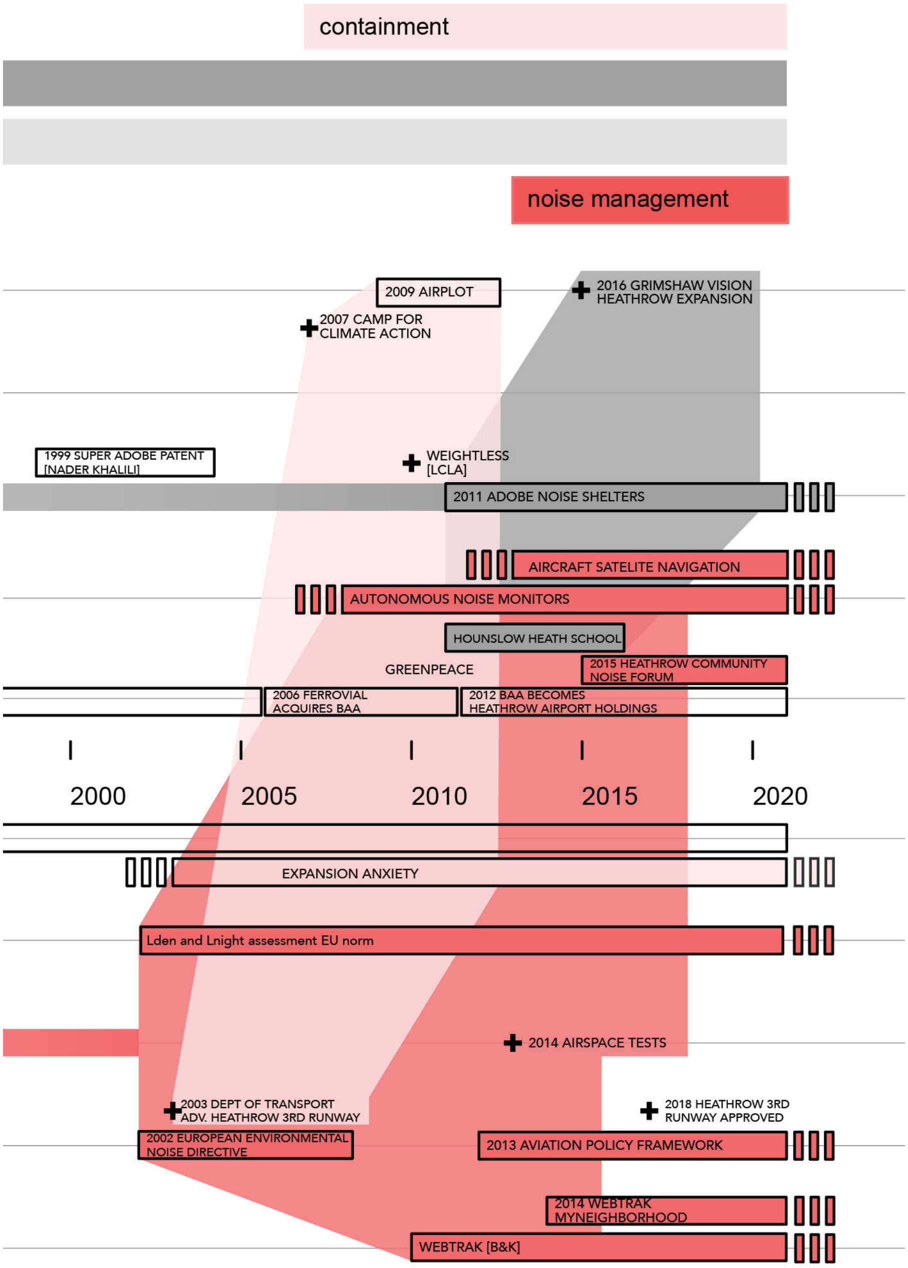
Cheong, Koon Kean. 2018. "Lecture II: Anticipating our urban future, trends, threats and transformation." Lecture, IPS-Nathan Lecture Series, National University of Singapore. 10 April 2018. In Cheong, Koon Hean. 2018. Seeking a Better Urban Future. IPS-Nathan Lecture Series. WORLD SCIENTIFIC. https://doi.org/10.1142/11246.

Cheong, Koon Kean. 2018. "Lecture III: Shaping The Future of Heartland Living" Lecture, IPS-Nathan Lecture Series, National University of Singapore. 10 April 2018. In Cheong, Koon Hean. 2018. Seeking a Better Urban Future. IPS-Nathan Lecture Series. WORLD SCIENTIFIC. https://doi.org/10.1142/11246.

Choe, Alan Fook Cheong. 1997. "Oral History." Singapore National Archives. Reel 7 Accn No. 001891/18 Available online http://www.nas.gov.sg/archivesonline/oral_history_interviews/record-details/e93e5d87-115f-11e3-83d5-0050568939ad (accessed 10 April 2019)

Ker, Liu Thai. 1996. "Oral History." Singapore National Archives. Reel 11 of 29 Accn No. 001732 Available online http://www.nas.gov.sg/archivesonline/oral_history_interviews/record-details/e93e5d87-115f-11e3-83d5-0050568939ad (accessed 10 April 2019)

Tay, Yi Wen (Executive Planner Urban Redevelopment Authority) and Goh Chin Chin. 2017. "A LUSH and Resilient City | LUSH 3.0." Lecture, PLENARY SESSION I: VERTICAL RESILIENCE, 2017 International Skyrise Greenery Conference. Singapore.



Data-genealogy tree of case-study 01: Heathrow Noise Landscape

5 Results, Discussion and Conclusions

In this chapter I review the results of my case studies relative to my research questions. In a first section I describe a new analytic tool, the data-genealogy tree, which builds off the data-assemblage but permits a time-based reading of architecture's role in this context. Using the data-genealogy tree I compare the three case studies extracting some over-arching insights, but also setting the table for the analysis in the two subsequent sections. In a second section I examine the impact of architectural interventions within the data-assemblage and data-genealogy. Relative to the possible obduracy of an embedded socio-technical assemblage, I interrogate the intended impacts of designers in the case studies and consider the results of their actions. In a third section, I examine formal changes in the built environment that are associated with the evolution of the data-genealogy. Finally in 5.4 I return to the idea of data itself as a product of design, and consider what my case studies may bring to this idea and what this may suggest for the practice of architecture in the data-driven city.

5.1 Results: architecture's accretion to the data-assemblage

Research Question 1: ***If architect and architectural artifact participate in an urban data-assemblage, what position do they take, what connections do they make, and what roles do they play?***

In response to my first research question, one of the primary results of my case study research has been to apply the data-assemblage model to each case study and work from the evidence I have gathered to define when each element entered the assemblage, what other elements it interacted with and what role it played.[1] Elements of the built environment and their authors have been the particular focus of this research.

My analysis of the case studies has led me to develop the data-genealogy tree, a method of describing the co-production of cultural and technological elements in the data-assemblage over time.[2] I will describe the data-genealogy tree as I have developed it and the ways it builds on and diverges from the data-assemblage model proposed by Rob Kitchin.

1 For explanation of the data-assemblage see section 1.1.2. See also: Kitchin. 2014. *The Data Revolution.* pp. 24-26.

2 In part this is inspired by Kitchin's discussion of the importance of genealogy in the study of the data-assemblage. See Kitchin. 2014. *The Data Revolution.* p.189.

With the data-genealogy tree I describe a paradigmatic concept of how a data-assemblage tends to evolve over time toward greater embeddedness.(fig. 1) Subsequently I review data-genealogy trees for each case study.(figs. 3-10) These trees describe the many ways in which the case study histories diverge from a linear model of growing embeddedness. Reorientations of the data-genealogy reflect changing motivations and the appearance of new technologies. They are of use later in establishing a basis to evaluate possible impacts of architect and/or architectural artifact in the reorientation of the data-assemblage. Finally I consider the value of the data-genealogy tree as analytic model for architecture's role in the contemporary city, relative to traditional architectural history, and relative to conventional ideas of architectural practice.

5.1.1 The data-genealogy tree

In the introduction to this thesis I announced the data-assemblage, as formulated by Rob Kitchin, as a primary tool for my analysis of the case studies. While the data-assemblage concept remains central to my research method, in order to extract over-arching understanding from my case studies I have developed a new conceptual tool – the data-genealogy tree. The data-genealogy tree builds off the analytic grid of the data-assemblage but goes further by charting over time the patterns of growing connectivity between technical and social elements which work in concert to produce data and leverage it to manage and change the city. *If the data-assemblage is a snapshot, then the data-genealogy tree is a film.*

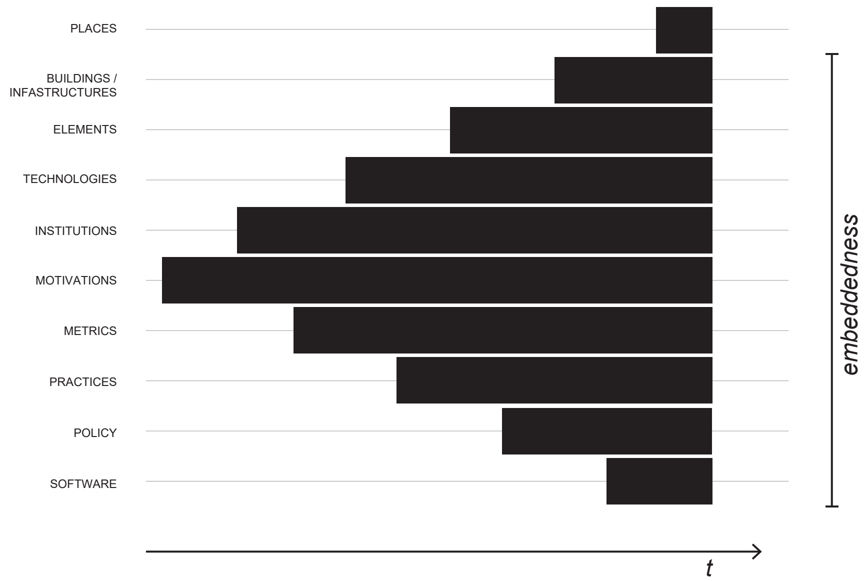
At the center of the data-genealogy tree is a timeline which runs from left to right and is regularly demarcated.(figs. 1, 3-10) Relative to this timeline I chart the occurrence of punctual events (represented by crosses) or the appearance of elements or conditions (as rectangular bars with defined durations.) Along the vertical axis of the data-genealogy tree I have defined a series of categories, based in part on the data-assemblage, across which the punctual events, elements and conditions are charted.

The central category in the data-genealogy tree is a human social or political motivation. I have deliberately made this choice to highlight perhaps the most important provocation of critical data-studies: that data, ' are never simply neutral, objective, independent, raw representations of the world but are situated, contingent, relational, contextual, and do active work in the world."[3] In the case studies I have chosen, the central motivation is disputed or unstable, reflecting Latour's description of a matter of concern: "highly uncertain and loudly disputed, these real, objective, atypical and, above all, interesting agencies are taken not exactly as object but rather as gatherings."[4] While the data-assemblage offers a less-hierarchical, more-balanced analytic grid; with the data-genealogy tree I have intentionally placed human motivations, and their controversies, at the center as the progenitor of the time-line.

While the progenitor in a genealogical tree disappears after giving rise to its successor, socio-technical systems tend to preserve elements which accrete into larger and more embedded networks. (See section 1.4.5) The motivation at the center of the data-genealogy tree persists over time and evolves in concert with other elements as they appear. This unstable core of the data-genealogy helps to account for evolutionary shifts in the larger data-assemblage.

3 Kitchin and Lauriault. 2018. 'Toward Critical Data Studies.'.
4 Latour. 2005. *Reassembling the Social.* p.114

Along the vertical axis on the left hand side of the genealogical tree I list ten categories. These categories were originally drawn from Kitchin's data-assemblage (he calls them *apparatuses*) although I have made substantial modifications which I describe in detail below. The categories are arranged so that below the central motivations are immaterial elements (metrics/ practices/ policy/ software) and above are material elements (institutions/ infrastructures/ elements/ buildings, infrastructures/ places). This division between top and bottom corresponds roughly to Kitchin's division of the data-assemblage into two stacks: process/tasks on one side and contexts on the other. (see Chapter 1 fig. 14)



1. Diagram of a paradigmatic data-genealogy tree, growing toward greater ***embeddedness*** over time

Kitchin's data-assemblage and the data-genealogy tree

Rob Kitchin's data-assemblage concept has been crucial in forming my understanding of the data-driven city. In this section I review the differences between the apparatuses of Kitchin's data-assemblage and the categories I have used in the data-genealogy tree.

Kitchin describes a data-assemblage as having 11 apparatuses – in the data-genealogy tree I have proposed ten categories that are derived from Kitchin's apparatuses but better articulate the scope, concerns and results of my research.

Motivation, or matter of concern, is of central importance for my research but is reflected only in Kitchin's 'Systems of Thought' apparatus where there is a clear divergence between the, 'Modes of thinking, philosophies, theories, models, ideologies, rationalities,' which Kitchin emphasizes as an epistemological basis for the data-assemblage, and the matter of concern that I emphasize as a motivating controversy driving data acquisition and analysis.[5]

5 Kitchin. 2014. *The Data Revolution.* p. 25, Table 1.3. The idea of a matter of concern comes in part from: Latour. 2005. *Reassembling the Social.* pp.114

Institutions and *Policy*, which have occupied much of my attention in the case studies, correspond to Kitchin's 'Organizations and Institutions' and 'Political Economy' apparatuses respectively. One exception would be Kitchin's inclusion of public and political opinion under the apparatus of 'Political Economy', which I would place under the category ***Motivation***.

Practices have been central to my research and also form a central element in Kitchin's model of the data-assemblage. One significant divergence between Kitchin's 'Practices' apparatus and my own category is over *Metrics*, which in my research is important enough to warrant its own category, and for Kitchin falls as a sub-element under the 'Practices' apparatus.

Three of the categories that I use help me to address my research object and are not part of Kitchin's model of the data-assemblage: ***elements***, ***buildings/infrastructures***, and ***places*** are all reflections of my concern for architecture and urban space. While Kitchin does include 'Materialities and Infrastructures', 'Subjectivities and Communities' and 'Places' as apparatuses in his data-assemblage, these are oriented toward contemporary patterns of data production and not to the production of space or built form as a result of data-driven process.

The final category I include in the data-genealogy tree is ***software***, which pragmatically allows me to track when a data-gathering process becomes digitally automated. Kitchin includes software in the process/task stack of the data-assemblage diagram (see Chapter 1 fig. 14). I have also included under the category of software online interactive interfaces that permit data-visualization or general data access (like Heathrow's webTrak website, or the Rijkswaterstaat's overstroomik.nl). Kitchin separates interfaces and code platforms from software in the diagram cited above, a distinction that I appreciate, but that seemed over-specific for my purposes.

The final apparatuses in Kitchin's data-assemblage are 'Finance', 'Governmentalities and Legalities', and 'Marketplace'. Finance and data marketplaces I will admit are likely under-represented in my research. In an effort to maintain thematic coherence, and limit the scope of my research I have under-emphasized some interesting examples of marketplaces like the autarkic energy-sharing grid developed for de Ceuvel and Schoonschip in the Buiksloterham of Amsterdam and briefly mentioned in Chapter 3. 'Governmentalities and Legalities' for Kitchin include data-standards and protocols, which I have included under *Practices*, while other sub-elements like file formats and intellectual property regimes exceed the scope of my research.

To chart the growing embeddedness of the data-genealogy tree over time I have attempted to arrange the categories/apparatuses of the data-assemblage in such a way along the vertical axis that a funnel-like shape would appear as the elements are mapped out over time. The growing width of this funnel would signal the increasing embeddedness of the data-assemblage. Diagram 1 depicts paradigmatically how this would work in a simple case. (fig. 1) The funnel shape depicted in diagram 1 is highly generalized, and only small portions of the case-study histories produce this form when charted with data-genealogy trees. The first five years of the Heathrow case study, for example, produce a funnel-like shape which is visible in figures 3 and 4.

The paradigmatic progression of the data-genealogy tree toward greater embeddedness, as I have observed it in my case studies, can be described by eight steps. Even as I describe these steps, I emphasize that I do not propose a rigid teleological model for the development of a data-assemblage, but rather a generalized paradigm which functions as a foil against which I will highlight significant deviations.

(1) An urban/ environmental problem (a *motivation*) initiates the formation of a data-assemblage. In Heathrow this problem is aviation noise, in particular the noise created by large jets like the Boeing 707 that appeared in the 1958. In Amsterdam, the problem of water level management is ancient, but acquired particular definition after the mid 17th century when an outbreak of plague motivated efforts to regularly and methodically flush the canals. In Singapore, density emerged as a concern parallel with colonial slum-clearance and slum improvement efforts.

(2) *Metrics* and *practices* of measurement emerge as means of assessing the matter of concern; benchmarks, scales, and key thresholds are established. These represent the basis for the collection of data; empirical measurements recorded in a way that permits wider sharing and understanding. At Heathrow the Wilson Report established the Noise and Number Index, in Amsterdam Johannes Hudde established the water-level datum, the *stadspeil*, and in Singapore colonial era measurements of people per acre were taken as part of a Diagnostic Survey performed by the Singapore Improvement Ordinance between 1952 and 1955.[6]

(3) *Institutions* are formed to guide the process of creating a new metric and collecting data. While institutions which establish the initial standards for data collection tend to be temporary (like the Wilson Committee), institutions which collect data may be established on a more permanent basis – like Amsterdam's Stadswaterkantoor which collected data for more than a hundred years from its position at Nieuwmarkt.[7]

4) Visualizations of the newly collected data re-present the initial problem. At Heathrow the Wilson Report established the convention of noise contours depicting concentric zones of noise increasing toward the airport runways. In Amsterdam the establishment of the water level datum permitted the creation of land elevation maps relative to the water system.[8] Singapore's HDB combined charts of density metrics with urban plans of their respective study areas, studying the benefits or downsides of different urban configurations and architectural types.[9]

(5) *Policy* builds off knowledge derived from new sets of data. At Heathrow after the 1963 Wilson Committee Report on Noise recommended subsidized noise insulation for residents in certain noise contours, the 1965 Airports Authority Act provided for 'grants towards the cost of sound-proofing buildings.'[10] In Singapore, the colonial era assessment of housing and overcrowding led to the establishment of the goal of constructing 10,000 dwelling units per year[11], subsequently adopted by the HDB. In Amsterdam assessment of climate change's probable impacts led to the new Delta Program.[12]

(6) Building off policy prescriptions, the built environment (*elements, buildings/infrastructures*) is engaged as a tool in mitigating the motivating urban problem. The deployment of architectural elements is in turn monitored, evaluated, and modulated by a regulating agency (like Singapore's HDB) or subsequent policy adjustment (like the UK's 2013 Aviation Policy Framework).[13] At Heathrow building insulation, insulated windows, mechanical ventilators are all employed to lessen the impact

6 See sections 2.2.1, 3.2.4, and 4.2.1 respectively.
7 See 3.2.4
8 See 3.2.3, 3.2.6. See also: Hooimeijer. 2014. *The Making of Polder Cities.*
9 See 4.2.3.
10 Parliament. 1971. Civil Aviation Act 1971. London, Her Majesty's Stationery Office. p. 26
11 Singapore Improvement Trust. "Master plan reports," *Tropical Housing & Planning Monthly Bulletin*, Vol. 1, No. 8 ([May 31, 1956]) p.18
12 Deltacommissie 2008. Working Together with Water: A Living Land Builds for its Future. Ed. Secretariat Delta Committee. Nov. 2008 (translation: Priestnall, I & van Otterloo, S.) p.21
13 See 2.3

of aviation noise on residents. In Amsterdam, water retaining features like green roofs are deployed in an effort to better retain rain water at an urban scale. In Singapore people living in overcrowded slums were resettled by HDB in standardized apartments in high-rise housing blocks at controlled, predetermined densities.

(7) Digital technologies for urban sensing and for sharing urban data (*software*) are integrated into and provoke reorganization of the assemblage. Due to the time frames I have chosen this occurs late in each of the case studies. Case studies beginning in the present day would likely evolve in a different manner. In each case study new digital tools build on top of existing metrics and policy frameworks, while permitting accelerated assessment and response. These technologies broaden the diffusion of information, and increase the fidelity of monitoring, and may also change the way the built environment is instrumentalized within the data-assemblage.

(8) *Places* in the city are formed or reformed in relation to the data-assemblage. As new spatial information in the form of data-visualization and mapping is disseminated among the city's resident's communal perception of the described spaces changes. A noise contour map, for example, modifies the way an individual living near Heathrow thinks of his neighborhood. In this way the data-assemblage can change perception of places, and even call into existence places that previously did not exist.[14] If we accept that places exist in the minds of the city's inhabitants, and not just as a physically demarcated spaces, then we understand that this effect of data and data-visualization on places can be profound.

The linear progression suggested above, though it reflects portions of each case study, is belied by the broader view afforded by the data-genealogy trees I have drawn for each case. The data-genealogy tree depicts not a monolithic data-assemblage growing regularly in embeddedness over time, but rather *clusterings of events and elements* which emerge, persist, and are then partially overwritten by new clusters. In the data-genealogy tree I have graphically marked these clusters with a colored overlay and given each a title which is shown in a color-coded key above the diagram. (See figs. 3-10) The heterogeneity of this visualization reflects the heterogeneity of the case studies, where I have noted political, cultural and technological changes producing impacts on the data-assemblage. The appearance of a new cluster is also of particular relevance to my research questions, as architect and architectural artifact may play roles in the appearance of new clusters

The clusters depicted in the data-genealogy tree reflect, of course, real-world events like the first flight of a B707 from Heathrow, but also the pattern of my own attention as I searched through my sources and curated the narrative of each case-study. The purpose of the data-genealogy tree is neither to provide a perfectly objective description of the data-driven city, nor to demonstrate with scientific rigor the presence or progression of embeddedness in a socio-technical system. It is, in contrast, a tool which permits the analyzer to chart out and compare the historical co-production of socio-cultural movements (architecture culture specifically in my case) and technological systems (the process and infrastructures of data-driven urbanism). Here I would like to recall the words of architectural historian Charles Jencks: "All history writing is selective and based on theories of what really matters, and there is no way around this limitation. But there are ways to compensate for perspectival distortion [...]"[15]

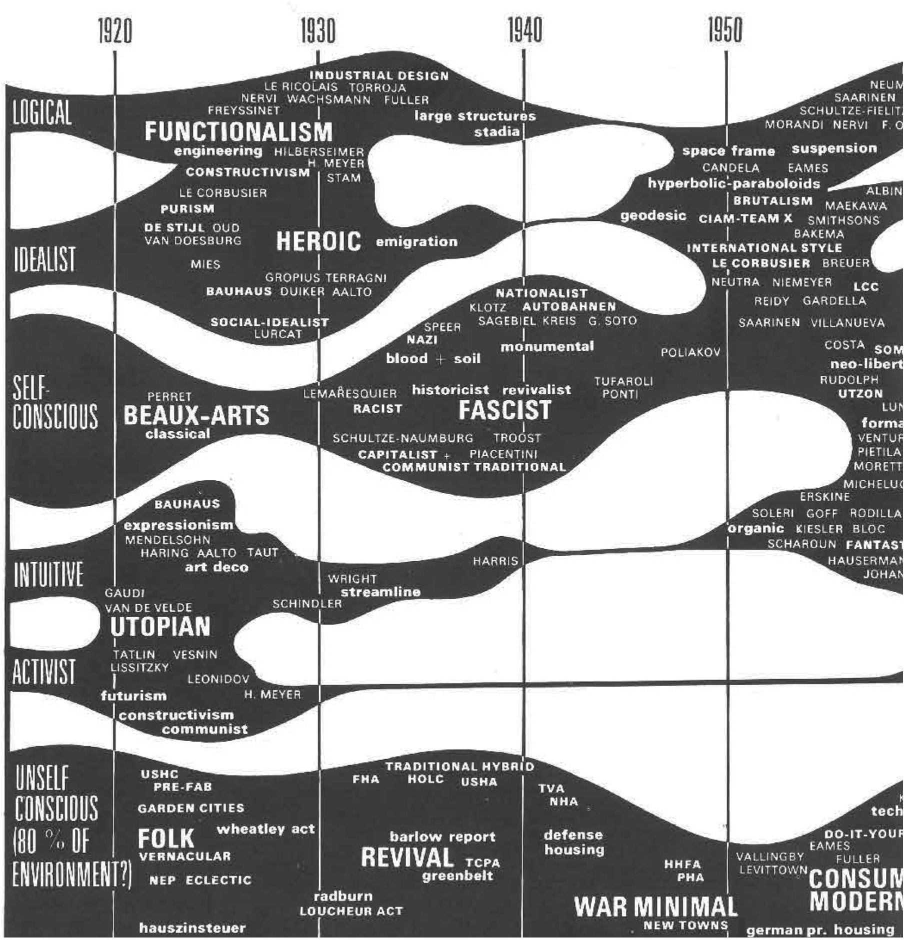
14 See Kitchin and Lauriault. 2018. Toward Critical Data Studies. Kitchin cites Ian Hacking's theory of looping by which 'systems of classification work to reshape society in the image of a data ontology.' In this text reference is also made to Tracey Lauriault's application of this concept to spaces.

15 Jencks. 2000. "Jencks' Theory of Evolution, an Overview of 20th Century Architecture" in *Architectural Review*

To compensate for the ‘perspectival distortion’ inherent in the historian’s subjectivity Jencks proposed ‘attractor basins’ which organized his famous ‘evolutionary tree’ diagram of architecture history and forced him to balance his narrative equally among six attractors. (fig. 2) The categories that organize the data-genealogy tree (derived from Kitchin’s data-assemblage) function in a similar way, asking the analyzer to consider material and immaterial, social and technical elements of the data-assemblage in turn, thereby rebalancing the analysis. The delineation of the cluster in the data-genealogy tree, like the fluid visualization of architectural movements in Jenck’s evolutionary tree, reflect the confrontation of the historian’s source material with theory in an effort to discern pertinent cultural moments.

