3 Simulating systems

For landscape architects, exploring the dynamic and often invisible forces and systems that shape landscape through digital tools or prototyping has immense potential. Environmental and civil engineering have a long tradition of testing design performance through physical modelling (such as wind tunnels or hydrological models) or digital simulations. Increasingly accessible software capable of modelling the fluid dynamics of wind, water, tides, heat, humidity and pollution present new opportunities for embedding temporality and change into design processes. This chapter explores how these digital tools, combined with access to real-time site data, are expanding landscape architecture's design and research practice to achieve increased performance capability and novel design outcome.

Increasingly, clients are demanding evidence of design performance. For example, in 2011 New York City Department of Parks & Recreation in collaboration with the Design Trust for Public Space released *High Performance Landscape Guidelines: 21st Century Parks for NYC*. As Deborah Marton the former Director of the Design Trust comments, this type of document reflects a major shift in the conception of open space, 'from park as end-product to park as work in progress'.[1] This repositioning emphasises the multifaceted role of the park in the city, providing recreation and relaxation, in addition to contributing to storm water capture, addressing water and air quality, increasing biodiversity, lowering heat island effect and improving the general liveability of the city

Simulations and real-time data offers landscape architecture techniques for introducing an evidence-based metric into design processes, heightening the performative ambitions of spaces and providing quantitative and qualitative arguments for the value of parks, gardens and green infrastructure. *Cities Alive: Rethinking Green Infrastructure* published by Arup in 2014 uses social, environmental

3.1
The Supertrees, *Gardens by the Bay*, Singapore.

and economic benefits to argue for green infrastructure.[2] Tom Armour, Global Leader Landscape Architecture at Arup, highlights the significance of metrics in the current economic context, stating 'we need to get the value out of landscape' by demonstrating its potential in lowering pollution and air temperature levels, reducing carbon and contributing to healthier cities.[3] Similarly, Stephanie Carlisle environmental researcher and designer at Kieran Timberlake, comments that 'if we want to have projects built we have to be able to argue about what they are and what they do'.[4]

Of course models do not represent reality and always provide an incomplete understanding of systems. Therefore designers must remain critical in their application of simulations, not defaulting unquestioningly to simulation results. As Rob Holmes states of simulations 'sometimes they are very useful and other times they are worrisomely misleading or unpredictably wrong, with the skill lying in the negotiation between and evaluation of those two possibilities'.[5] There is no question however of the value of digital simulations in extending a designer's understanding of the performance of designed systems and spaces, especially for engaging with 'factors and forces that remain outside humans' perceptible limits'.[6]

Modelling tools are increasingly available to practice and students. The popular environmental modelling software, Ecotect emerged in the 1990s from the work of Australian researcher Dr Andrew Marsh who initially conceived the software as a teaching tool. In 2008 Ecotect was purchased by Autodesk and is widely used as a performance and analytical tool for simulating shading, solar access, lighting, acoustic and thermal conditions. The use of computational fluid dynamics (CFD) modelling software such Aquaveo SMS and ANSYS Fluent (used in the design of *Phase Shifts Park* discussed in Chapter 2) are also becoming more common in landscape architecture.

The application of these modelling techniques, however, provokes the question of what landscape architects are qualified to interpret in reviewing the resulting models, given that most landscape architects lack the specialised knowledge of the engineer or environmental scientist. As this chapter documents, approaches vary and are unfolding. Director of Technology at OLIN Studio Christian Hanley comments that while he is not qualified to interpret the detailed data generated by simulation programs, digital modelling offers an understanding of how a design intervention may be affected by conditions such as wind or solar access.[7] Keith VanDerSys adopts a more generative approach, using modelling to reveal shifts in the magnitude and speed of systems that are 'representative of processes that have material consequences'.[8] Influenced by ecologist Gregory Bateson, simulations aid VanDerSys to uncover 'a difference that makes a difference', identifying conditions, behaviours and forces of greatest degree of change in which to intervene.[9]

The insertion of simulations and associated metrics into design processes have been accompanied by theoretical frameworks that reconceive of the city within a biological metaphor defined by metabolic flows of energy, information and matter.[10] This move from static space, (exemplified in the figure–ground diagram), to an urbanism of connectivity is featured in the AD *System City: Infrastructure and the Space of Flows* published in 2013. Leading design practices discuss their application of environmental systems modelling to urbanism.[11] Designers from Skidmore, Owings & Merrill for example highlight the value of these approaches, stating:

> As other sciences like sociology and economics continue to develop computational modelling paradigms, the abilities to leverage knowledge embedded in models across discipline boundaries promises to enrich all of those engaged. Metabolic flows and transactions are at the heart of all of these types of models. Through the use of these technologies we stand to gain a much better understanding of the metabolic patterns of cities, a stronger theoretical foundation regarding the fundamental nature of cities, and a greater ability to intervene.[12]

Similarly Foster + Partners' Applied Research and Development group conclude that while the computer cannot replace the 'human experience of the idiosyncrasies that make urban living inspiring' it does 'provide us with an increasingly sophisticated foil for testing ever-more elaborate hypotheses about what makes cities work'.[13]

More specifically within landscape architecture, recent symposiums and forthcoming publications reflect a growing interest in the potential of simulation and prototyping. In March 2015, PennDesign hosted the 2-day research symposium Simulating Natures, which explored how contemporary forms of media influence an understanding and formation of landscapes with a focus on computationally enabled imaging and models. Bringing together engineers, scientists, landscape architects, artists and architects, the symposium focused on three aspects of computational techniques and associated technologies; namely their value in perceiving a fluid conceptualisation of environment and systems; their capacity to analyse and simulate the behaviour of living systems and their value in making data tangible through human–machine interfaces or through real-time translations.[14] Bradley Cantrell and Justine Holzman's book *Responsive Landscape: Strategies for responsive technologies in landscape architecture* (2016) builds on these questions, showcasing interactive and responsive projects that respond to environmental phenomena and systems.[15] Their book highlights how iterative prototyping and feedback processes offer valuable operational techniques for understanding and responding to the outside world, in addition to showcasing the value of technological advancements such as autonomous robotics sensing and distributed intelligence to design.

Beginning with a focus on Singapore's *Gardens by the Bay* and PARKKIM's design for Danginri *Thermal City* in Seoul, this chapter focuses on the application of simulation modelling and real-time data in landscape architecture practice, teaching and research. These projects highlight the opportunity that simulation provides for designers to respond to specific and dynamic climatic conditions towards the development of optimum growing environments and external spaces of higher thermal comfort, while engaging efficiently with energy resources.

Modelling systems

Singapore's *Gardens by the Bay* emerged from an international design competition for a 54-hectare public garden. In 2006 the Bay south competition was won by the multidisciplinary collaboration of Grant Associates (landscape architects), Wilkinson Eyre Architects and the engineering firms of Atelier One (structural) and Atelier Ten (environmental). The predominantly UK-based design team had previous experience in the design of London's Kew Gardens Alpine House. The project's success relied on the establishment of a successful growing environment for a range of plants within Singapore's cloudy environment of subdued light and high humidity levels. The consortiums' scheme was ambitious, proposing 'a highly sophisticated and integrated three-dimensional network of horticulture, art, engineering and architecture'.[16]

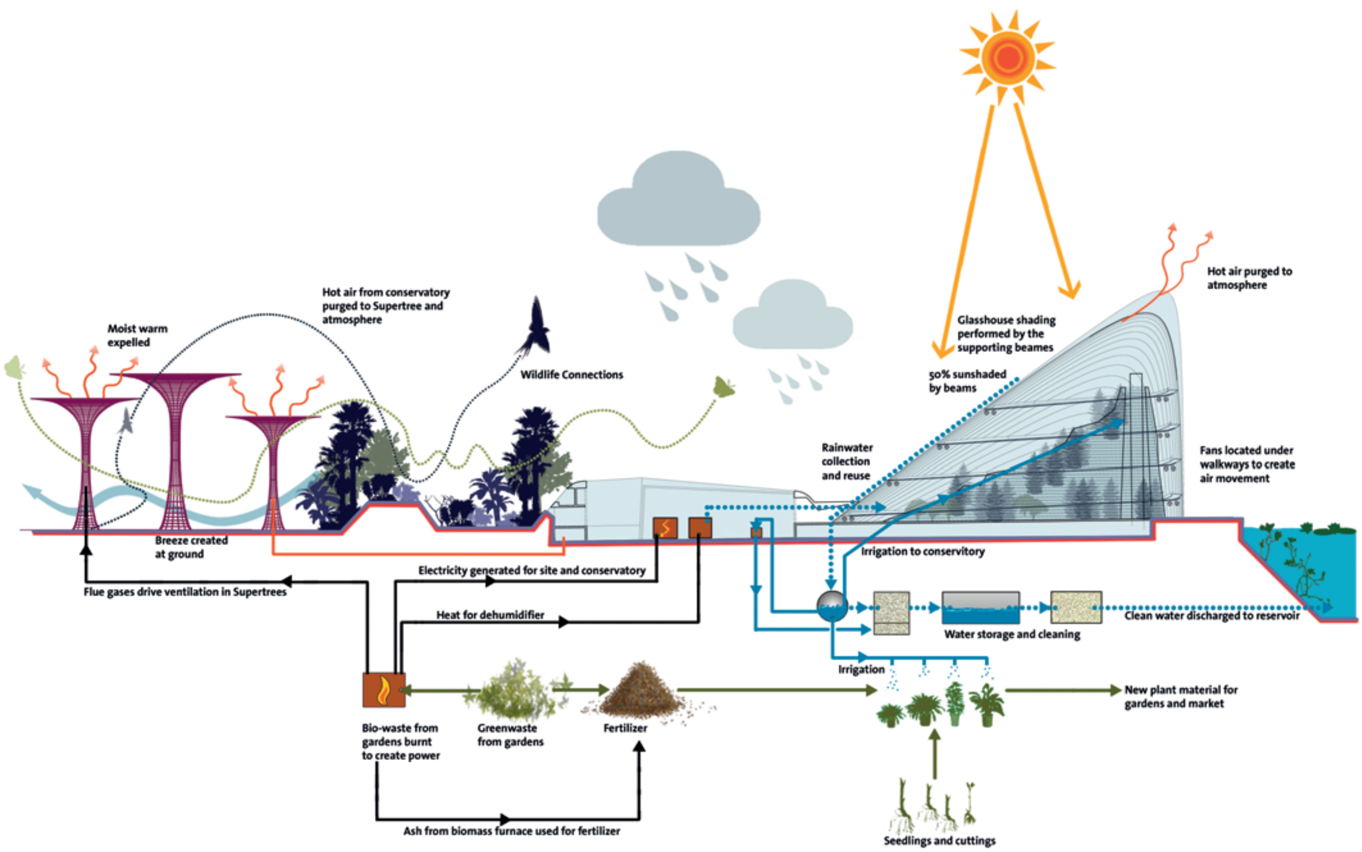
The design of the two feature biomes conservatories, shown in Figure 3.2, was particularly challenging. At close to 20,000m square, and up to 58 metres in height, the conservatories are some of the largest in the world. The challenge within the Singapore context was to adequately ventilate, cool and dehumidify the equatorial environment, while meeting horticultural lighting requirements and limiting the carbon footprint.[17] For 95 per cent of the year, Singapore's equatorial

3.2a
View of the 54 hectares public garden with the two conservatories featured on the left.

tropical climate maintains temperatures between 24 and 32 Celsius with humidity measuring between 17 and 21g/kg.[18] The Cool Moist (cloud mountain) Dome, designed for species from the mountainous tropical regions, requires mild air temperature night and day combined with an almost saturation level of humidity, while The Cool Dry (flower) dome replicates the Mediterranean springtime of mild dry days and cool nights.

Advanced environmental testing was critical to developing a carbon-neutral design that also achieves the necessary day lighting requirements. A combination of proprietary software such as Ecotect and Radiance and bespoke software generated by Atelier Ten, facilitated the evaluation and comparison of various proposals.[19] Daylight simulation techniques assessed the availability and quantity of daylight for the inhabited volume for each hour of a typical year.[20] A dynamic shading structure, responsive to the changing solar environment, emerged as the solution for achieving the desired growing environment. Internal light levels with and without shades were modelled for a complete reference year. The final scheme comprises 419 individually controlled external shades, featuring 'an intelligent self-learning algorithm' that adjusts shades in response to the sun paths, the geometry of the internal spaces and the external cladding.[21]

3.2b
Diagram from the competition submission showing the environmental system which is fueled by green waste and a bio-mass boiler.



Energy efficiency

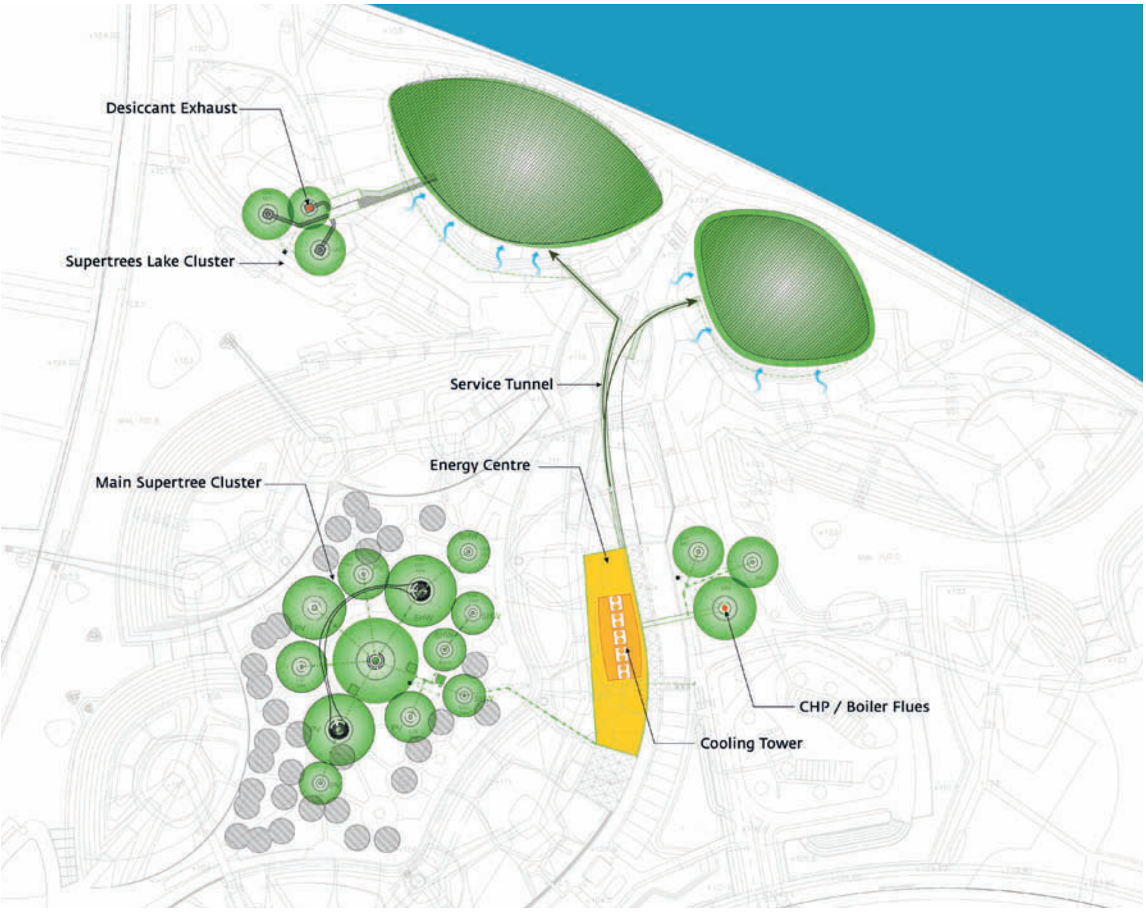
A carbon-neutral energy system to power the conservatories presented a further challenge. Initially solar was assumed as the energy source, however the cloudy nature of Singapore reduces its efficiency. Discussions with the National Parks Board of Singapore revealed that the city regularly prunes several million trees, generating extensive green waste largely incinerated or sent to landfill.[22] Plans altered to include a bio-mass boiler fuelled by the city and garden's horticultural waste. Steam from the boiler feeds a turbine to generate electricity. Remaining ash is used as fertiliser, while surplus energy is fed back into the grid.

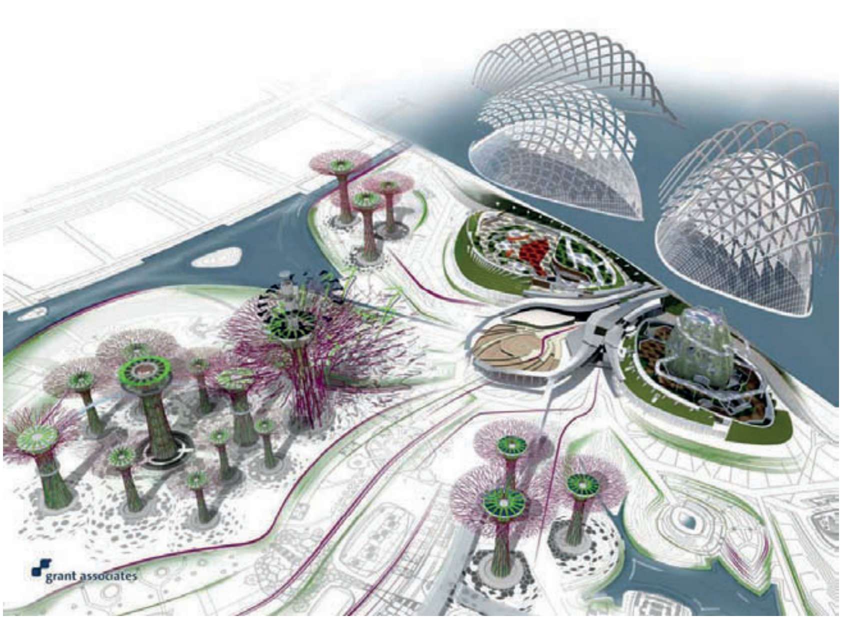
The iconic Supertrees perform an essential role in this complex energy system (Figure 3.2b) which was conceived as a larger symbiotic relationship that included the conservatories and gardens, through an exchange of energy, air, water, nutrients and water cycles. These spectacular tree-like structures are multifunctional 'environmental engines' designed to disperse hot gases generated by the biomass boiler and the desiccant process, generate energy through photovoltaic solar panels and provide shade for the public areas below as well as extensive valuable habitat for birds and insects.

The Gold Cluster of Supertrees, which is located near the entrance, conceals the major chimney from the energy centre's boiler, discharging non-toxic flue gases high above any occupied areas. The steam turbine powers the electric chillers, producing chilled water to cool the domes. Adopting principles of thermal stratification, chilled water runs through pipes within the floor slabs, while the rising warm air is vented out at higher levels or is captured to harvest heat. Computational fluid dynamic modelling allowed the engineers to analyse and optimise this airflow and accurately predict outcomes.[23]

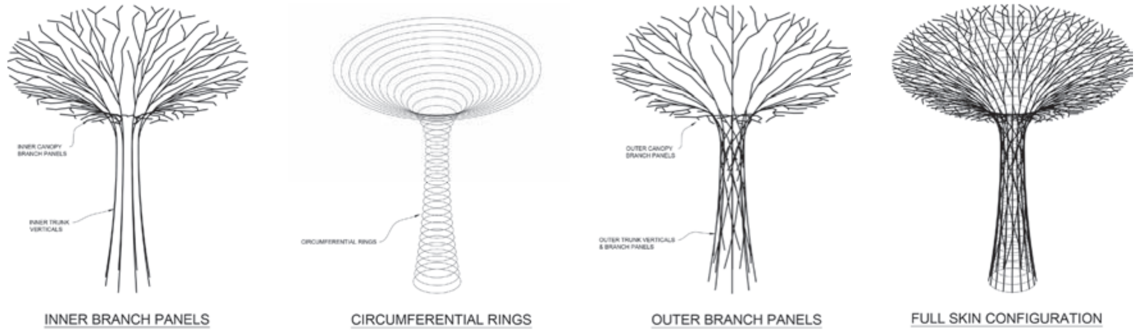
Any waste heat is used to regenerate the liquid desiccant, necessary to dehumidify the air for the Flower Dome (the cool-dry biome). Conventional cooling of humid air requires an energy-intensive process; chilled water removes water vapour through condensation, followed by reheating to the desired temperature.[24] In contrast this system uses liquid desiccants to remove water vapour from the air through a chemical process; leaving the air temperature similar but drier. Used in conjunction with conventional cooling systems, this technology requires less energy, while the desiccant is recycled through treatment from waste heat from the biomass boiler.[25] The Silver Cluster of Supertrees, masks the hot moist air discharge from the regeneration unit of the liquid desiccant dehumidification system.

This complex environmental system (Figure 3.3) encompassing the entire garden facilitates a number of 'virtuous cycles' involving either the reuse of resources or the maximisation of their use.[26] The Supertrees however were designed as far more than environmental infrastructure. Their inspiration, states landscape architect Andrew Grant, are the monumental karri forests of Western Australia (which feature a sky walkway) and the 1997 anime film Princess Mononoke depicting a young warrior's encounter with forest gods and those wishing to destroy the forest resources and beauty. Rising 50 metres to match the monumental scale





3.3a–b
Diagrams explaining the infrastructural relationship between the Supertrees, the conservatories and the environmental system.



