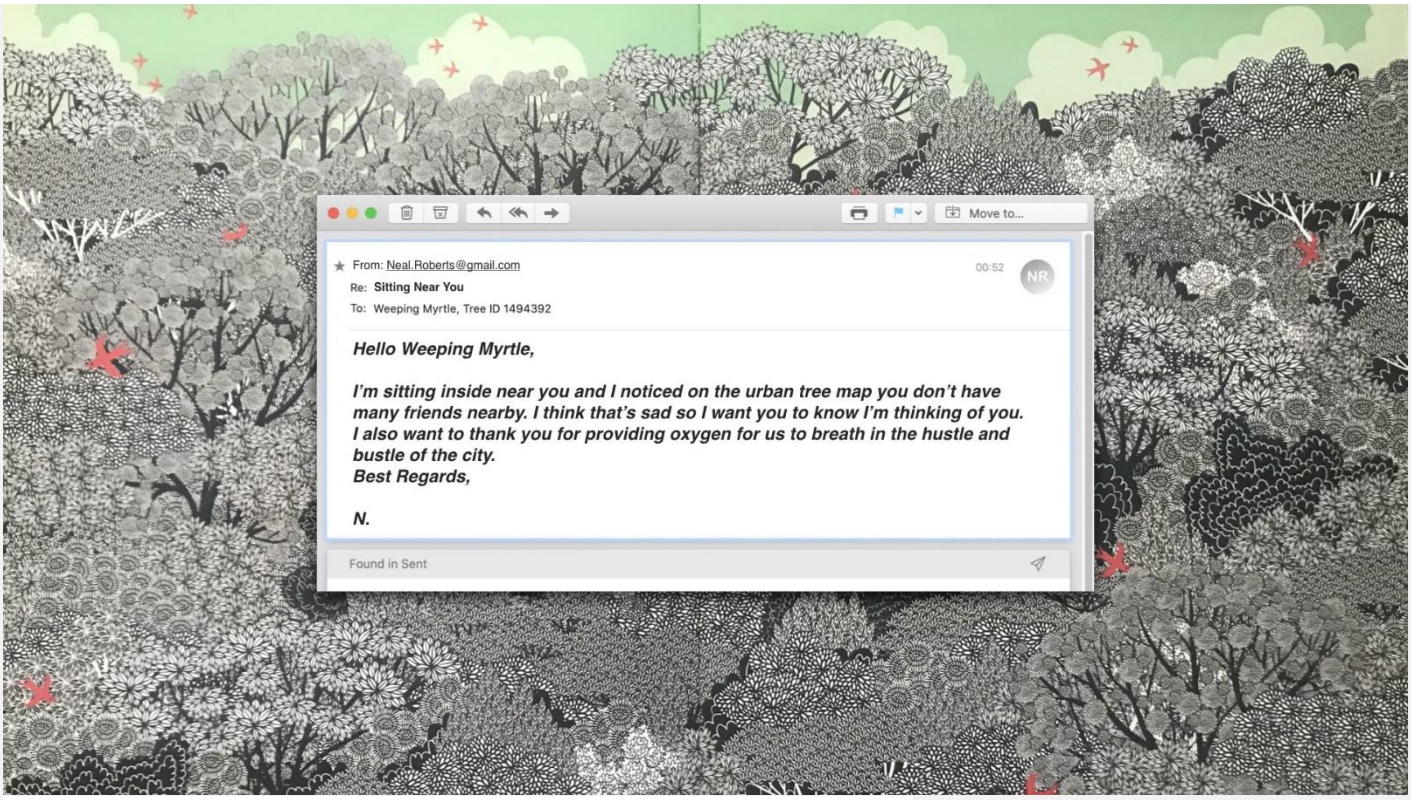


1 Treemail sent through Melbourne's urban forest visual platform, July 2015**Trees As Infrastructure**

Trees As Infrastructure

This is the second of two related articles. In the first blog, we examined why municipalities are struggling to reach tree-planting targets. In this blog, we develop a proposition for supporting cities to transition towards resilient urban forest infrastructures. Source: https://provocations.darkmatterlabs.org/trees-as-infrastructure-aa141acdf227