As I hinted earlier, the data-genealogy tree is only tree-like. In this sense it again bears some resemblance to Jencks evolutionary tree which Lydia Kallipoliti has described as being successful, “precisely because, graphically, it is not really a tree, […] it suggests information floating, rotating, [...], kissing and mating.”[16] The fluid looseness of Jencks’ visualization of architectural culture of the 20th century made it possible to chart out the complex interactions between the century’s most

16 Kallipoliti. 2013. “Turtles do not Successfully Mate With Giraffes: Pluralism Versus Cloud”



2. Detail from Charles Jencks’ *Evolutionary Tree.* from Jencks. 1971. *Architecture 2000 : Predictions and Methods.* p.46

prominent architects as well as era-defining political and technological events. (fig.2) Jencks depicted the evolution of architectural movements like waves that, upon meeting political or technological impediments, flow around them into new forms:

> "When the Fascists in Italy and Spain, and the leaders of Nazi Germany and Stalinist Russia self-consciously imposed their version as a state style it squeezed out contending approaches. The diaspora of Modern architects and the waning of other approaches are clear from the diagram: like evolutionary species whose habitat is destroyed they went virtually extinct (or emigrated from Europe and the USSR)."[17] (See fig. 2)

The clusters I depict in the data-genealogy tree, like the blobs in Jencks diagram, represent reorientations of the data-genealogy, driven by changing human/social motivations. The clusters are thus reflections of social/cultural currents which, given the complexity and diffuseness of these phenomena, merit loosely defined borders. Unlike Jencks' evolutionary tree, however, the data-genealogy tree charts clusters beginning from social, political and technological instigators with the events and actors of architectural culture appearing periodically as they have been highlighted in the case studies. The result is not a survey of architectural styles as in the case of Jencks' diagram, but a survey of socio-technical movements within which architectural events are embedded. The embeddedness of the architect and architectural artifact in this context, however, does not necessarily imply a lack of agency. In the next section I describe in greater detail the clusters I have identified in each case-study using the data-genealogy tree, as I build toward an analysis of the impact of the built environment in the reorientations that I identify in each time-line.

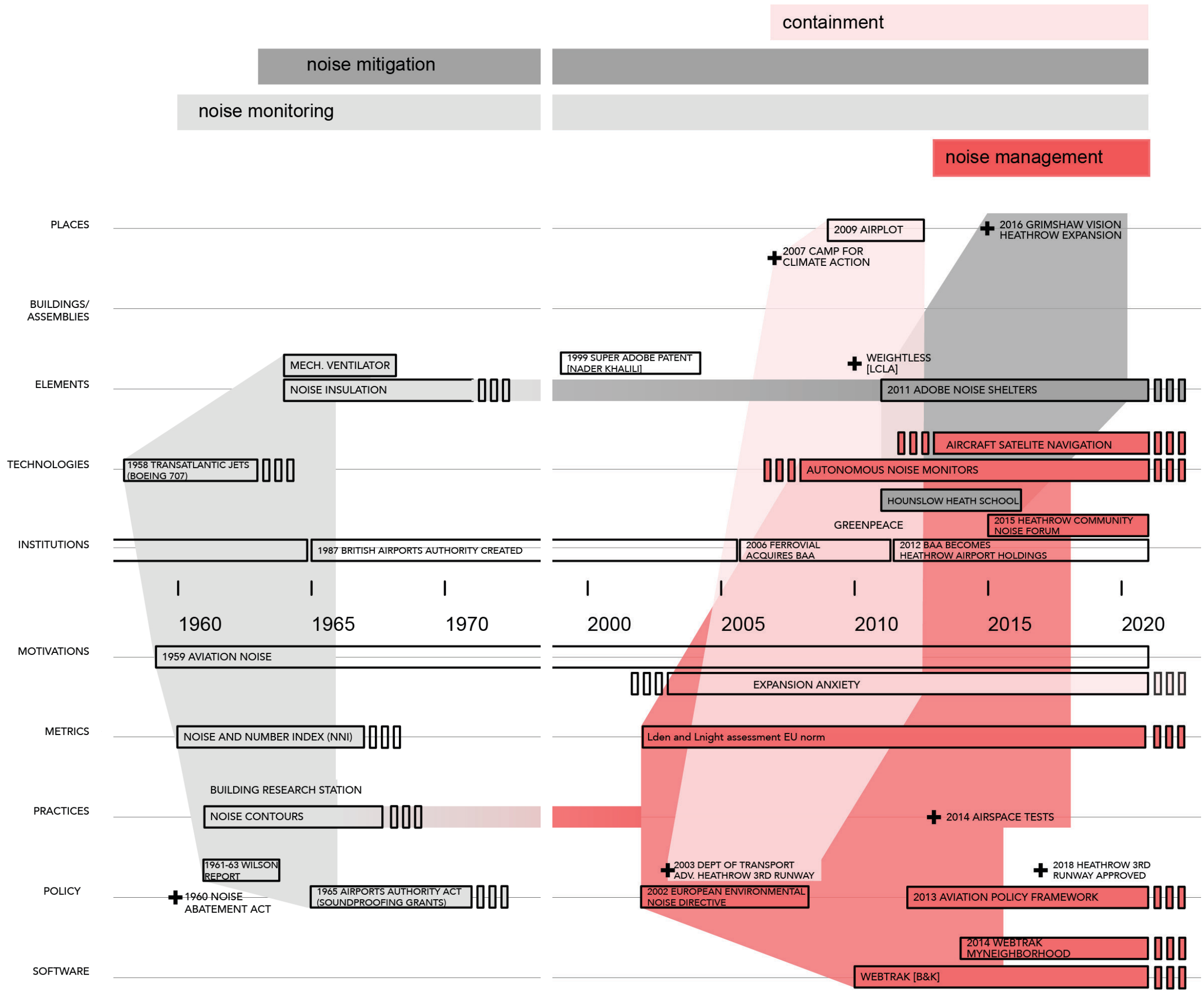
5.1.2 Describing heterogeneity within the data-genealogy tree

With the data-genealogy tree described in the previous section I have charted significant events in each of the case studies in the form of an expanded timeline. (see figs. 3-10) With these diagrams it is possible to understand an overall arc of a data-assemblage's development over time, but also to describe deviations from this trend, where the data-assemblage undergoes reorientation. These moments of reorientation are relevant to my research, especially when architect or architectural artifact contribute to re-orientating the assemblage. In the following paragraphs I return to each case study separately to highlight these reorientations.

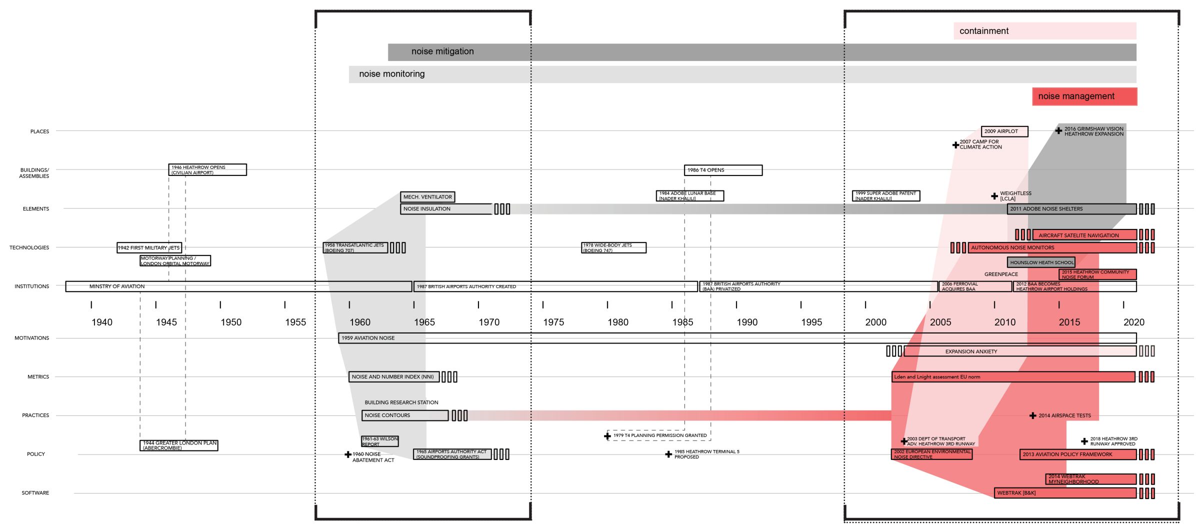
In the Heathrow case-study I identify four distinct clusters in the expanded data-genealogy tree. (figs. 3,4) The first two, *noise monitoring* and *noise mitigation*, are closely linked and arise in the early 1960s in response to protests over noise near Heathrow. The rubric *noise monitoring* brings together the metrics and practices of aircraft noise measurement and representation (noise contours). *Noise mitigation* begins with the building research station established by the Wilson report between 1961 and 1963 which proposed a policy of subsidized building technologies (insulated windows, insulated roofs and walls, and mechanical ventilators) to mitigate the growing impact of aviation noise on people residing near the airport.

A new protest movement, which I have labeled *containment* in fig. 3, arose with the 2003 proposal of a Heathrow expansion (an idea which dates back to the 1940s when the airport was first planned). These

17 Jencks. 2000. "Jencks' Theory of Evolution, an Overview of 20th Century Architecture" in *Architectural Review*



3. Details from Heathrow case study data-genealogy tree. At left, from the year 1958 to 1970. At right, from 2000 to 2020.



4. Overall Heathrow case study data-genealogy tree.

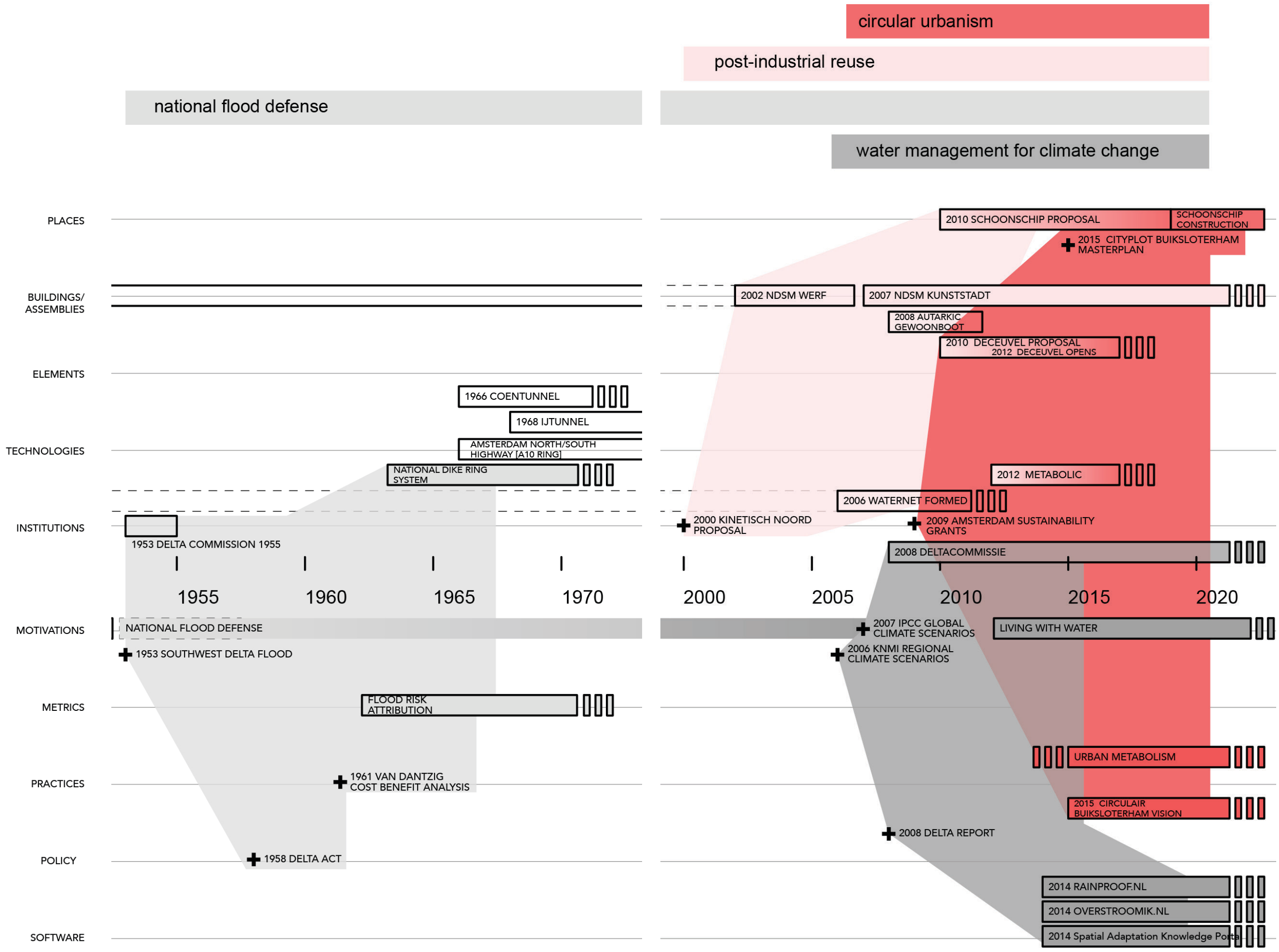
protests were represented physically beginning with the 2007 Camp for Climate Action near Heathrow and with the 2009 purchase of land by Greenpeace to block the expansion of the airport. Luis Callejas' project, "Weightless, Heathrow" has represented this protest movement in my research: an attempt by a landscape architect to fundamentally alter the data-assemblage. In discussing the potential impact of architects and architectural artifacts on the data-assemblage I will return to this project in the next section 5.2.

Finally, the contemporary data-genealogy tree in Heathrow is split into two distinct clusters. (fig.3) One cluster (*noise management*) is oriented toward tracking the airspace, measuring noise, and communicating these results to residents. The second cluster (*noise mitigation*) is oriented to expanded construction of noise-shielded spaces, like the Hounslow Heath adobe huts or the Grimshaw domes. There is a lack of integration between airspace monitoring and planning and ground-level urban planning; broadly this suggests that a singular 'smart city' near Heathrow is unlikely to emerge. More likely is a dichotomous condition of highly data-driven airspace juxtaposed with a reactionary and fragmented ground-space planning.

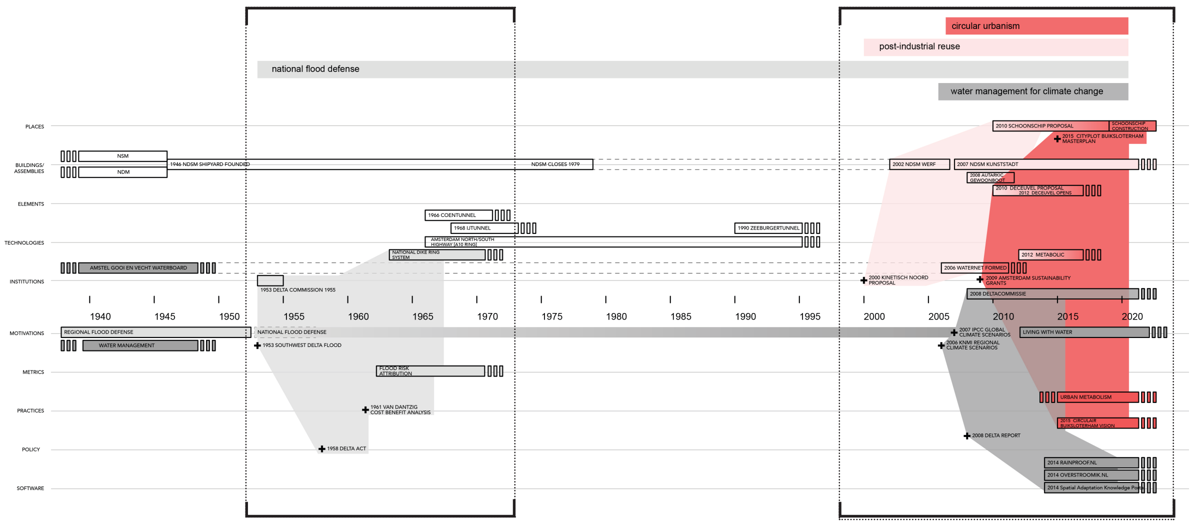
The data-genealogy tree for the Amsterdam case study, as I have drawn it, follows a pattern in some ways similar to that of Heathrow with initial concern over flooding in 1953 leading to new policies, practices, infrastructural systems and metrics of flood risk.(figs. 5,6) In Chapter 3 I identify practices and metrics dating back to the 17th century, for the data-genealogy tree, however, I begin with the establishment of the national flood defenses of the Netherlands after the 1953 flood in the south-west delta region. While the subsequent Delta report was the trigger for the famous Delta Works flood defenses in the Netherlands it was also the initiator for a national cost-benefit analysis of dike construction developed by David van Dantzig which in turn lead to the comprehensive system of dike rings which assigned a pre-determined annual flood risk for all physical areas of the nation.[18]

Climate change motivates a second cluster in the data-genealogy tree (fig. 4) titled *water management for climate change*. The IPCC global climate scenarios of 2007, motivated the national government of the Netherlands to re-evaluate their flood defenses and water-management systems leading to a new Delta report and the founding of a new Delta Commission in 2008. Not only was the climate changing, but the population of the Netherlands was rising and people were moving to new areas of the country. The Delta Commission thus proposed not only new works of infrastructure, but techniques of data-capture and data-visualization meant to raise awareness in the Dutch population of changing climatic conditions and possible flooding. These tools of 'raising awareness' parallel in some ways the tools of 'noise management' in the Heathrow case study – in particular their emphasis on personalization ('Please enter your address") and behavioral nudging via information distribution.[19] Associated with tools for data-visualization like the national risk map were also 'spatial adaptation' tools, which promote informed choice of building location and the selection of construction techniques more resistant to flooding and/or better capable of retaining water. These data-oriented tools remain almost entirely immaterial, with the exception of the catalogues of adaptive building techniques created by 'Atelier GroenBlauw' lead by architect Hiltrud Pötz.[20]

18 See 3.2.7 and 3.2.8.
19 See 3.3.1 and 3.3.2.
20 See https://www.urbangreenbluegrids.com.



5. Details from Amsterdam/ Buiklsoterham case study data-genealogy tree. At left, from the year 1953 to 1970. At right, from 2000 to 2020.



6. Overall Amsterdam/ Buiksloterham case study data-genealogy tree.

A concern for *circular urbanism* emerges parallel to the w*ater management for climate change* cluster. Here water management is a driving force due to the polluted soil and limited storm sewers of the post-industrial district Buiksloterham in Amsterdam Noord: a driver for the city's interest in 'circular' water conservation. Innovative water retention, and water cycling emerge here via the interaction of designers like space & matter, DELVA Landscape Architecture, with the City of Amsterdam, the newly re-organized water utility Waternet, and a grass-roots movement for reusing the post-industrial north originally called 'Kinetisch Noord' and led by Eva de Klerk. I identify this as a separate cluster, *post-industrial reuse*, that is initially unrelated to data-driven water management, but incubates and establishes a cultural precedent for projects like de Ceuvel and Autarkic geWoonboot (the predecessor of Schoonschip) and actors like Metabolic which in turn form the basis for the Circular Buiksloterham Vision document of 2015.

Unlike Heathrow, the grassroots movement in the Amsterdam case study becomes integrated with the national and city-wide elements of the water-management data-assemblage participating in new urban proposals, new proposals for technologies – like the Metabolism Map[21]- and physical instances of buildings in Amsterdam Noord.

The Singapore case-study data-genealogy tree appears initially more complex than that of two other case studies: I identify six different clusters defined by different motivations. (figs. 7-10) The distinction between colonial era motivations and motivations after the establishment of Singapore as an independent nation inspires the first separation in clusters between *density as pathology* in the colonial era and a post-colonial concern for *viable physical density*.(fig. 7) Density, an indicator of slum conditions in colonial Singapore, is recognized as a physical necessity and resource for the new nation after independence. *Viable physical density* is characterized by Liu Thai Ker's research into minimum standards for living space and the optimization of land.[22] This research transitioned into research on *livable physical density* as the standard of living increased in Singapore and concern for simple ratios of space per person were widened to include concern for how communities emerge within high-rise residential areas.[23]

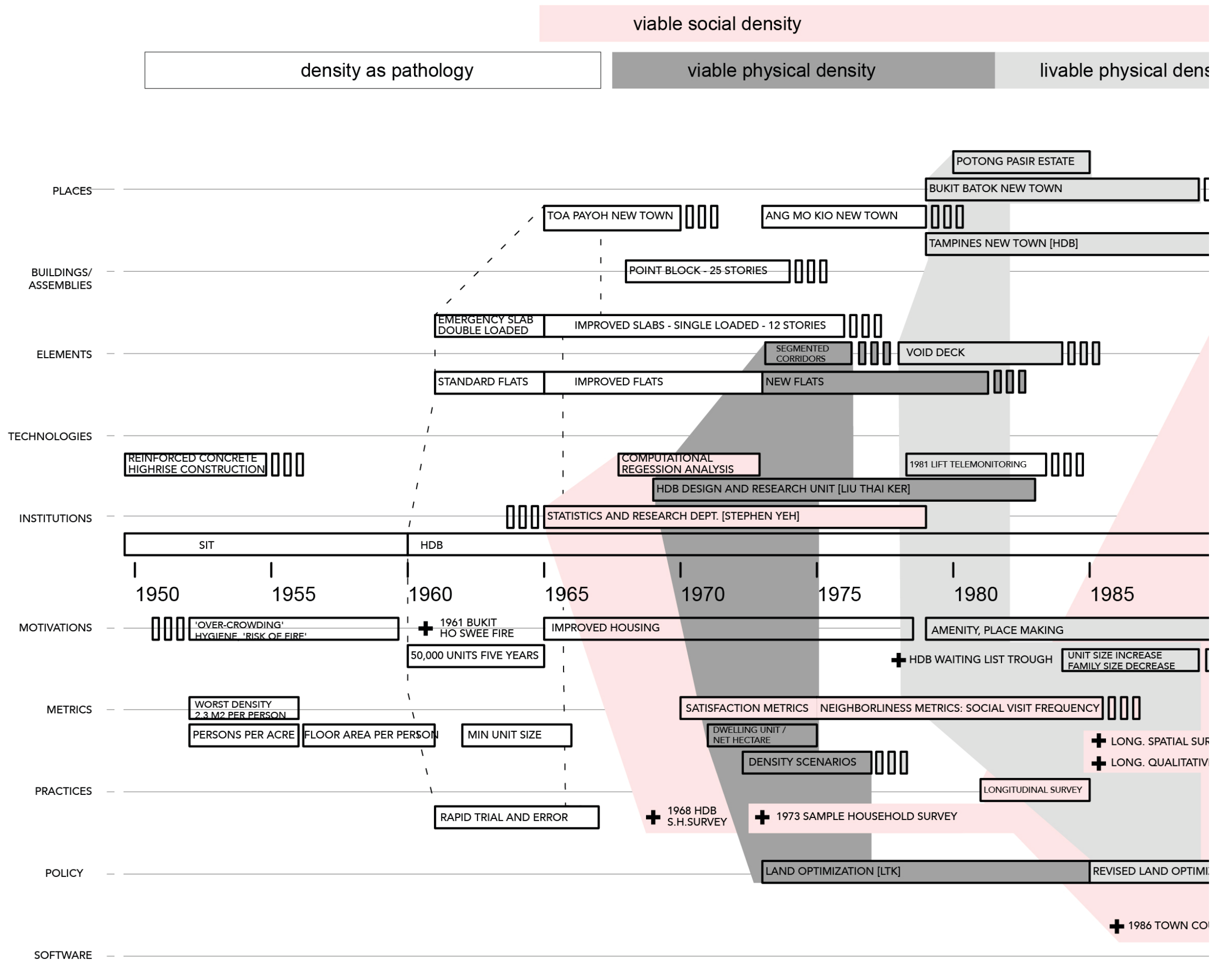
In parallel to the work of research-oriented designers like Liu Thai Ker, HDB's social scientists were investigating high-rise high-density urbanism as a social phenomenon. Surveys of satisfaction with housing and of neighborliness provided an initial baseline assessment of *viable social density* and contributed to significant changes in physical construction – like large kitchens and the development of the void deck. Later longitudinal sociological studies allowed residents to tell their own stories and focused on multi-generation family connections. I have gathered these efforts under the rubric *viable social density*.