INNER CANOPY BRANCH PANELS
INNER TRUNK VERTICALS
CIRCUMFERENTIAL RINGS
OUTER CANOPY BRANCH PANELS
OUTER TRUNK VERTICALS & BRANCH PANELS
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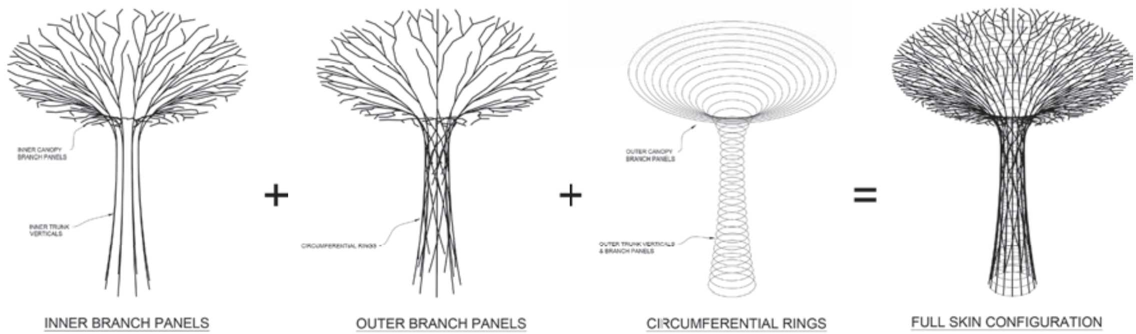
CIRCUMFERENTIAL RINGS
OUTER BRANCH PANELS
FULL SKIN CONFIGURATION



INNER CANOPY BRANCH PANELS
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OUTER CANOPY BRANCH PANELS
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INNER BRANCH PANELS
OUTER BRANCH PANELS
CIRCUMFERENTIAL RINGS
FULL SKIN CONFIGURATION

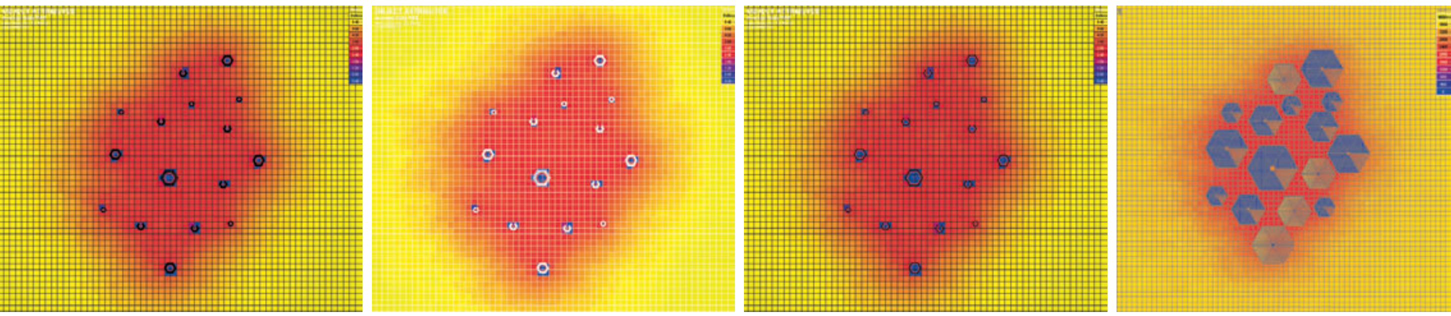
3.4a–b
The structural geometries of the Supertrees which were explored parametrically and conceived as doubly curved anticlastic forms (a). The largest configuration of Supertrees in the Lion Grove Plaza which features an aerial walkway, bar and viewing platform suspended 20m above the ground (b).

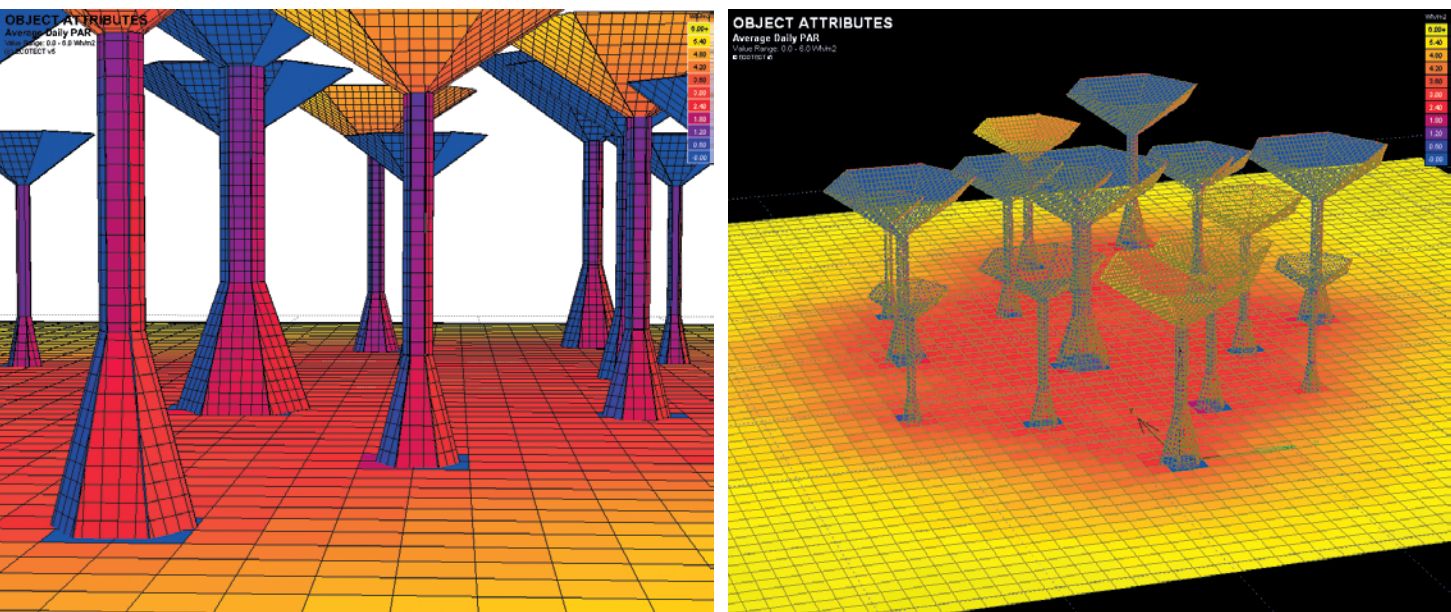
3.5a–b
Screenshots from using Ecotect software to test the siting of the Supertrees in relationship to sun paths and their shading potential for public areas in plan (a) and perspective (b).

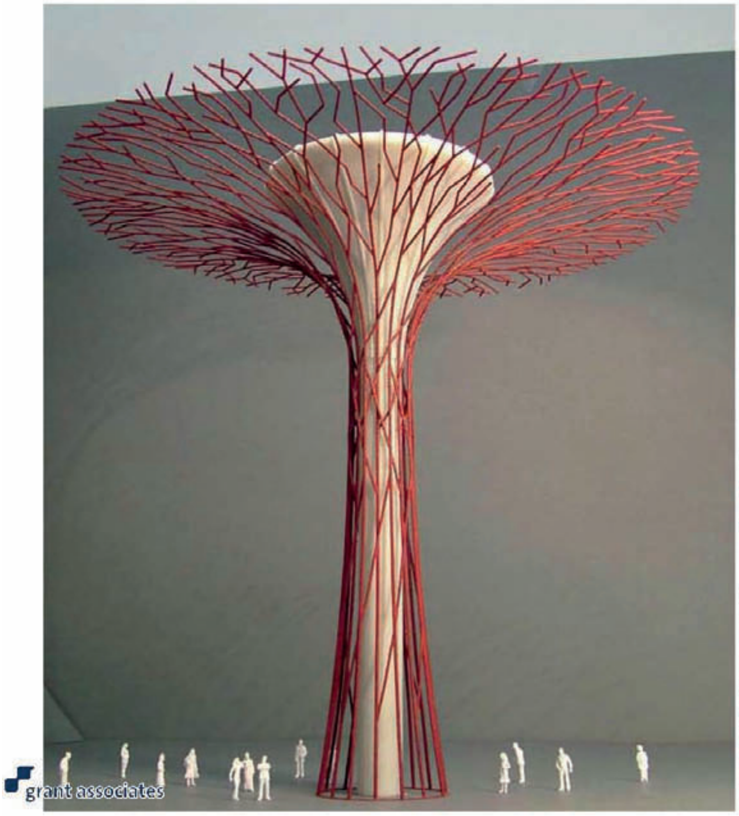
of the conservatories, the structures were conceived as a magical ‘other worldliness of space’, including a unique night-time experience.[27] The largest configuration forming the Supertree Grove are particularly immense, supporting a 135m long aerial walkway (Figure 3.4b) suspended over 20 metres above the gardens, with the tallest structure featuring a bar and viewing gallery.

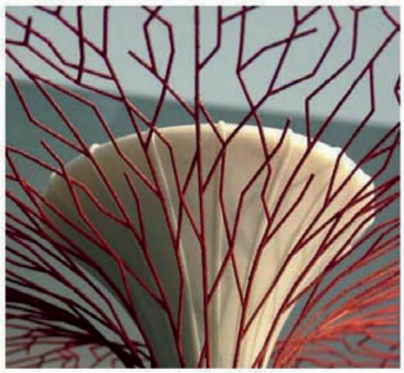
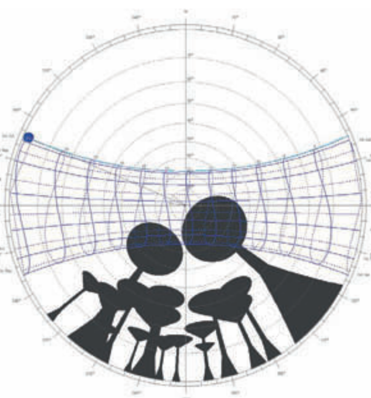
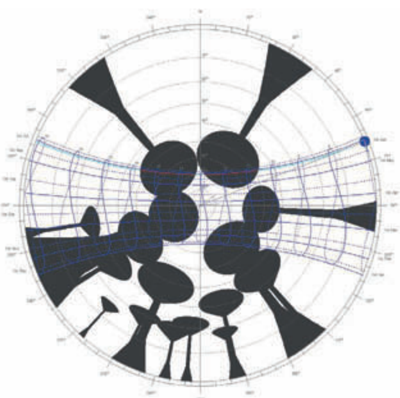
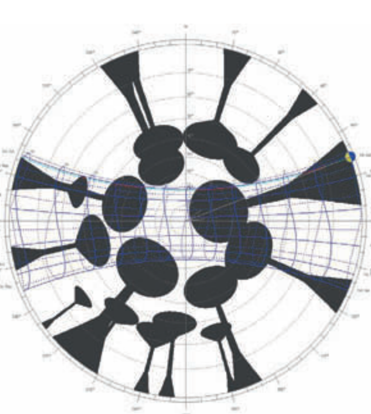
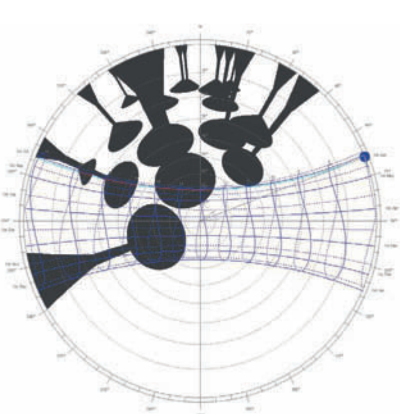
The competition entry featured an atmospheric fly-through developed with 3D animation technology by the firm Squint/Opera. Grant comments that this animation was influential in ‘defining the spirit’ of the Supertrees.[28] The designers were challenged to translate this mystical imagery depicted in the competition film into structures; while maintaining their structural strength, experiential qualities and performance as environmental infrastructure.

The landscape architects worked closely with structural engineers Atelier One (led by Neil Thomas), who had considerable experience in light-weight structures such as the design of travelling stage sets. The team also called on the engineering expertise of the University of Bath. First versions, stated Grant were very ‘clunky’ which ‘looked like bits of the Eiffel tower’.[29] Slowly the form evolved through a process of testing structural form and exploring environmental efficiency through physical and sectional analysis and 3D studies. Two key decisions influenced the final form; that the structural integrity would develop through a central concrete core, and that the diameter of the canopy would equal the height of the Supertree.






grant associates

The geometries of the structures were established parametrically, developed as two repetitious modules that 'overlap each other, and reinforce each other but give the appearance of being random'.[30] The form emerged as 'doubly curved anticlastic surfaces, using form to create stiffness'.[31] Planting panels were designed to attach either directly to the concrete core, or to the steel skin covering the core. This novel typology challenged Singapore's existing building codes, raising questions for authorities and engineers on how to classify them. Should they be considered buildings or bridges? Figure 3.4a documents the development of this form. Testing the overshadowing of the trees was an important stage of design development. Some of these testing are documented in Figures 3.5 and 3.6.

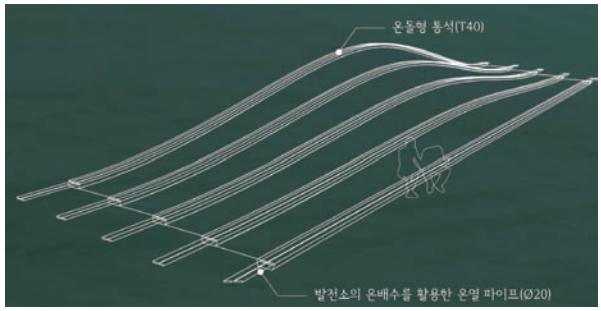
Officially opened in 2012, *Gardens by the Bay* has been awarded numerous international design awards in recognition of the quality of the public space, architecture and gardens and the innovative response to climate change adaption, sustainability and technology. The Supertrees have developed iconic status, quickly adopted as a symbol of Singapore. Grant Associates continues to explore relationships between environmental systems, technology and resources. This is demonstrated (in conjunction with Wilkinson Eyre Architects, Atelier One and Atelier Ten) in their competition entry for the UK pavilion planned for the 2015 Milan Expo. The future of food forms their inspiration, developed through an exploration of the integral relationship between the sea and land. Their design comprises a seawater greenhouse, which features a desalination process driven by natural processes.

During the course of the research for this book, it became evident that many landscape architects and designers were unaware of the infrastructural capability of the Supertrees. Anecdotally, our decision to feature the Supertrees on the cover of the book received mixed reactions, with some people questioning whether they were too object focused and thereby not 'landscape' enough. This response, combined with reactions to the climatic devices designed for *Phase Shifts Park* discussed in Chapter 2, exposes a tension concerning the use of obvert technologies within landscape.

This attitude is reflective of larger anxieties regarding the application of technology as a dystopian replacement to nature. Why replicate nature when you can simply plant a tree, and further isn't technology the primary cause of environmental issues in the first place? This argument is not without merit. For example Dutch artist Daan Rosegarrde's *Smog Free Project* uses patented ion technology to make the 'largest air purifier in the world' to create the cleanest park in Beijing.[32] The project is accompanied by the marketing idea of creating souvenir smog rings from the particles captured from the air, with each ring representing the cleansing of 1000m^3 of polluted air. Much emphasis is placed on the development of a 'smog-free movement' promoted through exhibitions and public events. Nowhere in the extensive promotional material however is there mention of the energy requirements and energy source necessary for the purification process. This raises questions over whether the energy source remains brown coal, which creates the irony of the purifier both cleaning and contributing to air pollution.

3.6a–b
A 3D printed model of a Supertree and a photosynthetically active radiation (PAR) study indicating the different levels of direct sunlight falling on the vegetated faces of the Supertrees and the surrounding surfaces.

But beyond this question of energy, the *Smog Free Project* also presents a very limited response to the broader question of pollution and the performative role of open space in the Chinese City. It is in this realm that landscape architects with their wider understanding of ecological and social infrastructure and systems, have a greater role to play, as demonstrated in the *Gardens by the Bay* and *Phase Shifts Park*. Landscape architects are in an ideal position to guide the use of technology, working with it to enhance the ecological performance and experience of the park.



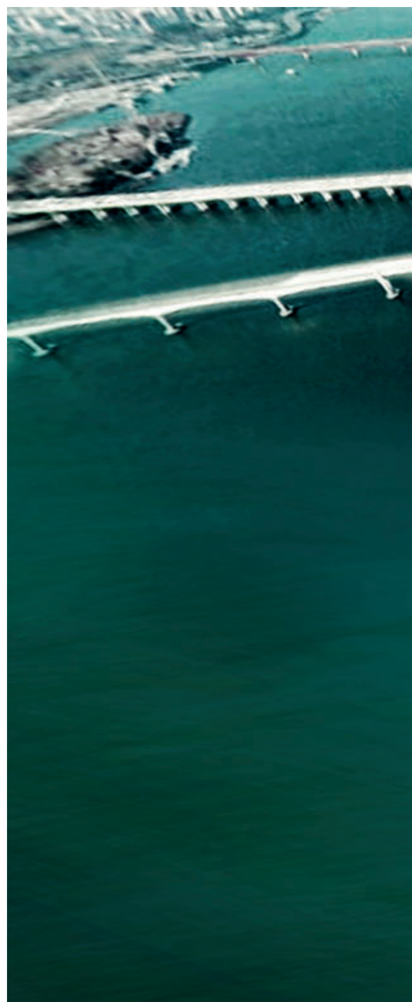
3.7
The heating system references the ondol, a traditional Korean technique for heating architecture.

In the case of *Gardens by the Bay*, technology was central to developing an environmentally responsive system that also provides exceptional recreational and aesthetic experiences. Andrew Grant stresses that the Supertrees should not be viewed as a replacement to nature or 'elements' to be reproduced in other locations. Instead, he highlights their origins in a very specific design context, emphasising their value in reconceiving infrastructure to operate intelligently to address environmental issues and limited energy resources.

Thermal comfort

The reconceptualisation of infrastructures and external spaces of cities is becoming increasingly urgent as we begin to experience the reality of climate change. With 2015 considered the hottest year on record, the implication of climate change on the liveability of our cities is becoming increasingly apparent, especially in Asia and Australia. A 2015 report identifies that Australia will be 'hit harder than the rest of the world', with temperatures predicted to rise by 5 degrees by 2090.[33] These effects are already being felt. Melbourne's 2014 record-breaking 4-day January heatwave is estimated to have contributed to 167 excess deaths[34] and cost an estimated loss of revenue of AU$37 million from businesses in the Melbourne metropolitan area.[35] This event, which is expected to be a frequent summer experience, has necessitated the design of urban heat refuges for the young and the elderly.

The design of open space for thermal comfort is emerging as a pressing issue in many Asian cities. There is no standard thermal comfort index for external spaces, with comfort relative to different geographic conditions. However there are agreed criteria that influence comfort indexes for perceived temperature; namely the relationship between air temperature, air velocity, air humidity, clothing, activity of the person and radiant temperature (solar and infrared radiation), all factors that can now be simulated within design.[36] As an example German climate engineers Transsolar are currently developing new design tools based on human biometerological data, driven by their experience in designing major sporting events in difficult climatic conditions such as for the World Cup 2022 Qatar.[37] Transsolar engineer Christian Frenzel highlights the value of comfort modelling in identifying

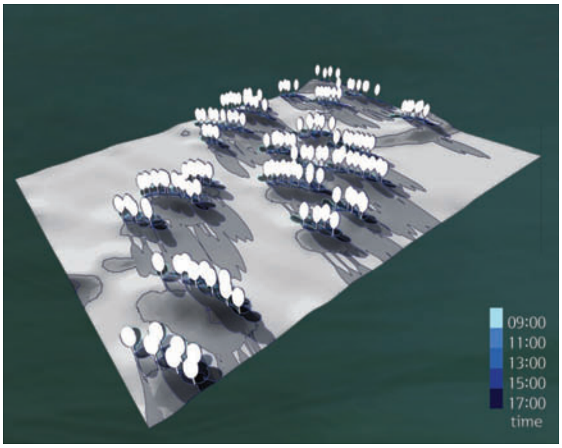


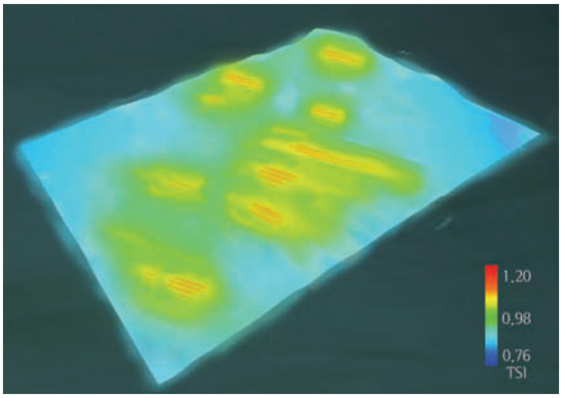
3.8a–b
Thermal City proposed a climate conscious park on the site of Korea's first thermal power station. A new power station is located under the park, with hot excess water from the power station circulating through stone surfaces to provide heated seating in winter.

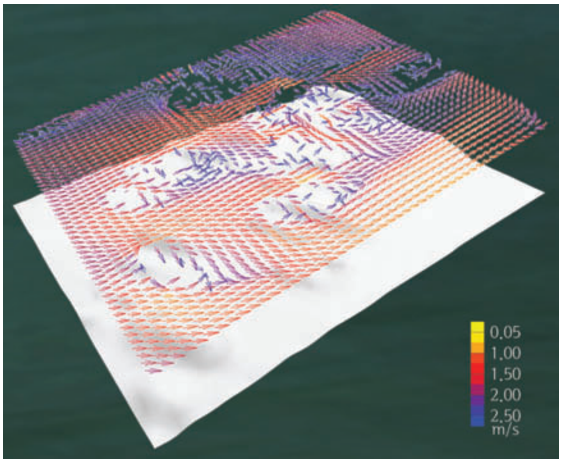
the potential to improve occupant comfort, with CFD software producing '3D recommendations in order to generate micro-scale comfort locations in a macro-scale context'.[38]

Likewise, Korean designers PARKKIM adopt thermal comfort levels as a major design driver in their 2013 competition entry for the Danginri underground Combined Heat Plant, the site of Korea's first thermal power station. In a world first, the old power station constructed in the 1930s will be replaced by an underground combined cycle power plant (requiring a space equivalent to five football pitches) with a cultural complex encompassing sport and performance facilities, eco-park and library planned above.[39] The complex is envisaged as a new landmark for Mapo-gu, Seoul, located next to the Han River.