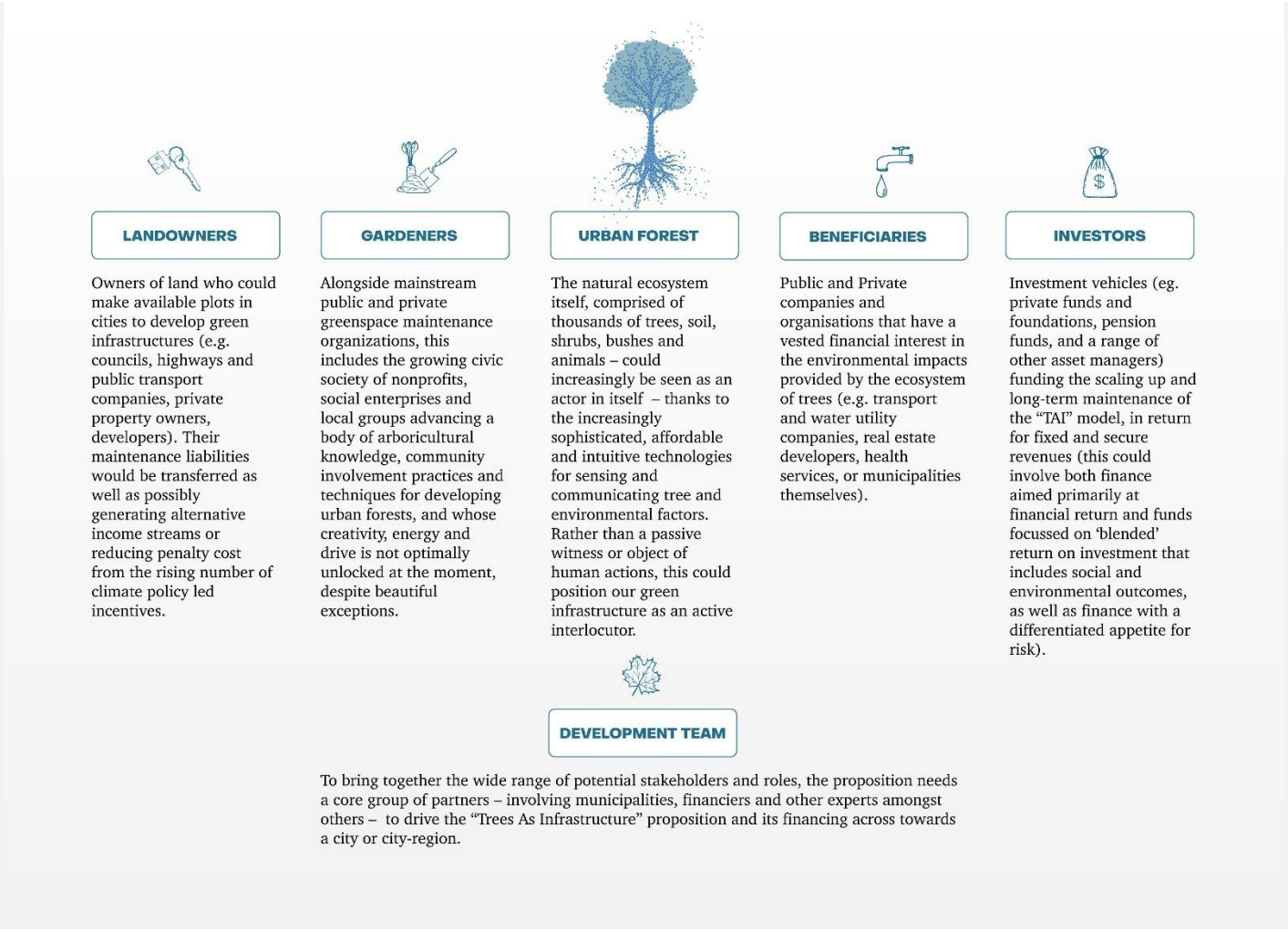
We know that achieving our increasingly higher climate mitigation and adaptation targets means learning to design and live in cities in radically different ways. It will require us to rethink the morphology of our streets, our consumption habits, our human development and economic growth principles, and our intimate relations with plants and animal species. Trees have existed before us and will continue to exist after we have gone. We have been cohabiting with trees for centuries, but at this moment we live alongside a highly processed urban forestry environment which has increasingly been 'optimised' to align with distorted economic and operational principles. How can we re-learn to appreciate urban trees for their true value, empathise with their needs to thrive, and actively 'cooperate' with them to achieve better outcomes in our cities? What will it take to break free from our perverse procurement and distribution models of green infrastructure to augment natural growth cycles? As anthropologist Eduardo Kohn writes, "To engage with the forest on its terms, to enter its relational logic, to think with its thoughts, one must become attuned to these."