Aging as a Singaporean national concern, announced in a 2013 Population White Paper, marked a renewed interest in the multi-generational family and how it can be supported by public housing. This shift in motivation is marked by a red cluster in the timeline titled *livable social density* which groups together software like the Elderly Monitoring Tool with new apartment types like the 2Room Flexi

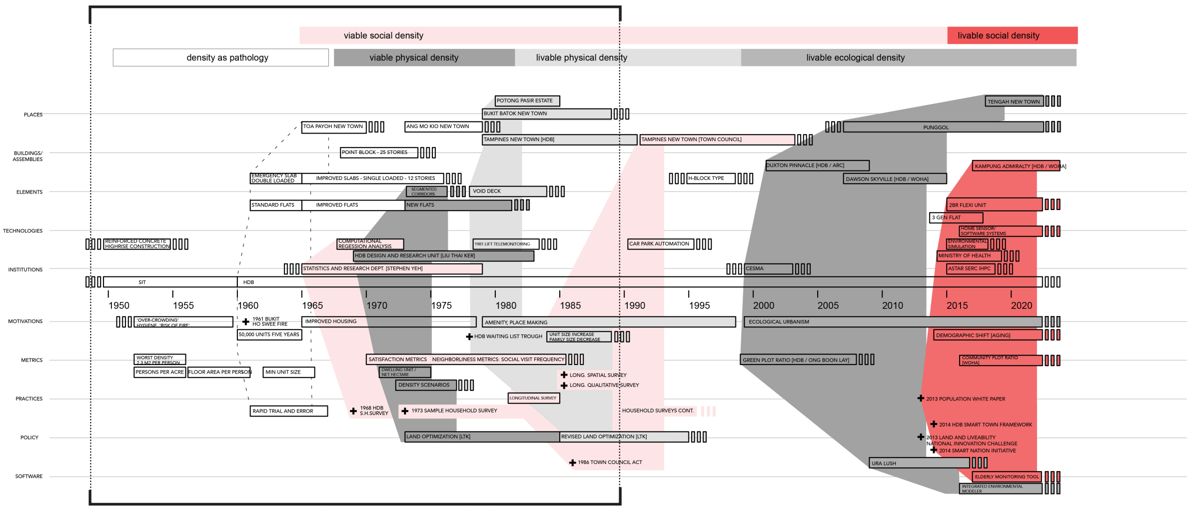
21 The metabolism map is an interactive online map concept proposed with the Buiksloterham Vision document. It would provide feedback to residents on the 'circularity' of their buildings based on urban metabolism data. See Gladek. 2015. *Circular Buiksloterham: Transitioning Amsterdam to a Circular City.*

22 See 4.2.3.

23 See 4.3.1.



7. Details from Singapore HDB case study data-genealogy tree. From the year 1950 to 1985.



8. Overall Singapore HDB case study data-genealogy tree.

Unit, and new mixed-use public housing developments designed for an aging population like Kampung Admiralty.[24]

Measurements of *livable ecological density* are introduced in the late 1990s with Ong Boon Lay's invention of the Green Plot Ratio while working with HDB subsidiary CESMA.(fig. 9) From this metric a variety of architectural innovations and urban policies appear. Singapore's planning agency introduces incentives for ecologically active spaces within the built environment (URA LUSH programme). Greenroofs, skybridges, skyparks multiply in prominent HDB projects like Duxton Pinnacle, Dawson Skyville, and Punggol Treelodge. I have grouped new tools for urban microclimate simulation like UM-MIST/IEM in this cluster as they have contributed to the design of new HDB eco-districts like Punggol and Tengah.

As in the Heathrow case study the introduction of new metrics, or new tools of data-visualization do not supplant existing metrics and techniques in the Singapore case study, but rather supplement them. Even in contemporary work by the HDB , measurements of dwelling units per net hectare provide a fundamental basis for the design of what continue to be high-density high-rise residential districts even as ecological features and social networking software are layered on.

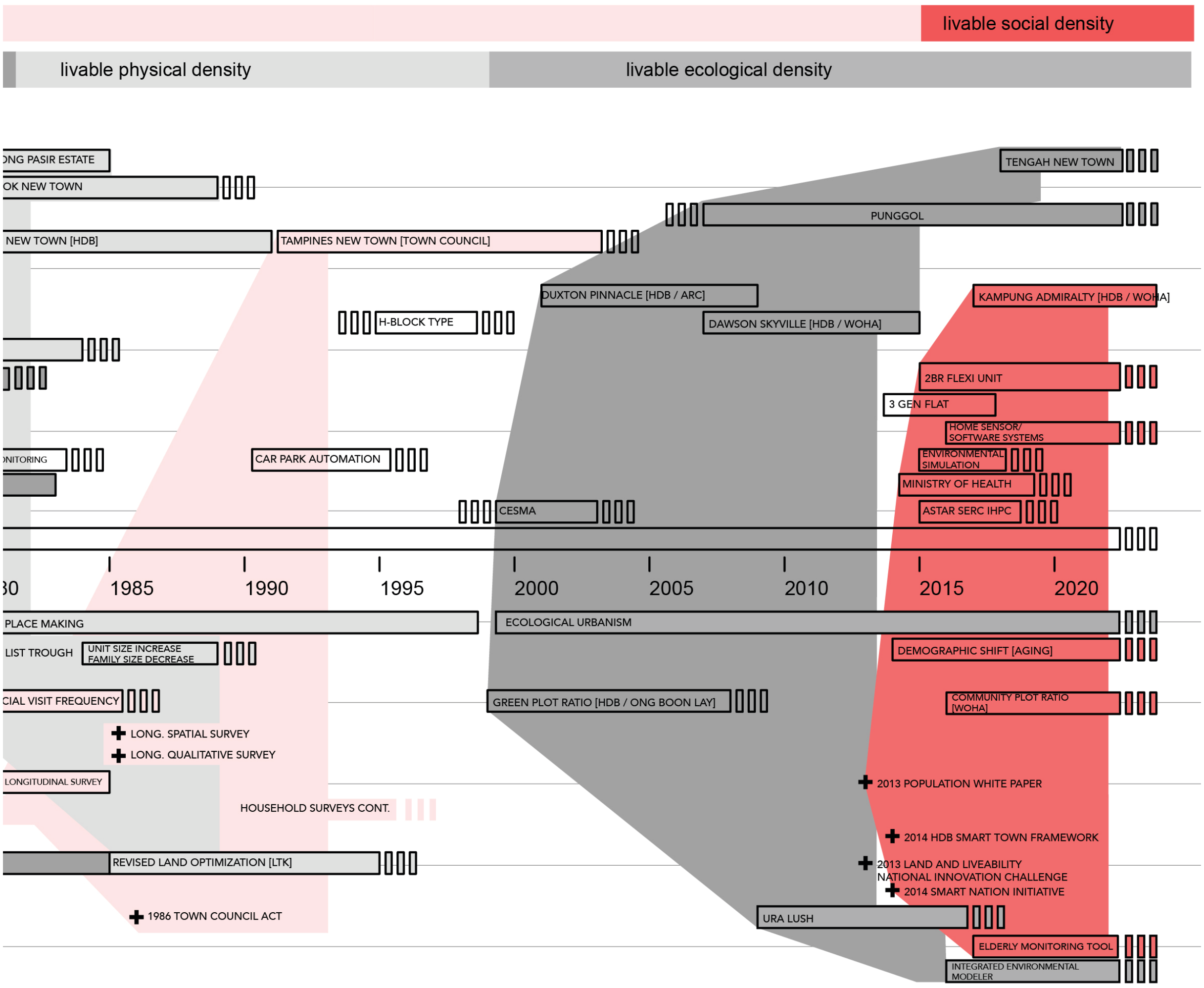
While the Singapore case study does not feature a distinct 'grass-roots' movement in the manner of the Heathrow or the Amsterdam Buiksloterham case studies, the integration of outside view-points by actors like landscape architect Ong Boon Lay and architects WOHA are associated with significant reorientations within the data-assemblage as I have defined it. As with the other case-studies I reserve discussion of this for the next section.

5.1.3 The quantitative turn and the data-genealogy tree

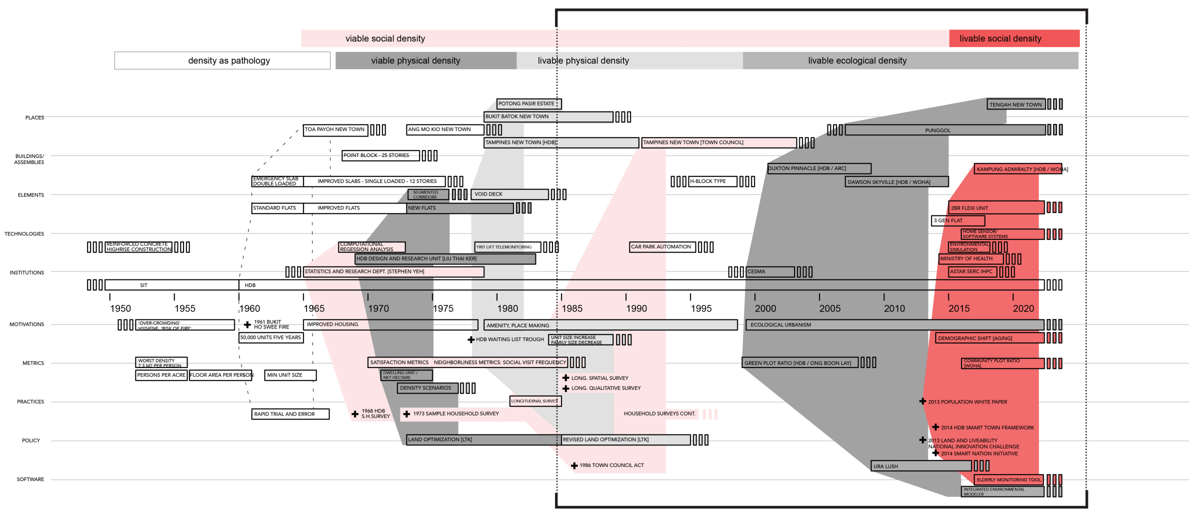
If we read across the data-genealogy trees for all three case-studies together we can chart the outlines of a *quantitative turn*, occurring between 2010 and 2015. In each case study at around this time broad clusters stretching from software to places coalesce around shifting motivations (see *noise management* in fig. 3, *water management for climate change* in fig. 5, and *livable social density* in fig. 9.) I am not the first to announce the appearance of this "Data Revolution" (Kitchin's 2014 book), but the data-genealogy tree does afford a new way of looking at this socio-technical shift by foregrounding the expanding integration of the elements of the built environment and their digital counterparts.

The data-genealogy tree is valuable in its ability to represent the quantitative turn not just as an event exterior to the process of architectural design, but as a disruption interior to design process. The quantitative turn is sometimes portrayed for the design professions as a contextual change, a shift in the 'exteriority' or 'topos' of architecture.(See section 1.2) This is of course true: the designer's understanding of the urban context is now difficult to disentangle from the many layers of urban data. However, the data-genealogy tree's depiction of the growing network of digital actors in which the elements and authors of the built environment are embedded suggests it may also be the 'interiority' of architecture which is shifting.

24 See 4.4.2.



9. Details from Singapore HDB case study data-genealogy tree. From the year 1985 to 2020.



10. Overall Singapore HDB case study data-genealogy tree.

The quantitative turn's impact on the interiority of architecture is effected in part through the digital agencies of networked building elements. For a green roof in Amsterdam to participate in a digitally tracked urban water retention system, it must follow many of the rules of this larger system. These composite agencies can be seen in Amsterdam's 'water management for climate change' cluster as described above, but also in Heathrow's 'noise management' cluster.(figs. 3-6)

Ultimately more important for the practice of urban architecture, the quantitative turn has greatly empowered the general urban public, exacerbating controversy not just over urban matters of concern, but how those matters of concern are measured. While data is deployed by large institutions to massage the perceptions of the urban public, this same public is now consuming this data with increasing skepticism and a social-media fueled ability to dissect both the methods of data collection and the normalized practices or conclusions packaged with this data. Data-empowered urban super-users increasingly demand a seat at the table in decisions that impact their lives, like the expansion of Heathrow airport and the resulting noise envelopes. For architectural and urban design decisions, there is pressure to open up to these communities of super-users, with important ramifications for architecture's 'interiority' or autonomy.

Urban/ architectural projects that harness the energy of super-user communities, like de Ceuvel and the Circular Buiksloterham masterplan in Amsterdam Noord, are associated with reorientations in the data-genealogy tree. Engaging these communities, however, is not as simple as stunning a jury with an atmospheric rendering, but requires a systematic long-term interaction with many people. This interaction is likely digital in nature, as in the CRWDBLDNG.nl platform developed by the architects *space&matter* where owners, crowds, investors and architects interact in a digital market to negotiate site, design, cost, etc. These new digitally participatory design processes impact design not only in the final 'turn-key' stage when the crowd achieves consensus on a design proposal, but also earlier-on via the anticipation of the designer who shapes the design to be open to the voice of the crowd. The nature of 'interiority' in design process is shifting away from single authors in the data-driven context, and the data-genealogy tree offers a tool for conceptualizing the complex gatherings of socio-technical agencies associated with this change.

5.1.4 Architecture's position in the data-genealogy tree

I have used three models in this thesis to depict architecture's role in the data-driven city: the data-genealogy tree (see figures 1, 3-10 in this chapter), the snapshot analytic grid of the data-assemblage (Chapter 1, fig. 14), and the cybernetic loops of the feedback framework (Chapter 1, fig. 15). While each provides a tool for understanding data-driven urbanism broadly and architecture's role in this context more narrowly, none are capable of reflecting the myriad intellectual and experiential affordances of Architecture with a capital A. When working with these tools for describing the data-driven city, we must accept that our description of architecture will be to some extent limited.

Of the three models, however, the data-genealogy tree does the best job of indicating the complex agencies of the architectural artifact by providing evidence of the clustering of social and technological innovations around totemic architectural happenings like de Ceuvel and NDSM in Amsterdam Noord. As an add-on, the data-genealogy tree goes some way in allowing us to see architectural artifacts instead as *happenings:* time delimited gatherings of motivations, practices, communities, places and forms. This viewpoint is valuable for the more detailed reading it permits in an architectural-historical sense, but also for the implications it has for architectural practice in the face of the quantitative turn.

The broad socio-technical and historical view that the data-genealogy tree provides, however, does come with a distortion of the object of research: architecture. Architecture has been depicted in each case study as an instrument of policy, used to modulate the intimate physical environment of its occupants – their homes, schools, workplaces. Over-emphasizing the instrumentality of architecture risks legitimizing a point of view in which architects and architecture in this context are reactive rather than proactive. The late appearance of architecture in the paradigmatic data-genealogy tree (fig. 1), when embeddedness is higher and the assemblage is more obdurate, seems to suggest that the architect's lack of agency is pre-determined by the data-driven context.

Additionally, some of what I have grouped under the term architecture in my case studies would be rejected by many practitioners and historians from that category. Yet technological objects and humble self-made homes have been the subject of prominent architectural and urban scholarship in the past. *Mechanization Takes Command* by Sigfried Gideon, Margaret Crawford's *Everyday Urbanism*, or Reyner Banham's *The Architecture of the Well-tempered Environment* have all opened this territory to inquiry. The holistic viewpoint afforded by the data-genealogy tree, instead of over-emphasizing unglamorous bits of the built environment, I believe might encourage practitioners to reassess their ability to engage with the 'unselfconscious eighty percent' of the built environment and expand the horizons of awareness and action for the discipline.[25]

Ultimately, the value of the data-genealogy tree to the study of architecture is not to describe a monolithic network of technologies and policies which overdetermine architecture's potential, but instead to provide an understanding of how variegated and changeable the genealogy of the data-driven city is; how its motivations fluctuate and its elements re-organize into new groupings with new orientations. Within the dynamic space of the data-genealogy tree architects can be initiators of new clusters driving the creation of metrics, policy, practices and software but also new communities and places.

25 See fig, 2. Jencks' final attractor basin is the 'unself conscious' i.e. not authored by an architect, which he estimates as eighty percent of the built environment.

5.2 Results: architecture's impact on the data assemblage

Research Question 2: *If the urban data-assemblage is formed through co-production of technology and culture,* ***by what means have architect or architectural artifact attempted to exert an influence on the development of data-driven networked urbanism? To what extent is it possible to assess the impact of architect or architectural artifact in the on-going evolution of the data-assemblage?***

One of the anxieties that led to the formulation of this thesis is that architecture may be irrelevant to the development of the smart city, and more specifically to the data-driven networked urbanism that forms the specific context to which I have devoted my interest.[26] This has motivated my development of the data genealogy tree to identify and describe the context of data-driven urbanism, and to search for the instances of architecture and the architects playing roles within this context. With this contextual study in place, however, how best to explain and evaluate the impact of architecture and architect upon the data-assemblage?

The question of impact of architecture is difficult to answer for two reasons. A study of the data-driven city would seem to require quantitative assessment of impact, and yet Donella Meadows has persuasively argued that mindsets, goals and rules are more powerful in changing systems than numbers, stocks or flows.[27] Thus a purely quantitative assessment of impacts focusing on numbers and flows would miss the most significant impacts on a system's leverage points. Second, and more practically, my case studies are quite diverse, so the measurement of impact in one case study would not be the same as impact in another.

In response to these concerns, and to provide a sufficient answer to the question of impact I have turned to the actors themselves, the architects and other designers who have contributed to the built environment of the case-studies. These actors are articulate professionals, capable of clearly stating their goals and explaining actions undertaken to achieve those goals. By recording the voices of these actors, I am able to achieve already a relatively complete understanding of the actions they took, their intentions and world view. This responds to the first half of this research question: 'by what means have architect or architectural artifact attempted to exert an influence on the development of data-driven networked urbanism?'

Beyond simply explaining their actions, these actors almost always offer a self-assessment of the impact of their actions toward reaching their goals. Results matter, and in presenting their work, architects and designers legitimize their work by explaining their results. By recording the self-assessment of these actors, I am able to achieve an initial understanding, albeit a subjective one, of the impact of their actions on the data-assemblage. I supplement these assessments with context and whenever possible with relevant data.

Several actors would have been appropriate to review here. I have selected contemporary actors operating in the context of what I have defined as *data-driven network urbanism*.[28] From each case study I have selected one or two architects and or designer for whom I have adequate access to their written and spoken words. From the Singapore case study, I consider the impact of the

26 See 1.1.2.
27 See Meadows. 1997.'Place to Intervene in a System.'
28 See 1.1.2 for definitions of key terms.

work of landscape architect Ong Boon Lay. From the Amsterdam case study I consider Sasha Glasl of *space&matter* and Eva Gladek of *Metabolic*. Lluis Callejas provides a designer's voice from the Heathrow case study. After considering goals, world view, actions, and assessments for each actor separately I return to a comparative analysis cutting across each of the case studies.

5.2.1 Ong Boon Lay: impact via policy

Ong Boon Lay, architect and academic, developed the Green Plot Ratio in the late 1990s while working on design projects in Singapore. The development of this metric is directly linked to current Singaporean planning policy like the URA's LUSH program which uses the GnPR to measure ecological contribution of plantings on buildings. Ong's design work, research and the GnPR metric are also associated with the bioclimatic architectural movement which has grown in Singapore since the 1990s. In the sections below I use Ong's words to explain the worldview and goals that led to developing GnPR, how he went about developing the metric, and the impacts of his actions as he assesses them. I subsequently discuss briefly the impact of the GnPR adding some quantitative and anecdotal information.

Ong's worldview is perhaps best expressed by his frustration with the lack of overlap between design of the built environment and study of ecology:

> "The built environment is assumed to be generally hard and impervious. Against this are planted landscapes, or greenery […] If the incorporation of plants into architecture is somewhat, if not equally, as effective as greenery on ground, then the antagonistic face-off between urban ecologists and architects/ planners/designers may be turned into one of collaboration."[29]

He envisions cities that use plants as tools to maintain a 'balanced' ecology: "A proper, and future, strategy for a sustainable city must not only include plants but be more precise in channeling plants towards balancing [...] urban metabolism."[30] For this to happen he describes two distinct goals, the first is a regime of ecological quantification specific to cities: "cities will need to be described in ecological terms such that the ecological impact of cities on the global environment can be identified and monitored."[31] Second, beyond simply monitoring ecology, Ong envisions a merging of natural and industrial systems into a singular ecology: "ecological processes of cities cannot be separated into industrial and natural systems but the two will need to be resolved and integrated."[32] Ong's goal is a dual merger of industrial and natural systems and of built environment and planted space into a unified framework of urban ecology. Furthermore, he foresees that his merged ecology that can be both monitored and 'balanced,' that is to some extent controlled or planned by human actors.

Ong begins with an existing biological metric the Leaf Area Index (LAI) of which he says: "[…]it can be used to quantify planning metrics in biological terms. Being in common use in the biological sciences, it provides a useful link between planners, ecologists and scientists."[33] To monitor ecological processes in a manner that combines both natural and industrial systems Ong proposes a hybrid metric, which

29 Ong. 2002. "Green Plot Ratio: An Ecological Measure for Architecture and Urban Planning." pp. 200-201
30 Ibid. p 210
31 Ibid.
32 Ibid. p 210-211
33 Ibid. p. 202

combines LAI with a common urban planning metric of Building Plot Ratio[34]:

> "The concept of a green plot ratio is developed by combining the concepts of LAI and building plot ratio (BPR). BPR is defined as the ratio of gross livable (or rentable) area and the site area."[35]

> "Since [GnPR] replicates the conventional planning instrument of BPR, it is easily understood by the design and planning professions while maintaining a direct correlation to scientific measures."[36]

The creation of the GnPR metric emerged over time, in part from Ong's work as a designer on urban scale projects. Describing an urban design near Shanghai in 1998, Ong uses GnPR to explain and argue for the value of design buildings that incorporate planted areas.

> "[…] the approach taken was to implement ecological measures as fundamentally and as extensively as possible. […] A key strategy was to incorporate skygardens—gardens incorporated into high-rise buildings above ground level. […] the first level of accommodation was raised 3 storeys above the ground […]. This allowed […] the void deck under the building to be extensively landscaped. There were two skygardens every three floors […] The roof was also greened. The individual buildings achieved a [GnPR] of about 2:1."[37]

In the design there are three different strategies for incorporating plants into the building, which have been neatly summarized by a GnPR of 2:1, essentially doubling the leaf area that would exist if the site were planted with grass. Additionally, unbuilt areas of the project are planned as nature reserve with a GnPR of 6:1, implying a high Leaf Area Index obtained by a large tree canopy overhanging many bushy plants. The ecological impact of the built areas and the nature reserve areas can be estimated with a single number.

Though Ong was engaged in doing design work, ultimately the idea of GnPR took on a life beyond his specific design proposals. The wider resonance of his ideas begain with a competition entry for the masterplan of area now known as One North in Singapore:

> "Although the design entry did not make it into the shortlist, the concept of [GnPR] was picked up and adopted by the organisers, Jurong Town Corporation, and will be applied in the final development of the project—now renamed 1 North."[38]

While designers may take many different actions based on their goals, they do not have perfect foreknowledge of what will make an impact. In the case of Ong, his research on urban ecology and the tool he developed – the Green Plot Ratio – has led directly to changes in policy in Singapore's urban planning.

Since 2009 Singapore's Urban Redevelopment Authority (URA) has instituted guidelines for the replacement of urban greenery within built areas in a program they call LUSH. Broadly this program encourages in the incorporation of green roofs, green walls, planters, and ground-level gardens in

34 Building Plot Ratio is also known as Gross Plot Ratio (GPR) of Floor Area Ratio (FAR). To avoid confusion with Gross Plot Ratio (GPR) I have tried to consistently abbreviated Green Plot Ratio as GnPR. In quotes from Ong Boon Lay I have replaced GPR his abbreviation for Green Plot Ratio with GnPR.
35 Ong. 2002. p. 205
36 Ibid.p. 206
37 Ibid. p. 208
38 Ibid. p. 209

NAME: Ong Boon Lay

ROLE: Architect, Landscape Architect, Urbanist

PROJECTS: Green Plot Ratio, Liuxiancun Ecocity, Bouna Vista competition entry

(image: https://vimeo.com/55526783)

goals/worldview:

"Ecological processes of cities cannot be separated into industrial and natural systems but the two will need to be resolved and integrated."[30]

"The built environment is assumed to be generally hard and impervious. Against this are planted landscapes, or greenery […] If the incorporation of plants into architecture is somewhat, if not equally, as effective as greenery on ground, then the antagonistic face-off between urban ecologists and architects/ planners/designers may be turned into one of collaboration."[27]

actions:

"The concept of a green plot ratio is developed by combining the concepts of LAI and building plot ratio (BPR). BPR is defined as the ratio of gross livable (or rentable) area and the site area."[33]

"Since [GnPR] replicates the conventional planning instrument of BPR, it is easily understood by the design and planning professions while maintaining a direct correlation to scientific measures."[34]

impacts:

"Although the design entry did not make it into the shortlist, the concept of [GnPR] was picked up and adopted by the organisers, Jurong Town Corporation, and will be applied in the final development of the project—now renamed 1 North."[36]

strategic areas of Singapore through a systems of requirements and incentives. In 2017 the URA expanded this program to use Green Plot Ratio (GnPR) to more accurately describe the density of greenery provided in their buildings. As described in Chapter 4, prominent Singaporean architects like WOHA have adopted the concept of Green Plot Ratio to explain and promote their work. It provides the basis for their claim that their Oasia Tower, for example, has a green plot ratio of 2000%. WOHA it should be noted, and as described earlier in Chapter 4, has redefined the metric in way that does not use LAI. Quantitatively the URA estimates that the LUSH program has, "contributed over 130 hectares of greenery (or 210 football fields) islandwide."[39] GnPR provides a mindset and metric for understanding the urban greenery collectively as a functioning ecological entity.

In recent years Ong has emphasized some of the limitations of GnPR. "The main problem with GnPR is that it is entirely numerical and as such does not address qualitative though important concerns."[40] An example of this is its failure to reflect ecological diversity in urban environments.[41] Also, when used as a planning tool in urban environments there is a necessity that the plants be monitored regularly to ensure that they are healthy, but it is impractical to assume from an administrative point of view that an exact LAI can be calculated at each inspection.[42] In spite of these limitations, GnPR provides one of the best quantitative reflections of urban plants' ecological contribution, like metabolizing atmospheric CO_2, and for this reason Ong argues, "indices like GnPR [are] essential if the actual benefits of sustainable greenery are to be identified and monitored."[43]

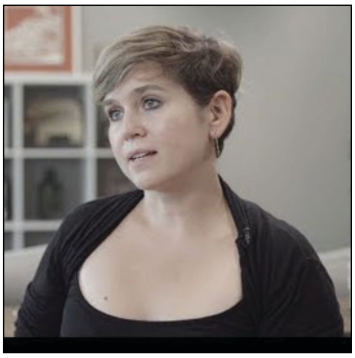
Ong is particularly apt voice to reflect on the data-driven city, as his vision is one the explicitly calls for quantitative identification and monitoring. Relevant to the research question treated here, on the impact of architecture in data-driven urbanism, is the experience of Ong as designer and researcher. While his early urban designs visions may not have been realized, he made a clear contribution toward achieving his large-scale goals of a merger between natural systems and the built environment by developing a quantitative tool sharable between urban planning and ecology. Concrete impacts, like the 130 hectares of greenery produced via the LUSH program, can be directly linked to his work.