PARKKIM's scheme *Thermal City* aims to create and control temperatures within the open space, observing that Seoul's challenging winters and summer seasons are becoming more extreme and longer, noticeably shortening the more comfortable spring and autumn seasons.[40] Topographic valleys, shown in Figure 3.8a, inspired by the once frequent sand dunes of the Han River, are aligned to maximise cool summer air flows and, combined with vegetation, provide barriers to the winter winds. In a major design innovation, excess heated water from the underground power station runs through pipes located under stone surfaces within the park (Figure 3.8), before expelling into the river as cool water. This feature has two functions; to address the ecological damage of pumping hot water directly in the river (a common practice in power stations); and to provide warm seating and microclimates within the park in winter. This technique references the use of ondol (or gudeul) found within traditional Korean architecture where heat from wood smoke is applied under a thick masonry floor to heat sleeping and living areas.







3.9
View of the proposed park showing the terraced landscape and the wind turbines used to generate energy.

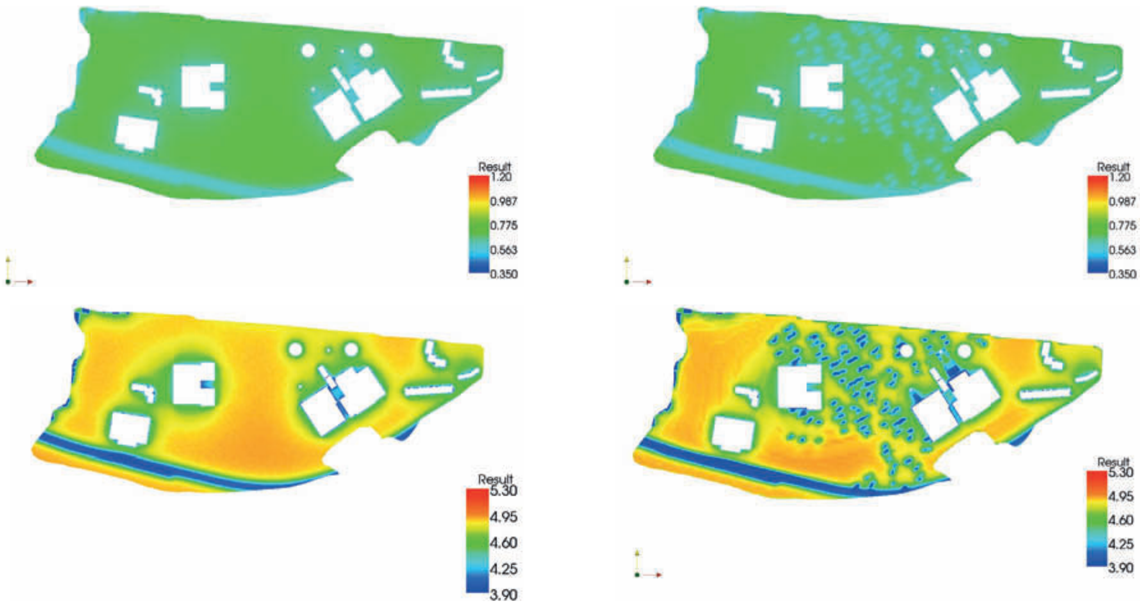
3.10a–c
Initial climatic testing of the proposed topographic form and the location of planting using Ecotect software.

3.11a–d
Arup's simulations testing thermal comfort indexes for Seoul in December (top) and June (bottom). The left images represent site conditions prior to the PARKKIM's scheme.

The park also produces its own energy through a solar canopy over the car park and wind turbines (Figure 3.9) located throughout the park.

During their design process, PARKKIM used the environmental simulating software Ecotect to test the effectiveness of their topographic form and siting of vegetation to improve cooling and shade, shown in Figure 3.10. In this process, PARKKIM engaged Arup for detailed analysis of thermal comfort performance, applying a Thermal Sensation Index equation which had emerged from research in Japan and Tel Aviv.[41] This index establishes a reading of 4 out of 7 as most comfortable with 3 to 5 as acceptable levels of comfort. Arup's simulation was used to test PARKKIM's design for June 2–5 p.m. (summer) and December 2–5 p.m. (winter) comparing site conditions before and after design implementation. As shown in Figure 3.11, during summer months the design extends areas of comfort from those located in the shadow of buildings into the central open space. In winter, the simulation result showed, while the mounds are beneficial during summer, the valley created between landforms could expedite wind velocity and worsen the thermal comfort partially: in response, PARKKIM strategically placed the heated stone seatings on the south-eastern slopes to warm the colder areas.

Gardens by the Bay, *Thermal City* and *Phase Shifts Park* (discussed in Chapter 2), all demonstrate the value of embedding simulation modelling within design. Simulation facilitates the testing of performance during the design process, as well



as providing evidence-based metrics to support design decisions such as quantifying energy and resource consumption and achieving thermal comfort levels. These innovative outcomes prove that a focus on performance does not diminish creativity and innovation, nor does simulation alone generate design. Instead it is argued by academics such as Elizabeth K. Meyer and Karen M'Closkey that the current emphasis on sustainable design guidelines complete with 'typical' design concepts is more likely to produce formulaic responses that diminish 'expression and experience'.[42] Meyer's 2008 manifesto *Sustaining Beauty: The Performance of Appearance: A Manifesto in Three Parts* for example criticises landscape architects for deferring from the challenge of design, in favour of the implementation of management guidelines.[43]

The value of simulations within design processes is further enhanced by the rapidly increasing ability for the designer to access real-time site data, the focus of the following section.

Real-time data

The concept of datascapes has intrigued many designers, most notably the Dutch designers MVRDV. Their 1999 publication *Metacity/Datatown* proposed a new development methodology premised on data-supported 'extreme scenarios', provocatively presenting city form derived entirely from data, without context, topography or ideology.[44] In the two decades since, interest in data has expanded exponentially, fuelled by the twenty-first-century phenomena of Big Data, where data is continuously generated and increasingly accessible. Big Data challenges the very production of knowledge, capable of revealing new patterns and relationships without guidance by a prior hypothesis. Consequently a 'new data analytics' where knowledge is generated directly from data has emerged, replacing earlier conceptualisations where theory is tested through the analysis of relevant data.[45] The sheer scale and pace of data production however relies on a critical engagement, or as Chris Leckie describes it 'the identification of high value problems'.[46] The challenge with Big Data, states Leckie, is transforming it into 'a little bit of knowledge', which requires the extensive filtering of events to find relevant issues or problems.[47] This filtering requires human intelligence, combining the identification of patterns in the data (through the computer) with the contextualisation of the data in relationship to problems.

As discussed earlier in this chapter, it is critical to recognise disciplinary limitations in interpreting data. That said, it can be predicted that data analytics, like coding, will form a major part of future generations' education embedded in school and university curriculum. As Nathan Eagle and Kate Greene state in their 2014 book *Reality Mining: Using Big Data to Engineer a Better World*, 'the era of Big Data is here and it isn't going to be over anytime soon'.[48] While acknowledging the importance of addressing privacy, individual liberties and security, Eagle and Greene believe 'that within a conscientious context of data collection, it's possible to use Big Data to engineer better systems and potentially a better world'.[49]

The data lab

The establishment of specialised data or media labs have accompanied this data expansion. Linking governments, institutions, private organisations and citizens, these labs pose new questions for engaging data, cities and society. Medialab-Prado formed in 2000 as part of Madrid City Council's Department of Arts, Sports, Tourism offers an early model.[50] Conceived as 'a citizen laboratory', the lab performs as a multidisciplinary hub supporting the development of collaborative and experimental cultural projects emerging from digital networks.[51] Future Everything, established in Manchester in 1995, explores how 'technological, creative and societal innovation' inspires change.[52] *Open Data Cities*, the lab's longest-running project (2009) was instrumental in establishing the *Open Data Cities* movement. This project proposed the open sharing of data from the Greater Manchester Region, encouraging citizen access to government workings (and democracy) and supporting developers and businesses in designing new applications from the data. Conceived as 'innovation ecology', the project encourages collaborations 'where the ability to aggregate and disseminate information through the Internet by individuals is a key enabling technology'.[53]

San Francisco (datasf.org) and London (data.london.gov.uk) were among the first urban authorities to publicly release large datasets concerning the urban environment. Cities throughout the world have since followed, encouraging public participation and more accountable governance. Designers can freely access datasets describing the economic, political, social and environmental workings of our cities. *Open Data Cities* is now considered an emerging body of practice with direct economic benefit, with research suggesting it contributes up to £6.5 billion to the UK economy.[54]

SENSEable City Laboratory at Massachusetts Institute of Technology offers a further model, exploring the potential of sensors and hand-held electronic devices to understand and transform the city.[55] Under the direction of Carlo Ratti, researchers develop projects ranging in scale from the regional to the individual. The *Hubcab* project (2014) for instance uses smart technologies to understand how taxicab services operate, proposing a more socially and environmentally accountable transportation systems.[56] *One Country, Two Lungs* (2014) places a miniature network of sensors on a team of 'human probes' who travel between Shenzhen and Hong Kong mapping the 'atmospheric boundaries' of particulate matter (PM 10), carbon monoxide (CO) and nitrogen dioxide (NO_2).[57] Conceived as an alternative to fixed ground monitoring of air pollution, the project develops a more accurate reading of human exposure, offering information relevant to public health research.

Generating data

Data opportunities extend beyond the use of third party sources to designers generating their own site data through portable technologies ranging from smart phones, digital cameras, 3D terrestrial laser scanners, hand-held Global Navigation Satellite Systems, in addition to small unmanned aerial vehicles (UAV) such as quadcopters and small drones. For a site-specific discipline such as landscape architecture this development fundamentally challenges the way site information is gathered and recorded. Jörg Rekittke and Yazid Ninsalam comment on the future of site information, stating:

> It will be handheld, respectively mobile and light, broadly affordable, and will allow digital landscape capture in the form of 3D data progressively in high precision, high density, and geo-referenced manner.[58]

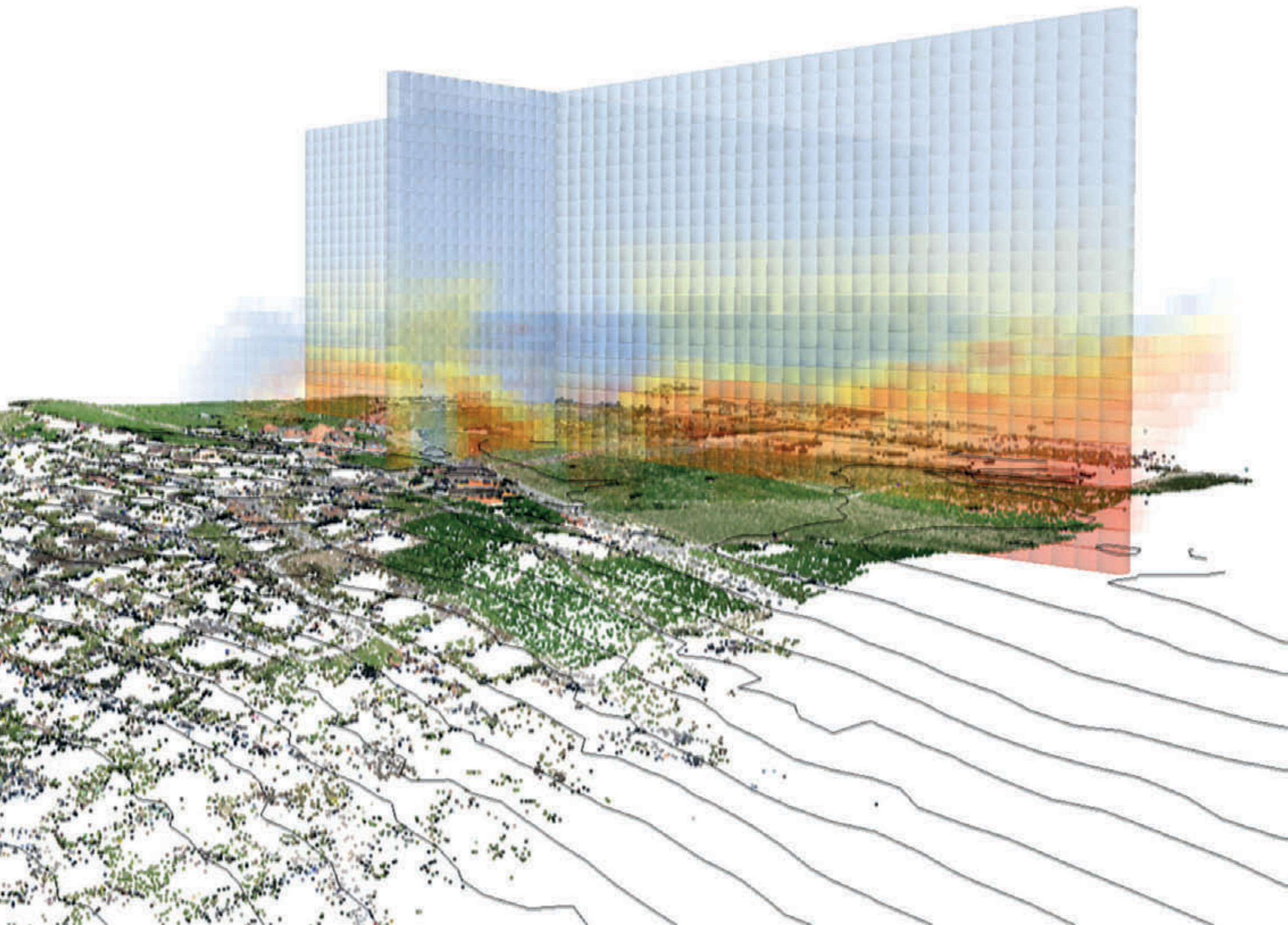
Christophe Girot from the ETH Zurich highlights the possibilities afforded by sensor-based data collection which can record and measure intangible characteristics of space such as humidity, lux, radiation, temperature and pressure. These phenomena, argue Girot, offer alternative modes for conceiving sites beyond the standard GIS data techniques that privilege surface-based data and the visuality of site analysis.[59] Real-time data contributes accuracy lacking within 2D site mapping, significantly extending the capability of the designer. Antoine Picon comments further:

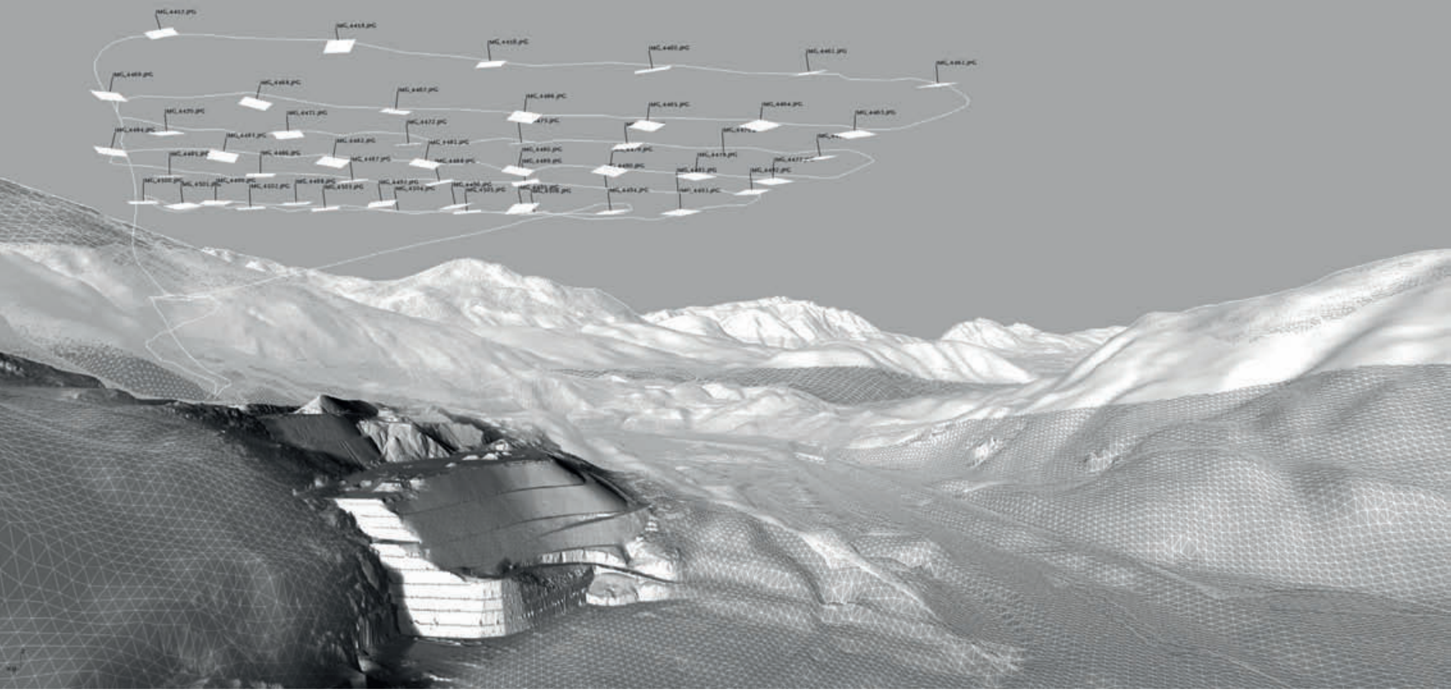
> mapping and monitoring become inseparable, just like the understanding of what lies beneath the eye of the observer and what is not yet there. Mapping understood as the exploration of scenarios of evolution rather than as the production of static representations enables the blending of these two categories.[60]

Since 2010 the postgraduate Master of Advanced Studies in Landscape Architecture (MAS LA) at ETH, directed by Pia Fricker, has focused on the integration of the latest information technologies within large-scale landscape projects. Students are encouraged to create their own data and provoke 'curiosity about the intangible'.[61] The MAS LA module Field Oriented Programming led by researcher James Melsom challenges 'the conceptual depth' of traditional modes of site analysis to measure and simulate ambient and micro climatic site attributes.[62] UAV drones (shown in Figures 3.12a–b) generate sets of data horizons (a term borrowed from aeronautical engineering that emphasis a vertical dimension) to establish 3D spatial scans.[63] The drones, fitted with microcontrollers and sensors to record humidity, dew point, air quality and temperature, are flown in layers (or horizons) to record the 'volumetric dynamics' of the site.[64]

Data from sensors, airborne and terrestrial laser scanners is presented within a 3D point cloud (shown in Figure 12c). A point cloud establishes data points within a geo-referenced, spatial coordinate system. Spatial data can also be accessed from 2D sources to construct a point cloud. In a process known as photogrammetry, a dense series of 2D images from digital cameras can be converted into 3D point clouds. Various software including GIS and modelling programs (for example Rhinoceros and Bentley Pointools V8i) can be used to transform point clouds into topographic maps, spatial models and mesh surfaces.

3.12a-c
ETH Zurich: using drones fitted with sensors to record atmospheric data such as humidity, temperature and air quality. The data can be translated into point clouds such as the voxel rendering of humidity shown in (c).





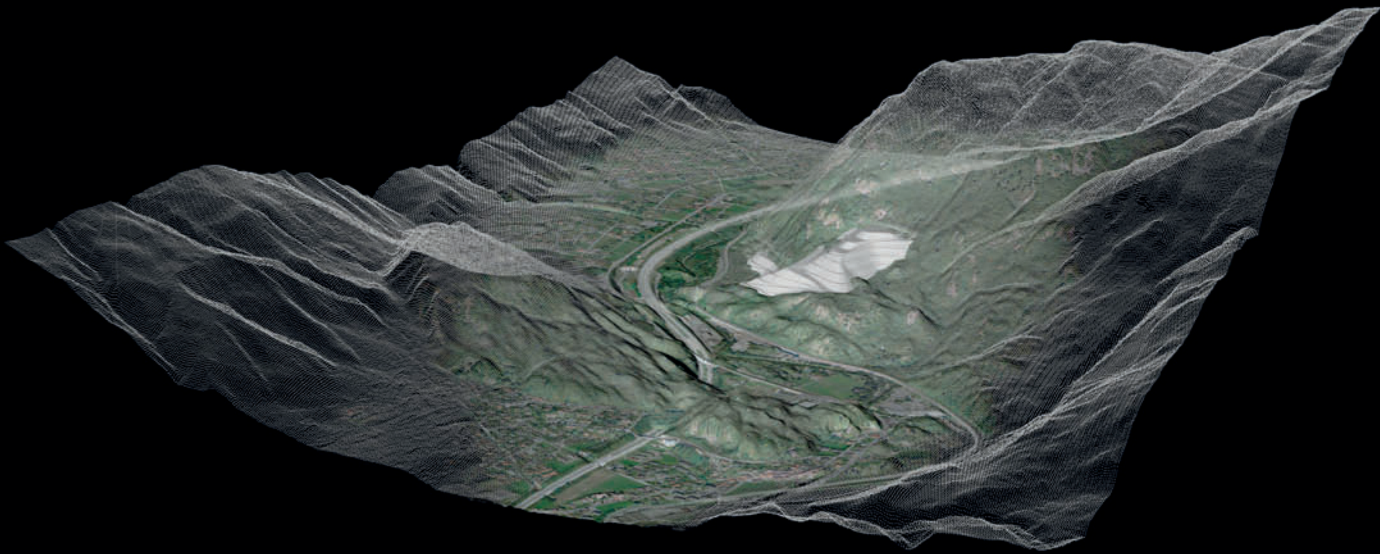
Transferring across programs is becoming increasingly efficient, with plug-ins such as gHowl (Grasshopper) allowing a simpler exchange of information. Smoother cross-translation platforms are encouraging a more fluid feedback between analysis and design, allowing designers to move analytical data into GIS, where it can be sampled, sorted and sifted and isolated, then translated back into a design model, where it can be further tested with simulation and the results fed back into design iterations. VanDerSys comments that earlier applications, tended to maintain activities within discrete 'rooms', requiring the replication of simulation within design models, rather than a more direct application.[65] This interoperability continues to improve through the constant evolution of plug-ins and software, offering faster and simpler workflows between data, simulation and design processes.