Our proposition, which we have termed Trees As Infrastructure ("TAI"), is a model for the distributed management of our 'live' green infrastructures that helps us to develop cities that bring people into symbiosis with urban forests. It is a model to help us nurture street trees instead of unduly holding them responsible for damages to structures, pavements, and utilities; to rewild our parks instead of excessively 'tidying' them to fit within public expectations for neat and controlled landscapes; to support us in making neighbourhoods more liveable by leveraging the preventative health benefits of trees. Our proposition involves a sequence of institutional paradigm-shifts that 1/ pool the necessary financial resources to maintain a thriving green infrastructure, 2/ develop new practices to care for and maintain our urban ecosystems, and 3/ monitor and evaluate the environmental, health and social impacts driving our urban afforestation targets.

In the following sections we will first describe how the Trees As Infrastructure model works. Second, we will explain the structural elements inherent in our proposition — such as outcomes micro-contracting, collective maintenance practices and data monitoring — to enable a distributed green infrastructure to thrive. Third, we will present some of the broader societal and governance implications of developing resilient urban forest futures.

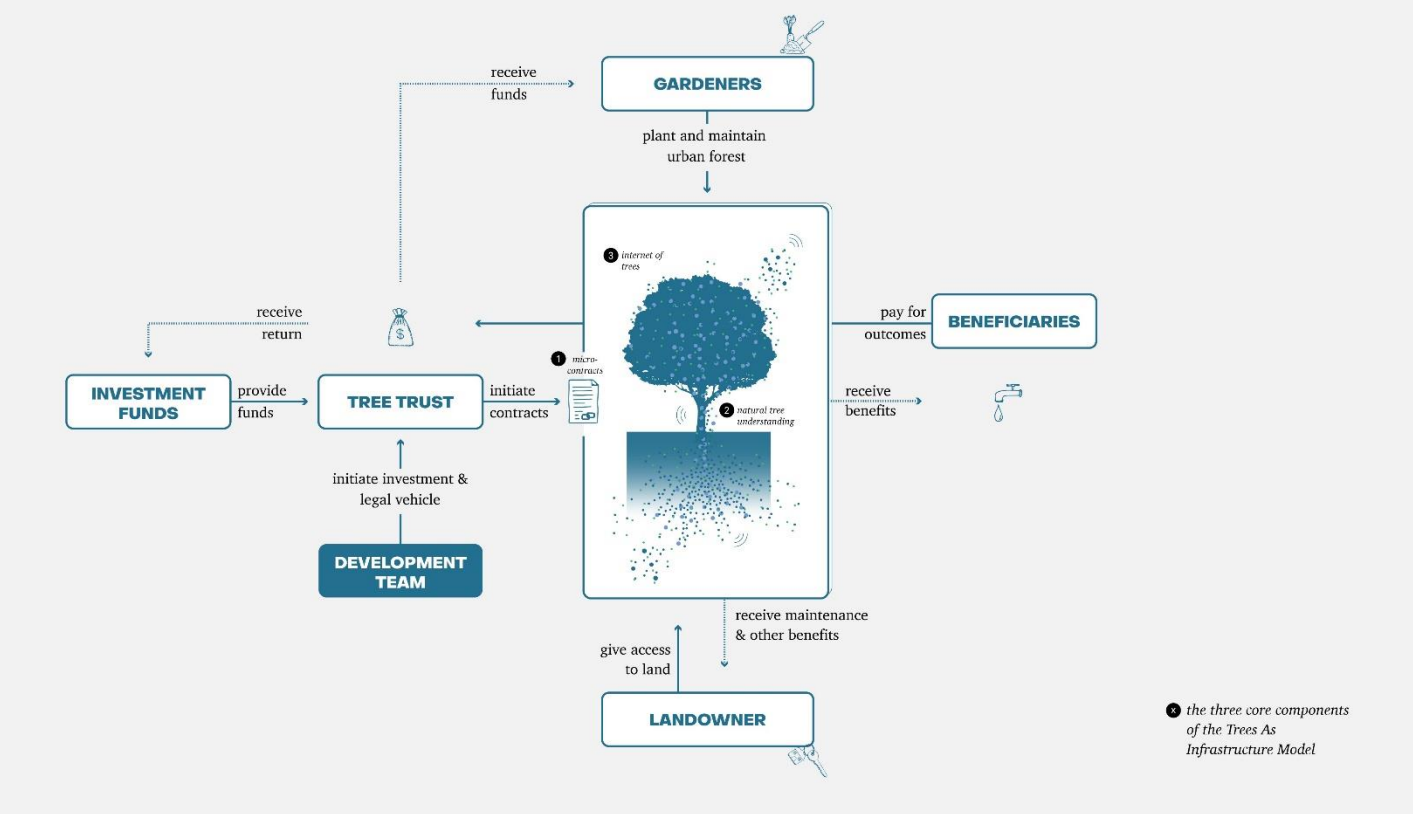
The Model For A New Forest Infrastructure