5.2.2 Eva Gladek: impact via example

Eva Gladek is an industrial ecologist and the founder of the ecological consulting group Metabolic. She was central in the creation of *de Ceuvel*, the *Circular Buiksloterham Vision* and the sustainability concept for *Schoonschip*, each of which have been discussed in more detail in Chapter 3. To understand her impact on the development of Amsterdam *Noord*, I try to understand her goals and actions below, and then review her self-assessment of the impact of her actions within the data-assemblage model.

> "I was getting very frustrated because I was doing a lot of advisory work and coming up with designs and concepts and seeing very little get executed. [...] I wanted to create an action agency where if I had good ideas on sustainability I could actually execute them and build them myself. […] That is why I created Metabolic."[44]

39 Ms Tay Yi Wen. 2017. *A LUSH and Resilient City | LUSH 3.0.* (Lecture)
40 Ong. 2012. p. 4.
41 Ong. 2012 "There is need then for green measures to reflect ecological diversity and health. This measure is linked to LAI in natural ecosystems, but for the reasons explained above, cannot be linked to urban landscapes as easily." P.4
42 Ibid. "Allowing for the variability of actual LAI, regulatory monitoring simply involves checking the landscape against the submitted plan and ensuring that the plants in question are healthy and well maintained." P.4
43 Ibid. p.7
44 Eva Gladek. Sustainable Urban Systems and Circular Cities of the Future: Learnings from Three Cities. 2018. (Lecture) 4:34



NAME: Eva Gladek

ROLE: Industrial Ecologist
Founder Metabolic

PROJECTS: de Ceuvel, Schoonschip, Circulair Buiksloterham Vision

(image: https://youtu.be/gjt5WTrnYdY)

goals/worldview:

"I was getting very frustrated because I was doing a lot of advisory work and coming up with designs and concepts and seeing very little get executed. [...] I wanted to create an action agency where if I had good ideas on sustainability I could actually execute them and build them myself. […] That is why I created Metabolic."[42]

"creating a sustainable economy [...] is the main mission of our organization."[43]

actions:

"This is a demonstration site in Amsterdam where we have a building where we collect urine […], turn it into fertilizer and use it in a greenhouse to produce food and demonstrate how we can close urban resource cycles. This is one way that we hope to inspire people like developers or architects or policy makers to think differently about resource management in cities."[46]

"We modeled all of the resource flows the energy and emissions the water the other resources and we did it on two time points so current state and the future we worked with stakeholders, around four hundred stakeholders, to develop a vision and goals with really measurable KPIs."[50]

impacts:

"Really what you want to do is you want to create change at scale. You need to change entire cities. And very interestingly for us de Ceuvel started that process of creating that change because we were asked by the city to come up with a strategy for all of a big neighborhood in Amsterdam."[49]

"Amsterdam also asked us to develop [...] the rules for tenders for developers who want to build. They have to prove that their buildings will be circular. They are scored against our circular evaluation tool. [...] This is really where it starts to scale because it's not just about one building or one little neighborhood it's about actually creating the rule base for all these new developments."[51]

Gladek's vision is 'creating a sustainable economy.'[45] Metabolic is designed with this goal in mind but as the quote above reveals, to specifically build things, execute plans, and take action. In order to achieve these goals Gladek defines three types of actions Metabolic takes: insights, implementation and activation. She goes into some detail to explain each. To explain *insights*, Gladek says:

> "We are collecting information about how the world works. All of the sectors that we think need to be changed towards a sustainable model and we are using the information to deliver insights to change-makers."46

In this quote we see that, in spite of fronting an 'action-agency,' Gladek still sets great value on the power of information, especially when delivered in the right way to the right people. In contrast to these *insights*, she describes *implementation* as building components of a sustainable economy via small individual business ventures:

> "When we see something that is potentially highly impactful we also set up our own projects and do our own experiments. When those experiments are successful we scale them up into ventures, into companies of their own. And we are building an ecosystem of these ventures, each focused on a specific part of the sustainability challenge […]"47

To explain ***activation***, she turns to an example from *de Ceuvel*:

> "This is a demonstration site in Amsterdam where we have a building where we collect urine […], turn it into fertilizer and use it in a greenhouse to produce food and demonstrate how we can close urban resource cycles. This is one way that we hope to inspire people like developers or architects or policy makers to think differently about resource management in cities."[48] (emphasis added)

In Gladek's telling the *de Ceuvel* project works via activation. Though it's sustainable impact is minimal compared to the flows of waste and energy in Amsterdam, to the extent that it can change the minds of key actors it is impactful. In describing the development of *de Ceuvel* Gladek emphasizes how the project has fed into spin-off ventures but also how it has influenced its participants to think differently. Describing how the *de Ceuvel* team evolved Gladek explains:

> "People really changed and learned. […] From the start of the project to the end you wouldn't recognize these people, the amount of confidence they had and what they learned that they could do."[49]

Of the *de Ceuvel* project's impact on its visitors she has this to say:

> "It's become a hugely popular site. We host delegations from around the world all the time. […] I was very surprised because [...] this is a small little project, but people are inspired and they're getting something out of it and I think the reason is because it's actually there, because we actually built something. [50] (emphasis added)

45 Ibid. 5:04
46 Ibid. 5:17
47 Ibid. 5:53
48 Ibid. 7:41 and 7:48
49 Ibid. 27:42
50 Ibid. 29:20

The construction of a physical artifact, according to Gladek's account, holds a special persuasive power. By its physical presence it acts as testament to the believability, the reality of a new way of doing things. Participating in the creation of the artifact also changes the person who contributes to its creation: they learn new skills, they become self-confident. Somehow the physical artifact,- in this case an architectural artifact – acts as an activator for the people who build and visit it, people Gladek refers to as, 'a new generation of change-makers.' Gladek emphasizes that the activating effect of the physical project, so effective at *de Ceuvel,* was a stepping stone for *Metabolic* to be able to achieve larger impacts in the city of Amsterdam.

> "Really what you want to do is you want to create change at scale. You need to change entire cities. And very interestingly for us *de Ceuvel* started that process of creating that change because we were asked by the city to come up with a strategy for all of a big neighborhood in Amsterdam."[51]

After the success of *de Ceuvel*, *Metabolic* was asked by the city of Amsterdam to contribute to the Circular Buiksloterham Vision, with Gladek, as primary author, providing the large scale conceptual framework that linked all the contributions from other participants like the landscape architect Steven Delva (who also contributed in a major way to *de Ceuvel*) and *studioninedots*. The Circular Buiksloterham Vision document, instead of being a physical construction, exists only on paper. It's value and impact comes from the information it contains and also from the legitimizing commitment of its signatories which include not only the city of Amsterdam, but also Waternet, and housing cooperatives/developers like *die Alliantie*.

> "We modeled all of the resource flows the energy and emissions the water the other resources and we did it on two time points so current state and the future we worked with stakeholders around four hundred stakeholders to develop a vision and goals with really measurable KPIs."[52]

From the data-intensive urban metabolism analysis of the Circular Buiksloterham Vision, *Metabolic* went on to provide specific guidance to urban developments in Buiksloterham like *space&matter*'s project *Schoonschip*.[53] With the combination of a physical prototype at *de Ceuvel,* the conceptual framework of the Circular Buiksloterham Vision document and their ongoing development consulting practice in Amsterdam, *Metabolic* has convinced the municipal government of the city of Amsterdam to apply their ideas more broadly:

> "Amsterdam also asked us to develop [...] the rules for tenders for developers who want to build. They have to prove that their buildings will be circular. They are scored against our circular evaluation tool. [...] This is really where it starts to scale because it's not just about one building or one little neighborhood it's about actually creating the rule base for all these new developments."[54]

Metabolic finds itself today writing the codes that will build the future of the city of Amsterdam. Gladek does a good job of articulating the impacts that Metabolic has had already, in terms of hard achievements like buildings and documents completed, but also in unquantifiables like minds and hearts changed. If her input on the development process in Amsterdam is implemented, it will make the urban-scale impact that she aspires to. Significantly this large-scale impact was initiated by

51 Ibid. 30:13
52 Ibid. 31:14
53 For more information on *Schoonschip* see 3.4.4.
54 Ibid. 32:30

building an architectural-scale prototype – *de Ceuvel*. Alone, however *de Ceuvel* would not be able to achieve the large systemic change that Gladek describes as her goal. Only combined with the data-driven practices of urban metabolism analysis and the conceptual framework of the circular city does Gladek achieve the credibility to impact the city code. Architectural artifact and data-driven argument combine in Gladek's example to produce one of the most convincing instances of impact in the case studies reviews in this thesis.

5.2.3 Sascha Glasl: impact via community

Instead of harnessing data, as in the case of Ong Boon Lay or Eva Gladek, architects *space&matter* leverage associated methods of digitally mediated finance and crowd networking to produce unique, unexpected urbanisms. This agency is reflected in the data-genealogy tree of the Amsterdam case study (fig. 5) which identifies the *de Ceuvel* project as the initiator of a new data-assemblage cluster supporting an emergent circular economy. Founder Sascha Glasl articulates the fundamental goals of the office as leveraging finance (ventures) and online communities to make change in the city, but also as fighting for the value of architectural form in this context.[55]

The worldview expressed by Sascha Glasl is one where the dominant actors changing the city are private developers and where the primary tool for making urban change is finance. To introduce and define his practice Glasl tells the story of an ideas competition they won in 2009 for a housing development in North Holland. When he they went to the award ceremony they mingled with the many developers in the audience, among whom were 'concept developers,' *Conceptontwikkelaar* in Dutch, who often back urban developments in Holland. The *Conceptontwikkelaar* develops a concept before contacting an architect. In Glasl's words:

> "They really just [...] tell architects,'Can you make a little sketch for me?' They don't think of architecture and design as a very holistic kind of idea of getting all disciplines together [...] what an architect in my opinion should do."[56]

Glasl defines the goals of his practice relative to the role private developers play in contemporary Dutch cities. Like a developer, he would like to have the ability to initiate large scale change in the city, but unlike a developer he wants to do so in a holistic way, listening to many voices and not just finance. The work of *space&matter* has been dedicated to finding a way to initiate creative urban architecture by including many voices, and without significant financial backing.

The actions *space&matter* have taken are simple but perhaps not what one would expect from an architect. They first seek to bring together and motivate a community of small scale actors, like artists or people looking for homes. This community as whole provides the financial backing for the project through small contributions, but also provides labor and knowledge, helping to conceive and build the project. In this process *space&matter* organize and motivate the group, manage finances and regulation, and finally they fight for a few key moments of large scale form which organize and define the project.

55 Sascha Glasl opened the design office in 2009 with two other partners. Space&matter are the architects behind the *de Ceuvel* and *Schoonschip* projects in Buiksloterham, Amsterdam.
56 Glasl, Sascha. 2014. "Space & Matter." Lecture, Academy of Art University. San Francisco, CA. 04:44- 04:52

NAME: Sascha Glasl

ROLE: Architect,
Founder space&matter

PROJECTS: Sweets Hotel, de Ceuvel, Schoonschip, CRWDBLDNG.NL, webuildhomes.nl, SmartLofts

(image: https://vimeo.com/98671834)

goals/worldview:

"They really just [...] tell architects,'Can you make a little sketch for me?' They dont think of architecture and design as a very holistic kind of idea of getting all disciplines together [...] what an architect in my opinion should do."[54]

actions:

"you are not only the architect - and do the permissions and the drawings and the building - but also you have to manage the whole community and keep them all motivated all the time."[58]

"I always defended the design of the boardwalk which is nicely shaped and somehow puts that all together. And at the end everyone likes that also. It costs a little bit more than a straight one, more efficient one. But people just like to walk there to think, having a discussion, giving a tour sitting here and working here."[59]

impacts:

"At the opening there were more than two thousand people. [...] The next weekend again, and the weekend after again. So, we really had to organize that. There were so many bikes and people, a lot of noise, trash. We really had to deal with the success of this project."[60]

"All target groups you can think of are there, you know there are sometimes some hippies naked swimming there, a guy with a suit, a minister is walking there, for example people from the municipality having a meeting, and uh there is an animation festival in one of the houseboats [...]"[61]

De Ceuvel was the test case for the *space&matter* method. Glasl describes the competition in this way:

> "You have to build 1000 square meters of atelier space, you have to deal with the pollution there, you don't win money, you only get the place for ten years, after ten years you have to clean up, you go away. So it was very challenging, very challenging.[57]
>
> We need a lot of friends who also want to stay there because we had to guarantee […] in the competition all the people who want an atelier space there. You have to make also a whole financial plan. […] I think not a lot of municipalities do that but they [Gemeente Amsterdam] try to stimulate a lot of people also to team up. They also see that architects not only have to make a nice sketch […] they also have to get the people together and also program everything. And then we got the people together, this is more-or-less the starting team. [shows picture]"[58]

At *de Ceuvel* the project could not happen without the backing of not only design team members like landscape architect and sustainability consultant, but also the interest and support of the artists and young professionals interested in participating and eventually owning atelier space on the site. Glasl doesn't claim full responsibility for the idea that the architect should be a community organizer, but credits this instead to the city of Amsterdam, who wrote the competition with this in mind.[59]

In presenting the process of creating the design Glasl highlights the constraints of the site and budget by explaining that only two teams were able to submit for the project in the end. He contrasts this with the Guggenheim Helsinki competition which had many hundreds of entrants.[60] He emphasizes that taking on a community-building type of project is a significant additional challenge to the architect:

> "You get a lot of stress with these projects when you are not only the architect - and do the permissions and the drawings and the building - but also you have to manage the whole community and uh keep them all motivated all the time."[61]

He also explains that in this context it was also difficult to work with architectural form, and he found himself always needing to justify his design decisions. In particular he had to defend his design for a sinuous boardwalk connecting all the houseboats (see fig. 26):

> "I was fighting for this boardwalk [...] I always defended the design of the boardwalk which is nicely shaped and somehow puts that all together. And at the end everyone likes that also. It costs a little bit more than a straight one, more efficient one. But people just like to walk there to think, having a discussion, giving a tour, sitting here and working here."[62]

Glasl evaluates the impact of his project, not simply by the fact that it was built, but by how it was received. Of particular importance for him are quantity and diversity of the people visiting the project:

> "At the opening there were more than two thousand people. We never expected that, we always were a bit afraid that at the café there would be never visitors. It's a bit too far from the city center but at the

57 Ibid. 27:42
58 Ibid. 28:09
59 Ibid. 26:46. 'The municipality they organized a competition and they asked not only for architects to come with a design here they asked like a whole marketing group to team up and to come for a solution for this place."
60 Ibid. 32:05
61 Ibid. 34:56
62 Ibid. 36:33

> opening there more than two thousand people. The next weekend again, and the weekend after again. So, we really had to organize that. There were so many bikes and people, a lot of noise, trash. We really had to deal with the success of this project."[63]

Diversity of interest in the project also, for Glasl, proves the impact of the project – that they achieved a project that allows an organic group of interested individuals to form regardless of typical market segmentation based on wealth, education, or political persuasion.

> "We never aimed for a certain target group. A developer for example when they build something they always say the target group is XYZ. [...] We we said no, the common denominator here is sustainability and culture. We we tried to somehow just get that together and then never thought about it anymore. And what happened now is that all target groups you can think of are there, you know there are sometimes some hippies naked swimming there, a guy with a suit, a minister is walking there, for example people from the municipality having a meeting, and there is an animation festival in one of the houseboats [...]"[64]

While de Ceuvel is a physical platform for gathering people together, *space&matter* have also developed online platforms for gathering groups of people together. One platform they named CRWDBLDNG.NL proposed projects for converting vacant office spaces into residential projects. The catch was they had not yet secured the rights for renovation the vacant office space- instead they relied on the CRWDBLDNG.NL to advertise a possible architectural project and bring together a group of people interested in buying a unit in the development. If enough people joined the group, they would approach the owner of the vacant building with an offer to buy the property. Glasl explains that *space&matter* has transformed a former Amsterdam District Office into apartments based on this working method.[65] The *space&matter* project *Schoonschip*, which was discussed in Chapter 3 was developed using a similar system of gather a group of interested buyers before beginning the building process, although this happened outside of the CRWDBLDNG.NL platform.

A similar online platform developed by *space&matter* called WeBuildHomes.NL presents a menu of diverse designs from several different architects. Each design is a potential entry in a rowhouse development. Visitors to the website are invited to choose a design they like and make a commitment and initial investment to building the project. A degree of predictability and economy is achieved by asking the designers to work with a library of standardized construction details and elements. This project began as a competition, has been successful in completing at least one development.[66]

The worldview of *space&matter* might be best described as that of the finance-driven city, a pragmatic reflection on what has elsewhere been called neo-liberalism.[67] Their viewpoint however does not preclude thinking of their work within the data-assemblage model. In this context, with the projects of *de Ceuvel* and *Schoonschip* they have been able to initiate, organize and sustain quirky innovative urban happenings which have also contributed to the development of bottom-up regimes of data-driven circular urbanism.

63 Ibid. 38:26
64 Ibid. 39:15
65 49:20
66 www.webuildhomes.nl still active as of 10 April 2019.
67 Harvey. 2005. *A Brief History of Neoliberalism.*

5.2.4 Lluis Callejas: impact via aesthetics

The case study of Heathrow offers up examples of architectural work that are more difficult to assess in their impact on the data-assemblage. For Lluis Callejas, the Greenpeace Airplot competition for Heathrow was one of the first competitions for his practice, and it came to define for him many of the processes he would use, how we would work as an architect/landscape architect.[68]

Callejas goes into some detail in describing his goals for the project, which he articulates in contrast with the goals of the competition sponsor, Greenpeace.

> "The competition was started because […] Greenpeace wanted to stop the construction of the third runway. But maybe more importantly because all the people that live around the airport of course don't want this runway to happen because they have this condition already happening and it's going to be a lot more intense with a third runway. So, we were a lot more interested in these people living around the airport than actually the Greenpeace intentions, that of course are a lot different."[69]

Callejas emphasizes that by focusing on the experience of the people living around Heathrow, he was diverging from the goals of Greenpeace which were more narrowly concentrated on stopping a third runway. Callejas' vision was inspired by a volcanic ash cloud that spread across Europe at the time he was working on the competition:

> "This is the eruption of the Eyjafjallajökull volcano in 2010. […] Maybe you remember this basically stopped all the navigation, the aerial navigation of Europe during a few days and it was the worst since World War Two."[70]

Inspired by the ash cloud he developed a design that would allow the residents to achieve a similar airport-halting effect:

> "In order to replicate that phenomena [of the Eyjafjallajökull ashcloud] and to involve these people we started to look at the […] blocks that surround the airport. This is a suburban airport there are some farms, two-to-three story houses, very low. […] These maps are just the intersection between the air routes and the houses so this is the ideal location to interfere with air traffic in order to stop the airport for a few days."[71]

In this description the data-driven nature of Heathrow's airspace is used against it by plotting a cloud of points to maximize interfere with air-traffic. Callejas map is a reversal of a noise contour map: instead of mapping which houses are most impacted by overflight, it shows which houses can have the most impact on airspace. What is less clear, however, is why the project needs to be a cloud:

> "Because of aerial regulations one object is enough, because they need to stop the airport. But what we were a lot more interested in is the effect of this installation in a massive scale and we were of course a lot more interested in this than in the Greenpeace background of the competition."[72]

68 Luis Callejas. 2012. Lecture, Knowlton School of Architecture. 00:47 "this project shows a lot about the procedures that we do in […] in the studio, how we work" and 04:32 "just to show you how we work we started to do these very exaggerated collages, but that was of course the ideal situation that we started to imagine that that is this of course may be very expensive."

69 Ibid. 02:23

70 Ibid. 01:40

71 Ibid. 03:21

72 Ibid. 5:07

NAME: Luis Callejas

ROLE: Architect, Landscape Architect, Founder LCLA

PROJECTS: Weightless [Heathrow Airplot Competition]

(image: http://www.pavillon-arsenal.com/en/videos/lectures/except-cycles/11015-luis-callejas.html)

goals/worldview:

"In order to replicate that phenomena [of the Eyjafjallajökull ashcloud] [...] It was about having these people putting objects or something in the air that will transform the airport into something not useful anymore for a few days."

"Because of aerial regulations one object is enough, because they need to stop the airport. But what we were a lot more interested in is the effect of this installation in a massive scale and we were of course a lot more interested in this than in the Greenpeace background of the competition."

actions:

we started to look at the […] blocks that surround the airport. This is a suburban airport there are some farms, two-to-three story houses, very low. […] These maps are just the intersection between the air routes and the houses so this is the ideal location to interfere with air traffic in order to stop the airport for a few days. To […] provoke the same issues that the ash cloud was producing […]

impacts:

"this project shows a lot about the procedures that we do in […] in the studio, how we work"

One floating balloon would be enough to close all of Heathrow's airspace, so Callejas himself questions the need for so many, for a cloud of floating objects. Callejas admits, then, that his ultimate goal is the 'effect of this installation in a massive scale.' While he remains perhaps intentionally ambiguous about what effect he is after, he follows up this claim by showing an image of a model of the house balloons blurring into a cloud.[73]

Callejas' competition entry has had little local impact at Heathrow. In the data-genealogy tree as I have drawn it for this case study the entry comes at the end of the protest movement. Nothing follows it. Greenpeace has since withdrawn from the Heathrow site and no balloons were ever flown into the Heathrow airspace. In its final presentation the project is not meant to be taken literally; Callejas last words on it emphasize its presence as an image only.

While an architectural image may change hearts and minds, Callejas' images are not of the sort intended to inflame emotions and provoke action. Instead they present sublime scenarios that invoke a daydream-like sensation of contemplating reality and yet being profoundly detached from it. The Heathrow Airplot/ Weightless project suggests that architecture, at least for Callejas, has its core interests in a separate realm from the data-assemblage. It suggests that anxiety about architecture impacting the data-driven city may be misplaced. Callejas provides an example of critical distance from the data-driven city, illustrating its absurdities, mining it as material for aesthetic effect. This is one possible role for the architect in the data-driven context.

5.2.5 Architecture's impact on the data-driven city: synthesis, and snowballs

The impacts created by the actors presented in this section provide a valuable contrast to the lack of agency the paradigmatic data-genealogy tree seemed to imply for the architect in section 5.1.[74] Instead of policy leading to data-driven monitoring and instrumentalized architecture, in these cases designers have initiated change via practice or research that has led to large-scale communal or regulatory change. In the data-genealogy tree, we can see how these designer's projects have initiated systemic change, with new developments in technology, data-gathering practices, institutions and policy glomming on to an initial architectural happening. For instance in fig. 5 the ***circular urbanism*** movement in Amsterdam was initiated by *de Ceuvel* following the actions of Sascha Glasl and Eva Gladek (among others).

The impact of *de Ceuvel* did not emerge from nowhere but built off a vaguely-defined desire by the Amsterdam municipal government to foster sustainable urbanism at the abandoned shipyard in 2009. The designers (*space&matter, Metabolic and DELVA)* interpreted with great creativity the city's broad guidelines within the physical constraints of the site and budget (choosing to use recycled houseboats for example.) They synthesized various values (sustainability) with technological ideas (smart grid, urban metabolism) and constructional ideas (reused building materials, remediative landscape) into built form and a communal happening. Most importantly the designers (here Gladek in particular) crafted an actionable conceptual core for the project by taking vaguer notions of sustainability and shaping them into a more precise idea of circularity. Without these interpretative and synthetic actions which produced tangible evidence of built form and a working technological prototype- the vague policy aspirations of the city government would remain not only unrealized, but without meaning. *De*

73 Ibid. 5:32
74 See 5.1.3

Ceuvel is meaningful built form in that it was recognized by many people from diverse backgrounds as a reflection of their own as-of yet unarticulated hopes for the city. This wave of community enthusiasm was crucial in the snowball effect of the project: individuals and institutions wanted to be part of the success and ideas behind *de Ceuvel*, and the Circular Buiksloterham movement was set in motion.

Interpretation of a brief and synthesis of many diverse elements into a coherent built whole are the traditional activities of the architect (and urban designer and landscape architect) but in the data-driven context they appear to be more urgently needed to offer meaning and direction to a new kind of urbanism. Designer's need to stretch their disciplinary boundaries to work synthetically in this undefined and technologically driven environment: taking vague aspirations and giving them greater specificity, gathering together a wider array of technologies, needs, and activities into spaces and forms, and providing an actionable conceptual core that can capture hearts and minds.

Is there a recipe for making an impact as a designer in the data-driven city? Above all it seems to require collaboration – though I have highlighted individual voices, none of these individuals would have been able to act alone. Often their actions emerge from a milieu of growing concern and act to catalyze growing chains of action of which policy change is only one.

Though there is no one recipe for impact, I believe each of these examples offers valuable lessons for emulation and could represent means of action for designers in the data-driven context. I would enumerate three most evident lessons as follows:

> (1) Develop metrical tools to articulate the value of your interests and design. Ong Boon Lay provides an example for this mode of impact.
>
> (2) Gather a community to make a project possible and to change mindsets. Sascha Glasl's work with communities provides the best example for this mode of impact, but Eva Gladek is particularly articulate on how working together in a team changes mindsets.
>
> (3) Build something. The architectural artifact as physical prototype has great power to convince the skeptical, change minds, and act as a gathering point for the as-of yet unrealized or un-articulated aspirations of a community. Eva Gladek's experience building prototypes at *de Ceuvel* illustrates this mode of impact.