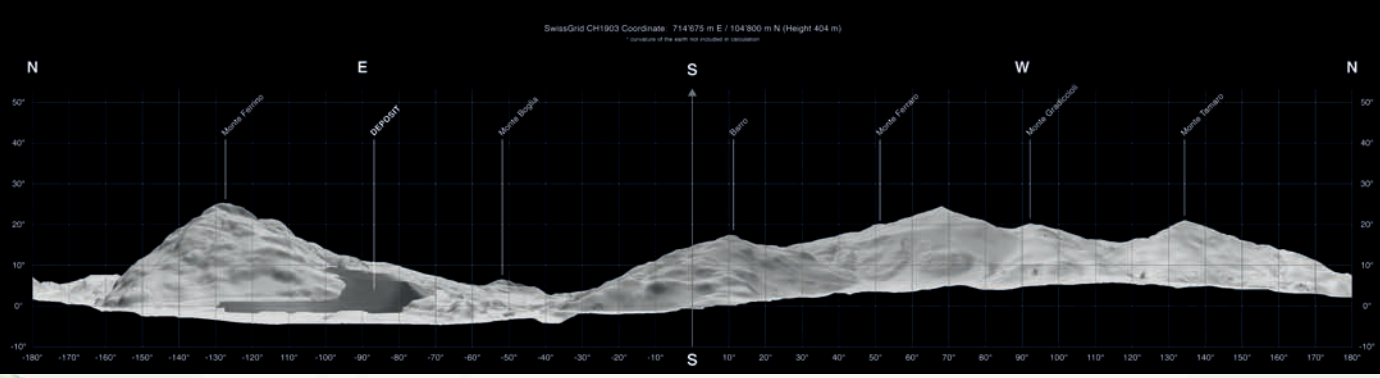
3.13
Flight pattern of the fixed-wing UAV and photo-capture locations used in the development of a geo-referenced point cloud model.

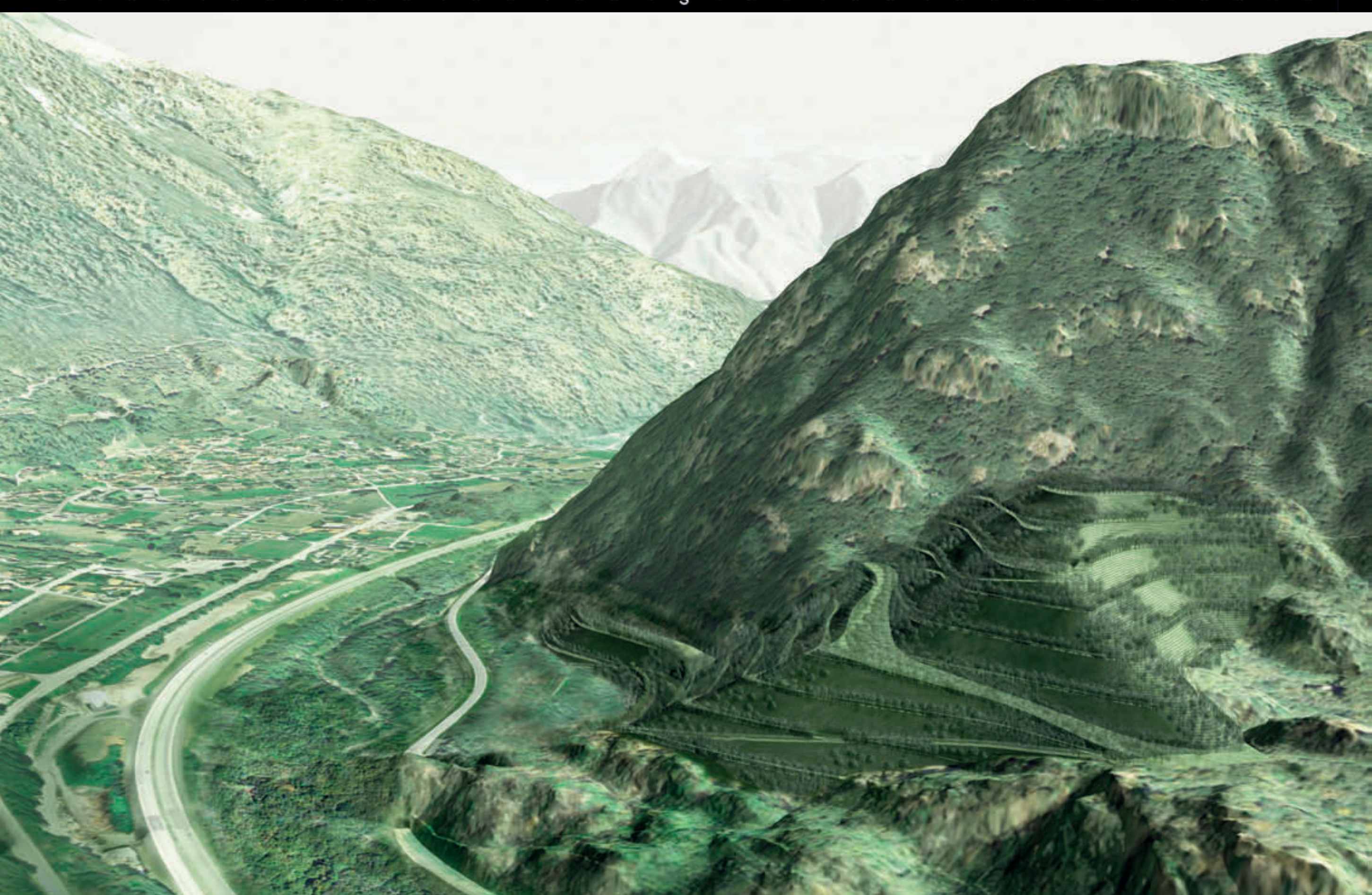
Girot's investigation into data-driven techniques owes much to his critique of existing tools and practices, unable to deal with large 'unwieldy' 3D datasets that can be 'difficult to convert into meaningful workable formats'. He argues that 'a renewed approach to landscape through such modelling can provide a stronger, well-informed basis for design'.[66] To this end, researcher Ervine Lin programmed a suite of custom tools enabling ETH students and researchers to manipulate, reconstitute and edit point clouds within Rhinoceros.

The value of these approaches is well demonstrated by Atelier Girot's design for the *Sigirino Alptransit Depot*, which is a 'landscape by product of the largest infrastructure project in Swiss history'.[67] Over 3.7 million cubic metres of material was excavated from the Ceneri Base Tunnel to form the *Sigirino Alptransit Depot*, a highly visible piece of 'artificial nature'.[68] Forming the largest artificial mound in Switzerland, the design team were challenged to mechanically stabilise this excavation material and to facilitate plant growth on inorganic substrata. Detailed point cloud models offered the designers a valuable technique for engaging the mound with the surrounding landscape.

3.14a–b
The 3.5 million m^3 Sigirino Depot embedded in the 3D geo-referenced point cloud model of the valley and below the Panorama of the Sigirino Depot from the village Mezzovico, Ticino, Switzerland (a).
Visualisation of the final stage of the Sigirino Depot (b).




SwissGrid CH1903 Coordinate: 714'675 m E / 104'800 m N (Height 404 m)
* curvature of the earth not included in calculation
N
E
S
W
N
Monte Ferrino
DEPOSIT
Monte Boglia
Barro
Monte Ferraro
Monte Gradiccioli
Monte Tamaro
50°
40°
30°
20°
10°
0°
-10°
-180° -170° -160° -150° -140° -130° -120° 110° -100° -90° -80° -70° -60° -50° -40° -30° -20° -10° S 10° 20° 30° 40° 50° 60° 70° 80° 90° 100° 110° 120° 130° 140° 150° 160° 170° 180°



Working in collaboration with the LVML (Landscape Visualisation and Modelling Laboratory) of the ETH Zurich, the designers used geo-referenced point cloud technology produced by a terrestrial laser scanner (Figure 3.13). These accurate models allowed them to test and verify design iterations, offering detailed understanding of how this monumental landform would perform in relationship to drainage, planting and visual impact. The incremental creation of point clouds was used by engineers to alter the distribution of material throughout the project's evolution, and adjust the final implementation on site (Figure 3.14). These models were also valuable in presenting the project to the Swiss Confederation for final approval.

3D models of site are beginning to replace the 2D survey plan as the starting point for site analysis. This significant representational revision observes Brian Osborn, fundamentally extends the type and accuracy of information considered within site analysis, transforming the traditional site survey into a strategy of site surveillance.[69] The site is observed 'as an ongoing act of keeping watch' departing from the 'perceived fixity in conditions' offered by the survey which is 'often done only once'.[70] This dynamic analysis, when combined with parametric modelling encourages design responses that encompass true variable field conditions. To explore the potential further, Osborn introduced the subject Surveillance Practices into the University of Virginia's landscape program in 2014, to examine how Big data might change the spatial practices of landscape architects.[71] Working across analogue and digital, students developed techniques for recording site data for the abandoned Milton airport, including making their own sensors such as the soil moisture sensor (shown in Figure 3.15).

3.15a–b
A soil moisture sensor made with Arduino (a). An ibutton (b).

Explorations from this subject highlighted the new possibilities for recording the dynamic behaviours of systems, which have so far been overlooked in landscape architecture. For example Jenna Harris's project *Drawing the [O]rganic [Soil] layer*, explored processes of carbon storage and exchange, recognising the significance of the natural decaying of organic carbon in releasing carbon dioxide into the atmosphere.[72] Her surveillance practice interrogated the relationship between plant litter, top soil decomposition and the rate of top soil formation.[73] Four techniques were developed for recording data; a detritus meter for testing plant material; a surface temperature gun, a decomposition tester for recording environmental conditions and soil colour testing for understanding soil conditions. The mapping of this data highlights the manipulability and relationship of parameters that influence the renewable resource of soil such as decomposition, plant type, soil type and surface temperature.

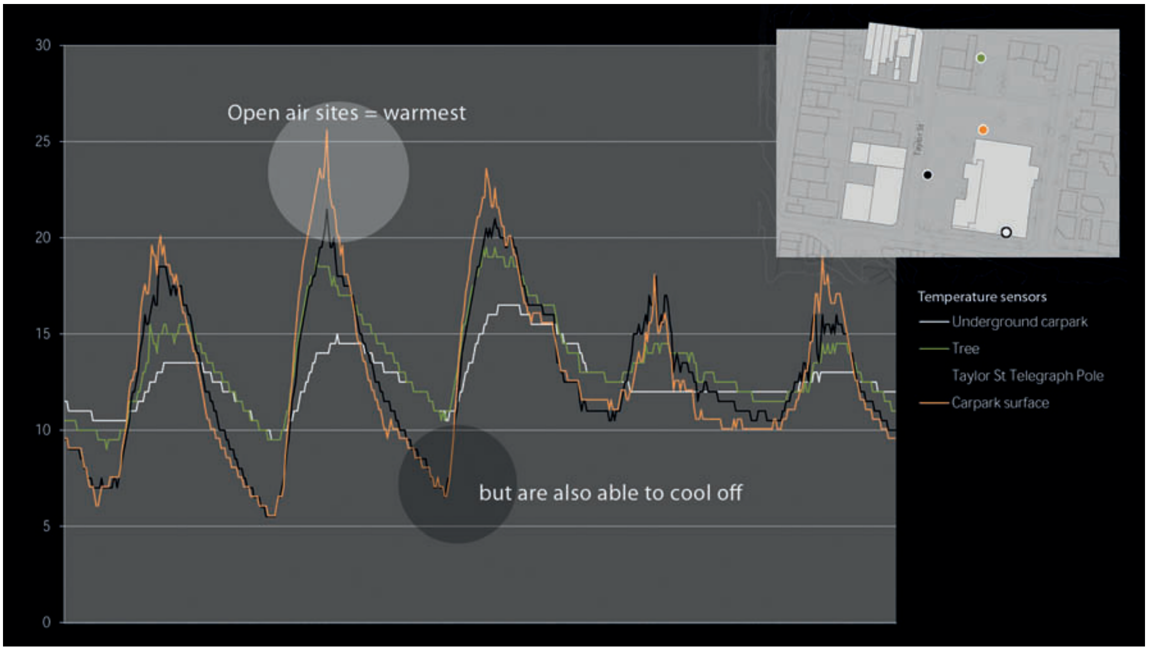
Monitoring performance

Cheap and easy to use, sensors not only record site phenomena and processes but also enable the performance monitoring of constructed designs. Ibuttons ($20–50) shown in Figure 3.15 are small durable computer chips with an internal battery that can be mounted discretely in soil or on paving to log periodic humidity and

3.16
Diagram interpreting the behaviour of heat recorded in a suburban carpark in Melbourne using ibuttons.

temperature. The graph shown in Figure 3.16, developed from ibutton recordings documents the fluctuating heat conditions in a suburban car park in Melbourne. This continuous data recorded peak temperatures but even more importantly for designers, highlights the ability of materials and spaces to cool down quickly, offering more rigorous understanding of the performative characteristics of heat, materials and spatial contexts. This accuracy is an important contribution to landscape architecture, which has often been guided by 'rule of thumb' principles that may not hold true in more complex contemporary contexts. For example this exploration of heat revealed that temperatures under trees were cooler during peak daytime temperatures but then retained heat for longer through the afternoon and evening.

This ability to accurately record and understand the performance of landscape systems, aided by data gathering technologies, is leading to the establishment of applied landscape research labs. The University of Toronto's GRIT (Green Roof Innovation Testing Laboratory) and Burnley Living Roofs project at the University of Melbourne both emerged in response to the limitation of standards guiding the green roof industry. In 2010, Professor Liat Margolis established GRIT Lab on the roof of the John H. Daniels Faculty of Architecture, Landscape, and Design[74] (Figure 3.17). The Lab's interdisciplinary focus differs from other green roof studies, which typically isolate biological, hydrological and thermal functions according to their respective science and engineering fields of study.[75] Instead, GRIT Lab focuses on the interrelations and co-benefits between plant growth (cover and diversity), growing media composition and water inputs (rainfall and irrigation) to better understand which variables are most critical for water retention and reduction (to improve urban water management), thermal cooling (to reduce ambient temperature and



associated energy consumption for cooling during the summer), and habitat value (e.g. pollinators, insects). To properly understand the full complexity of green roof performance, GRIT Lab brings together faculty and student researchers from the Landscape and Architecture, Engineering and Biology programs, as well as members of the green building industry and the municipality.[76]

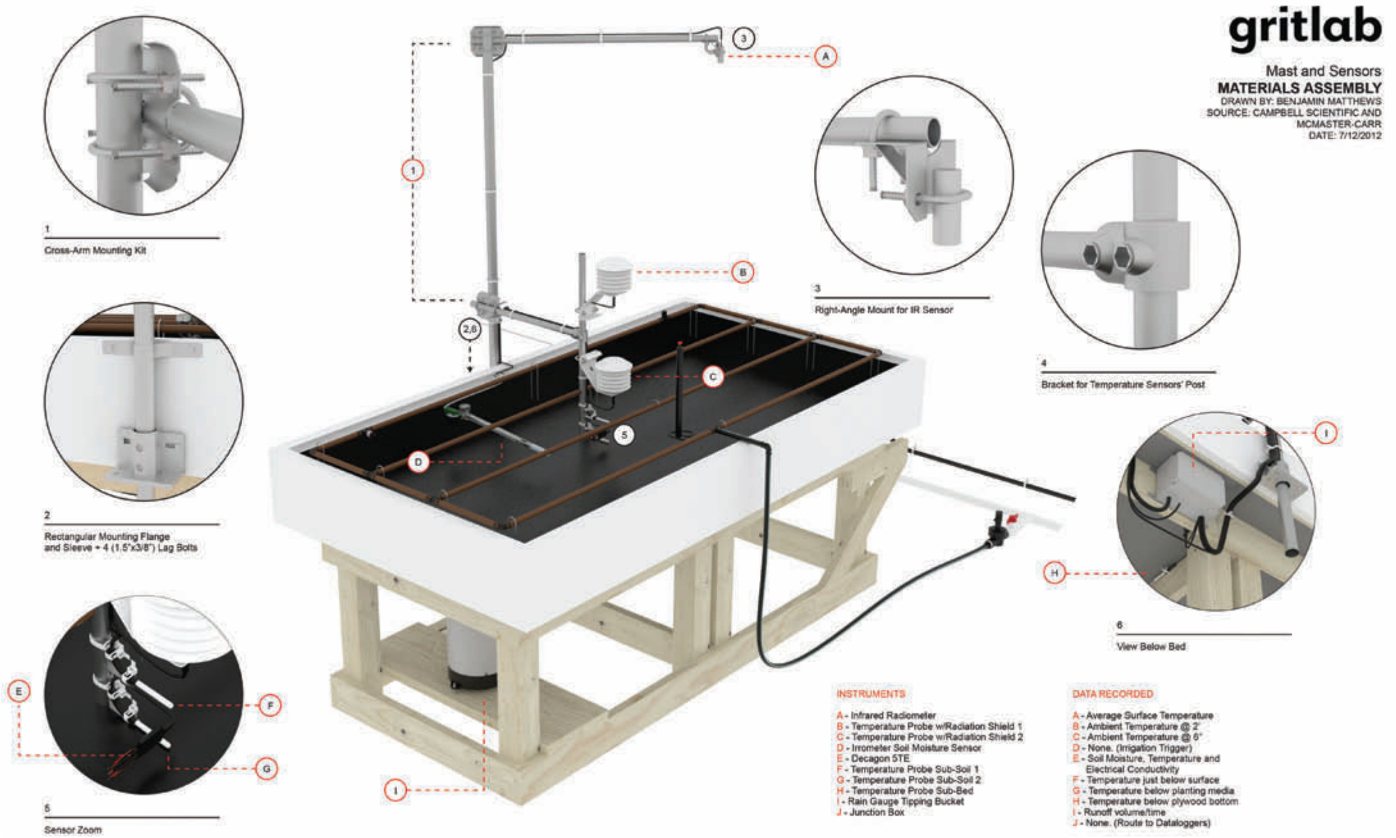
The green roof experimental design establishes four testing variables (Figure 3.19). Two planting types – a pre-vegetated Sedum mat and a mix of 16 grass and forb species are tested within two different planting substrate types – FLL compliant (free-draining low organic and high mineral content) and a high organic content (compost) blend that is intended to support vascular plants.[77] Two depths of the planting substrate (10 cm and 15 cm) offers a further variable, while the beds are also tested against three irrigation schedules – no irrigation, timer activated, soil moisture sensor activated.[78] Each of the 33 beds, present a different combination of these variables, and also reflect common green roof products, assemblies and maintenance practices in the Toronto region and beyond.

The modules are equipped with eight sensors including a rain gauge tipping bucket to measure discharge flow rates, soil moisture sensor, infrared radiometer to record surface temperature, and five thermal sensors set along a vertical axis to measure cooling (Figure 3.18). Data from the sensors, recorded at 5-minute intervals is then analysed: first in relation to plant growth (surveyed bi-weekly manually)[79] and second in relation to data from an on-site weather station, which

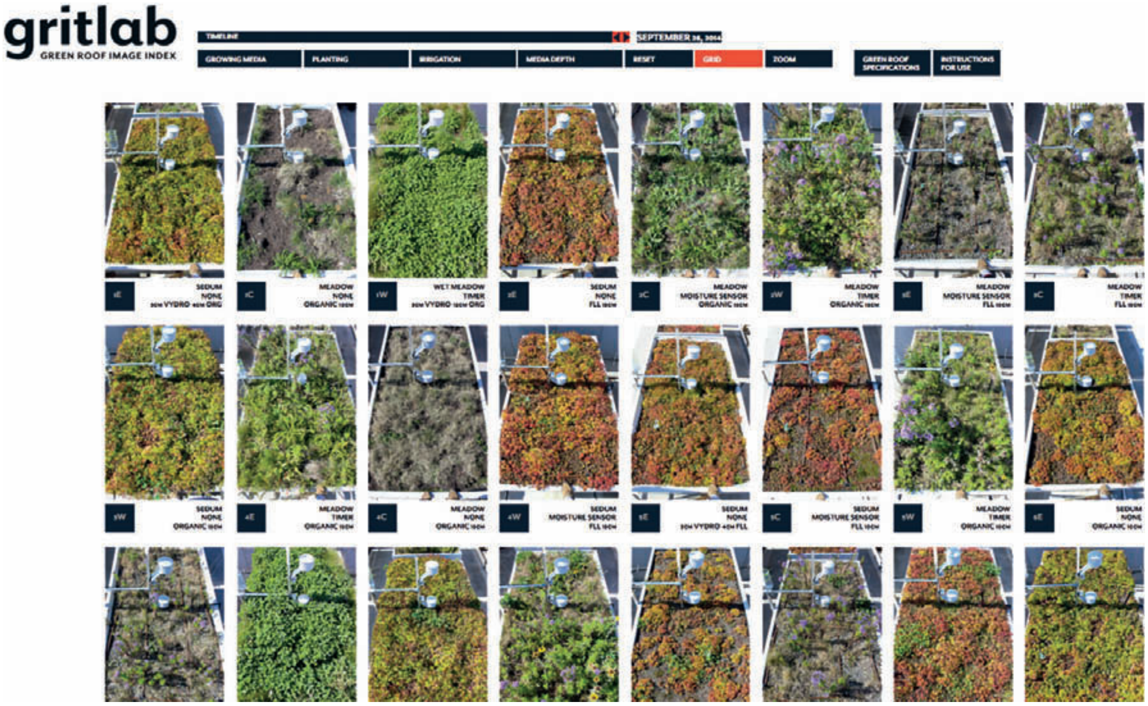
3.17
The testing modules of the GRIT Lab constructed on the roof of the John H. Daniels Faculty of Architecture, Landscape, and Design at The University of Toronto.