Despite the fact that many of our ambitious tree planting initiatives are led by city administrations, ultimately the successful creation of urban forests cannot depend on municipalities alone — successful green infrastructures, like most holistic outcomes that policymakers seek to achieve, will require the involvement, investment and care of the many actors that occupy and shape the city; from communities to landowners, and from multiple public sector bodies through to the private sector, whether start-up innovators or large-scale utilities. Below we suggest the roles of a few of them:



2 The city actors involved in developing Trees As Infrastructure

The Trees As Infrastructure proposition connects these now disparate city actors under one model to form alliances, interactions and investment streams that will support the growth and maintenance of urban forests. The following diagram indicates the relationships and organisation within our model. The stages outlined below are indicative and will differ according to the specific city's cultural context, morphology and economic horizons.



3 Organogram of the Trees As Infrastructure model

Stage 0: Set up

The *Development Team* sets up a '*Tree Trust*', an independent legal and financial vehicle able to contract with multiple parties and obtain finance from a range of sources (including both philanthropic, public funding as well as private sector capital looking for a financial return, or 'outcomes buying').

Stage 1: Inception

The *Development Team* collaborates with beneficiaries to identify a green infrastructure project and determine its metrics of success.

Stakeholders form outcomes-based contracts with the *Tree Trust* to participate in the planting and maintenance of urban forestries (eg. *Beneficiaries* commit to pay for the financial or other benefits that they will receive from positive environmental impacts; *Gardeners* agree to provide services to grow the healthiest parcel of urban forest).

Stage 2: Development

The green infrastructure project is initiated. *Landowners* provide access to plots. The *Tree Trust* provides funds to *Gardeners* that carry out the work, whether new planting or maintenance and care.

Stage 3: Evaluation

The newly developed urban forest is monitored across its lifespan and its success is measured (e.g. Increased canopy cover, nutrients in soil, biodiversity levels, reduced heat island effect…).
Beneficiaries pay for the outcomes achieved (see next section); the *Tree Trust* structures part of the payments from beneficiaries as fixed revenue to investors while continuing to finance the work of *Gardeners*; *Landowners* keep receiving maintenance works on their plots.