Still mysterious however, is the specific importance of architectural form to making impact in the data-driven city. In these case-studies we have a clear understanding of environmental problems, environmental flows, the exchange of money, social interactions and aggregations – but architectural form remains persistently present and yet unvalidated. Glasl's battle to preserve his design of the boardwalk of de Ceuvel is a good example. He knows it is important, but has difficulty explaining and justifying it to the group. In the end everyone likes it but because no one can explain it, not least Glasl, who refers to it as 'magic.'[75] Has our collective emphasis on a quantified city, as financiers, social-networkers, and urban metabolists become so over-powering that we no longer have the vocabulary to explain, argue for, and legitimize architectural form? In a next section I examine what the case studies of this thesis can show us about the influence of the data-driven city on architectural form, and the role architectural form plays in this new urbanism.

75 Glasl, Sascha. 2014. Lecture, Academy of Art University. San Francisco, CA. 40:02

5.3 Results: architectural form within the data assemblage

Research Question 3: *If the architectural artifact is embedded in an urban data-assemblage, and if it participates in a form of coproduction**, is there evidence of a formal change in an architectural type or its elements associated with embeddedness in the data-driven context?***

The cumulative evidence from the case studies I have assembled does not suggest a discernible formal style associated with architecture in the data-driven city. I do, however, see evidence to make three more limited claims about the formal nature of architecture in the data-driven city related to the way architectural form is created at the scale of its elements and at the larger scale of the organization of those elements within physical frameworks and distributed 'clouds'.

5.3.1 Elements: overwriting the allography of architecture

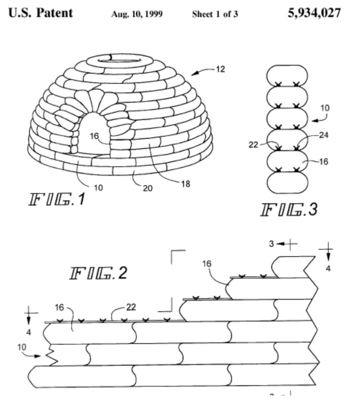
The data-driven context encourages the use of discrete, replicable architectural pieces with consistent quantifiable properties and behaviors. As a result of a systemic desire for quantifiable pieces, architecture in the data-driven context is chunky: a non-homogeneous mixture of standardized elements and unique custom-built constructions. The standardization of elements in this context is not identical to the standardization of 20th century mass-production, but is a more fluid procedure working via multiple vectors to ensure not a totalizing standardization, but a limited conformity adequate to larger systemic needs- an alternative and perhaps more accurate term might be *parametrization*.

I have chosen to call the discrete, replicable pieces of architecture ***elements***. Examples of elements in my case studies include Amsterdam's green roofs, Heathrow's adobe domes, HDB's apartment types, Schoonschip's concrete buoyancy tanks. These elements are quantifiable in that they can be relied upon to, for example, retain X liters of water, reduce noise by Y decibels, house an average nuclear family with a rate of satisfaction exceeding Z percent. The quantified properties of these elements are entered into large urban databases, and their dependable behaviors fulfill the necessary functions in larger automated urban systems.

I must acknowledge a debt to Koolhaas' 2014 Venice Biennale, 'elements of architecture,' which depicted architecture as made of discrete pieces with their own independent genealogies. This research also permitted Koolhaas to frame a parallel critique of the smart city: 'Soon, your house could betray you.'[76] The elements I identify in my case studies, however, do not entirely correspond to Koolhaas' elements. The elements biennale focused on a limited set of common elements: floor, wall, ceiling, roof, door, window, façade, balcony, corridor, fireplace, toilet, stair, escalator, elevator, ramp. The goal of the biennale was to shift the perspective of the profession from a fantasy of homogeneous masterworks toward the more mundane reality of architecture as collage and bricolage. The term elements, in my research as I would use it describes the handholds that the data-assemblage has within the architectural artifact. While some of the elements in my case studies would fit the categories of the 2014 biennale– green roofs in Amsterdam, or void decks in Singapore's public housing – others, like de Ceuvel's houseboats, Nader Khalili's adobe huts, or HDB unit types, would not. These things might fit more readily under the category of unit or module as it was used in the discourse on megastructure in the 1960s:

76 Koolhaas. 2015. "The Smart Landscape.' in ARTFORUM

FORM: ELEMENTS

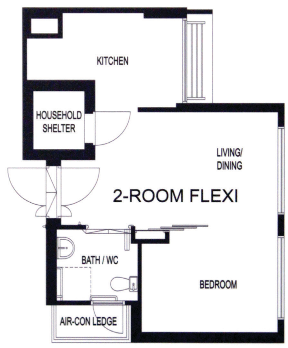


11. Super Adobe Patent 1999. Nader Khalili.


12. Construction Smallberry Green 2014. SmallEarth.

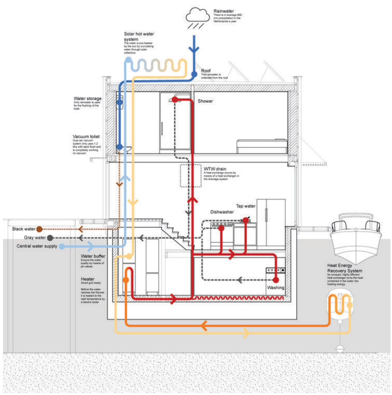
13. Intensive Green Roof Detail. Amsterdam Rainproof.


14. Am.Rainproof example Green Roof. De Dakdokters



15. 2-room Flexi Unit 2018. HDB.


16. Kampung Admiralty, residential towers.


17. Houseboat Circular System. Schoonschip.


18. Construction of standard floating conrete base. Schoonschip.

> "Professor Tange presents a proposal for a mass human scale form which includes a megaform, and discrete, rapidly changeable functional units which fit within the larger framework."[77]

The conflation of the terms *element* and *unit* in this text may be forgiven as it permits me to describe a set of un-dissolvable architectural pieces that provide a point of quantification and monitoring in the data-driven context. These elements are controlled by standards.

Standards written by non-architects control- at least in part- the elements I describe in my case studies and ensure their required parameters and function within larger data-driven systems. The control of the element by an exterior actor complicates and/ or overwrites the allographic process by which the architect communicates his vision for the execution of the architectural project[78].

A standardizing document explains and enacts the parameters and performance of architectural elements. It can be a performative text like the UK's *Airports Authority Act* of 1965, 'which provides for grants towards the cost of sound-proofing buildings.'[79] Architectural drawings can also function as standardizing documents. This is the case for the detail that defines the 'intensive green roofs' used in Amsterdam, or the floor plan that defines a "2-Br Flexi Unit' for Singapore's HDB. (see figs. 13,15) In data-driven urban systems the document that controls the standardization of an elements is increasingly an engineer's *functional system diagram*.

In the Schoonschip project in Amsterdam, the *functional system diagram* created by Metabolic determines how each house boat exchanges heat with the canal, and how it exchanges energy and waste with the central dock.(see fig. 17, 19-24) As a result each of Schoonschip's houseboats must be built on a concrete buoyancy tank with embedded manifolds for heat exchange with the canal and specific connections for the smart dock. Metabolic includes all their instructions for architectural construction in a Kavelpaspoort or parcel passport which includes the *functional system diagram* and describes how the individual houseboats need to be shaped and behave to interface with the apparatus of the smart community. Extracts from Metabolic's *kavelpaspoort* show influence on diagrammatic control of electric and water systems (figs. 19,20) but also of the spatial distribution of these systems in section (figs. 21,22) as well as their constraints on the plan (fig. 23) and more general constraints on facade (fig. 24). Each of the architecture's traditional allographic tools (plan, section and facade) accept some degree of control from the engineers at Metabolic in Schoonschip's *kavelpaspoort*.

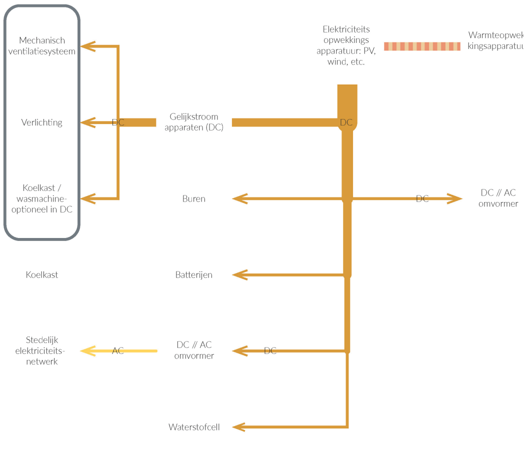
While standards have controlled the construction of architecture for centuries, contemporary efforts to link elements together in distributed networks – like *Schoonschi*p's smart grid – result in an expansion and acceleration of this process. Just as past regimes of standardization influenced the form of architecture, contemporary standardization has formal impacts that must be navigated by the architect.

77 Maki, Fumihiko. 1964. I*nvestigations in Collective Form.* p.9

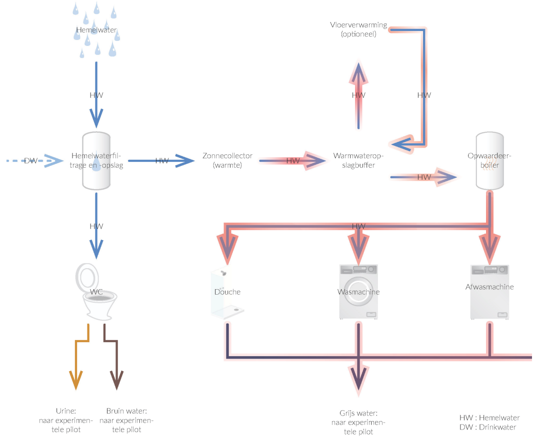
78 Carpo. 2011. *The Alphabet and the Algorithm.* Section 1.2 P.15-20 For a discussion of Nelson Goodman's description of allographic arts, 'scripted by their authors to be materially executed by others,' and a historical overview of the practice of allography in architecture. We might also recall Robin Evan's description in *The Projective Cast* of the difficulties encountered by Hans Scharoun in controlling the construction of the Berlin Philharmonic. Instead of constructing a complex form, the projects discussed here construct complex social technical systems and require new regimes of control via drawing sets shared among multiple authors – not just the architect.

79 Parliament. Civil Aviation Act 1971. P. 26

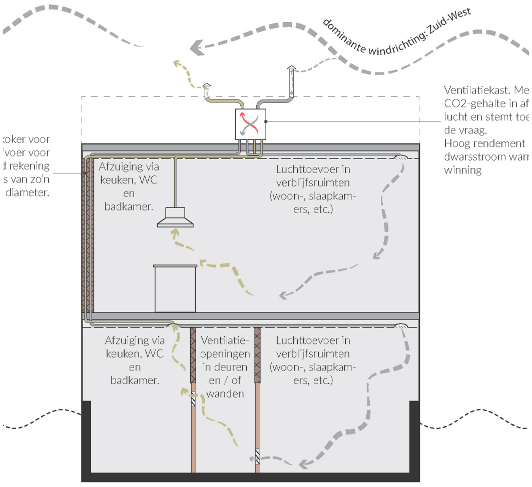
FORM: ELEMENTS (functional system diagram)



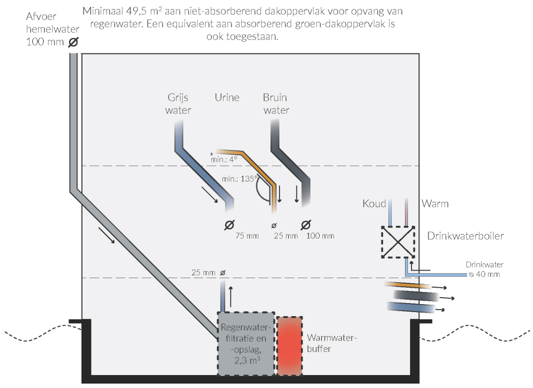
19. Schoonschip electrical system diagram (Metabolic)



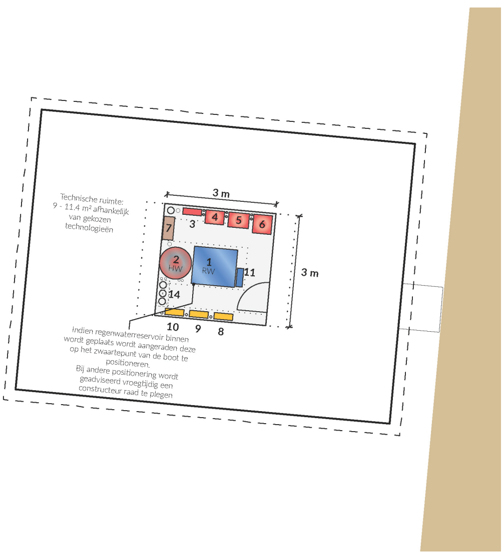
20. Schoonschip water system diagram (Metabolic)



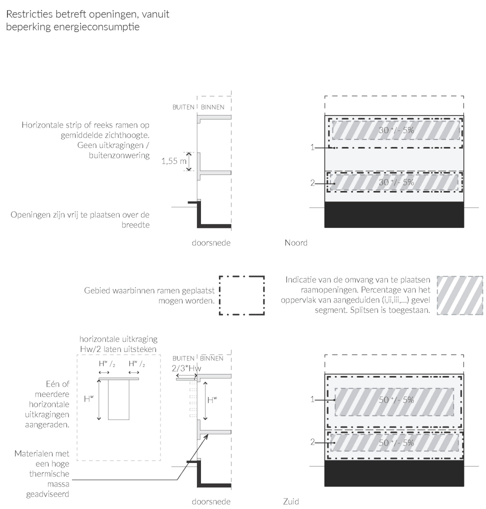
21. Schoonschip ventilation system diagram (Metabolic)



22. Schoonschip mechanical systems diagram (section) (Metabolic)



23. Schoonschip mechanical systems diagram (plan) (Metabolic)



24. Schoonschip facade restrictions diagram (Metabolic)

Standards encroach on an architect's control over the form of a design, but also permit the integration of knowledge from other disciplines and actors. In WOHA's projects for HDB the plans of the public housing units are standards which the architect must accept and integrate into their design. The unit plans are developed by designers at HDB who bring to the table the generational knowledge of their institution.(fig.15) Similarly Metabolic's instructions in the *kavelpaspoort* may limit some aspects architectural form-making, but ensure the embedding of Metabolic's domain knowledge in the *Schoonschip* houseboats.

Standards also always require *interpretation:* adaptation of general guidelines within a specific context in a meaningful way. In the case of WOHA's *Skyville* each apartment type is present in three different variations, that allow them to craft small neighborhoods and the overall form of the building.(fig. 28) At *Schoonschip*, the functional system diagram, while it predetermines some parameters of the footprint, roofs and facades of the houseboats, nonetheless permits formal differentiation. In Dutch projects like *Schoonschip*, *Cityplot Buiksloterham*, and *de Ceuvel* the scenographic variety of façade and roof designs overlaid on the standardized dimensions and elements of their 'circular' systems produces projects that are *decorated machines*. The architects seem to compensate for the standardization and integration of data-driven systems by promoting the image of diversity elsewhere. The model for this formal strategy looms in the mist across the IJ: MVRDV's Silodam.

Supporting function of a larger urban/ecological system is important to many of the architects in the case studies I have looked at. In these cases the design control that they relinquish to a standardized element is not perceived as a loss, but as supporting a desired larger-scale performance to emerge. Sascha Glasl has described his active efforts to recruit Metabolic to the de Ceuvel project, to solicit their expertise, and defines his primary goals in alignment with their goal of producing a sustainable economy.[80] Glasl's also professes the view that the architectural artifact should emerge from many voices.[81] Shared authorship via closely followed standards is crucial to achieving goals that require coordination of parameters and behaviors – in this case building a functioning circular community.

While each of the above examples involves an architect working to incorporate a standardized element into his design, a contrary example is presented by the Heathrow adobe domes. With the Heathrow domes an architect's design is incorporated into a data-assemblage without the architect's intervention. The Heathrow domes use a patented construction technology first developed by architect Nader Khalili as a way of creating shelters on the moon for NASA in the 1980s, and later adapted it to be used as an earthquake proof refugee shelter. Even in an unexpected context, used for a different purpose, and executed by different actors after the death of Khalili, the domes near Heathrow are unmistakably formally linked to him. The formal consistency of these domes has been ensured not only through the patent, but Khalili's choice to make the patented technology available free for non-commercial use, and his establishment of a non-profit organization Cal-Earth to teach and propagate the technique. Julian Faulkner, the founder of SmallEarth and builder of the Heathrow domes, learned the building technique at a Cal-Earth training. Because Khalili's domes have dependable structural (and acoustic) characteristics they are amenable to integration in a data-assemblage as functioning physical nodes- propagating meme-like in the absence of their creator.

80 Glasl, Sascha. 2014. "Space & Matter." Lecture, Academy of Art University. San Francisco, CA. 28:06
81 Ibid. 4:49- 5:20

The menus of architectural details made available via *Amsterdam Rainproof* or *GroenBlauw Netwerken* work in a way similar to the propagation of Khalili's dome design.[82] Basic drawings for relevant design interventions are presented in a menu, often referencing their original creator or authors or exemplary projects, for the use of a wider, informal public. Amsterdam municipal government encourages the propagation for designed elements which meet certain standards they hope to attain for their city- in the case study I highlight in particular the propagation of green roof designs. An architectural idea is passed on and re-used by many actors, changing the built form of the city without the oversight of the original designer.

In the data-driven context the allographic art of creating architecture is partially overwritten by standards requiring the architectural artifact to incorporate pre-defined elements with specific parameters and/or behaviors. These elements enter the body of the architectural artifact as semi-digestible chunks, defined by non-architect authors. While construction standards have existed for many years, some relatively new types of standardization are rapidly growing in the data-driven context. In particular, the *functional system diagram* is growing in allographic power as the elements of architecture seek to organize into rapidly interacting functional wholes: smart grids or circular systems of resource/waste flows. The growing presence of standardized elements obliges the architect to assemble a heterogeneous architectural body which must include, organize and explain the presence of these foreign elements. In the case studies of this thesis I have observed two distinct strategies for organizing architectural form filled with standardized 'smart' elements. I describe these strategies, frameworks and clouds, in the following sections.

5.3.2 Frameworks: collective form in the data-driven city

The design problem confronting the architect in the data-driven city is to assemble a collection of standardized and increasingly smart elements into an architectural whole. By framework I designate one strategy for assembling a collection of elements by crafting a physical construction linking an array of elements and determining their spatial relations to one another. Unlike the purely topological organization of a network, where spatial translation of a node does not alter the pattern of connectivity, the framework has a specific and meaningful spatial condition that may complement or complicate its connective function. The framework as an architectural construction also has a didactic function, teaching its inhabitants how to recognize and operate within the collective.

Examples of frameworks in my case studies exist in the Singapore and Amsterdam case studies. They share some features although their purposes are different. If we compare the Schoonschip plan (fig.25) and WOHA's Skyville (fig. 28), we see a formal similarity: a zig-zagging path connecting clusters of standardized units. Here the connecting element – the zigzagging walkway – provides circulation connecting the houseboats or dwelling units. The walkway is a space of social encounter, widened to accommodate gardens and open space for extemporaneous social activity.

More than just fattened circulation space, the framework didactically articulates the formal conditions of community, defining the grouping of elements and common space between them. *De Ceuvel*'s village-like clustering of houseboats is linked by a sinuous boardwalk, which obliges the visitor to take a longer path through the site, enforcing the importance of a view across the canal and the need to observe and interact with the community of creative-class weirdos in their landed-houseboats.(fig.26)

82 See 3.3.1, 3.3.2, and www.rainproof.nl and nl.urbangreenbluegrids.com.

A glance at the plan of *de Ceuvel* is enough to ascertain that the purpose of the boardwalk is not purely connective: it comes tantalizingly close to providing shortcuts at two central points before immediately swerving away. In interviews the designer, Sascha Glasl, acknowledges that the path imposed by the boardwalk is frustrating but explains that he wanted to force visitors to see the best views.[83] A rope swing has since been installed at the central pinch point of the boardwalk, allowing people to bypass the extra loop imposed by the designer. Glasl seems delighted by the lengths people have gone to overcome the deliberate inefficiency of the path he designed, explaining that it has become a playful moment in the project.[84] While the architect may provide the framework to didactically establish the spatial conditions of a new community, perhaps the best evidence of an actually functioning community is their ability to defy the inconveniences imposed by the architect.

As in *de Ceuvel*, the framework determines the inter-relationships of sight and orientation between elements of the project and the multi-functional open spaces framed between them. The terraced gardens of WOHA's *Kampung Admiralty* fill the interstices between towers of elderly-friendly housing and a large health clinic. Views and paths between these two separate but co-dependent groups of elements are mediated by gardens. In WOHA's Skyville massive vertical shafts are framed between towers of dwelling units, increasing cross-ventilation, allowing the tower to rise taller by broadening its base, but also creating a space rich in visual and auditory potential for interaction above the promenades and gardens of the skybridges.(See Chapter 4 frontispiece.) WOHA calls these sky villages:

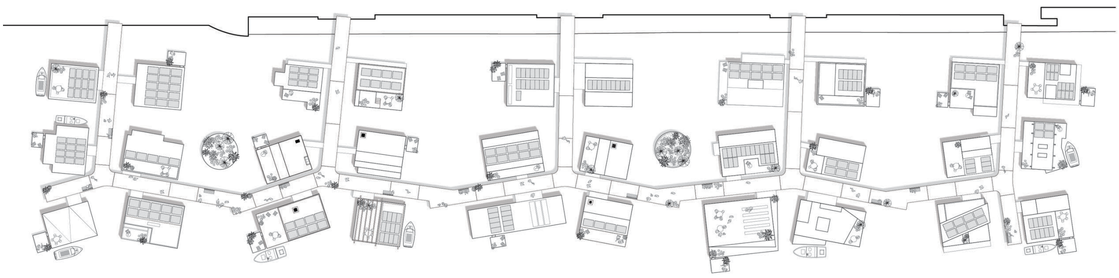
> "Architects and planners are now obliged to regenerate sociability – human interaction – at the scale of the city, and within the apartment complexes. […] Sky Villages can be layered within high-rise towers to form clusters of apartments/families, which effectively function as visually and aurally connected aerial neighbourhoods […] Open landscaped areas on Multiple Ground Levels can perform as 'village greens' for the 21st century […] communal areas adjoin the circulation routes, as they would in villages […] Sky Villages can be overlooked and overheard from every apartment in the cluster, so that community connection is enhanced, and neighbourhood security can be maintained."[85]

In this quote we can read WOHA's design process – units are grouped into vertical 'clusters' around a communal area, the 'sky village', which is linked to a circulation path. The result is meant to be overseen and overheard by the surrounding clusters. This is a version of the precinct concept developed by HDB in the 1980s, but now placed many stories up in the air: a vertical stacking of precincts.[86] In WOHA's projects the framework is analogous to the connective structures of the megastructure movement whose heyday was many decades earlier.

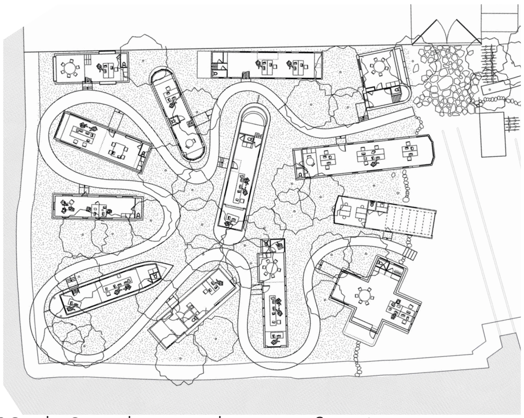
Echoes of the megastructure movement of the 1960s are especially discernible in WOHA's visionary follow-up to Skyville called *Permeable Lattice City*.(fig. 30) This urban vision expands the skybridges of Skyville to the size of six-lane boulevards and proposes subway cars running between the towers of dwelling units. In *Permeable Lattice City* all the city has become one large building. The comparison

83 Glasl, Sascha. 2014. "Space & Matter." Lecture, Academy of Art University. San Francisco, CA 37:07 "here is a boardwalk on the other side why don't you put them closer? Then you force the people to go to the nice side which is here on this side. I said, 'Yeah yeah yeah.' I will just force them to have the best view and then they can go back.
84 Ibid. 37:20 "You know one day you are not there and they put a little rope here and then now it's like the perfect shortcut for everyone. A lot of kids, not only kids, are playing here. I think everyone uses this rope here."
85 Bingham-Hall and WOHA. 2016. *Garden City Mega City : Rethinking Cities for the Age of Global Warming* p.68
86 See 4.3.1.

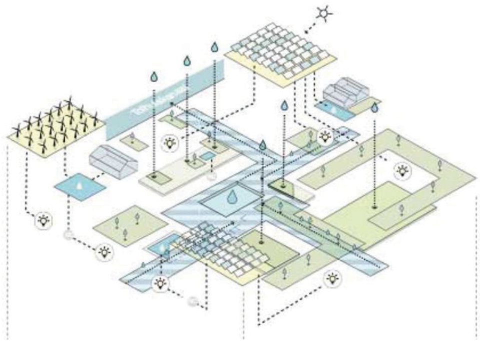
FORM: ARRAYS (FRAMEWORKS)



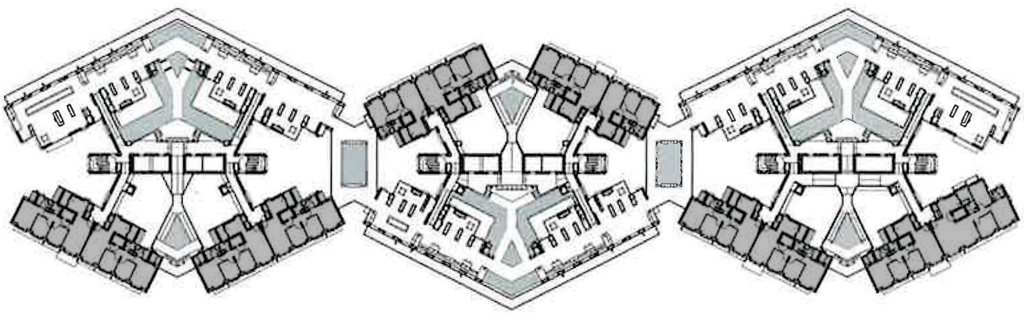
25. Schoonschip masterplan. space&matter.