3.18
The layout of the testing modules which features eight sensors.

3.19
Variations of the test plots which offer different combinations of growing media, planting, irrigation schedules and media depth.



gritlab
Mast and Sensors
MATERIALS ASSEMBLY
DRAWN BY: BENJAMIN MATTHEWS
SOURCE: CAMPBELL SCIENTIFIC AND MCMASTER-CARR
DATE: 7/12/2012
1
Cross-Arm Mounting Kit
2
Rectangular Mounting Flange and Sleeve + 4 (1.5"x3/8") Lag Bolts
3
Right-Angle Mount for IR Sensor
4
Bracket for Temperature Sensors' Post
5
Sensor Zoom
6
View Below Bed
INSTRUMENTS
A - Infrared Radiometer
B - Temperature Probe w/Radiation Shield 1
C - Temperature Probe w/Radiation Shield 2
D - Irrometer Soil Moisture Sensor
E - Decagon 5TE
F - Temperature Probe Sub-Soil 1
G - Temperature Probe Sub-Soil 2
H - Temperature Probe Sub-Bed
I - Rain Gauge Tipping Bucket
J - Junction Box
DATA RECORDED
A - Average Surface Temperature
B - Ambient Temperature @ 2'
C - Ambient Temperature @ 6"
D - None. (Irrigation Trigger)
E - Soil Moisture, Temperature and Electrical Conductivity
F - Temperature just below surface
G - Temperature below planting media
H - Temperature below plywood bottom
I - Runoff volume/time
J - None. (Route to Dataloggers)



gritlab
GREEN ROOF IMAGE INDEX
TIMELINE
GROWING MEDIA
PLANTING
IRRIGATION
MEDIA DEPTH
RESET
GRID
ZOOM
GREEN ROOF SPECIFICATIONS
INSTRUCTIONS FOR USE

records solar radiation, precipitation, humidity, and wind speed and direction. This allows for comparison between individual beds as well as with local climatic conditions.

One of the primary challenges of integrating real-time data acquisition is the need to troubleshoot and calibrate sensors. This is because the sensors that are currently available on the market are designed for different contexts, or applications. For instance, the soil moisture sensor was designed for natural mineral soils, found in agricultural applications. At the GRIT Lab, this sensor is embedded within the planting substrate, which differs greatly in composition and structure from agricultural soils. After having monitored the soil-moisture measurement readings for several weeks, it became clear that calibrating the sensor according to the specific composition of the planting substrates is essential for accurate water balance analysis.[80]

By correlating weather data, irrigation schedules, soil moisture, and runoff rates, the research team is able to evaluate materials and maintenance in relation to hydrological performance. Finally, the hydrological analysis at the GRIT Lab is not limited to the specific planting substrates that are currently being tested. In fact, the statistical modelling is based on understanding the composition and structure of the two different substrate types in relation to weather patterns and irrigation schedules, which can then be applied to a variety of planting substrates on existing green roofs around Toronto through core sampling and soil analysis, etc.

The research work at the GRIT Lab is intended to inform the 2009 City of Toronto Green Roof Construction Standard and potentially improve the current construction practices to optimise the performance of green roofs. In 2013 GRIT Lab received the ASLA Professional Award of Excellence in Research.[81]

The Burnley Living Roofs project is the first research facility to interrogate the particularities of designing and maintaining green roofs in Australia. Three different roof types were designed in collaboration with landscape architects from HASSELL. A demonstration roof operates as an exhibition and teaching space; featuring seating and gathering areas located among irrigated and non-irrigated planting zones which vary in soil depth. A research roof provides a testing ground for design experiments such as investigating the insulation properties of green roof profiles, while the biodiversity roof featuring insect, bird and reptile habitats indigenous to Melbourne explores the influence of different materiality and substrate on biodiversity. These projects are monitored for performance and fed back into the development of standards appropriate to the particularities of the Melbourne context.

Unobtrusive data gathering capability also means research agendas can easily extend to in-situ sites, away from the laboratory. Luis Fraguada, researcher at IAAC, Barcelona, and James Melsom's research at ETH adapts the sensors used on the UAV drones to public transport infrastructure (such as trams) to capture data corresponding with human usage patterns. Temperature, humidity, light levels and air quality data can verify and contribute to climate simulation models, as well as producing publicly available data of value to designers.[82]

Smart systems

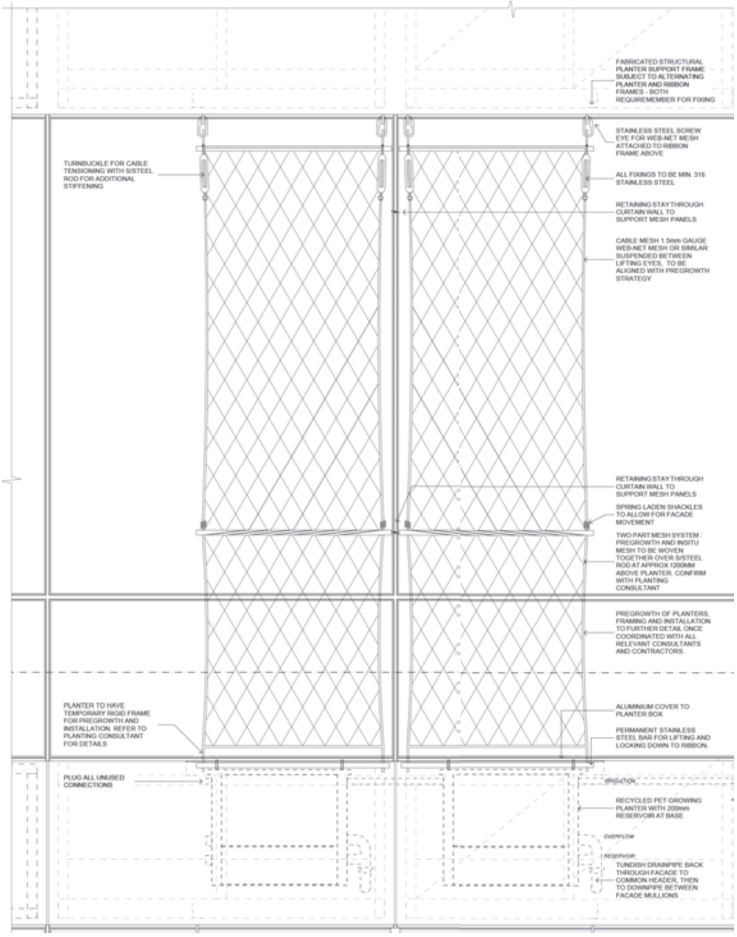
The potential of real-time data extends beyond the recording of information or performance to the development of smart or intelligent design systems. Smart systems have their origins in the Internet of Things (IoT), defined as 'making a computer sense information without the aid of human intervention', thereby reconceiving the Internet as a 'network of interconnected objects'.[83] Facilitated by wireless networks, objects use data to interact with the physical world, thereby developing a 'smart environment'.[84] In 2013, there were approximately 9 billion interconnected devices, with this expected to increase to 24 billion by 2020.[85] These devices provide analytics and applications, ranging from visions for an entire smart city through to smart building management of heating, ventilation, air-conditioning and energy usage.

In June 2014, IBM in conjunction with the Lodha Group, announced the construction of smart city infrastructure for the new Indian city of Palava. Premised on efficiency and participation, IBM aims to use 'advanced data driven systems to integrate information from all city operations into a single system to improve efficiency and deliver an enhanced quality of life for residents'.[86] Anthony Townsend in his 2013 book *Smart Cities: Big Data, Civic Hackers and the Quest for a New Utopia* highlights how smart systems alter the way designers engage with urbanism, necessitating the need to 'draw on informatics and urbanism simultaneously'.[87] However he also warns of defaulting to smart technology to solve problems, to the detriment of more fundamental societal, economic and political changes.

Within landscape architecture, the design of 'smart' infrastructures, systems and open space responsive to fluctuating and unpredictable environmental conditions has enormous potential, especially in the era of climate change. Through real-time sensors and control mechanism, infrastructure can respond to cloud-based control systems such as weather reports offering cost-saving measures, resource management and in some cases the diversion of disasters in extreme-weather events. These systems are easily and cheaply constructed, using components from companies such as ioBridge (founded in 2008) or Arduino (established in 2005) that provide solutions to connect 'things' to the Internet.

The North American engineering firm Geosyntec Consultants for examples develops water infrastructure systems such as retention systems, rainwater harvesting systems and roof irrigation linked directly through the cloud to the National Oceanic and Atmospheric Association forecast.[88] These water systems can respond to predicted changes in conditions – emptying before extreme-weather events or not irrigating when rain is predicted.[89] Engineer Mark Quigley considers this the beginning of 'high performance green infrastructure' shifting from sub-optimal passive systems' to 'making decisions in real time to achieve specific environmental goals'.[90]

Smart infrastructure is essential to HASSELL's design for the *Medibank Building* in Docklands, Melbourne, considered a benchmark for green infrastructure in Australian cities. The design of a 'green' headquarters forms a central part of



Medibank's repositioning from a standard health insurance business into a more aspirational vision where well-being and prevention are highlighted. The project is one of the largest green façade projects in Australia, building on research from The Burnley Living Roofs project discussed earlier, and the extensive research and development of Fytogreen Australia, a specialist in roof garden, vertical gardens and green façade construction.[91] The design features two 20 metre vertical green walls, roof gardens as well as 520 planter boxes of climbers (Figure 3.20) which form a living façade over 18 levels.

Managing Director of Fytogreen Geoff Heard highlights the challenges of living façades, which far exceed the demands of roof gardens or green walls. Each façade orientation experiences different environmental conditions while access for ongoing maintenance is limited. Smart irrigation systems are critical to their success. This design is irrigated from the 250,000 litres of water, which is collected and recycled through the building. A Galcon system provides an 'online' cloud-based irrigation management application which delivers real-time data information on dynamic flow management, irrigation logs, and water consumption reports, as well as system failure warnings sent to contractors' email and smart phones.[92] This information can be further supplemented with sensor input recording factors such as temperature, wind, soil and rain.

A 'predictive' management strategy informed by real-time weather station

3.20a–c
Medibank Private Headquarter, Melbourne: the challenging growing conditions of the living façades required the plants to be pre-grown off site in their planter boxes (for up to 6 months), before being slotted into their façade position.

input could further extend the capability of the system. However Heard is wary of this technology in regard to green façades. Unlike green infrastructure and parks located on the ground, there is little buffer for planting on built structure if data proves inaccurate.[93] He also identifies limitations in the existing irrigation systems to link effectively into cloud-based data.

The concept of smart systems is not limited to constructed projects, as demonstrated by the United States Forest Service establishment of 'smart forests'.[94] Data collected from web cams, humidity and temperature sensors, combined with instruments for solar radiation, wind vanes and rain gauges offer scientists real-time information to inform their management strategies for the changing climate. Until recently, Forest Service scientists had little data on urban forests, with most information gathered from wilderness areas. The Forest Service is increasingly including more urban sites (such as Alley Pond Park in Queens) into their sensored system to gain a more comprehensive understanding of the impact of climate change on urban ecology.

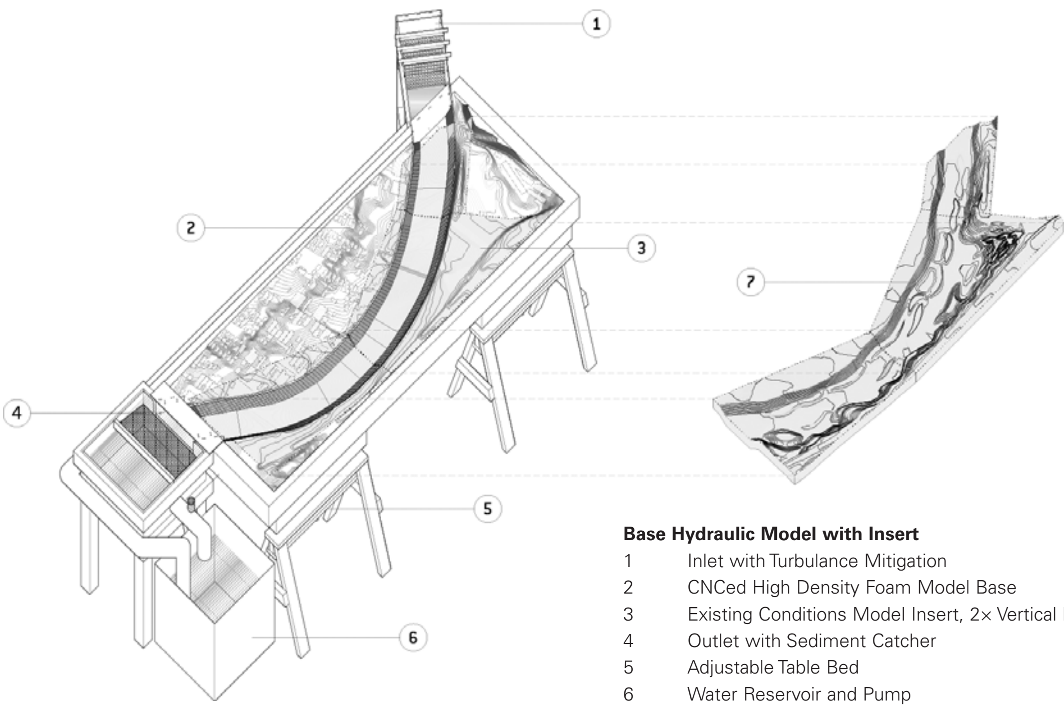
So far this chapter has introduced two ways in which designers engage with the simulation of systems; firstly embedding digital simulation directly within design processes and secondly using real-time data and sensors to develop new analytical understandings of site, to research the performance of space and systems and to develop smart or intelligent design systems. In the following section, we introduce the use of physical and digital prototyping within design processes as further techniques for understanding relationships between form, effect, data and systems.

Design as a laboratory

A prototype is defined as a sample or a model used to test an idea or process that offers knowledge. The terminology is rarely used with landscape architecture, more commonly associated with engineering, industrial design, architecture and electronics. Engineering has a long history of using scaled-down physical models to explore the fluid dynamic of wind and water or in the study of material movement. But as Enriqueta Llabres-Valls and Eduardo Rico highlight, it is important to consider dimensional analysis when applying knowledge from scaled-down prototypes. Dimensional analysis concerns the achievement of 'similitude' between the prototype and the real condition, establishing a comparable ratio, either 'geometrical (scaling down), kinematic (similar shape of flow lines) or dynamic (where ratios between forces and pressures are similar)'.[95]

In a pre-digital era, it was not unusual for engineers to produce large-scale physical models to understand dynamic water flow valuable in the management of extensive catchments. For instance the US Army Corps of Engineers constructed physical models of Mississippi River (1949–73) and Chesapeake Bay (1978) to inform management strategies.[96] Digital simulation has replaced many aspects of the physical model. However, for landscape architecture, the ability to understand materiality in relationship to flow is significant, and remains difficult to simulate

3.21a
Construction of the hydraulic model for the Bowtie River Prototype.



Base Hydraulic Model with Insert

1 Inlet with Turbulance Mitigation
2 CNCed High Density Foam Model Base
3 Existing Conditions Model Insert, 2× Vertical Distortion
4 Outlet with Sediment Catcher
5 Adjustable Table Bed
6 Water Reservoir and Pump
7 Alternative Design Model Insert

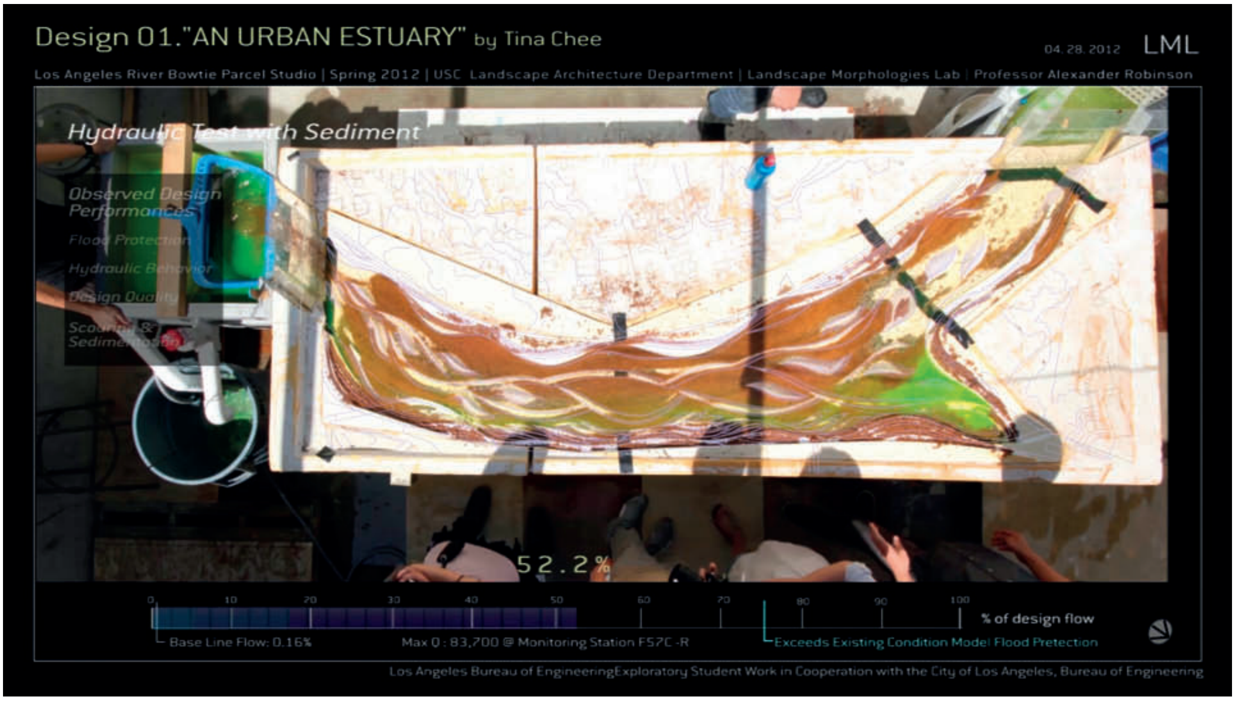
digitally. While parametric modelling and the virtual simulation of systems offers understandings of the relationship between form and systems, these models provide limited engagement with the specific materiality of landscape. A physical prototype engaging both fluid and medium therefore remains a valuable interrogation of dynamic processes such as sedimentation, revealing 'dependencies of different elements' in dynamic environments.[97]

The Landscape Morphologies Lab (LML) at the University of Southern California (USC) utilises a combination of robotics, physical and virtual modelling to examine relationships between landscape morphology, infrastructure and performance.[98] Established in 2011 under the leadership of Alexander Robinson, the LML collaborates with government agencies such as Los Angeles Bureau of Engineering and the Army Corps of Engineers and the USC Landscape Architecture Program and School of Engineering to develop infrastructural outcomes that combine design with efficiency.

The Los Angeles River is a major site of investigation. In collaboration with the City of Los Angeles's LA River Project and graduate landscape architecture studios, the LML constructed a physical hydraulic model of a section known as the Bowtie Parcel. This concrete section of the river is currently under review, thereby providing an excellent opportunity to test alternative design proposals. Working with the physical model and running water (Figure 3.21), successive design studios test the performance of new morphological forms presented as 3.5 metre foam inserts. The dynamic hydraulic tests are visually documented, recording processes of sand sedimentation and deposition, scouring and water flow.

A focus on the Owens Lake Dust Control Project introduces robotics to the exploration of materiality and flows. Since the 1920s, Owens Lake, situated in Lone

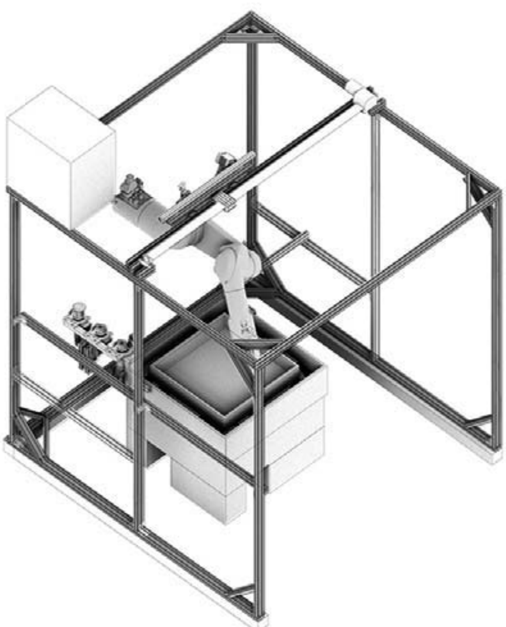
3.21b
Testing new inserts in the hydraulic model. The use of coloured dyes aid the comprehension of water flow.



Pine, California has been depleted by the Los Angeles Aqueduct, creating over 100 square miles of salt bed and frequent dust storms. In 2008 the Los Angeles Department of Water and Power proposed a 'moat and row' technique of berms, fences and ditches to control the dust.[99] This waterless method was never implemented, with concerns raised over habitat destruction and visual impact. However, Robinson also highlights reaction to the extreme 'operational efficiency' of the scheme as a further issue, with evidence of the public and some agencies arguing for a more 'creative' response.[100]

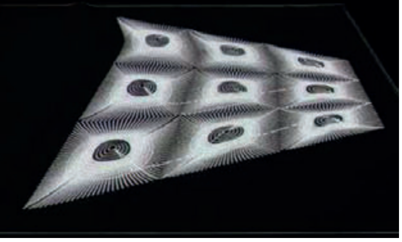
The LML developed a multimedia system comprising a robotic sand modeller, a 3D scanner, projection capability and a custom software interface for exploring alternative dust mitigation techniques (Figure 3.22). The project aims to 'create a common ground where designers, engineers, and the public can dynamically engage in the multiple concerns inherent to the lake'.[101] An interactive Landscape Prototyping Machine will be exhibited at a visitor centre in Lone Pine (next to Owens Lake). This exhibition will allow users to 'tune' aspects of proposed landscapes to their preference such as selecting dust control surface treatment and adjusting water levels.

LML's application of robotics in the exploration of dust mitigation remains experimental, with its application yet to be tested at the scale of the site. However, it demonstrates important prototyping techniques for engaging with material processes. While limited in empirical measurement, these techniques generate qualitative information concerning behavioural relationships between site materiality, form and the fluid dynamics of air and water. Robinson comments further:



3.22a–b
The Rapid Prototyping Machine with 6 –axis robotic arm, vacuum box, sand box, tool changer, projector and laser 3d scanner (a). Custom end arm tools for the robotic arm for subraction and calibration (b).

3.23a–b
Algorithmic Toolpaths: The tool paths are generated by custom algorithms which are projected onto the sand prior to implementation. The resultant topographic form is scanned and input into custom analysis software where the form can be analysed for performance.