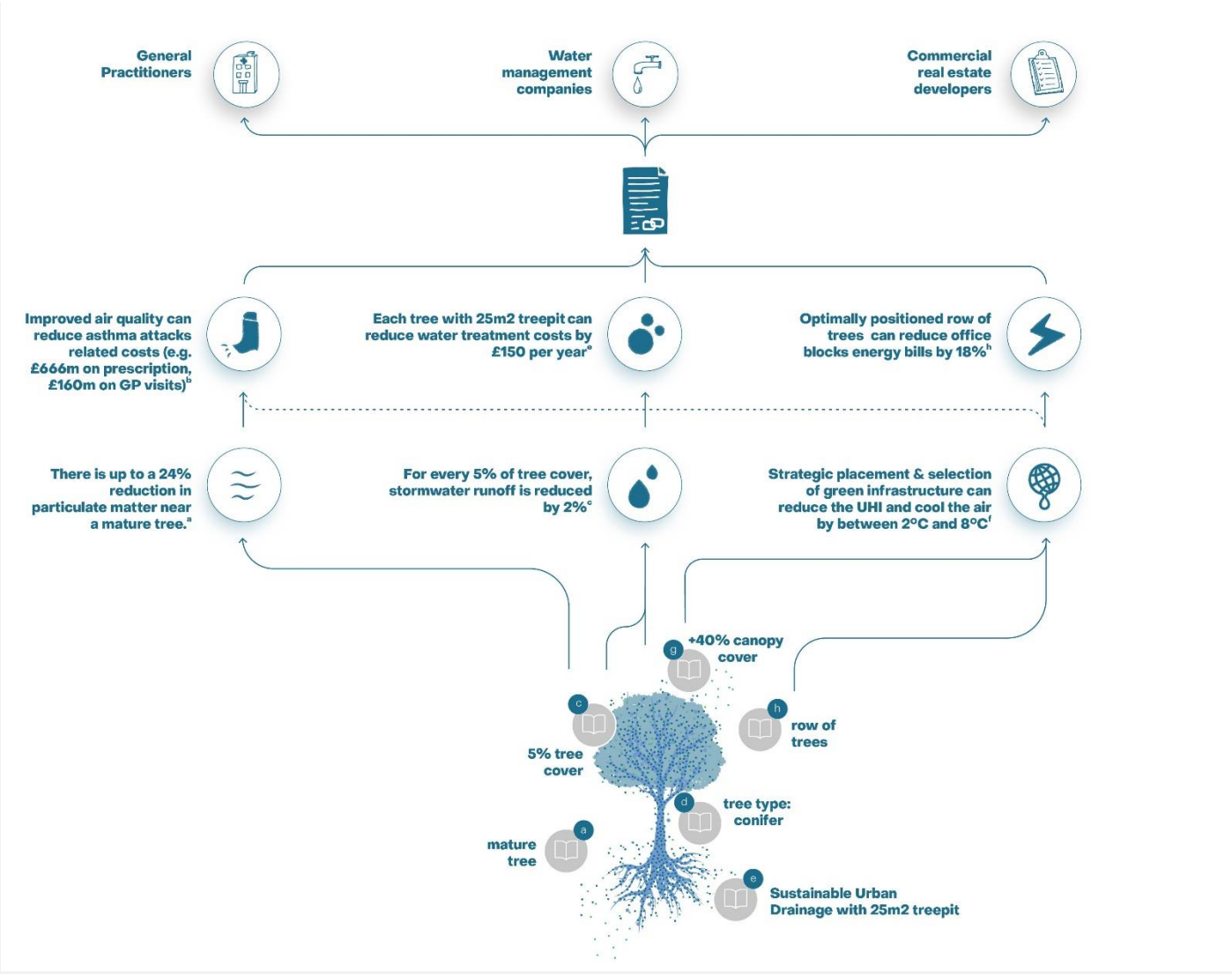
The Components Of Trees As Infrastructure

Trees As Infrastructure is as much about forming new urban stakeholder relations through agreements and value sharing transactions, as it is about shifting cultural behaviours towards urban nature. In this respect, the different components of Trees As Infrastructure address the financial, bureaucratic and cultural relations with urban trees. In the following paragraphs we will unpack how the "TAI" model is 1/ funded and procured, 2/ maintained and cared for, and 3/ monitored and evaluated.