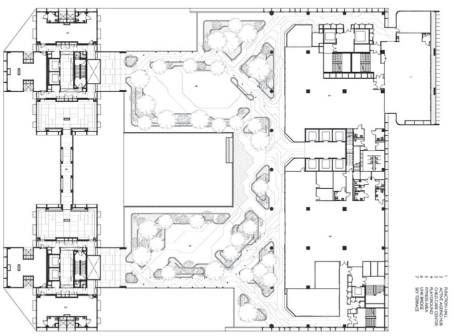
26. de Ceuvel masterplan. space&matter.



27. Cityplot Buiksloterham Roof network. DELVA, Studioninedots



28. Skyville 36th floor plan. WOHA.



29. Kampung Admiralty 6th floor plan. WOHA.

30. Permeable Lattice City. WOHA.

to Tange's 1961 Tokyo Bay masterplan or Archigram's Plugin City seems inevitable. Projects like *Schoonschip* and *de Ceuvel*, though of much smaller scale, cluster capsule-like units along a central branch in compositions similar to megastructural projects like Candilis Josic Woods' 1961 plans for Le Mirail in Toulouse. Given these similarities, and that some of the architects I describe actively refer to their work as megastructure, should the 'framework' idea I propose be recast as an extension of the megastructure project?[87]

WOHA actively adopts the mantel of megastructure, calling their projects, 'domesticated megastructures,' in their 2016 book Garden City Mega City.[88] The megastructural idea matches their interest in large high-density constructions which they describe as prototypologies, or functional components within an envisioned future ecological city.

> '20th century cities were planned as collections of segregated components, which were measured in terms of their economic productivity […] rather than their overall contribution to the city as components within a self-sufficient system.' [89]

Their vision is of the future is of an integrated human/ecological system, in which each building 'plugs in' to the larger urban machine:

> 'An individual innovation can only be deemed successful if it serves as a fundamental component of a system that performs better than ever before.'[90]

WOHA in these passages attests to a mindset which conceives of architecture as a functional, quantitatively assessed pieces within an urban system. Their design strategies – the seven strategies they lay out in Garden City Mega City – further break down the architectural artifact into standardized elements and frameworks each with their own function (and quantitative monitoring) in the urban/ecological whole. While these ideas echo the plug-in nature of 1960s megastructure, I would emphasize several significant differences between the architectural artifacts I have studied in the Singaporean and Dutch case studies.

WOHA's work presents large scale lattices that, though they do occasionally resemble a megastructural node-network organization, diverge from this precedent with an indiscrete fuzziness. Vegetal overabundance that exceeds human control defines the aesthetics of WOHA. The garden moves indiscretely up and down WOHA's facades linking the true ground of the city with a multiplicity of artificial grounds. In parallel a regime of ecological quantification, with its roots in the research of Ong Boon Lay, makes these gardens more than just ornament by linking them to larger ecological systems.

WOHA's work also distinguishes itself from megastructure by a hard-nosed economic pragmatism. Though lush hanging gardens may be the most memorable image of WOHA's work, these gardens only exist as links between much larger clusters of generic program: apartment units, hotel rooms, medical clinics, office space. WOHA organizes these clusters of elements into utilitarian stacked grids,

87 In many ways these projects also echo the structuralism of architects like Herman Hertzberger, Aldo Van Eyck, Piet Blom. In my discussion below I have chosen to focus my reflections on megastructure alone largely for the sake of clarity, but I feel that a more in depth discussion is warranted that would expand comparisons to the various strains of structuralism and also take into account their efforts at participatory design. A parallelism between recent architectural work and structuralism is discussed in: Valena, Tomáš. (2011). Structuralism reloaded : Rule-based design in architecture and urbanism. Stuttgart: Edition Axel Menges.

88 Bingham-Hall and WOHA. 2016. p. 18

89 Ibid. p. 194.

90 Ibid.

a strategy especially apparent in the HDB projects where budgets are tight. The standardization and repetition of these gridded clusters responds to the fundamental economics behind each project, achieving a bottom-line economic feasibility which sustains the extravagant sky-gardens. While in their writings WOHA highlights the quantification of ecological and social parameters of their work, their work belies an underlying economic pragmatism. Even in the utopic vision of Permeable Lattice City their economic pragmatism is reflected in the vertical ‘pillars’ which support the lattice of skygardens: they are composed of generic stacks of repetitive housing units reminiscent of HDB slabs. This formal pragmatism, striking in comparison to 1960s megastructure, is particularly revealing in contrast to the formal extravagance of the digital formalism of the 1990s and 2000s. WOHA emphatically communicates that gridded clusters of standardized elements provides a realist economic basis to even their most fanciful visions.

Unlike WOHA, the Dutch designers reviewed in the case studies would be unlikely to identify their work with megastructure, particularly because of the effort they put into developing a participatory approach to design. Megastructure produced an image of bottom-up formal diversity in what was in reality a monolithic whole created by a single designer. Projects like *de Ceuvel*, *CityPlot Buiksloterham*, and *Schoonschip*, in contrast, make space for other actors to contribute to the overall form of the project in a process that hybridizes architectural design and masterplanning.

Studioninedots’ *CityPlot* from Buiksloterham defies a megastructural reading via a pluralistic framework. The framework in this masterplan/architecture hybrid is a pattern of ground parcelization that permits large-scale and small-scale actors to contribute. Corner parcels are made large enough to house condominium developments initiated by banks or Amsterdam’s large housing cooperatives. Several of these large projects were pre-allocated for designs by the masterplan architect. Smaller plots are designated for self-built houses and small business financed by individuals. Construction on these smaller plots is controlled by a *kavelpaspoort* which, as in the case of Schoonschip, controls some formal characteristics of the constructions and ensures their ability to participate in the holistic sustainable systems of the project. A system of alley-like pedestrian passages through the center of the block links the units together via a central open space which is integrated with the project’s overall water management system. The green roof system diagram (fig. 27), produced by DELVA landscape architects, reaches an accommodation between a holistic systems approach and small-scale formal auto-determination. The resulting project mixes a village-like image of vernacular formal variety with project-wide regulation of sustainable systems.

Schoonschip is also a masterplan/architecture hybrid. Though *space&matter* have designed the connecting framework – the smart dock – and at least one of the houseboats, the other houseboats are produced by different architects for their individual owners. Formal similarities and systemic functional uniformity are once again guaranteed by the *kavelpaspoort*. The result is a deliberately framed diversity. The overall form of the Buiksloterham projects, *de Ceuvel*, *Schoonschip*, and *CityPlot Buiksloterham*, is more village-like in its diversity of scales and scenography than it is megastructural. The systems thinking behind the projects however produces a regularity of form and organization that, communicates the presence of its organizing logic.

Formal differences between contemporary data-driven projects and 1960s megastructure also reflect fundamental economic differences between the two eras. Tange noted that his invention of the megastructure was inspired by the fact that, 'the accumulation of capital has made it possible to build in large-scale operations.'[91] The pharaonic infrastructure projects of the post-war nation states which inspired Tange's design of the Tokyo Bay masterplan were the result of massive capital accumulation driven by rapidly developing economies. The Buiksloterham projects, in stark contrast, emerged from efforts to return to building in Amsterdam Noord after the financial crisis of 2007. With large institutions unable to finance the expensive remediation necessary for polluted sites like de Ceuvel, small actors like *space&matter* were allowed to experiment and see what they could come up with. These Dutch post-crisis projects are all to some extent crowd-funded and crowd-built, pragmatically tapping unconventional sources of labor and capital. This economic pragmatism echoes a separate contemporary investigation of the 'Discrete' taken on by Gilles Retsin:

> '[The Discrete is] focused on an economy of reality. The Discrete is willing to trade a few degrees of resolution, formal differentiation and 'excitement' for scalability, impact and agency, for example, to rethink the production of housing. It is also willing to trade elegant but academic material optimisation for large amounts of cheap materials if that will increase access and efficiency. It is not afraid of seriality, long straight lines, bulky elements, unfinished forms, raw materials – or even boxes […]'[92]

Participating in the data-driven context, architects in our case-studies have separately pursued similar formal strategies of establishing frameworks to organize and connect groupings of parametrized and digitally linked architectural elements. These formal strategies are similar, but do not constitute a shared style of the kind described by Retsin: the Singaporean and Dutch projects have more in common with other architectural projects in their own region than with each other. Though the frameworks in the case studies are sometimes evocative of the megastructures designed at the beginning of the information age, they remain different in scale, function and appearance. The most significant difference from Megastructure is the ability of the current generation- particularly the Dutch- to accommodate and give form to the participation of diverse actors, an affordance I return to in the final section of this thesis.

To respond specifically to the research question, I would conclude that the association of the framework/element formal strategy with the data-driven context is firmly established in the case studies. In a project like Schoonschip, in particular, the goal of creating a circular project leads to parametrization and digital interlinking of elements via a functional system diagram, and the establishment of a shared infrastructural dock which permits interfacing between units (sharing data, energy, etc). In this case we can trace exactly why the formal strategy is used and how it arises from a data-driven process. Furthermore, the element/framework trope is repeated in many of the projects in the case studies, as reviewed above, to the extent that I would claim a more general association with the data-driven context based on the simultaneous need for quantifiable elements and architectural wholes.

By inserting large-scale frameworks into assemblies of semi-autonomous elements the architectures discussed in this section betray a certain conservativism, or resistance to a purely data-driven architectural condition. These architectures deploy top-down frameworks to organize inchoate groups of elements into understandable, useable assemblages. A separate line of contemporary architectural thinking, however, seeks to allow architectural elements to inhabit bottom-up assemblages without the imposition of a large-scale framework. To explain his recent description of a 'particlised' architecture,

91 Maki, Fumihiko. 1964. *Investigations in Collective Form*. p.11. This passage discusses the quote from Tange, which is taken from an article in Japan Architect, October 1960, titled "Technology and Humanity."
92 Retsin. 2019. 'Discrete Architecture in the Age of Automation.'

Mario Carpo cites Kengo Kuma:

> "In the past, such a flat [particlised] world was only thought to be a mess, and unaccountable: something that could not be handled. […] However, contemporary technology makes it possible to process this mess of specific particles without the introduction of structure, hierarchy, or assembly."[93]

In the architecture of the 'Discrete' as characterized by Carpo or Retsin we see a very different kind of 'chunky' architecture, which would make designer-imposed frameworks obsolete. The architecture of the 'Discrete', however, still remains very much architecture: singular sculptural objects that occupy a site and define a potentially habitable space. In the case studies of this thesis, in contrast, a more radically distributed type of urban form can be discerned which abandons singularity of site and space for cloud-like dispersion following the functional logics and constraints of the data-driven city, and is the subject of the next section.

5.3.3 Clouds: distributed form in the data-driven city

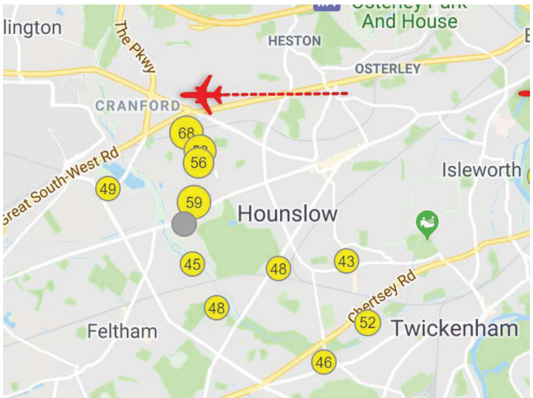
The cloud, unlike the framework, connects groups of architectural elements without a physical connection but rather via the data-flows of an interactive map. Though not physically linked, the spatial condition of each individual element in the cloud is meaningful in relation to the city and in relation to the other elements of the cloud. Collectively the cloud works to produce some larger-scale effect, like the urban ecology of URA's LUSH program.(fig. 37) Unlike a network, the cloud is mostly indifferent to topological conditions (patterns of connectivity), or to directional patterns of flow. Indeed, as I will describe below most of the clouds described in the case studies are centralized networks, where the cluster of physical elements all link back to a centralized map which monitors and controls them. As architectural form the cloud is not visible in its whole to an individual observer and is obliged to signal its presence and function via data-visualization typically as an interactive map. If the connecting framework in the cloud is not longer architectural, but a piece of software, does the architect have any business working with clouds, and do clouds even constitute architectural form?

While I will argue that clouds represent a potential domain of architectural action, I must acknowledge that most clouds in the preceding case studies are assembled and managed by large institutions or municipal governments. At Heathrow the cluster of noise sensors and the online map that communicates their data to the community are a good example of an institutionally managed cloud of elements (here managed by *Heathrow Airport Holdings Limited,* the operator of the airport).(fig.31) The adobe huts at primary schools near Heathrow are also an example of a cloud of elements.(fig. 32) While no public map of the huts exists to my knowledge, they function together to permit outdoor learning at primary schools near Heathrow.[94] This cloud is managed between the primary schools near Heathrow, who control the use of their grounds, and the operator of Heathrow Airport who provide partial funding for the adobe hut construction. The criteria by which the domes are funded, their proximity to Heathrow's noise contours, will be closely tracked by *Heathrow Airport Holdings Limited*, in particular as the 3rd runway expansion will likely bring new primary schools into the airport's noise contours and may provoke an extension of the program.

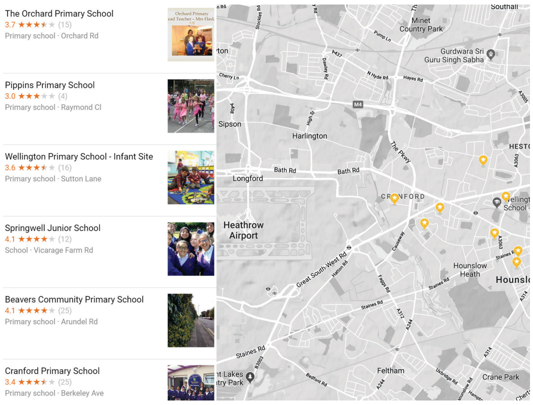
93 From Carpo. 2019. "Particlised: Computational Discretism, or The Rise of the Digital Discrete." The quote comes from Kuma. 2004. Materials, Structures, Details, p 14.
94 See 2.4.1. See references for full URL.

CLOUD	ASSEMBLER	FUNCTION/ MOTIVATION	ELEMENTS	LINKAGE
HEATHROW NOISE SENSORS	Heathrow Airport Holdings Limited	monitor/communicate aviation noise	noise monitoring stations	online interactive map (WebTrak)
HEATHROW ADOBE DOMES	Heathrow Airport Holdings Limited	permit outdoor learning at primary schools	adobe domes (superAdobe patent)	agency map
WEIGHTLESS	Luis Callejas Landscape Architecture (LCLA)	protest expansion of Heathrow airport	helium-filled reproductions of homes	architect's map, image
AMSTERDAM GREEN ROOFS	Gemeente Amsterdam (municipal govt.)	retain runoff, raise awareness	green roof	online interactive map
OVERSTROOMIK. NL	Rijkswaterstaat	flood shelter awareness	all buildings in national database	online interactive map
SWEETS HOTEL	space&matter (architects) Grayfield (developer) Seven New Things (hotelier)	reuse obsolete bridge houses as hotel rooms	bridge houses	online interactive map
LANDSCAPING FOR URBAN SPACES AND HIGH-RISES (LUSH) PROGRAMME	Urban Redevelopment Authority (URA) Singapore	promote urban ecology	skygardens, roof gardens, planters, vertical gardens, gardens	urban masterplan, agency map
HDB HOUSING MAP	Housing & Development Board (HDB) Singapore	promote awareness of market for HDB apartments	HDB apartments	online interactive map

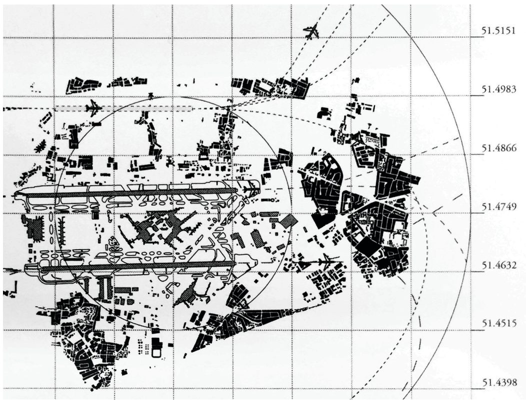
FORM: ARRAYS (CLOUDS)



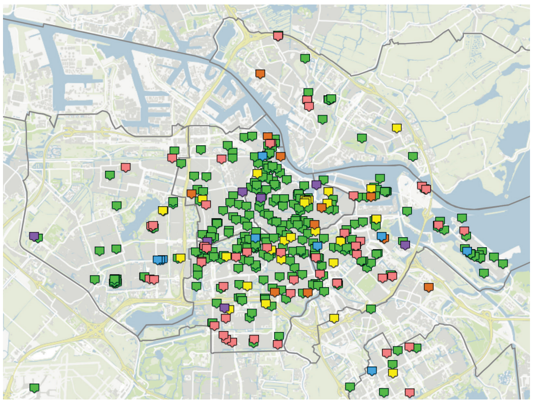
31. Heathrow noise sensors via WebTrak.



32. Heathrow Adobe Huts. Author's map via Google.

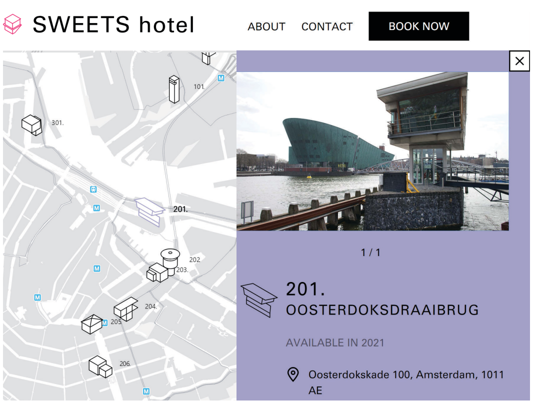


33. Airplot competition, Barrage balloons map. Drawing LCLA.

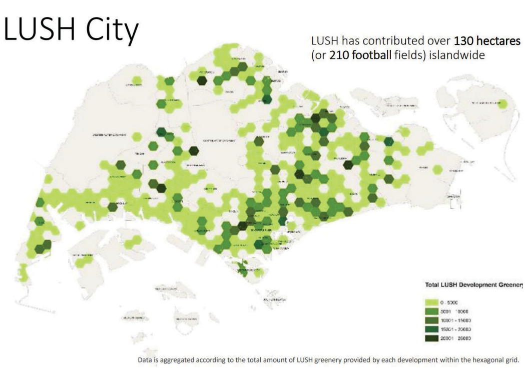


34. Green Roofs via maps.amsterdam.nl.

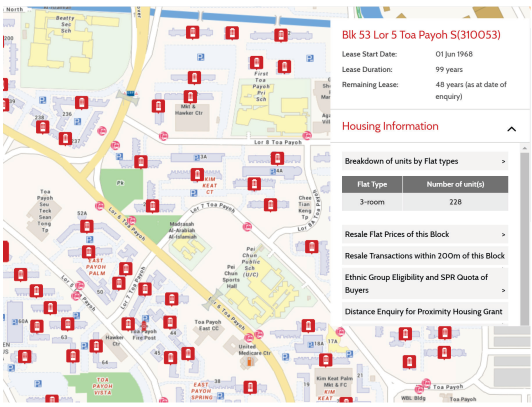
35. Viable shelter in flood scenario via overstroomik.nl.



36. Sweets Hotel via sweetshotel.amsterdam.



37. LUSH impact map via URA.



38. HDB Housing Map via hdb.gov.sg.

The Rijkswaterstaat (national water management agency) in Netherlands is the initiator of the overstroomik.nl map which aims to raise public awareness of appropriate shelters in the case of flooding.[95](fig. 35) This online map gathers together all buildings in the national database and assesses their suitability as shelters in a possible flood event: truly a very large cloud that exists for now only as an eventuality. The Amsterdam municipal government has gathered the city's green roofs together in a data-base that is linked to a subsidy and an information campaign promoting the construction of new green roofs.[96] (fig. 34)This cloud of green roofs works together to retain rain water and reduce the risk of flooding due to overwhelmed storm sewers. Here online maps provide a spatial and quantitative (m2 per green roof) overview of the cloud, and associated online tools promote its growth.

In Singapore the Urban Redevelopment Authority's LUSH program (Landscaping for Urban Spaces and Highrises) promotes and monitors greenspace in private developments producing a cloud of architectural elements which augment the city's ecology.(fig. 37) Recently the HDB has also begun organizing the property data of its public housing units in an online map.(fig. 38) This map provides information on lease length, flat types, and recent resale prices, providing greater transparency on the market for existing HDB units.

Institutions, not architects, are responsible for deploying these clouds of architectural elements and the maps that control them. The map, in these cases, is the only link between each of the elements permitting the overall cloud to be monitored and understood but also modified and redirected. Specifically in the case of Amsterdam's green roofs and Singapore's LUSH re-greening program the mapping and monitoring of elements is intimately linked to policies which promote the expansion of the program. The clouds represent an expansion of the prescriptive power of the online map described by Antoine Picon:

> 'The map tells the city's story to those who make it, and by the same token helps to give it a self-reflexive dimension. […] The map allows the spatialized intelligence of the city to represent itself to itself.'[97]

The cloud not only represents intelligence, but active power to control the present use and future development of the form of the city. As such they are most appropriately used by public institutions to achieve civic goals, but, because they influence the development of the form of the city, they mix politics with aesthetics, and invariably overlap with the domain of architecture. Picon, has made a parallel observation about the complex nature of smart maps:

> 'What is made visible reveals both the existence of things in common and subdivisions that stipulate each individual's place and prerogatives within the overall social and political structure. In this broader sense, the map is revealed to be inseparably political and aesthetic.'[98]

If clouds remake the form of the city, and recruit architectural elements into their networks, then perhaps the architect might consider them a field for his own activity. In the case studies I have reviewed at least two examples of architects working on clouds have come up. Luis Callejas' Airplot competition entry has been discussed directly, and *space&matter*'s Sweets Hotel has come up peripherally in relation to their other projects in Buiksloterham.

95 See 3.3.1. See references for full URL.
96 See 3.3.2. See references for full URL.
97 Antoine Picon. 2014. *Smart Cities.* P. 136
98 Ibid. P. 138

LCLA's project for Heathrow has been belabored elsewhere in this thesis, and I raise it again here only to consider how the architect might work at the scale of the cloud, and what the implications of mixing political and aesthetic aspirations at this scale may be. LCLA's Airplot entry begins from a political position: the idea of connecting a group of frustrated people and giving them a means of acting in protest against the expansion of Heathrow. However, LCLA then retreats from actively engaging this political position, and instead presents and assesses the project via the language of aesthetics: as an image, as an effect, as an instance of the sublime. The organizing entity in this cloud is dual: the architect's map initially and subsequently the image of the cloud, which would float in the sky for all to see. This image, if it had been built, would be a constructed map of dissent: a physical index of subdivisions in the political structure.

Sweets Hotel is a second example of an architect-initiated urban cloud, in this case putting aesthetics and politics to work at the service of a business plan.(fig. 36) Amsterdam is full of obsolete bridge houses. In another era these houses were inhabited by bridge operators, who would control the raising and lowering of the bridges when a boat needed to pass beneath. Today Amsterdam's bridges are controlled by a centralized digital system and the houses have been left empty.[99] Architects *space&matter* developed a business plan around these abandoned bridge houses. Each bridge house, they argued, could act as a room of a hotel spread out over the city and managed online via websites. They proposed naming the hotel *Sweets* as part of a branding strategy. Falling on the heels of Airbnb's founding in 2008 and WeWork in 2010, the idea behind *Sweets* was timely in its use of the online platform, but distinguished by its place-based collection of interesting architectural pieces.

The bridge houses are the property of the city of Amsterdam, and were unlikely to be released piecemeal for the use of private individuals. In 2012 *space&matter*, along with developer *Grayfield*, and hotelier *Seven New Things* pitched the *Sweets* hotel concept to the city of Amsterdam. They argued that the hotel would introduce travelers to new neighborhoods, and provide a different experience of the city.[100] The bridge houses also constitute small monuments in the city of Amsterdam, marking its industrial and infrastructural past. *Space&matter* worked to valorize this historical identity, putting on a show at the Amsterdam Architecture Center (ARCAM) and publishing a guidebook to the bridge houses.[101] The combination of coherent overall business plan and valorization of Amsterdam's architectural heritage seems to have convinced the city to sign on; the hotel opened to guests in the spring of 2018.

Though the *Sweets* hotel concept is web-platform based, it could not exist absent the careful application of architectural intelligence. It is easy to over-emphasize the importance of the online platform because of its novelty and functionality: allowing clients to understand the concept, book a room, get in and out and obtain needed services. The web-platform, however, is of little value without the comprehensive architectural work involved in developing the hotel. Physically the bridge houses were renovated and standardized for hotel use, but more significantly they were revalorized as historical monuments. *Space&matter* developed a politically-desirable concept which supported the image of Amsterdam's post-industrial adaptation, an image which made it desirable for the city to permit the use of public infrastructure in a private project. Without the architect's ability to conceive of the distributed cloud of bridge houses as micro-monuments, as an urban aesthetic whole, via

99 Sweets Opening, Official Press Release March 15, 2018
100 Ibid.
101 The guidebook, titled, 'SWEETS – Overzicht Inzicht Uitzicht.' was a limited-edition print dating to 2012 and available via the ARCAM center. It was authored by the architects *space&matter*.

guidebook and public exhibit, and finally also as a coherent business concept the connective power of the online platform would be irrelevant. In this case, at least, the parallel political and aesthetic demands of the cloud required the skilled application of architectural expertise to be executed.