> Feedback systems, such as modelling and analysis tools, are paired with designer-based generative processes to create a condition that further empowers the unparalleled cognitive-design ability of effective designers and other individuals to discover good solutions. These tools and methods promise to allow landscape architects to gain further agency and expertise in the design of infrastructures, high-performance living systems, and almost any twenty-first century landscape.[102]

Digital prototyping however does not require expensive robotic equipment or complex programming knowledge. Plug-ins such as Grasshopper's Firefly, developed in 2010, offer accessible techniques for linking real-time feedback between hardware devices such as the Arduino microcontroller or mobile phones, and the Internet to drive 3D geometry within a parametric model.[103] The developers Andrew O. Payne and Jason Kelly Johnson explain further:

> Firefly's toolset gives the designer the ability to quickly test how well a design will perform when confronted with different real-world environmental conditions, saving on physical prototyping costs and times. It also opens up the possibility to control digital prototypes using a range of real time data – creating 'live models' whose parameters can be iteratively tested until a desired set of outcomes are achieved.[104]

The North American based Dredge Research Collaborative utilises these technologies in their prototyping explorations. This multidisciplinary group investigates human sediment handling practices through design studios, research and events.[105] In January 2014, the DredgeFest Louisiana symposium brought together government, academics, practitioners, students, theorists and the public to interrogate the control of the Mississippi River. Workshops featured prototyping techniques, utilising Grasshopper, Firefly and Arduino.

The Adaptive Devices workshop, devised by Bradley Cantrell, David Merlin and Justine Holzman, explored the design potential of sedimentary technologies to control navigation, floods and the manipulation of sedimentation. Participants focused on 'the landscape-making potential' of dredgers, silt fences and turbidity curtains explored through prototyping devices, together with physical modelling. Similarly Alexander Robinson and Richard Hindle's Hybrid Landscape workshop combined physical (sand modelling) and digital modelling tools to develop morphological alternatives for the 'bay bottom terracing' of Louisiana's Vermillion Bay.[106] These alternatives were then evaluated according to landscape performance metrics.

Next we focus on three studios, which embed systems prototyping into their design processes, effectively shifting the conceptualisation of the design studio into the design laboratory. Importantly, these examples introduce a design process which commences with the prototyping of a dynamic system (physical, digital or combined) which is then hacked or modified during the course of the design process. This differs from earlier examples such as *Gardens by the Bay* (which modelled a closed system) or PARKKIM's *Thermal City* which tested design outcome against more singular phenomena such as heat or wind.

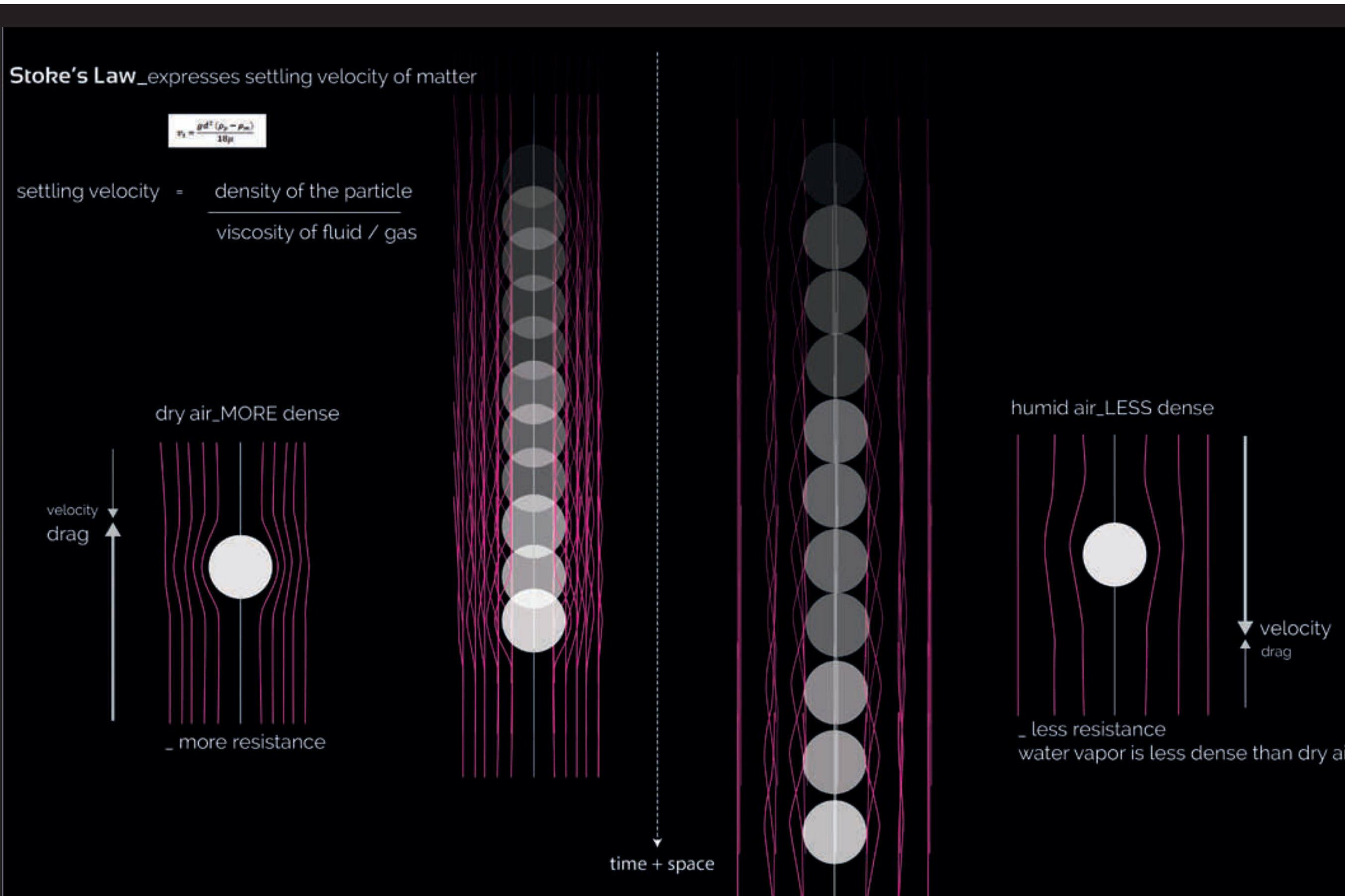
Synthetic ecologies

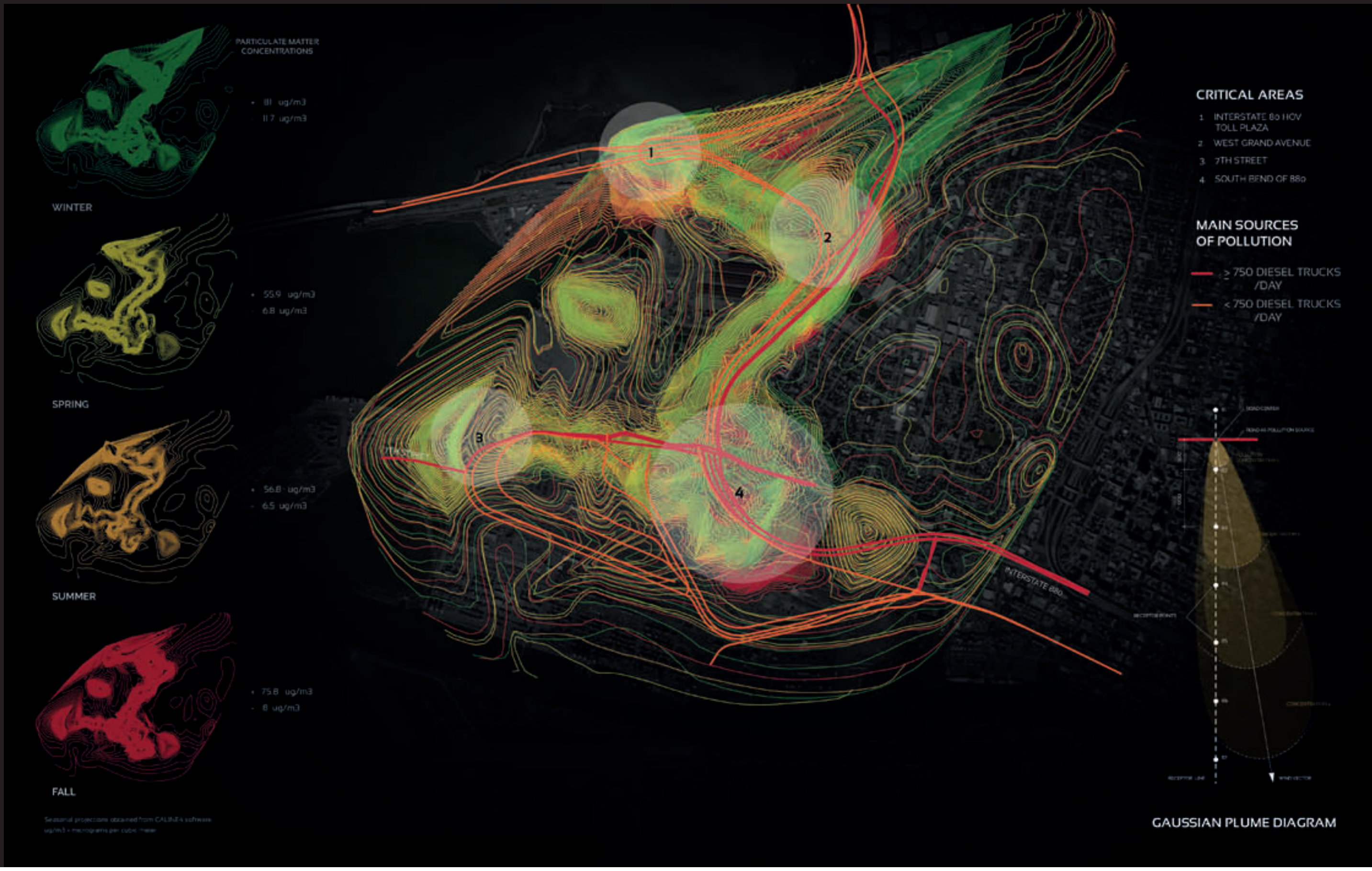
For over a decade, Bradley Cantrell has used design studios and practice to explore the potential of 'sensing, automation and robotics in the conceptualisation of ecologies'.[107] Acknowledging that ecological systems do not reach a climax, Cantrell proposes the idea of 'synthetic ecologies' utilising real-time sensing of site phenomena to develop adaptive management strategies.[108] 'This view of ecological systems, through the lens of responsive technologies', states Cantrell 'posits that the designer is responsible for the creation and implementation of processes that curate, manage, and sculpt landscape systems'.[109]

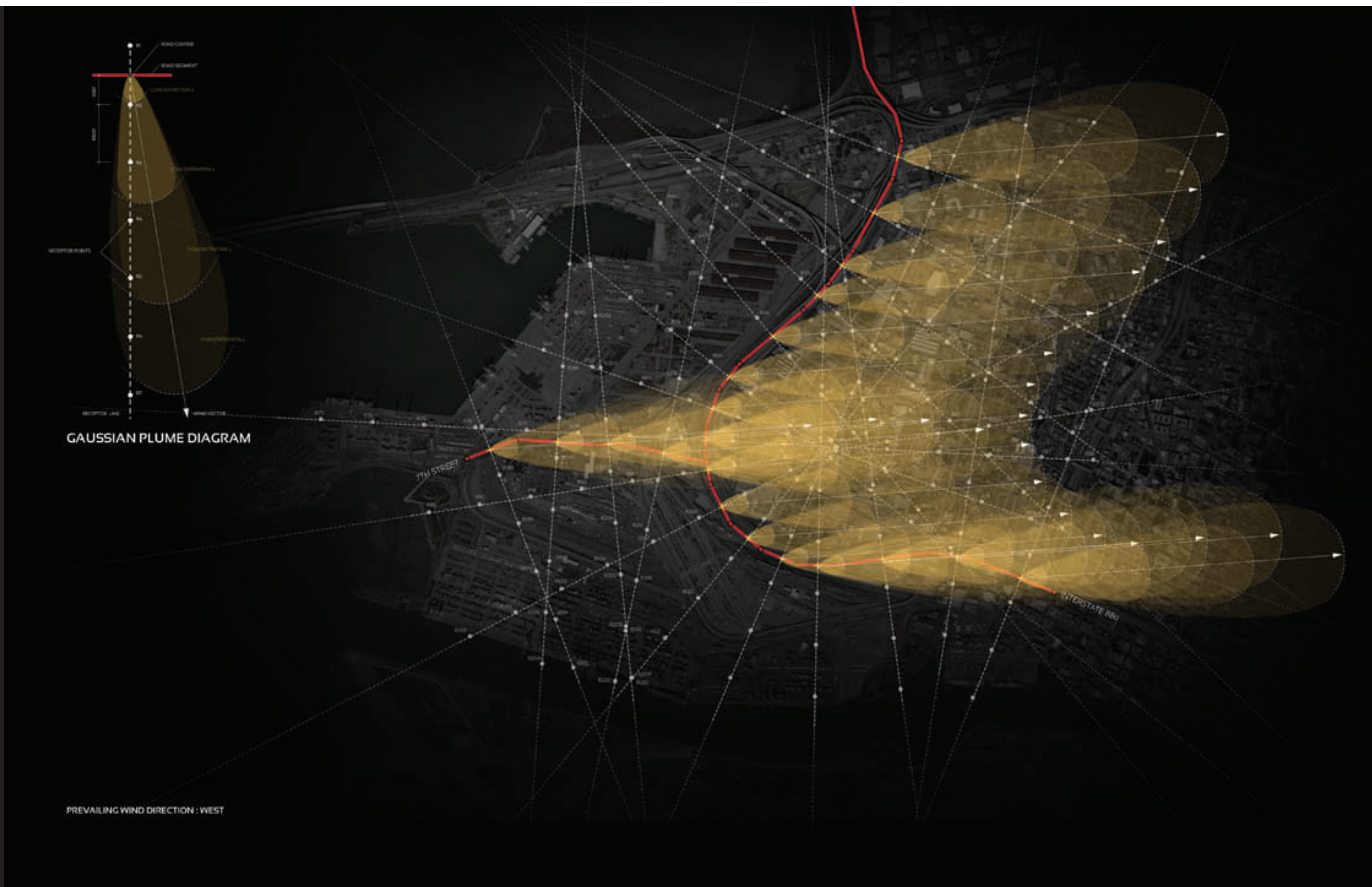
This philosophy underpins the 2013 design studio Synthetic Urban Ecology taught by Bradley Cantrell and Justine Holzman at the Louisiana State University. Focusing on West Oakland and the Port of Oakland, the studio used a combination of virtual and physical prototypes to interrogate the 'relationship between urbanity, industry, ecological fitness, habitat, and infrastructure'.[110]

For Cantrell and Holzman, the prototype model is not simply a representation of system. Instead it has dual functions: to deconstruct the site processes to provide

3.24
Diagraming Stoke's law to understand the relationship between humidity,particulate removal and velocity.




PARTICULATE MATTER CONCENTRATIONS
81 ug/m3
11.7 ug/m3
WINTER
55.9 ug/m3
6.8 ug/m3
SPRING
56.8 ug/m3
6.5 ug/m3
SUMMER
75.8 ug/m3
8 ug/m3
FALL
Seasonal projections obtained from CALINE4 software
ug/m3 = micrograms per cubic meter
CRITICAL AREAS
1 INTERSTATE 80 HOV TOLL PLAZA
2 WEST GRAND AVENUE
3 7TH STREET
4 SOUTH BEND OF 880
MAIN SOURCES OF POLLUTION
≥ 750 DIESEL TRUCKS /DAY
< 750 DIESEL TRUCKS /DAY
INTERSTATE 880
GAUSSIAN PLUME DIAGRAM


GAUSSIAN PLUME DIAGRAM
7TH STREET
INTERSTATE 880
PREVAILING WIND DIRECTION : WEST

3.25a–b
Documentation of the wind conditions and air pollution dispersal in West Oakland.

3.26a–b
Design Strategies for *Metabolic Forest* by Silvia Cox and Prentiss Darden.

a datum or baseline to measure change, compare and understand iterations; and to operate as a 'malleable and hackable' model to test 'site proposals, data acquisition/construction, and performative tweaks' in a series of speculations and inquiry.[111]

This approach is demonstrated in the scheme *Metabolic Forest* by Silvia Cox and Prentiss Darden which focused on the health issues of particulate matter found within diesel emission. A digital prototype model interrogated the processes of air pollution, testing multiple factors including wind speed and traffic idling, calculating particulate matter concentrations and mapping their levels across the year.[112] This digital prototype was constructed according to Stoke's law (Figures 3.24), a mathematical equation describing the settling velocities of small particle in a fluid. The resultant model identified 'rules for manipulation that respond to the overall performance of the ecology's capacities' allowing for the conceptualisation of a site-specific ecological fitness.[113] The model offered a framework (derived from vegetative, soil and atmospheric performance) for conceiving a range of conditions that would support specific growth patterns or suggest new trajectories for species to colonise as the ecosystems evolved. These conditions were also matched with specific cultural and social performance criteria to create a set of complementary or counter protocols to suggest new forms of ecological and cultural crossover.

In phase two, students assumed the role of 'curator of processes', to propose an adaptive management strategy.[114] Cantrell and Holzman adopt the term 'catalytic resistance' as a tactical description for engaging with 'ecosystem's adaptive and generative capabilities' as distinct from designing a defined system. This target of resistance, states Cantrell, operates 'to sculpt and inflect' allowing for the 'small adjustments to effectively manipulate the overall structure of the network over time'.[115]

For example the *Metabolic Forest* scheme (Figure 3.26) as the name suggests, developed an urban forest system shaped by the ambitions to capture and metabolise air pollution and to provide biomass as an economic resource (to be used for biofuels, fibre and timber), aligned with the port's reconceptualisation as an ecoport.[116] The staged implementation, begins with a tactical strategy for decreasing pollution around residential and recreational areas, through sensored misting devices which emit a fine mist when emissions are high. This mist leads to less dense air, encouraging particulate matter to fall more easily to the ground, before being metabolised by mycorrhizal fungi in the soil. A strategic network of misting devices establishes an adaptive urban forest conceived within the two processes of absorption and biomass production.

The design is positioned as 'a synthesis of technological and natural components', considered 'part hardware and software'.[117] The forests are intrinsically linked to areas of high pollution, growing in areas where mist is emitted in response to high pollution level. The urban forest network also contributes to a greater public understanding of the largely invisible phenomena of pollution through LEDs embedded in the misting device to display daily pollution levels.

The strategy is both tactical and performative, generated by an understanding of pollution gained through the digital prototype, with this knowledge then applied within the specific social, economic and ecological context of urbanism. As demonstrated in these outcomes, the interrogation of ecological systems through prototyping does not, by default, direct designers to an overtly 'naturalistic' design response. Instead the modelling exploration makes apparent the often invisible forces and processes that impact on the formation and performance of landscapes. This is demonstrated further in the following example where CFD modelling forms an important tool for engaging wind and water in the conceptualisation of a design intervention for a community art program on the Delaware River.

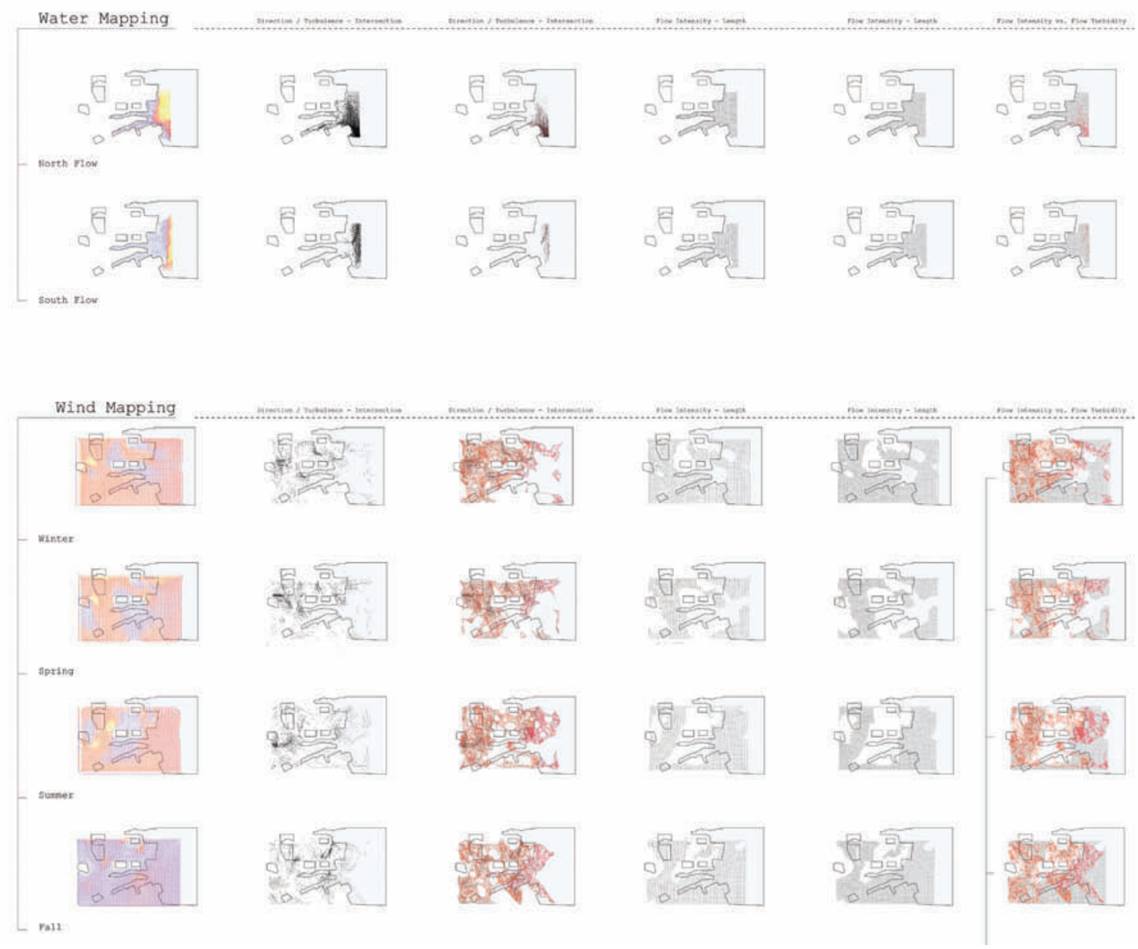
Simulated natures

In 2014, the Department of Landscape Architecture at the University of Pennsylvania ran the Simulated Natures seminar as part of their Digital Media curriculum sequence. Developed by Keith VanDerSys, the seminar interrogated the temporal and relational qualities of landscape through computational tools including computational flow dynamics (Aquaveo SMS, ANSYS Fluent and Ecotect), geospatial analysis (GIS) and parametric software (Grasshopper). These tools, state VanDerSys, form the basis for engaging with the 'invisible' information (data and flows) that shape ecological and social formations, offering an engagement with 'the forces and factors outside humans' perceptible limits'.[118]

3.27a–b
Exploration of form & forces using the Paneling Tool.