1 / Micro-contracting the outcomes of urban forests

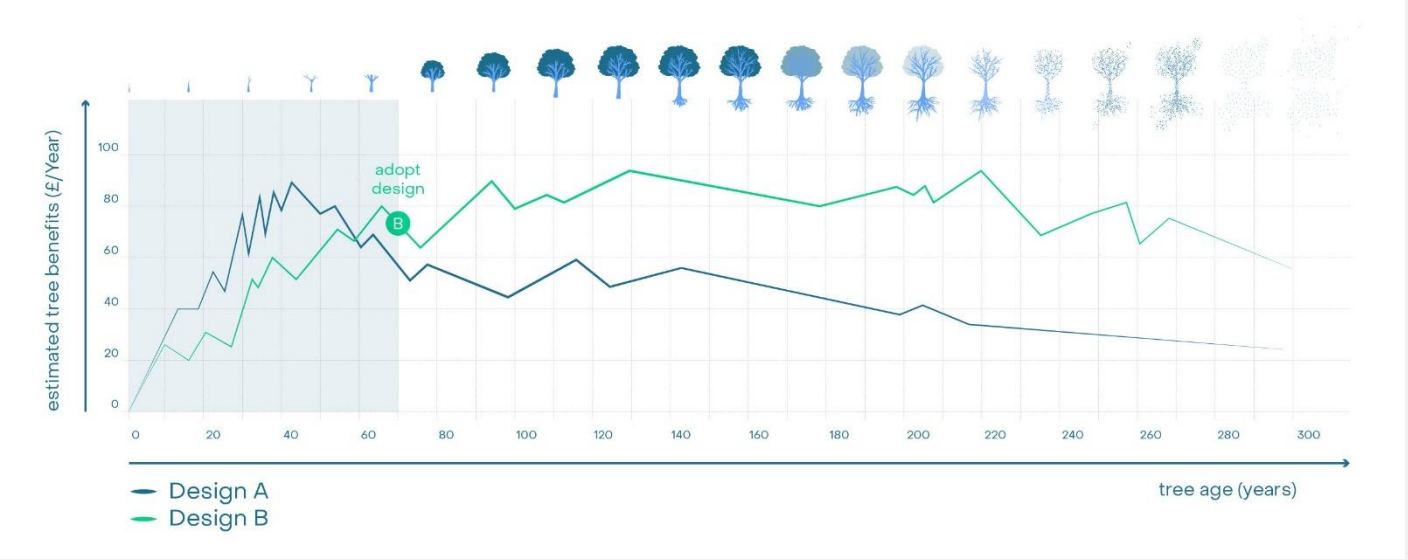
Using smart contracts, *Beneficiaries* agree to recognise that the environmental impacts of green infrastructures reduce some of their operational costs. For example, water & sewer utilities could see a reduction in sewer maintenance costs because of lower peak water runoff, and face fewer fines for sewer overflows by using the water retention capabilities of urban forestries; commercial building owners could benefit from a reduction in air conditioning cost. Gardeners, on the other hand, are contracted for the outcomes that a rewilding project produces, whilst the public health system may achieve lower mental healthcare costs because of people active in tree planting, possibly through social prescribing. Therefore, the contracts involved in the Trees As Infrastructure model, have two main qualities (1) they enable multilateral agreements and (2) are outcomes-based.

First, many-to-many contracts are vital as no single stakeholder holds the necessary amount of funding to support the transition towards resilient urban forests. Research has shown that Environmental Impact Bonds, when just one Beneficiary is in charge of delivering a green infrastructure project at scale, might significantly augment environmental and financial risk levels, compromising local authorities or residents (e.g. unclear maintenance strategies or increasing water utility bills). On the other hand, the Forest Resilience Bond raises funds by combining capital and incentives from multiple parties that have a direct stake in the success of a forest development and management, such as forestry management bodies, utility companies and beverage companies. Similarly, the Trees As Infrastructure model relies on the participation of multiple *Beneficiaries* to secure funding for a project.