The cloud represents a new scale of action for the architect with formal implications that are not yet fully explored. It may ultimately be a locus for sublime meteorological aesthetics of the sort imagined by Luis Callejas, or more mundanely the organizing structure which makes possible an economic revalorization of isolated architectural pieces in a larger business model as in the work of *space&matter*. That this scale of operation represents a formal change, at least within the context of my case studies, seems to be a justifiable claim: few if any of these clouds exist prior to 2010. The one exception may be HDB's apartments, which via standardization and centralized control were already cloud-like in the late 1970s even with limited informatic feedback.

In architectural history a close parallel is the field condition discourse associated with landscape urbanism of the early 2000s, which however did not emphasize the coalescence of the elements via shared dataflow and a centralized map. The exploration of field conditions for an architect like Stan Allen was explicitly formal, emerging from study of the work of sculptors like Barry le Va. Allen's field conditions also had a visual gestalt, which was in some ways like a two-dimensional graphic.[102] In contrast the clouds I have highlighted in my case studies are functional entities which do not cohere into a visual whole, though they retain aesthetic and possibly formal implications.[103] Allen's field conditions also touched on the behavior of crowds and bottom-up formal processes suggesting a possible participatory or political implication.[104] The cloud-like objects studied in my case studies are more overtly political, a perhaps inevitable result of their urban scale, functional aspirations, and association with the interactive map. As established in the quote by Antoine Picon above, contemporary practices of mapping seem invariably to mix the political and the aesthetic, a property which I observe extends to architectural elements organized in clouds. While the clouds I have described may be the most overtly political objects in my case studies, design in the data-driven context invariably reposes on ideas of communal consensus and decision-making- an implication which I explore in a concluding section.

5.4 Design in the data-driven context: transdisciplinarity and pluri-partisan consensus

> "'To ensure a sustainable future society, we must use our new technologies to create new citizen systems that maintain the stability of government, energy and public health systems around the globe. Our current digital feedback technologies are already capable of creating the level of dynamic responsiveness that our larger more complicated modern society requires. We must use these technologies to reinvent societies' systems within a feedback framework: one that first senses the situation; then combines these observations with models of demand and dynamic reaction; and finally, uses the resulting predictions to tune the system to match demands being made of them."[105]

102 Allen, Stan. 1999. *Points lines : Diagrams and projects for the city.* See Chapter, *Field Conditions*: 'The field is fundamentally a horizontal phenomenon – even a graphic one – and all of the examples described thus far function in the plan dimension.' P.98

103 Ibid. p.92

104 Ibid. 'Crowds and swarms operate at the edge of control. Aside from the suggestive formal possibilities, with these two examples architecture could profitably shift its attention from its traditional top-down forms of control and begin to investigate the possibilities of a more fluid, bottom-up approach. Field conditions offer a tentative opening in architecture to address the dynamics of use, behavior of crowds, and the complex geometrics of masses in motion.' P. 101

105 Pentland. *Social Physics*. p. 138.

I began this thesis with a discussion of Alex Pentland's Feedback Framework, as has described it in the passage above. The feedback framework is the fundamental idea behind the data-driven city: that overlapping systems of automated feedback between digital sensing, data analysis and system 'tuning' will 'maintain the stability' of our cities. The goal he envisions is essentially homeostasis, a preservation of a social/environmental status quo. In this homeostatic condition data allows automated systems to monitor and adjust for homeostasis more rapidly and accurately than humans ever could. In the feedback framework, data allows machines to communicate with machines.

Perhaps the most important lesson I have gathered from the historical case studies in this thesis is that the homeostasis of urban feedback systems rarely persists longer than a few decades. Invariably overall motivations change, new technologies appear, or environmental conditions shift. In the case studies we have see climate change challenging the Netherlands' water defenses, Heathrow's expansion forcing an update of noise monitoring and mitigation, and Singapore's rising prosperity and changing demographics producing radically different public housing. So while Pentland revealed the potential of new technology to produce more integrated and extensive urban feedback frameworks, his focus on maintaining stability is a short-term focus.[106] Long-term thinking on cities must acknowledge that data-driven urban systems need to be re-oriented on a regular basis. What is revelatory about these moments of reorientation is that data is not used to run an automated system, but is used as an objective-enough mediator allowing human beings with different perspectives and personal interests to join a common discussion and work toward consensus on how the city's form and function (i.e. software) should change.[107] At turning points in the city's development, data helps people talk to each other.

In the turning points identified in my case studies, institutions and individual actors come together to assess an existing system, develop concepts for its adaptation, present argued proposals for the adaptation, negotiate a solution, and come to consensus. This process is, in each of the case studies I have looked at, based heavily on data but also steered by the ambitions and values actors bring to the process. Actors I have described working on adapting urban systems include politicians, developers, engineers, social scientists, and statisticians, but also architects, landscape architects and urban designers.

Architects are on the front-line of debates over how the city's systems will be remade, yes providing illustrations, but also finding ways to interject concepts and values. The architect does the difficult work of moving from vagueness of quantitative goals to the specificity of physical realization: an essentially hermeneutic process of interpretation. Moving beyond a position of illustrator, to thinker in the data-driven city, the designers in the case studies find themselves working with data alongside their traditional disciplinary tools- an epistemic broadening rather than a shift.

Architects working with data find themselves acting holistically; acting as project coordinator in the data-driven city means reaching across disciplinary (and social) silos. Architects also find themselves

106 In fairness to Pentland, he does promote the use data to communicate with people for example: "The key to citizen involvement in management of a data-rich city is visualizing the data." Pentland. 2014. Social Physics. p. 141. And the idea of the feedback framework (see quote opening this section) is presented as a 'citizen system' which seems to imply at least a degree of public transparency.

107 The objective framework – what data, collected in what way- in the ideal consensus scenario would be constructed by the group instead imposed by a single member or outside actor.

asked to represent the interests of different partisan groups in the city in often divisive situations (consider Heathrow.) While the data-rich context data permits the architect to optimize a partisan position, the case studies have shown it can also allow designers to build off of shared quantitative goals toward pluri-partisan solutions.

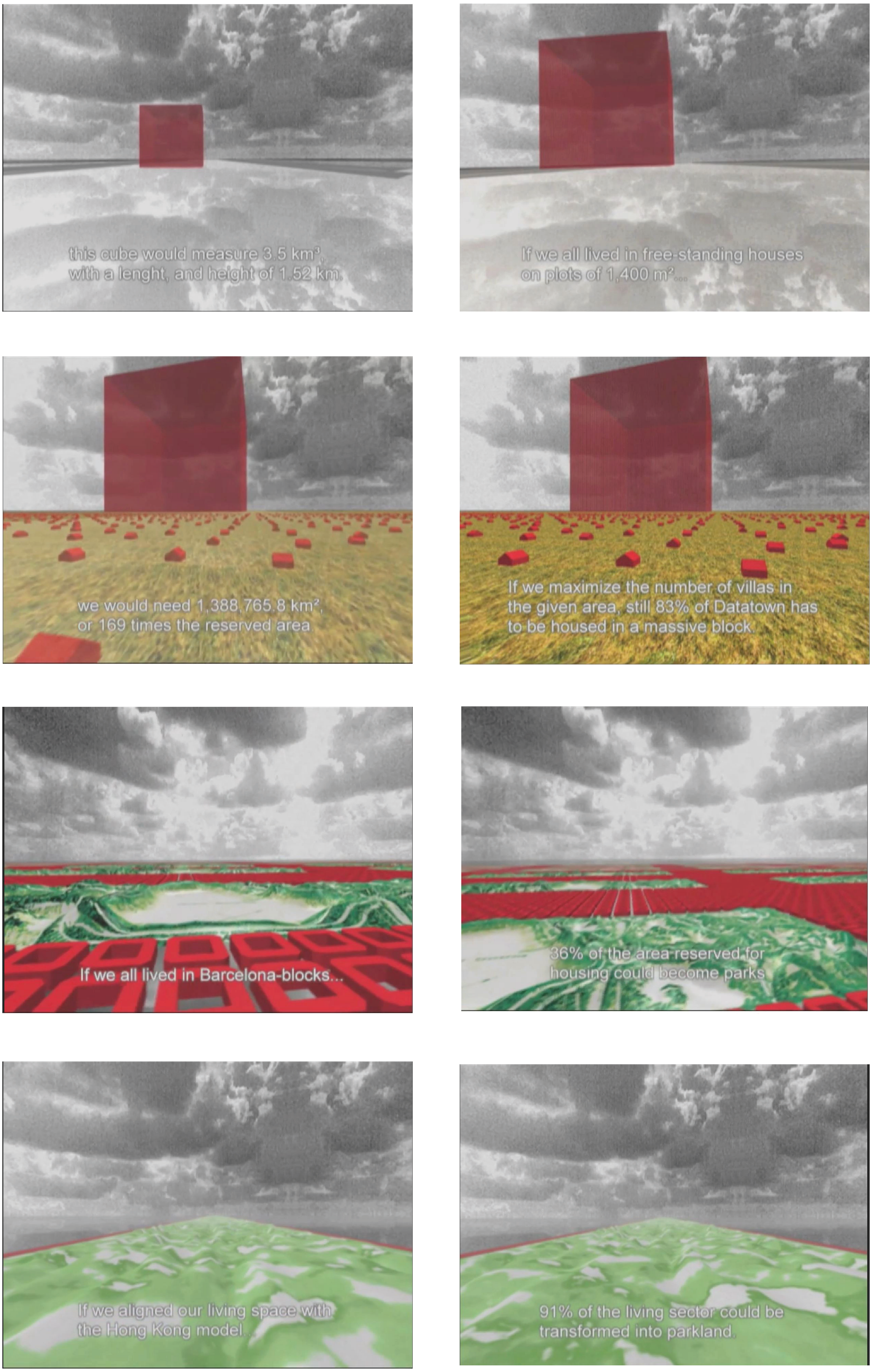
5.4.1 Crossing disciplines, changing mindsets

Data does not work without expert consensus. Without agreement over how measurements will be made, and benchmarks and scales, will be used, empirical data cannot be shared. The creation of data is not simply an effort to establish empirical understanding of our world, but more importantly an effort to establish a shared empirical view of the world. Practices of empirical measurement and communication are controlled by experts who have deep knowledge within their disciplinary silos. Acousticians work with time averaged decibel metrics like LAeq, biologists and ecologists work with Leaf Area Index, developers emphasize Gross Plot Ratio and net-to-gross floor area ratio (or grossing factor). Working with these expert communities the architect is an outsider, who brings different motivations and values to the table which can provide valuable transdisciplinary insight. Ong Boon Lay and the creation of the Green Plot Ratio in Singapore is a good example of an architect contributing to transdisciplinary thought in a data-driven context.[108]

Ong, an architect and early proponent of ecological urbanism, perceived a gap between the quantitative tools urbanists used to understand and plan the city and those used by ecologist and biologists to understand natural systems. In his design projects he sought to span this gap, proposing plantings in and around buildings as part of a larger ecosystem. To justify his efforts both within the community of ecologists and in the eyes of his urban developers like Singapore's Jurong Town Corporation- Ong developed the Green Plot Ratio, combining the biological measure of Leaf Area Index with the urban planning metric of Plot Ratio. This allowed him to explain and justify his designs in both contexts. The Green Plot Ratio has since taken on a life of its own, increasingly adopted by Singapore's city planners as a means of understanding and planning an ecological city. Ong's contribution, aimed at producing urban master plans, instead contributed to changing the mindset behind Singapore's urban planning, providing a transdisciplinary tool that made it possible for urban planners to think like ecologists and ecologists to think like urban planners.

In the data-driven city the use of data to legitimize a design project can take on a life of its own, and achieve impacts separate from and greater than an individual design project. The synthetic work of the design professions lends itself to pragmatic trans-disciplinary creativity, finding points of connection between disciplines where communication or cooperation can provide benefits to the city at large. Acknowledging this transdisciplinary synthetic ability, and its often quantitative nature, does not mean the designer should abandon design and try to become a statistician, or worse an expert in everything and nothing. It should, however, demonstrate that the designer's analytic work solving a design problem and advocating for a design often produces intellectual fruit which have value above and beyond the creation of a single building. In the data-driven city, careful construction and repackaging of the analytics associated with the design process can represent a valuable service provided by the architect and a possible leverage point to contribute to broader change in the data-driven city.

108 See 4.4.3.



39. Frames from MVRDV's Metacity/ Datatown. (1999)
Stroom Centre for the Visual Arts, The Hague

5.4.2 Maximizing a partisan position

The traditional role of the architect is to produce a building based on a commission from a client. This role makes the architect a partisan, taking on the goals of the client and using all reasonable means at his disposal to achieve those goals. Partisanship in the data-driven city is augmented: the architect has the means to quantitatively optimize a client's position. This seems to be a natural position for the designer to take in most situations: designing a high-rise for a developer, the architect will work to maximize rentable floor area of the most lucrative types. The case studies in this thesis suggest, however, that on controversial large-scale urban problems maximizing a partisan position can be problematic.

In the case of Luis Callejas' proposal to block the expansion of Heathrow, Callejas worked on behalf of Greenpeace to develop a system that would maximize interference with Heathrow's airspace by overlaying maps of flight paths with maps of the homes of noise-impacted residents.(fig. 33) The most-affected people, according to Callejas' proposal, would fly balloon facsimiles of their homes into the path of oncoming planes and prevent them from flying to or from Heathrow.

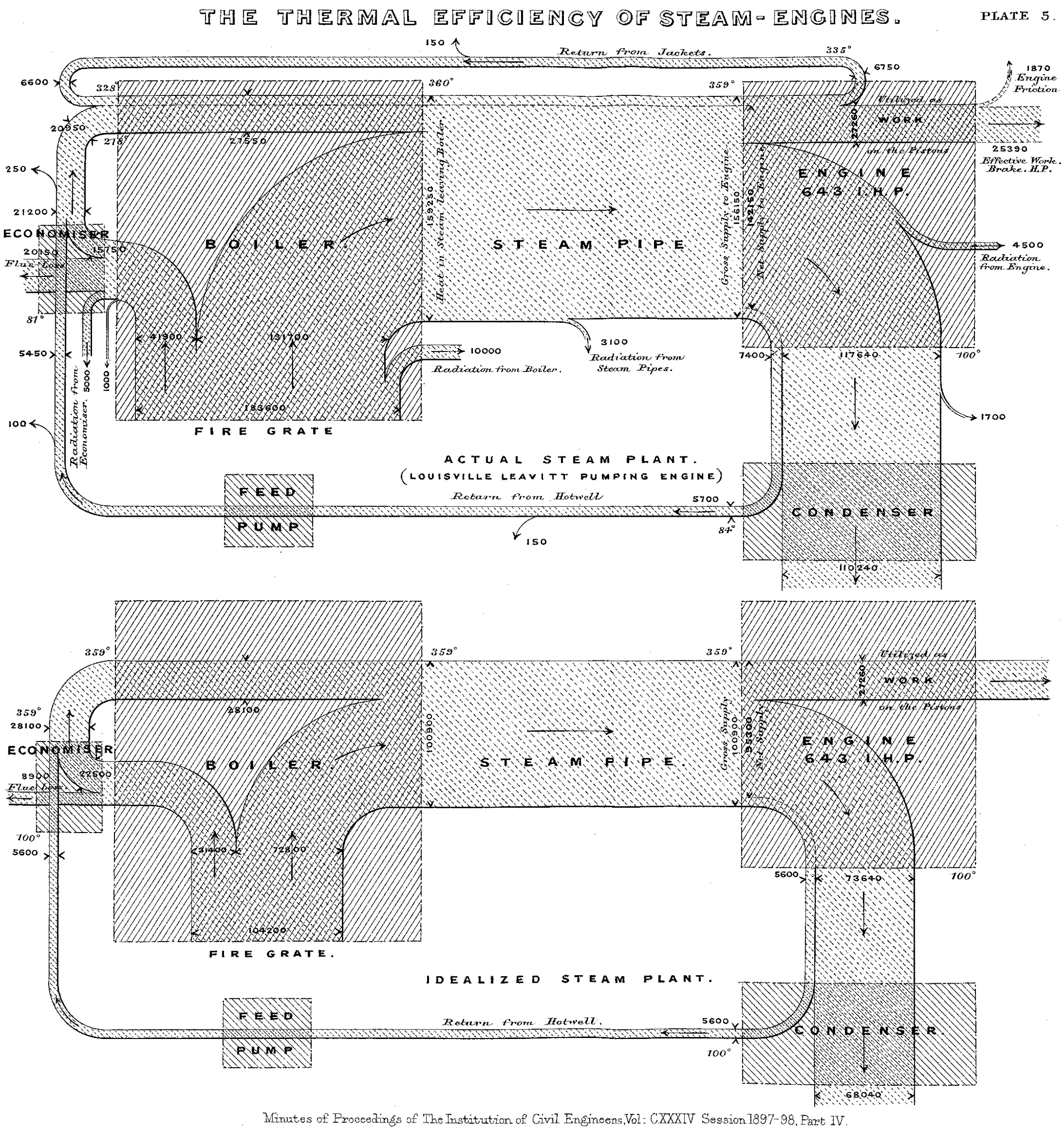
The project was never built. Callejas did not win the competition and Greenpeace backed away from confrontation with Heathrow a few years later, selling their plot of land in the third runway expansion area. Callejas' proposal failed for a few reasons: it was sustained only by one client, who ultimately did not choose it and then abandoned the project. While protest movements continued to exist around Heathrow, like the *Grow Heathrow* protest garden[109], Callejas' proposal failed to establish a connection with these grassroots entities. More fundamentally, the proposal could not reflect the complexity of the Heathrow conundrum: many people depend on Heathrow, including nearby residents whose livelihoods are built around the airport's activities and desire to live close to it.[110] Partisanship in a controversial context like the Heathrow Expansion may seem disingenuous: do you really think you can push one position so hard the other side will give up or admit defeat? At the same time, this is the traditional role of the architect: a partisan actor who takes up the motivations of a client regardless of the 'bigger picture.' Working with urban data, however, architects since at least the mid-1990s have adopted working methods which move beyond narrow partisanship.

5.4.3 Pluri-partisan and synthetic visions

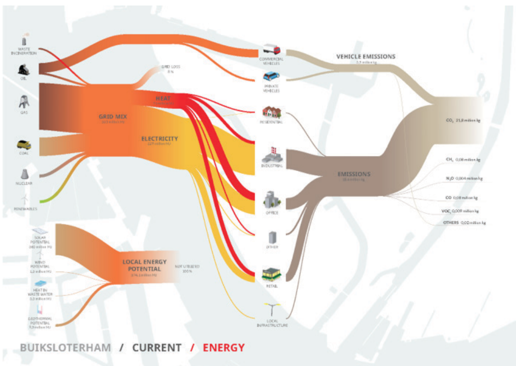
Bart Lootsma emphasizes that partisanship is not the only method of action open to designers working on urban problems.[111] Lootsma summarized this position in his argument for MVRDV's datascape design method:

> "No one else has found as convincing a way to connect advocacy planning to larger collective interests and goals, by showing the spatial consequences of the desires of the individual parties involved in a design process, confronting them with each other and <u>opening a debate with society,</u> instead of just fighting for one or the other, as most architects would."[112]

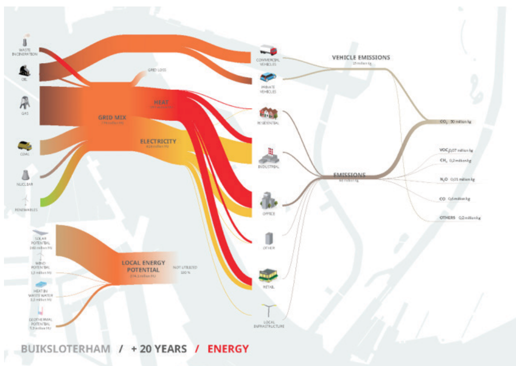
109 Laville, Sandra. 2019. "Bailiffs Move in on Heathrow Runway Protest Camp." The Guardian, February 27, 2019, sec. Environment.
110 See Boucsein et al. 2017. *The Noise Landscape* LHR Chapter. pp. 125, 128
111 Lootsma has returned to this statement as an idealized description of what an architect should do: "Today an architect must communicate with the affected parties – be it the building commissioner, the authorities, the future inhabitants or the users, neighbors, technical consultants or the press – and negotiate their needs and interests both on an organizational and also aesthetic level. For this it is necessary for the architect to analyze a complex situation and to be able to offer perspectives that are as far-reaching as possible and also back by society, and not just the pragmatic solution to an acute problem – and this especially when it has to do with urban planning." [Lootsma, Bart. 'Architect as Mid-field Strategist' In (2016). Reality bytes : Selected essays 1995-2015. Basel: Birkhäuser. P.297]
112 Bart Lootsma. 2003. What is (really) to be Done? In *The theoretical concepts of MVRDV.*



40. Matthew Sankey. The Thermal Efficiency of Steam Engines. 1897 Plate 5: Actual steam plant compared to idealized steam plant.



41. Metabolic. Sankey Diagram, current energy use Buiksloterham. 2015.



42. Metabolic. Sankey Diagram, +20 Years energy use Buiksloterham. 2015.

In this quote Lootsma describes what could be interpreted as a non-partisan position, where the designer illustrates the 'spatial consequences of the desires of the individual parties.' The designer does not take on a specific position but rather shows the ramifications of urban practices taken to their extremes.

It is tempting to equate the non-partisan position of Winy Maas with the idea of objectivity, in the sense that it is a transcendence of any individual 'subjective' position in the service of a broader and more neutral understanding. The non-partisan attitude corresponds in this (mis-) interpretation to empirical objectivity, the idea that by rigorously basing conclusions on empirical results (data), a general truth may be revealed. That the designer should aspire to empirical objectivity, as a sort of neo-positivist, however, is clearly not the aspiration of Winy Maas' datascape, nor do I believe ultimately that it is the position Lootsma envisions for the architect.

As Lootsma writes, the datascape scenarios do not empirically prove what urban decision must be made, but rather they *open a debate with society*. In parallel, the case studies of this thesis do not describe the creation of empirically objective non-partisan positions, but rather *pluri-partisan* positions where different individual parties come together to support an urban vision. The use of data within the case studies is not for establishing an absolute truth but rather to project a generalized, negotiable and objective-enough goal that permits many actors to gather under its umbrella.

The Buiksloterham Vision document, and Liu Thai Ker's establishment of HDB high-rise high-density site planning represent significant forms of pluri-partisan data-informed reorientation of an urban system. These two examples are valuable not only as illustrations of pluri-partisan design via data, or as contrasts to the partisanship of the Heathrow case study, but also as actually-existing counterparts and contrasts to the datascape model developed by MVRDV and advocated by Lootsma. Datascape was developed by MVRDV as an expansion of research by design, in contexts where data was interpreted to be inevitable and over-determining. Perhaps most importantly, the datascape was a guerrilla tactic for the designer to regain agency in large-scale urban processes that seemed to exceed or reject his intervention.[113] MVRDV's datascape, at least as developed in the late 1990s, was a domain explored by the architect alone as a speculation. In contrast the 'actually-existing' case-studies I have presented show pluri-partisan data-informed design within alliances of architects and other professionals, often within public institutions or under the auspices of a public institution.

In a 1999 exhibit they called *Metacity/Datatown,* MVRDV further developed the *datascape* idea.(fig. 39) The exhibit presented scenarios for the development of an imaginary territory named *Datatown*. Extrapolating from contemporary Dutch statistics, they consider different possible urban futures in a hypothetical setting. For example, the 'living sector' of Datatown allowed MVRDV to explore the implications of four types of residential urbanism taken to their extreme: single family villas, Barcelona blocks, 'Hong Kong' high rises, and a single cubic volume.[114] The text narration states: 'If we all lived in

113 Pig City, the most notorious of the data-scape projects, was covered in the popular press in the Netherlands and misconstrued by some as an attack on animal rights. Winy Maas is said to have hired body-guards to protect himself from animal-rights activists. See Salewski. 2012. p. 264.

114 Narration of Metacity/Datatown animation – 3:00 Available online http://www.architectureplayer.com/clips/metacity-datatown: 'If we all lived in free-standing houses on plots of 1,400 m2 we would need 1,388,765.8 km2 or 169 times the reserved area. If we maximize the number of villas in the given area, still 83% of Datatown has to be housed in a massive block. If we all lived in Barcelona-blocks, 36% of the area reserved for housing could become parks. If we aligned our living space with the Hong Kong model, 91% of the living sector could be transformed into parkland.'

free-standing houses on plots of 1,400 m^2 we would need 1,388,765.8 km^2 or 169 times the reserved area. If we maximize the number of villas in the given area, still 83% of Datatown has to be housed in a massive block.'[115] In contrast, housing the same population in Barcelona blocks allows 36% of the living sector area to be used as park space.

While *Metacity/ Datatown* may have presented its information in the form of conditional statements, in its framing of its statements and images it crafts an indictment of suburban sprawl. The film is an undisguised critique of contemporary Dutch urbanism; demonstrating in the simple terms the spatial wastefulness of suburban sprawl, which Maas referred to as a "slick' of houses-with-a-small-garden," in the initial *Datascape* essay.[116] Though *Metacity/ Datatown* is clearly partisan, it is not prescriptive: no ideal city is proposed. Instead the viewer is left with a set of options, some clearly bad and some which may be difficult to choose between. How would one choose between Barcelona-block urbanism with 36% park space, or Hong-Kong style urbanism with 91% parkland? The datascape works by recruiting the rational decision-making skills of the viewer to a generalized, data-defined problem that shifts their individual perspective. *Metacity/ Datatown* however leaves the ultimate question of how the city should be built open to debate; different actors would self-orient toward different options it presents. The datascape thus is not purely non-partisan, but is more accurately *pluri-partisan, open-ended* urban design.