The seminar operated as a mini studio (3 hours a week) with the first half structured as a series of exercises to introduce students to digital techniques and to develop their understandings of the relationships between data, processes and effect. Students began with a topographic exploration developed with the Grasshopper plug-in Paneling Tools (which supports the modelling of panelling patterns). The resultant landforms (Figure 3.27) were then interrogated for its effects on drainage to reveal patterns of dispersal. These exercises build on knowledge developed in previous grading classes, but with emphasis on the relationship between landform and water behaviours. VanDerSys encouraged students to look for shifts in time and speed of water flow, moments that 'are representative of processes that have material consequences' such as erosion and collection.[119]

In the next phase, a more precise engagement with temporality and quantity was introduced to the CFD simulations through the use of real-time data from the NOAA (National Oceanic and Atmospheric Administration) website. Models were run as a time sequence, requiring students to consider the implications of data sampling. For example at what interval should tidal flux be examined, every 10 minutes for 20 hours or over longer intervals? Output values from these simulations were then exported into Grasshopper where they were transformed into



visual representations of vectors, forces and quantity. These were also animated to simulate flow in real time. Learning how to import and export data across software platforms (for example as organised lists of comma separated values) formed an important objective.

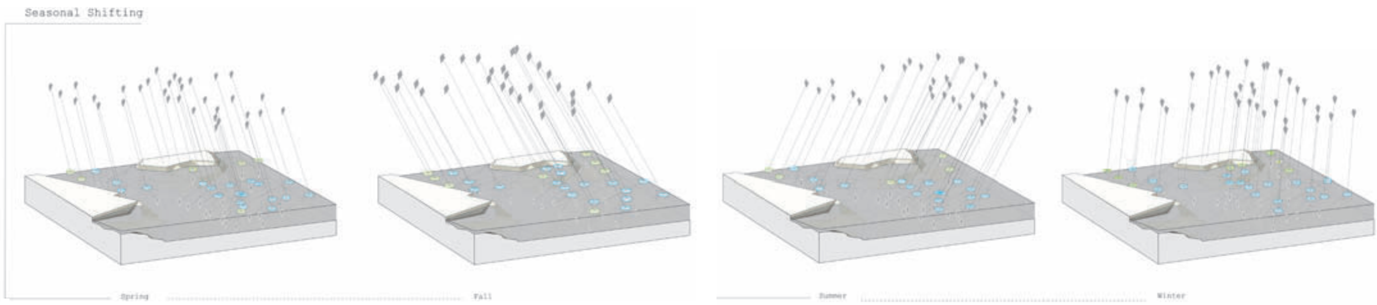
In the final exercise, students returned to the initial panel exercise, this time to apply an 'effect' to develop landform. Unlike the first exercise where the form was largely arbitrary, the now uncovered behaviour of water (force and flow) becomes the generator for topography, the result of a generative analytical process.

In the second half of the semester, students applied this new knowledge in the development of an intervention for old piers (inaccessible due to structural issues) along the Delaware River. Rather than renovating the pier, the Delaware Waterfront Corporation is exploring the idea of art as an activator. Students were asked to reconsider the concept of landscape art and intervention, challenged to develop something temporary that could also provoke awareness about the Delaware River redevelopment and/or environmental issues.

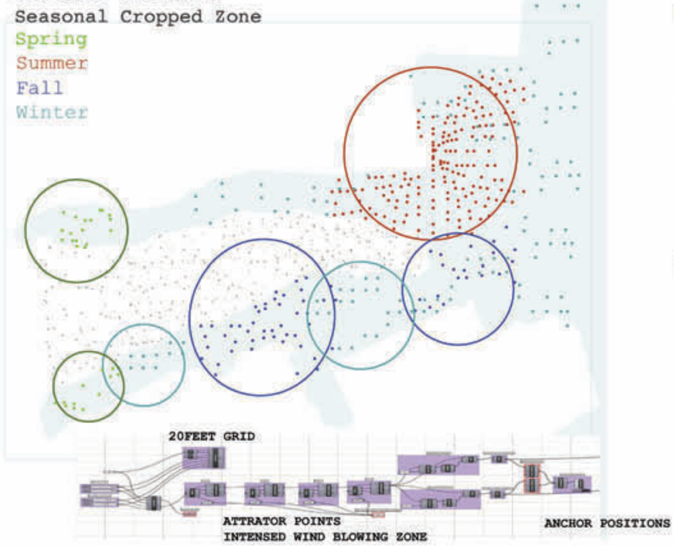
3.28
Documenting the intensities and turbulences of wind and water in the *Gliding Networked Flows* project.

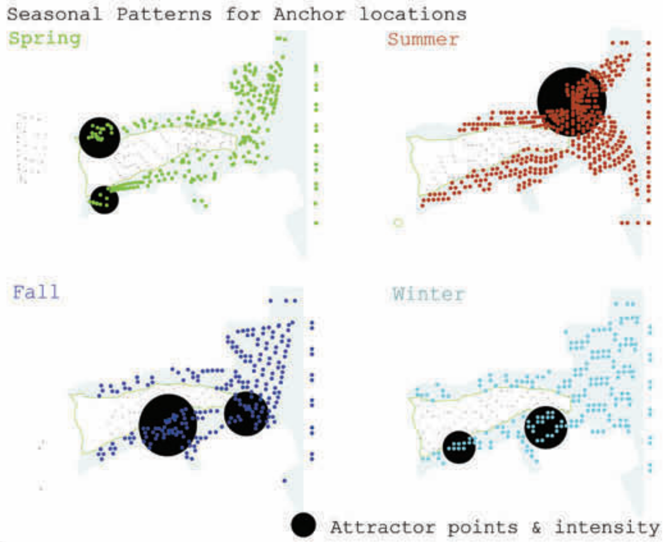
3.29
Kite flying simulations.

3.30a–b
Determining the seasonal anchor points for the kites.

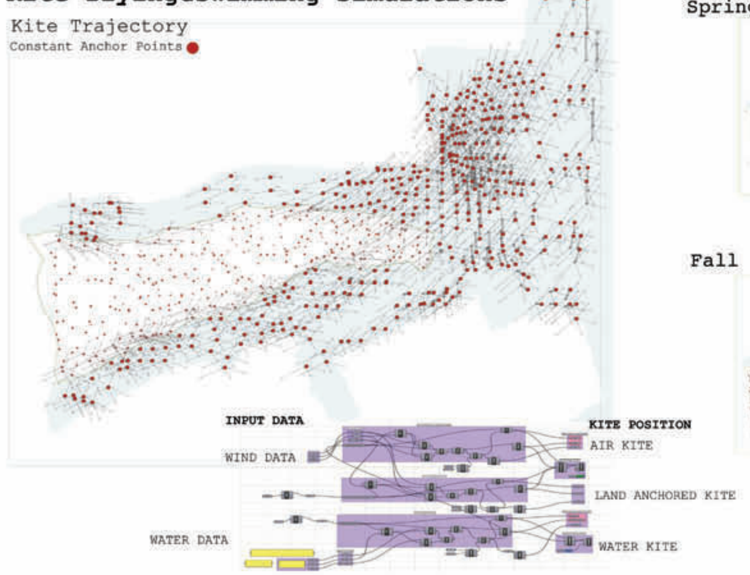


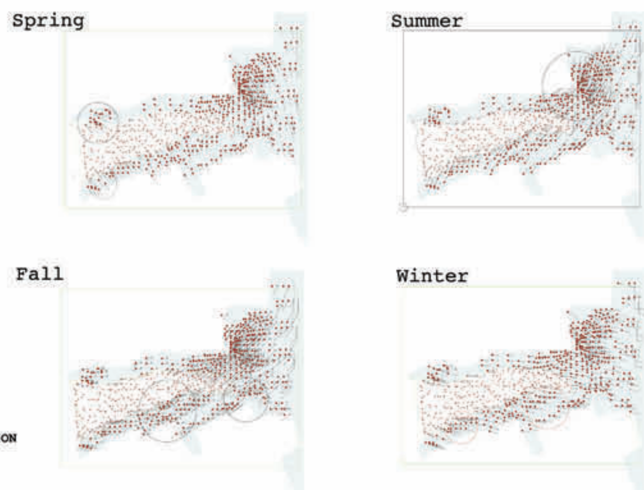
Anchor Points

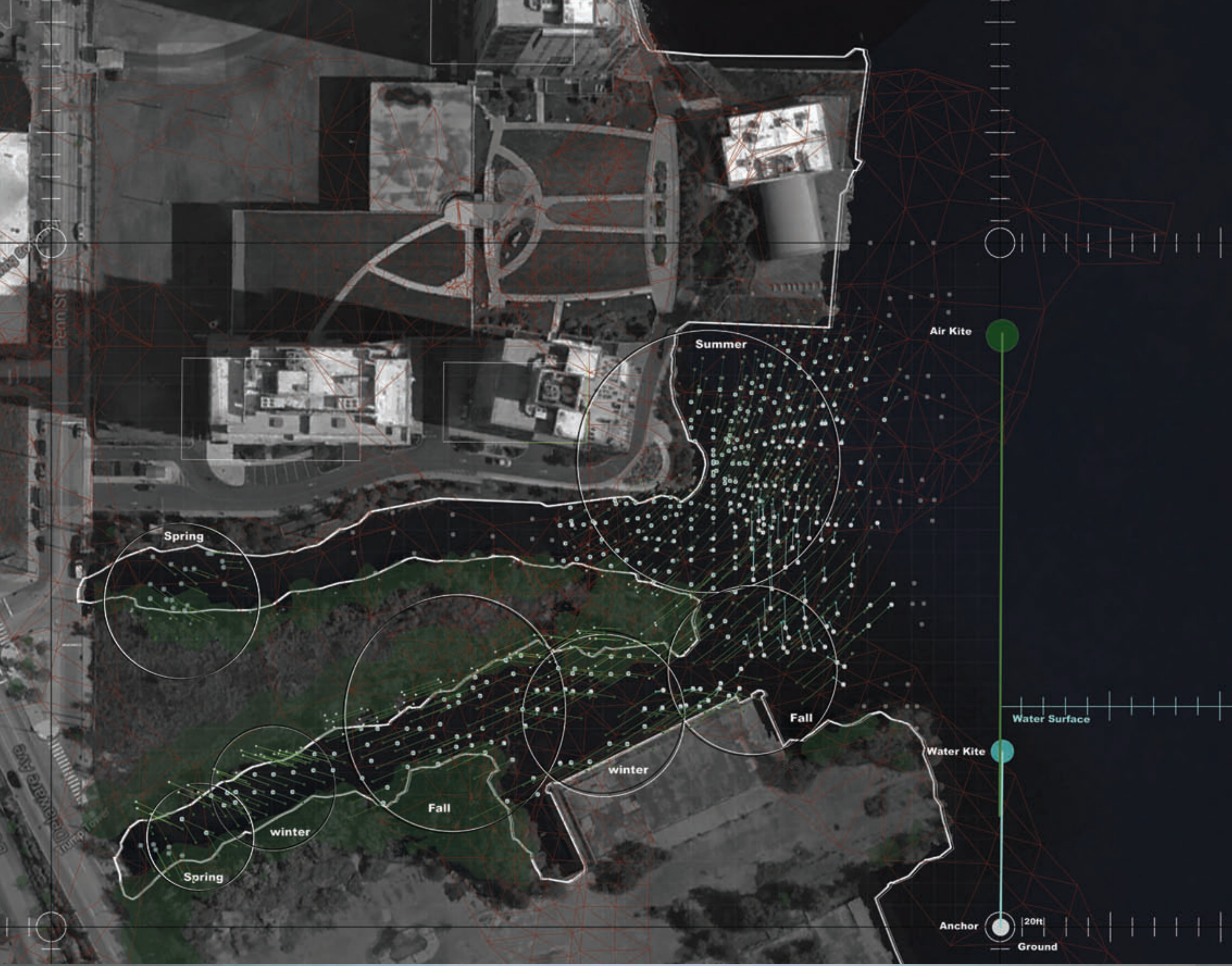




Kite flying&swimming simulations






Summer
Air Kite
Spring
Fall
Water Surface
Water Kite
winter
Fall
winter
Spring
Anchor
20ft
Ground
Penn St

3.31a–b
Gliding Networked Flows by Chris Arth, Leeju Kang and Elise McCurley.

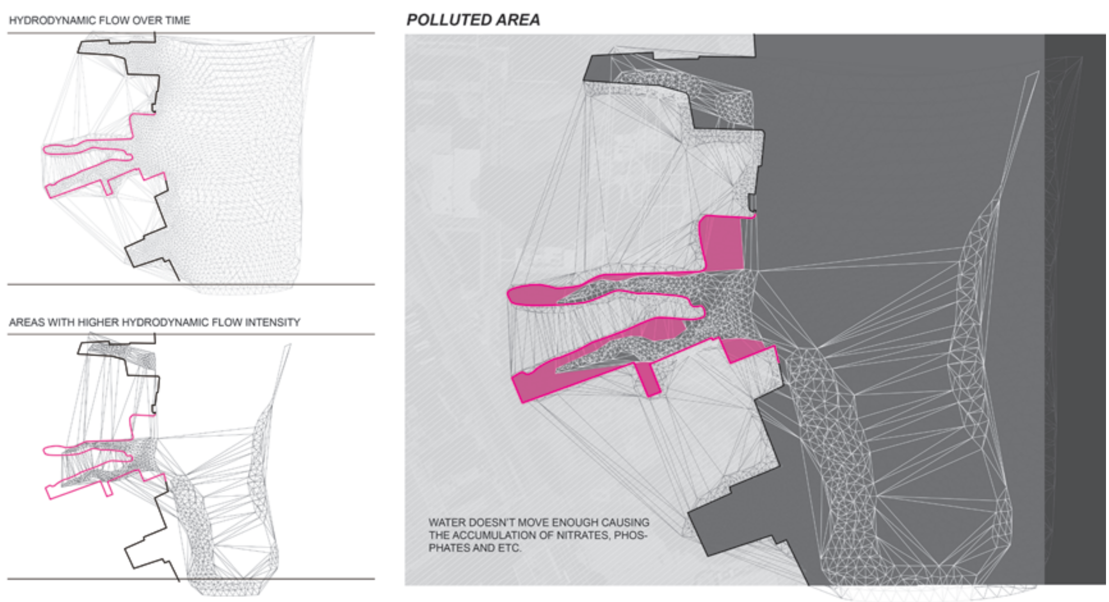
With a focus on wind and water movements, teams of four explored these invisible conditions and their relationships to each other through simulations and imagination, exposing moments of greatest flux and forces which could be heightened or registered through devices.

The scheme *Gliding Networked Flows* by Chris Arth, Leeju Kang and Elise McCurley proposes a series of kites that register the amount of drag and force within the water landscape. Their site simulations, shown in Figure 3.28, identified the most intense areas of conflicting wind and water direction, considered across the full seasonal range of the year. These points of intensities and attractors informed the seasonal anchor points for the kites. The amount of anchor drag is dependent on the relationship between the tidal conditions and wind patterns, which registers in two ways: by the flocking behaviours of the kites and through colour change of the kites. Arduino movement sensors capturing water fluctuation trigger the projection of colour onto the kite's reflective surface.

The *Windy Islets* scheme by Drew Grandjean, Shunkuang Su and Qing Zhang used hydrodynamic simulations (explored with Aquaveo SMS) to document patterns of high and low water movement, which also identified where areas of less flow accumulate pollutants of nitrates and phosphates.

Their design response features a series of floating wetlands constructed from PVC material and planting suitable for pollution remediation. These are sited in areas of low water movement. Given that plant roots in water quickly exhaust the available oxygen supply, the wetlands each include a wind turbine that drives a bubbler. Importantly, this bubbler produces an apron of air around each island, providing extra oxygen for the plants. The wind turbine, which also features an LED light on its tip, leans towards areas of higher intensity aerodynamic flow, thereby operating as a wind index on the water surface.

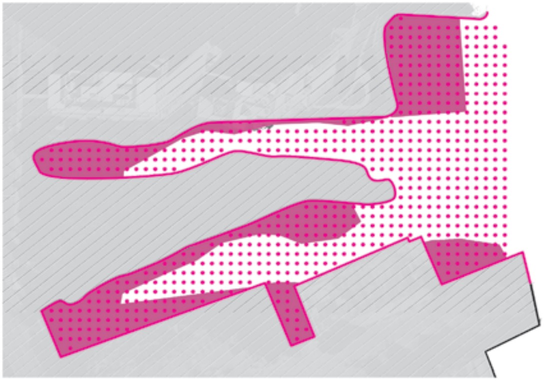
These designs demonstrate how the '"invisible" information of microscopic and macrocosmic forces' can inspire a design intervention reflective of the topological properties of landscape.[120] Computational tools, such as CFD modelling



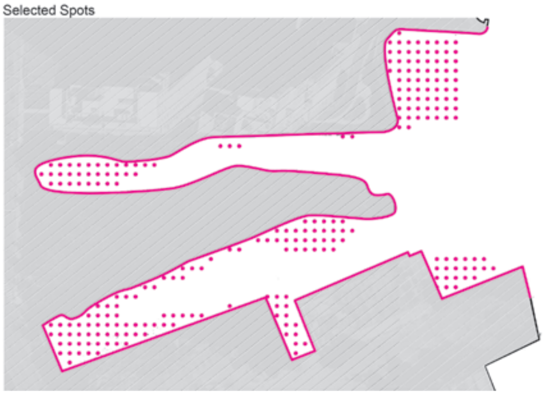
3.32
Testing the hydrodynamic flow of water and pollutants.

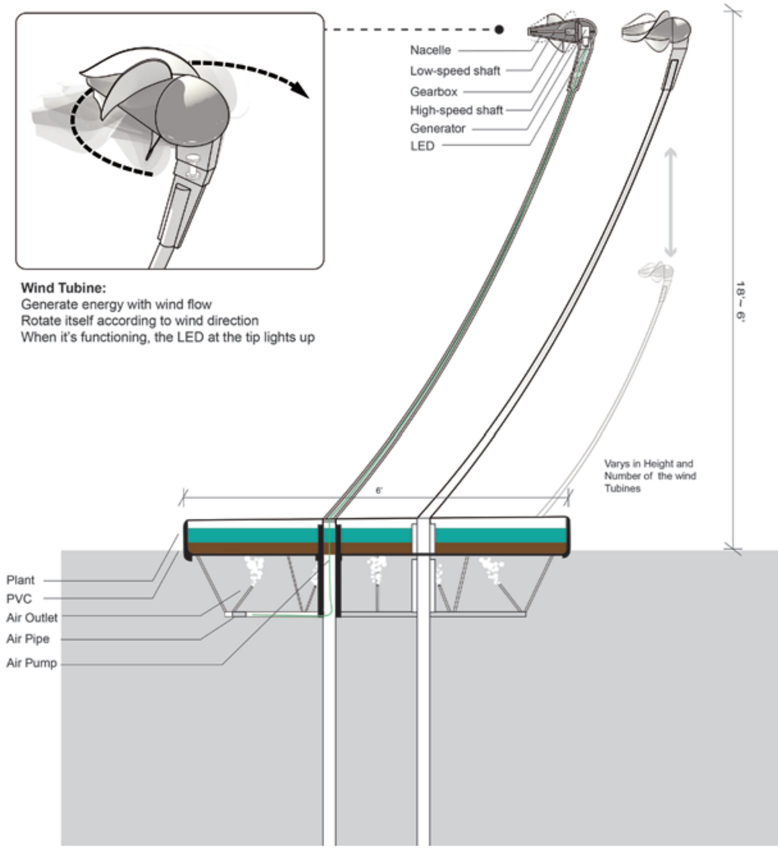
FLOATING WETLAND PLACEMENT

Point Grids

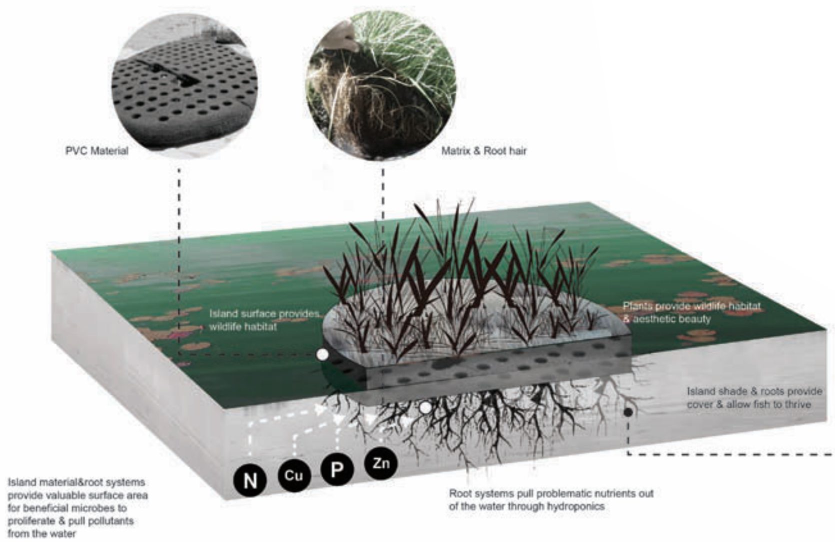


Selected Spots





FLOATING WETLAND



Cause of different kinds of plants were planted on floating wetland, the flower appear various color during seasonal change

Oxygen: Plants require oxygen for respiration to carry out their functions of water and nutrient uptake. In soil adequate oxygen is usually available, but plant roots growing in water will quickly exhaust the supply of dissolved oxygen and can be damaged or killed unless additional air is provided. A common method of supplying oxygen is to **bubble air** through the solution.