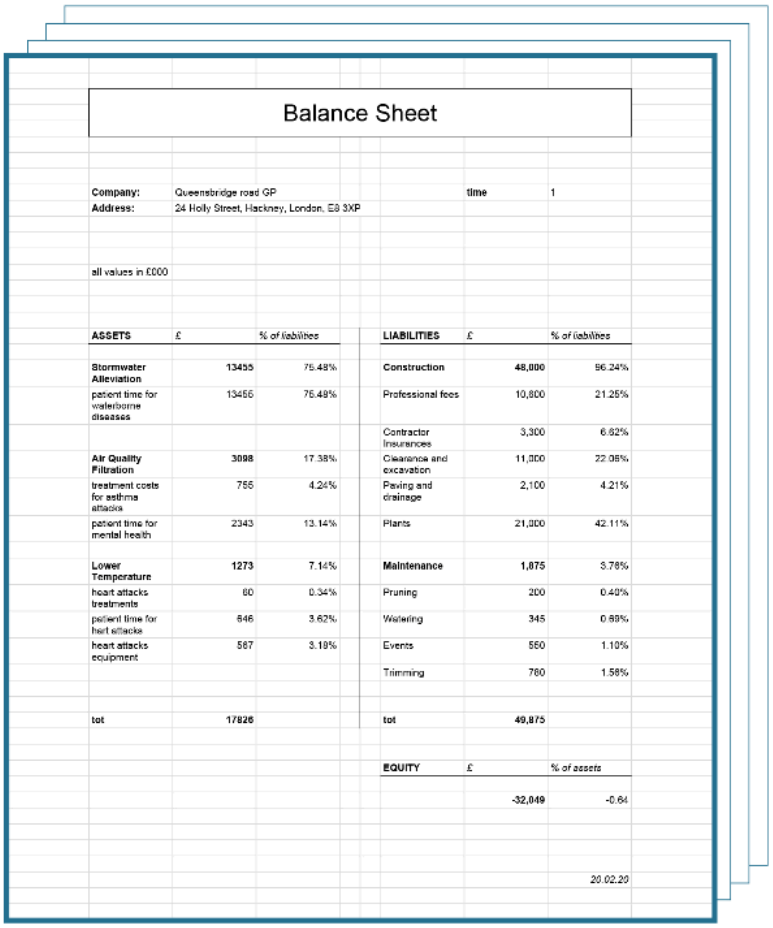
4 Flow chart of an example green infrastructure project, showing the possible ecosystem and social benefit analysis for multiple Beneficiaries

Secondly, these multilateral contracts are based on the outcomes that a green infrastructure project generates. Neither of our current traditional approaches of 'tree as product' or 'tree as cost' have been able to generate the finance required for the increasing urban tree planting targets. The several examples already alluded to above show how we could invest in the urban forest as an 'outcomes provider', taking into consideration both positive ecosystem and social impacts. Of course, such impacts are complex and interconnected. However substantial progress has been made in modelling outcomes of complex systems (e.g. data-driven surrogate models for climate modelling such as Climate Change AI) to predict the variables and conditions that can bring about desirable outcomes. Rapid advances in sensing and modelling systems could enable stakeholders to connect around shared outcomes and align missions and operations towards growing a thriving urban forest.



5 data-driven outcome/impact modelling comparing the estimated future benefits of two different green infrastructure designs

If the urban forest is an outcomes provider, we need to change how we account for the trees in our cities. Currently, municipal trees tend to be accounted for as costs on the balance sheet. But what would it take to shift this practice and account for trees as assets? The benefits they generate are not owned by one single stakeholder but affect many of us. Similar to how the city of Gibson put its aquifer on their balance sheet (which enabled it to acknowledge its current value based on the cost of having to replace it with grey infrastructure), urban trees could be seen as shared civic assets. Dynamic assets valuation could help us spread their value amongst several financial beneficiaries sharing the outcomes of the infrastructure. As the urban forest grows, environmental benefits will multiply, raising the value of this asset — and we already know the benefits of urban forests grow exponentially, not linearly. Similarly, an unpredictable shock such as extreme weather might disrupt the benefits of the green infrastructure, reducing the value of the assets. Taking into account such factors in combination with the outcomes generated, we can start calculating future projections of the urban forest. This can help us (a) make more informed decisions about where and how to develop our urban forest (see image 5) and (b) start understanding the financial incentives for Beneficiaries and investors to support green infrastructures.