MVRDV's *Metacity/Datatown* scenarios of 1999 closely parallel the density scenarios carried out by Liu Thai Ker in 1970s Singapore- though no direct link exists between the two periods and groups of designers. Liu tested high-rise and low-rise development land use, and extrapolated to the scale of Singapore to make the case that high-density urbanism would be the only viable model for the new nation.[117] HDB's scenario studies, however, were never open-ended, but were rather arguments supporting their decisions about how to build Singapore. By exploring low-density urbanisms and vernacular urbanisms, Liu recognized the existence of other positions on how the city could be built, and contrasted them with his own high-density high-rise vision within a self-consistent quantitative system of evaluation. Liu's density scenario's for HDB might be called *pluri-partisan prescriptive*, since they do prescribe one chosen way of building the city, but seek to recruit a broad audience to understand and assent to this mode of urbanization.

Unlike *Metacity/Datatown*, HDB's scenarios provided the basis for an actually-existing urban system of public housing construction. They provide a general framework that is both oriented toward a wider public but also interpretable by HDB's designers who would need to apply its prescriptions within the constraints of specific sites. The history of the development of this framework of the intervening forty years – the adjustment of the building spacing to maintain density, the development of more complex ideas of community and placemaking, and ecological augmentations – contribute to our understanding that the designer can use data not only as a mediator for a pluri-partisan urban vision, but also as a basis for the development of self-perpetuating self-reflexive urban systems open to significant periodic adaptation. While the HDB in the 1960s worked in a undeniably top-down manner, the other pluri-partisan case study in this thesis (Circular Buiksloterham)demonstrates that purely top-down design is not the only method of crafting an urban vision via data.

115 Ibid.

116 Maas. 1996. 'Datascape.' in *FARMAX*

117 From Liu Thai Ker. 1975. 'Design For Better Living Conditions.' In *Public Housing In Singapore*."An identical exercise was carried out for low-rise development, using all four storey buildings. […] To achieve 2,000 units of flats, it takes around 10 hectares of land with high-rise buildings but 17 hectares with four-storey buildings. […] The gap is thought to be too big, involving too much extra land, for the general application of low-rise development in Singapore except or exceptional cases."

In the Buiksloterham vision document data provides the basis for broad consensus and multi-party cooperative design. Eva Gladek, the industrial ecologist working at the lead of the Metabolic Team, presented future scenarios for water, energy and material use in Buiksloterham with particular reliance on the *Sankey diagram*.(figs. 41,42) The Sankey diagram is reductive: it describes the metabolism of the city using a tool developed by a 19th century engineer to quantify the many small inefficiencies of steam engines in comparison with an idealized engine.(fig. 40) However, its quantitative reductivism provides a basis for large scale urban/environmental goals to be explained, discussed and agreed upon. Within this simplified framework consensus can begin to emerge; 'lets us reduce water consumption form x liters per person today to y liters per person in 20 years.' It also permits nuanced trade-offs to be discussed in a clear framework: i.e. 'to achieve our goal is it better to reduce household or industrial use of water.'

Metabolic's data visualizations are not non-partisan and not objective, but rather come with a built-in set of value-based assertions. Metabolic actively pushes for scenarios where material and energy flows will be minimized and whenever possible made 'circular'. Circular urbanism's most powerful image is the output of the urban system wrapping around and returning as an input. Though presented via an engineering diagram this is undeniably a subjective value judgment; a judgment about what is the 'good' way to live together in the city. While Metabolic's proposals are subjective and do include the built-in values of their creators, they are quantitatively specific enough to permit nuanced negotiation (and performance tracking) and they are abstract enough that their interpretation and implementation can become a communal effort.

In the Buiksloterham vision, designers like *DELVA landscape architect*s and *studioninedots* unfolded the physical implications of Metabolic's broad quantitative goals and their circular value system. The final proposal, also, was not just for the physical form of the city, but for its system of digital sensing and analysis. This holistic spatial/systems planning was steered by specialists at AMS and TU Delft, but synthesized via the work of the primary authors (Metabolic, DELVA, studioninedots). In this sense the design proposals at Buiksloterham are not just interpretive of shared quantitative goals, but also synthetic in their aspiration to combine data-driven technologies with urban form into an idea of place and community.

5.4.4 In conclusion

Data is used by architects to understand the city, to communicate with others about the city, and to establish the basis for pluri-partisan goals for how we want to live in the city. While maximized partisanship is possible in the data-driven city, it also reaches its limits in the dilemmas and trade-offs of urban life in the Anthropocene. The architect can work with the quantitative goals of the data-driven city in an interpretive manner, taking shared quantitative goals, and creating the built forms which will actualize them in specific physical environments. The architect, however, must also work in a synthetic manner, taking shared goals and the disjunct elements of the data-assemblage and crafting a vision of a meaningful urban environment from these pieces. It is not often that an architect will be called upon to create a new urban system from scratch, in the manner of Liu Thai Ker's work at the Building Research Group at HDB. However, the homeostasis of the urban feedback framework must periodically evolve, and at these points of evolution the architect is needed to pull together a physical interpretation of how we collectively – to the extent we can agree on this- want to live.

The architectural forms of the data-driven city are very likely to be non-homogeneous, incorporating parametrized elements in larger assemblages organized by physical frameworks. While these architectures may echo the metabolist and structuralists architectures of the past, they distinguish themselves by a pluralistic financial basis which relies on the support of both big and small actors and is reflected in a village-like diversity of spaces and materiality. Data-driven urbanism quantifies both industrial and natural systems in a single metabolism. This quantified and instrumentalized ecology veils the architectural form of the data-driven city with fuzzy greenery that is both garden and machine.

The possibility for architectural elements to organize themselves in distributed clouds in the city, functioning together as businesses or public infrastructures, subordinates architecture's synthetic function to that of the database and its interfaces. At the same time these clouds provide a new domain open to architectural exploration, seemingly simultaneously political and aesthetic, with possibilities that are not yet decided.

The social and formal conclusions of this research are not separate packages but two sides of the same coin, dependent on each other and self-influencing. Though much contemporary debate is devoted to concern that a data-driven city will force the architect to take on the positivist shackles of the scientific method, or worse become the agent of a totalitarian smart state, the case studies of this thesis suggest quite simply that data helps the architect speak clearly with a wide range of people. With this clear communication, the persistent problems of our Anthropocene era cities can be addressed together, and architectural forms can emerge that teach us to appreciate the significance of difficult compromise.

Post-script: the data-driven moment

I had a moment of panic as I re-checked my citations for this manuscript: the words 'data-driven cities,' which I distinctly remembered as the title of part III in Alex Pentland's *Social Physics*, had disappeared. Instead, they were replaced by the words 'data-rich.' After some searching I discovered that I had not lost my mind, but that there had been some changes made between the 2014 and 2015 editions of *Social Physics*. 'Data-driven cities', the title of part III and 'data-driven society' the title of part IV had been replaced by 'data-rich cities' and 'data-rich society,' and a new preface had been added. I emailed Pentland to ask about the changes, but did not receive a reply. The content of the 2015 preface, however, provides some clues about why these changes were made. Pentland writes:

> "While offering the promise of more effective, transparent, and accountable government, this new tidal wave of data about people's behavior has also sparked deep concern about privacy. A valid fear about big data is that with more and more detailed information we become vulnerable to manipulation by companies, government, and criminals. Nor will big data just go away… we will cling to our cell phones and credit cards as fiercely as we cling to life itself. Does this mean that the future will belong only to those with the biggest computers and the most data?"[1]

In the year after he published *Social Physics* Pentland encountered criticism, concern and even fear. The fear he describes, that ordinary people will increasingly be dominated by governments and tech corporations via big data technology, is the dark side of 'data-driven.' Though Pentland envisioned a big-data future of, 'effective, transparent, and accountable government,' (the feedback framework) he recognizes by 2015 that fears about this future are 'valid.'

Data-driven implies that data (and those who control it) are in the driver's seat- that they have a primary agency in data-driven cities and data-driven society. Data-rich instead suggests a more indeterminate condition, in which we discover a new wealth of data without assuming who is in control. To his credit, Pentland is a leader in creating the data-rich world, by working on privacy protection standards and on open data. By switching these titles in his book Pentland will ruffle fewer feathers, but has anything fundamentally changed about the content, or is this just a bit of cosmetic work around the edges?

As I did the research for this thesis I did find many instances of data-driven urbanism: feedback loops in the monitoring and control of the city. Often these feedback loops began as a data-informed human practices, and were made increasingly automated in the last two decades. These feedback loops along with the pieces of the city they control can reasonably be said to constitute instances of automated data-driven urbanism, though they might just as accurately be called neo-cybernetic urbanisms. The data-driven city still exists, remains rightfully controversial, and merits our critical interrogation as well as our creative support.

1 Pentland. 2015 edition. *Social Physics.* p. viii.

I found, however, that as I researched the *data-driven* city my attention was drawn to *data-mediated* spaces and situations. These were controversial moments where data was used, yes in big data bases and visualizations and in smart systems, but most fundamentally to allow a group of people to wrap their heads around a difficult urban problem and try to establish a basis for arguing and negotiating it, (even cooperating to work on it.) At Heathrow, Amsterdam, and Singapore urban data is not just feeding science, cybernetics or AI, but also new forms of human communication. Some of the instances we have seen in these case studies are less than ideal *data-mediated* psychological group massage (Heathrow my Neighborhood too). Others represent more ideal communication and support the formation of legitimate consensus and unleash latent enthusiasm for new urban organizations and forms (Circular Buiksloterham.) While Pentland chose to re-title his chapters, 'data-rich,' if given a similar opportunity I might choose, 'data-mediated.'

References:

Books and Journal Articles:

Allen, Stan. 1999. *Points + Lines : Diagrams and Projects for the City.* New York: New York : Princeton Architectural Press.

Banham, Reyner. 1969. *The Architecture of the Well-Tempered Environment.* London : The Architectural Press.

Bingham-Hall, Patrick. 2016. *Garden City Mega City : Rethinking Cities for the Age of Global Warming.* First edition. Rethinking Cities for the Age of Global Warming. Singapore Pesaro Publishing.

Boucsein, B., Ortner, F., and Jehle, J. "London Heathrow [LHR]." In *The Noise Landscape : A Spatial Exploration of Airports and Cities*, edited by Benedikt Boucsein, 121-137. Rotterdam : nai010 publishers, 2017.

Carpo, Mario. 2011. *The Alphabet and the Algorithm.* Cambridge, Mass: Cambridge, Mass. : MIT Press.

Carpo, Mario. 2017. *The Second Digital Turn : Design beyond Intelligence.* Cambridge Massachusetts: Cambridge, Massachusetts : The MIT Press.

Carpo, Mario. 2019. "Particlised: Computational Discretism, or The Rise of the Digital Discrete." in Retsin, ed. "Discrete : Reappraising the Digital in Architecture." Architectural Design 89 (2): 86–93.

Evans, Robin. 2000. *The Projective Cast: Architecture and Its Three Geometries.* First MIT Press paperback edition. Cambridge Massachusetts: Cambridge, Massachusetts : MIT Press.

Fraser, J. M. 1957. "THE WORK OF THE SINGAPORE IMPROVEMENT TRUST." *Ekistics*, vol. 4, no. 25, pp. 37–38.

Giedion, Sigfried. 1948. *Mechanization Takes Command : A Contribution to Anonymous History.* New York: New York : Oxford University Press.

Harvey, David. 2005. *A Brief History of Neoliberalism.* Oxford : Oxford University Press.

Hooimeijer, Fransje, and Maarten Laupman. 2014. *The Making of Polder Cities : A Fine Dutch Tradition.* Heyningen : JAPSAM Books.

Kitchin, Rob. 2014a. "Real-Time City? Big Data and Smart Urbanism." In *GeoJournal* 79 (1): 1–14.

Kitchin. 2014b. *The Data Revolution : Big Data, Open Data, Data Infrastructures & Their Consequences.* Los Angeles: Los Angeles : SAGE.

Kitchin, Rob. 2015. "Data-Driven, Networked Urbanism" Available at SSRN: https://ssrn.com/abstract=2641802 or http://dx.doi.org/10.2139/ssrn.2641802

Kitchin, Rob, and Tracey Lauriault. 2018. "Toward Critical Data Studies:: Charting and Unpacking Data Assemblages and Their Work." In Thatcher, Jim. *Thinking Big Data in Geography : New Regimes, New Research*. Lincoln: University of Nebraska Press.

Jencks, Charles. 1971. *Architecture 2000 : Predictions and Methods.* New York: Praeger.

Jencks, Charles. 2000. “Jencks’ Theory of Evolution, an Overview of 20th Century Architecture” in *Architectural Review* (July 2000)

Kallipoliti, Lydia. 2013. ‘Turtles Do Not Successfully Mate with Giraffes: Pluralism Versus Cloud,’ in N. Hume, A. Coover, P.Ruppert (Eds), *Fresh Punches: Experimental Architecture Exhibition Catalogue* (Brooklyn, NY: SuckerPunch Daily, 2013).

Koolhaas, Rem, James Westcott, Stephan Trüby, Ben Davis, Harvard University. Graduate School of Design, and Mostra internazionale di architettura. 2014. *Elements of Architecture.* Elements. [Venice] : Marsilio.

Koolhaas, Rem 2015. “The Smart Landscape: Intelligent Architecture” *Artforum International*. APRIL 2015, VOL. 53, NO. 8

Latour, Bruno. 2007. *Reassembling the Social : An Introduction to Actor-Network-Theory.* Oxford : Oxford University Press.

Liu, Thai Ker. 1975. “Design for Better Living Conditions.” In Yeh, S. H. K. *Public Housing in Singapore - a Multi-Disciplinary Study.* Singapore: Singapore UP, 1975. pp.117-184

Lootsma, Bart. 2016. ‘Architect as Mid-field Strategist’ In *Reality bytes : Selected essays 1995-2015.* Basel: Birkhäuser. P.297

Lootsma, Bart. 2003. “What is (really) to be Done? The theoretical concepts of MVRDV.” In Patteeuw, Véronique, et al. *Reading MVRDV.* Rotterdam : NAi Publishers.24-63.

Maas, Winy. 1996. “Datascape.” In FARMAX: Excursions on Density. edited Winy Maas and MVRDV. Rotterdam: 010 Publishers, 1998. 98-102.

Maki, Fumihiko. 1964. *Investigations in Collective Form.* Vol. Nr. 2. St. Louis: St. Louis : The School of Architecture, Washington University.

Manvell, Douglas. 2015. “From noise monitoring to noise management: A better way to deal with noise issues.” In *INTER-NOISE and NOISE-CON Congress and Conference Proceedings*, I*nterNoise15*, San Francisco, CA. Institute of Noise Control Engineering. pp. 2361-3321, 2473-2484(12)

Margaret Crawford, and George Baird. 2008. *Everyday Urbanism.* Expanded ed. New York, New York: New York, New York : The Monacelli Press.

Meadows, Donella H. “Places to Intervene in a System.” In *Whole Earth Review* (Winter) 1997. revised and republished as “Leverage Points: Places to Intervene in a System.” Sustainability Institute. 1999.

Ong, Boon Lay. 2002. “Green Plot Ratio: An Ecological Measure for Architecture and Urban Planning.” *Landscape and Urban Planning* 63 (4): 197–211. https://doi.org/10.1016/S0169-2046(02)00191-3.

Ong, Boon, A Ho, and Kim Ho. 2012. “Green Plot Ratio- Past, Present & Future.” Conference paper in *Tropics 2050*. Singapore: National University Singapore.

Pentland, Alex P. 2014. *Social Physics : How Good Ideas Spread : The Lessons from a New Science.* New York: New York : Penguin Press.

Picon, Antoine. 2015. *Smart Cities : A Spatialised Intelligence.* Chichester West Sussex: Chichester, West Sussex : Wiley.

Retsin, Gilles. 2019. “Discrete Architecture in the Age of Automation.” in Retsin, ed. “Discrete : Reappraising the Digital in Architecture.” Architectural Design 89 (2)

Valena, Tomáš. 2011. *Structuralism reloaded : Rule-based design in architecture and urbanism.* Stuttgart: Edition Axel Menges.

Government/ Institutional Documents:

Committee on the Problem of Noise. 1963. Noise: Final Report. London, Her Majesty’s Stationery Office.

Deltacommissie. 2008. Working Together with Water: A Living Land Builds for its Future. Ed. Secretariat Delta Committee. Nov. 2008 (translation: Priestnall, I & van Otterloo, S.)

Gladek, Eva, Sandrine van Odijk, Pieter Theuws and Albert Herder [Metabolic,studioninedots & DELVA Landscape Architects.] 2015. ‘*Transitioning Amsterdam to a Circular City: Circular Buiksloterham Vision & Ambition.’* Online: Gemeente Amsterdam. “Buiksloterham: circulaire stadswijk.” Amsterdam.nl, https://www.amsterdam.nl/projecten/buiksloterham/circulair/. Accessed 9 Nov. 2018.

Metabolic. 2015. *Schoonschip Kavelpaspoort: Kavel 1 Type C.* Metabolic, Amsterdam. June 2015.

Parliament. 1971. Civil Aviation Act 1971. London, Her Majesty’s Stationery Office.

Sweets Opening, Official Press Release March 15, 2018. Online: https://sweetshotel.amsterdam/wp-content/uploads/2018/05/15032018-OPENING-Press-release-SWEETS-hotel-ENG.pdf (accessed 25 March 2019)

Urban Redevelopment Authority. 2017. An Overview of the Lush Programme: Annex A. Singapore, URA Circular No : URA/PB/2017/06-DCG. Online: https://www.ura.gov.sg/Corporate/Guidelines/Circulars/dc17-06 (accessed 09 April 2019)

Popular Press:

Laville, Sandra. 2019. “Bailiffs Move in on Heathrow Runway Protest Camp.” *The Guardian*, February 27, 2019, sec. Environment.

Websites:

Amsterdam Rainproof. https://www.rainproof.nl/ (accessed 06 September 2018).

HDB Map Services, Housing & Development Board Singapore. https://services2.hdb.gov.sg/web/fi10/emap.html# (accessed April 9, 2019).

London Heathrow Webtrak. https://webtrak.emsbk.com/lhr (accessed 06 September 2018).

Overstrom Ik? http://www.overstroomik.nl/ (accessed 06 September 2018).

Sweets Hotel, Amsterdam. https://sweetshotel.amsterdam/ (accessed April 9, 2019).

Urban Green-blue Grids. https://nl.urbangreenbluegrids.com/ (accessed 09 April 2019).

WeBuildHomes. https://www.webuildhomes.nl/ (accessed April 8, 2019).

Lectures/Interviews/ Films:

Callejas, Luis. 2012. “Luis Callejas- Winter+Spring 2012 Baumer Lecture Series #7.” Lecture, Knowlton School of Architecture, Ohio State University, OH. Online: https://youtu.be/Pa0CkOrNbOo (accessed 08 April 2019).

Gladek, Eva. 2018. “Sustainable Urban Systems and Circular Cities of the Future.” Lecture, Center for Livable Cities. Singapore. September 6, 2018. Online: https://youtu.be/7o0qpe0vDwk (accessed 08 April 2019).

Glasl, Sascha. 2014. “Space & Matter.” Lecture, Academy of Art University. San Francisco, CA. October 27, 2014. Online: at https://youtu.be/lltb61jdm48 (accessed 08 April 2019).

MVRDV (Winy Maas, Jacob van Rijs and Nathalie de Vries). 1999. ***Metacity / Datatown.*** Video from installation at Stroom, Centre for the Visual Arts, The Hague, exhibited from 12 December 1998 through 13 February 1999. Adapted version online: http://www.architectureplayer.com/clips/metacity-datatown (accessed 15 April, 2019).

Tay Yi Wen (Executive Planner Urban Redevelopment Authority) and Goh Chin Chin. 2017. “A LUSH and Resilient City | LUSH 3.0.” Lecture, PLENARY SESSION I: VERTICAL RESILIENCE, 2017 International Skyrise Greenery Conference. Singapore.

Frederick Peter Ortner
Media x Design Lab | École polytechnique fédérale de Lausanne
BC 101 (Bâtiment BC) Station 14 | CH-1015 Lausanne, Switzerland
peter.ortner@epfl.ch | fportner.com

Professional Experience

École polytechnique fédérale de Lausanne, Media x Design Lab
Studio Instructor and Doctoral Candidate, 2015-
Studio Instructor and Researcher, 2012-2015

Moshe Safdie Architects, Cambridge, MA
Architect, 2011-2012

SsD Architecture, Cambridge, MA & New York, NY
Associate Architect, 2010
Intern Architect, 2007-2010

Harvard University, Cambridge, MA
Teaching Assistant, 2008

Skidmore, Owings and Merrill, New York, NY
Technical Intern- Architecture, 2006

Cesar Pelli Architects, New Haven, CT
Intern Architect, 2005

Education

Architecture License, State of Massachusetts, USA
Completed 5,600 hours of supervised internship and all seven required exams for professional practice in the United States of America. 2012

Harvard University Graduate School of Design, Cambridge, MA
Masters in Architecture, 2009
Thesis: "Performance of Urban Ornament." Advisor: Dr. Ingeborg Rocker

Yale University, New Haven, CT
Bachelor of Arts in Architecture, 2005
cum laude, distinction in Architecture

Awards

Faculty Design Award, Harvard GSD, Cambridge, MA
Granted by the recommendation of the Architecture faculty for design excellence upon completion of the MArch I program. 2009

DAAD Hochschulsommerkurs Scholarship
Merit based travel scholarship for the study of German language. Universität Heidelberg, 2005

Teaching Experience

Graduate level studios:

Studio Lead, "Mathematics of the Equatorial Villa."
Sustainable Design Option Studio, **SUTD**. Spring 2018

As visiting faculty for one semester at SUTD, I designed this options studio problematic and syllabus, developed and led the theoretical and technical workshops and worked bi-weekly with students as their design tutor.

Instructor, "Made in Glasgow: Automated Urban Manufacturing."
Masters Architecture Studio **EPFL**. Fall 2018 with Media x Design Lab

I coordinated the precedent and manufacturing process research. I wrote scripts to simulate drone corridors, drone noise, and to integrate drone noise simulation with existing urban noise datasets. I guided student design efforts in weekly desk-crits.

Instructor, "Xixinan: Anhui Rural Return."
Masters Architecture Studio **EPFL**. Fall 2017 with Media x Design Lab

I lead workshops in design analytics using open data with GIS tools and drone-generated photogrammetric point cloud of a rural village in Anhui province, China. I met with students in bi-weekly desk crits to provide design criticism and guidance.

Instructor, "Singapore Prototypologies: Mega-incubator."
Masters Architecture Studio **EPFL.** Spring 2017 with Media x Design Lab

Instructor, "Singapore Prototypologies: Parametric urbanism,"
Masters Architecture Studio **EPFL.** Fall 2016 with Media x Design Lab

Instructor, "Artificial Morphogenesis: The Guangzhou Tower Delta Studio,"
Masters Architecture Studio **EPFL.** Spring 2013 with Media x Design Lab

Instructor, "Growth Typologies: Leshan Hillside Urbanism,"
Masters Architecture Studio **EPFL.** Fall 2012 with Media x Design Lab

Graduate Thesis projects:
Thesis text supervisor: "makecollaborate." Mathieu Bujnowskyj, **EPFL**. Fall 2015

Thesis text and project supervisor: "Anamnesis. Plan urbain évolutif (Huilongguan, Pékin, Chine)."
Alexandre Sadeghi, **EPFL**. Fall 2013-Spring 2014

Thesis text and project supervisor: "Méta-hutong: une couture entre quartiers traditionnels (Pékin, Chine)."
Charles Sarasin, **EPFL**. Fall 2013-Spring 2014

Workshops:

Organizing Committee, Pedagogical Lead: "Relational Space /Relational Urbanism."
ETHZ/EPFL Doctoral Summer School, Summer 2018.

For this ETH Board-funded doctoral summer school, I developed the concept with one other colleague from ETHZ and one from EPFL. I lead the pedagogical program, integrating guest lectures on AI, BigData, human geography and participatory planning, with readings, and group and individual exercise. A related publication with *EspaceTemps* is forthcoming.

Instructor, with Andrei Gheorge: “Angewandte Architecture Challenge: Polymer Folding Scapes”,
Universität für angewandte Kunst Wien, Summer 2014

Publications, Conference Proceedings, Lectures

Conference Paper: “Design-driven Data.”
CAAD Futures 2019. (abstract accepted, publication pending)

Invited Lecture: “Measuring Noise, Managing Noise, Designing for Noise.”
Fribourg Haute Ecole d’Ingénierie et d'Architecture, 26 Nov. 2018
for, ‘Architecture et Perception.’

Conference Paper: “Circular Buiksloterham: A Case Study of Architecture in the Data-driven City.”
Scaffolds, Open Encounters with Society, Art & Architecture. [EPFL, KU Leuven, TUDelft]
Brussels, 22-23 Nov. 2018
(abstract accepted, presentation given, publication pending)

Book Chapter: “Metric as Mediator: Data-driven negotiation over Heathrow’s Noise Landscape,”
in Christiaanse, Kees *The Noise Landscape: A Spatial Exploration of Airports and Cities.* nai010 publishers, Rotterdam. 2017

Book Chapter: “London-Heathrow Portrait,” with B. Boucsein and J. Jehle.
in Christiaanse, Kees *The Noise Landscape: A Spatial Exploration of Airports and Cities.*
nai010 publishers, Rotterdam. 2017

Conference Presentation: “Data-driven urbanism and the optimization of architectural form,”
EPFL+IUAV PhD Masterclass, Venice Biennale, Venice. 2016.

Conference Presentation: “La typologie: contrepoint à la vision *big data* de la ville. »
Geopoint 16, Lausanne. 2016.

Article: “Artificial Morphogenesis: The Guangzhou Tower Delta Studio,” with J. Huang and T. Patt.
in *Landscape Architecture Futures* 2013.10 Vol.1 No.5 p.138-149

Ce document a été imprimé au Centre d'impression EPFL,
imprimerie climatiquement neutre, certifiée myClimate.