3.33
The floating wetlands featured in the *Windy Islets* proposal by Drew Grandjean, Shunkuang Su and Qing Zhang.

combined with access to real-time data, expose what VanderSys describes as 'the conditions of consequence'.[121] Used in conjunction with the designer's imagination, the simulations contribute to the generation of designs responsive to the effects of the dynamic systems.

In the final example, we significantly shift scale to explore how a combination of digital and physical prototyping can be applied at a regional scale in the interrogation of the controversial large-scale mining and extraction processes in Alberta, Canada.

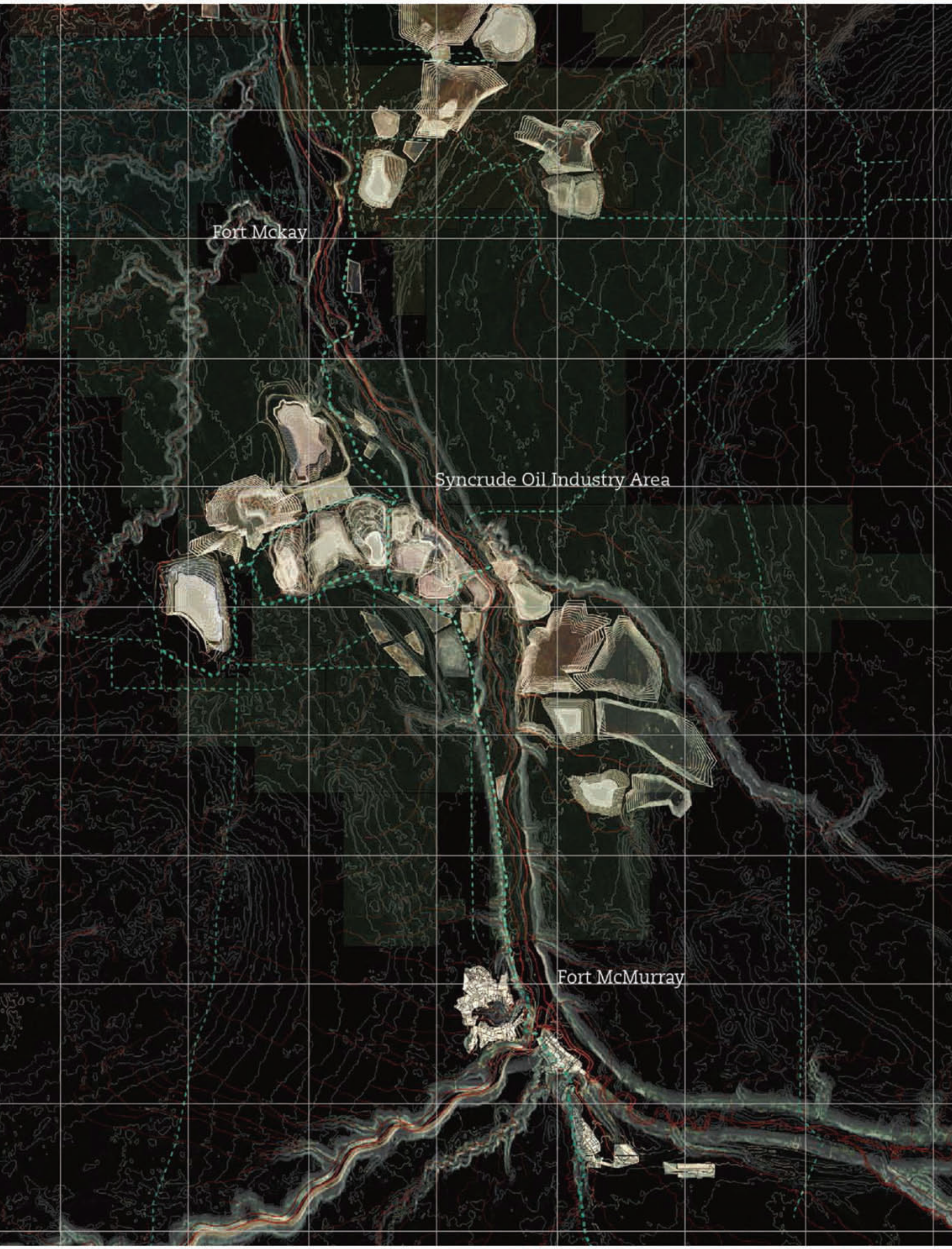
Proxy modelling

The Relational Modelling practice of Enriqueta Llabres-Valls and Eduardo Rico was briefly introduced in Chapter 2. Llabres-Valls and Rico are particularly interested in the representational challenges of working with spaces in constant flux, exploring relationships and interfaces between 'mathematically defined relationships within a digital model' and the 'materially formed proxy models'.[122] Their 2014 studio focused on the mining and extraction processes in the Athabasca Tar Sands Area in Alberta, Canada (Figure 3.34) which offered a valuable platform to explore these ideas. This studio formed part of the Master of Urban Design, Relational Urban Design Cluster (RU18) at the Bartlett Architecture School, University College London.

This controversial mining process leads to the generation of extensive sedimentation within tailing ponds of a scale similar to the natural formations of the sand braided rivers channels found to the north of the mining areas. Currently, less than 2 per cent of the waste tailing ponds has been rehabilitated.[123] Orthodox techniques for engaging with this landscape, post mining, observe Llabres-Valls and Rico, involves either 'a naturalistic postrationalisation (devolving the landscape to nature) or a romantic one (describing it as industrial heritage)'.[124] Their studio, run in conjunction with Zachary Fluker, explored the alternative approach of considering the formation of landscape concurrently with the production process.[125]

The studio's innovation lies in conceiving an interface linking three models: a mathematical model engaging ecological, social and economic factors; a proxy model exploring the physical and ecological simulation of landform patterns as they change over time and a digital model offering analysis on the emerging behaviours and conditions evident in the proxy model. Together these different modelling and prototyping techniques encompass top-down and bottom-up influences, and offer the designer important knowledge for intervening in this complex ecological, economic and industrial process.

The mathematical model worked across ecological, social and economic factors to establish relationships and behaviours of these systems within a database. Importantly this data encompassed both site-based factors such as ecology and external influences like fluctuating oil prices to develop a system reflective of indeterminacy and change, linked to broader global and national influences. The model facilitated the testing of systemic flexibility, calculating quantity of change when one


Fort Mckay
Syncrude Oil Industry Area
Fort McMurray

3.34
The Territory of Athabasca Oil Industry.

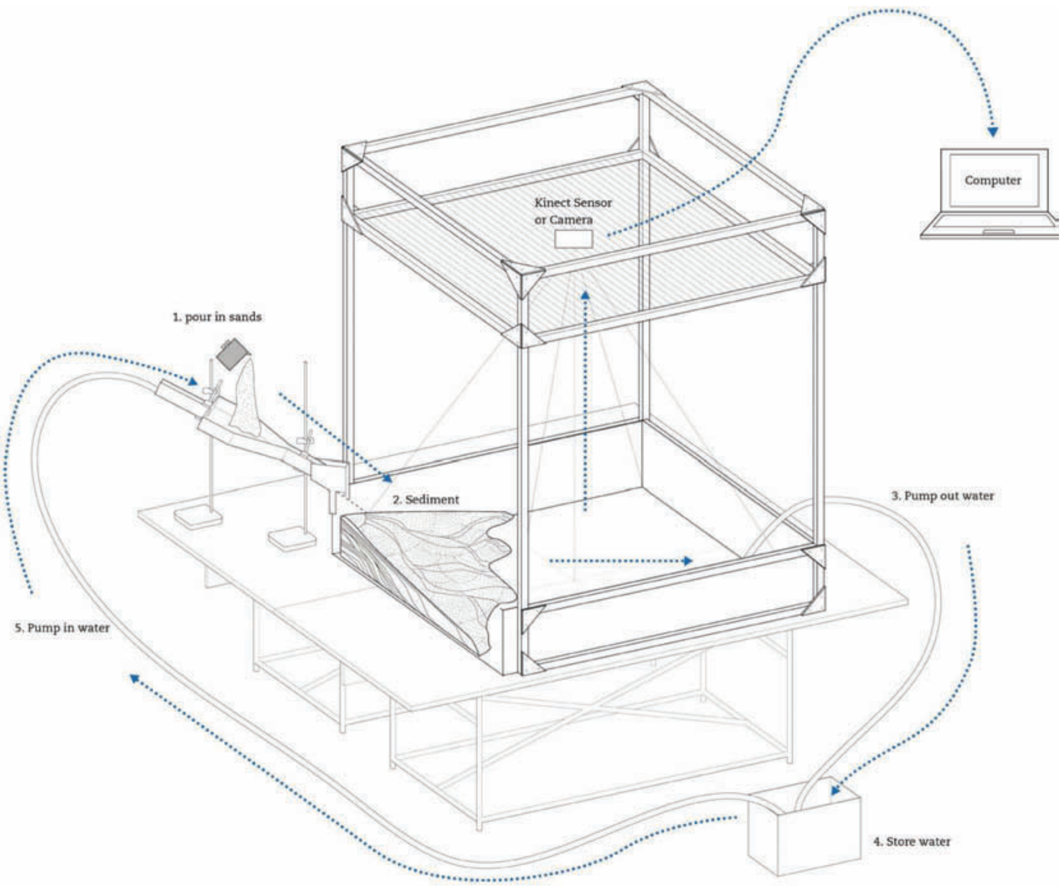
or more variables alter.[126] The ecological data for this model was supplemented by the analysis of the physical and digital model, discussed later in this section.

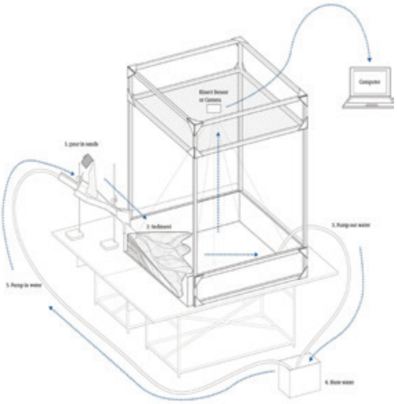
The proxy model presents a very different type of time-based model to that of the mathematical, instead focusing on the patterns and processes of formation. In the case of the Athabasca Tar Sands Area, a scaled-down model of the Gilbert delta (characterised by large bodies of water, with little wave movement) was developed as the proxy model. This large physical model shown in Figure 3.35 simulated the tailing discharging process of sand mining. Sediment and water were dropped into a corner of a tank with water flowing towards another corner. Over time the process established layers of sedimentation spreading within a fan-delta shape. These processes were recorded using a Kinect sensor or video camera.

Once a level of complexity was achieved, the proxy model provided the vehicle to test interventions and acquire knowledge of material behaviour. These included testing saturation levels, introducing artificial built channels to direct water to areas of mine extraction and exploring different forms of dams and obstacles. Figure 3.36 documents the different processes applied as the students worked across physical and digital models.

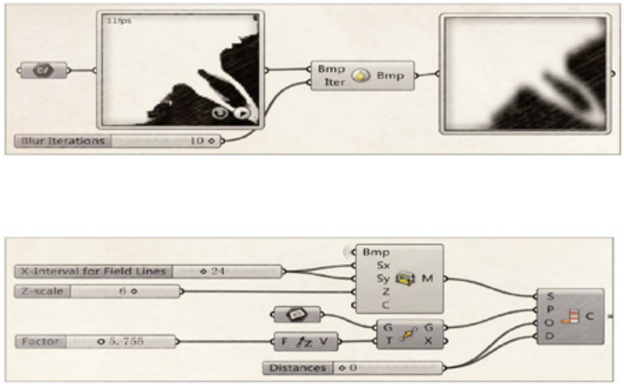
3.35
The proxy model comprised of a computer, a Kinect scanner or camera, a simulation tank, a sand container, a water pump and a fish tank.

Importantly, the Kinect sensor and the video camera allowed the changes emerging in the proxy model to be translated into a digital model. Beginning with a physical (proxy) model, the video recording of the processes was translated into a bit map, from which a Grasshopper definition captured the contour lines and

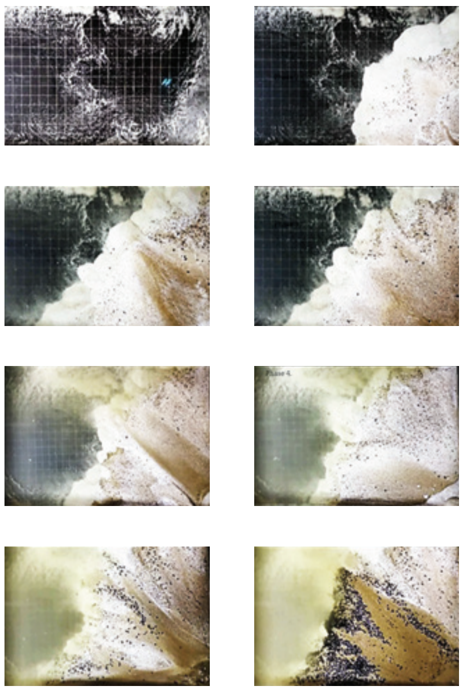


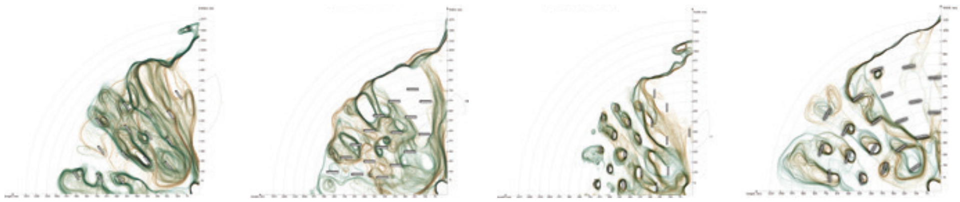


1. Testing different materials and water processes through the proxy model.

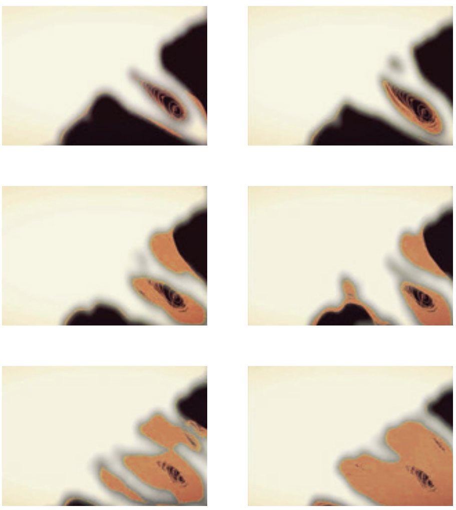


2. The video recording of the proxy model is translated (using bitmap and Grasshopper) into a digital topographic surface.

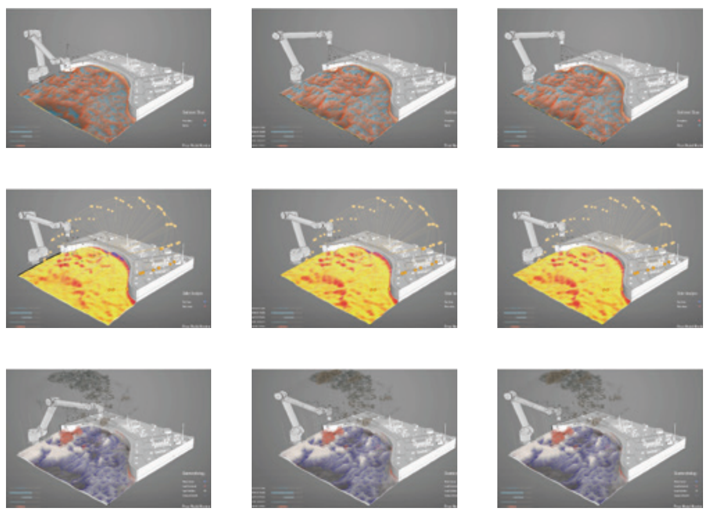




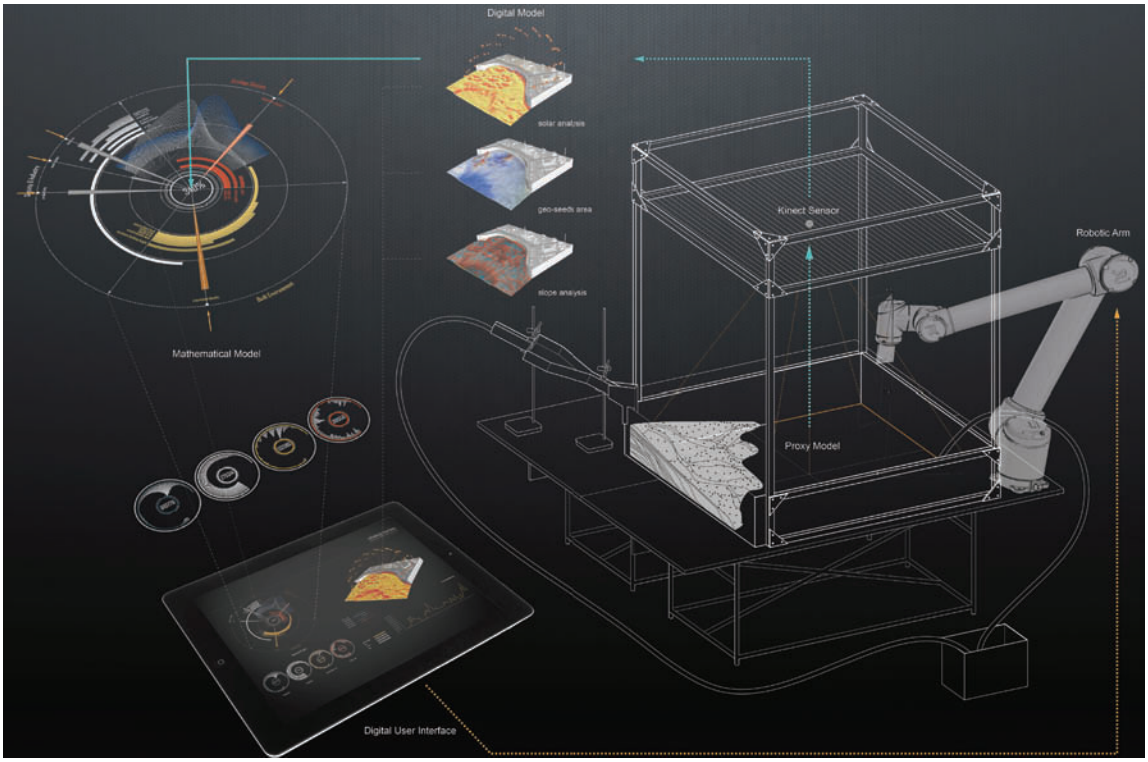
3. Physical interventions in the proxy model through the introduction of obstacles and different saturation levels.



4. The relational interface allows the designer to simultanously manipulate and evaluate outcomes.



3.36
The proxy-model process connecting the physical and digital models.



vectors, which were then translated into a topographic surface comprising meshes and contours.

3.37
The digital interface connecting the mathematical, proxy and digital models.

The resultant digital model can then be analysed, offering further knowledge about emerging behaviours and conditions forming in the proxy model. Analysis of slope, wind, surface water flow and solar analysis can be fed back into the mathematical model, helping to calibrate its data against these more specific site conditions.

All three models link to a digital interface, which simultaneously allows the designer to manipulate and evaluate outcomes. As shown in Figure 3.37, this digital interface controls a robotic arm that manipulates the physical model, the results of which are analysed and fed back into the mathematical–ecological model.

This studio offers an exciting glimpse of a design future, where a landscape system can be prototyped and then analysed (using a real-time feedback loop) according to ecological, social and economic performance. This mix of physical and digital prototyping, which engages top-down and bottom-up influence, shifts the design of landscape systems beyond broad speculation, into a relational model reflective of systemic methodology and the material processes of the site.

When asked to describe her future vision for design and landscape architecture, Claire Fellman, Director of Snøhetta's New York office, identified the ability to design more directly within dynamic systems, harnessing GIS data, Grasshopper and simulations so that design 'really becomes about landscape performance and ecological systems'.[127] The three design studios just described present design processes that are close to matching Fellman's vision. Rather than 2D site plans, these models or prototypes of systems provide the apparatus for design, constructing a continuous feedback loop, that interrogates relationship and behaviours between the biological and synthetic. Within these techniques, the system remains dynamic, fluid and ever present.

Conclusion

Landscape architecture is often described as the art of time. Until recently the discipline lacked techniques that could integrate and speculate on change directly within design processes. Simulation, physical and digital prototyping, combined with access to real-time data, offer landscape architecture new operative techniques for conceiving and testing the dynamic behaviours and relationship of systems and phenomena.

This chapter has identified two approaches for intergrating these techniques within design processes: first, applying digital simulation of systems directly within design processes to test performance; and, second, a more fundamental reconceptualisation of design processes which position the physical and/or digital prototyping of systems as the starting point, in which to hack, test and explore design interventions. Real-time data is central to both of these approaches, offering iterative feedback to designers.

Technology such as sensors offer further prospects to engage with change within the constructed design, offering opportunity to design 'intelligence' responsive to fluctuating and dynamic environmental and social conditions, in addition to measuring and monitoring performance post construction to customise longer-term management strategies. In a further advancement, real-time data combined with portable technologies for gathering data such sensors, laser scans and photogrammetry reframe site analysis from a 'visual' understanding of site conditions to a more comprehensive engagement with intangible phenomena and invisible forces such as heat, pollution, wind and water.

Performance underpins all of these techniques, however, as demonstrated in the design examples, this focus does not reduce the designer's ability to produce innovative and novel outcomes. This increased role for metrics and data raises questions over what knowledge best equips future landscape architects to maximise these new tools of simulation and prototyping. Many landscape architects interviewed for this book highlighted the need for the discipline to move away from more general rule-of-thumb knowledge gained from areas such as horticulture to instead realign with more comprehensive knowledge of systems, ecology and environmental sciences.

We continue the discussion on prototyping in the following chapter, with a focus on new digital-inspired techniques for fabrication and construction.