Balance Sheet

Company:	Queensbridge road GP		time	1	
Address:	24 Holly Street, Hackney, London, E8 3XP				
all values in £000					
ASSETS	**£**	**% of liabilities**	**LIABILITIES**	**£**	**% of liabilities**
Stormwater Alleviation	**13455**	75.48%	**Construction**	**48,000**	96.24%
patient time for waterborne diseases	13456	75.48%	Professional fees	10,800	21.25%
			Contractor Insurances	3,300	6.62%
Air Quality Filtration	**3098**	17.38%	Clearance and excavation	11,000	22.06%
treatment costs for asthma attacks	755	4.24%	Paving and drainage	2,100	4.21%
patient time for mental health	2343	13.14%	Plants	21,000	42.11%
Lower Temperature	**1273**	7.14%	**Maintenance**	**1,875**	3.76%
heart attacks treatments	60	0.34%	Pruning	200	0.40%
patient time for hart attacks	646	3.62%	Watering	345	0.69%
heart attacks equipment	567	3.18%	Events	550	1.10%
			Trimming	780	1.56%
tot	17826		tot	49,875	
			EQUITY	**£**	**% of assets**
				-32,049	-0.64
					20.02.20

6 Representation of a digital ledger showing how initial project costs are offset by long term benefits.

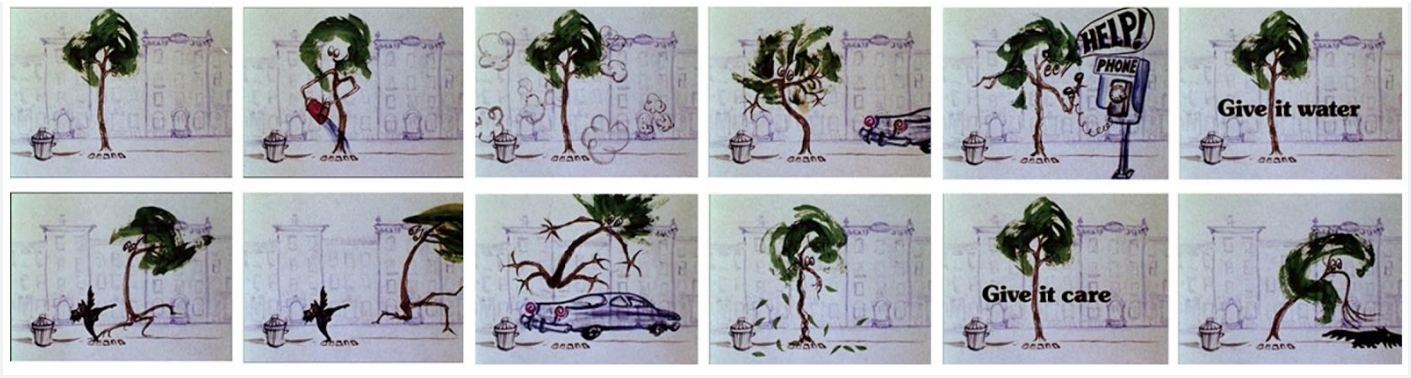
2 / Distributed Life Maintenance via ‘Natural Tree Understanding’

If the development of urban forestries requires a massive transformation in our cities to host and nurture green spaces, financial incentives are not enough. The future requires a great cultural change — new kinds of shared attitudes, embedded in urban forestry practices — to advance relationships that are amiable, arborescent, others reticulate or parasitic. If we are to live together in cities with more and more trees, gifts from and care for this green infrastructure needs to be at the centre of our exchanges. After all, trees take generations to grow, and we all have a stake in their thriving — demanding a relational and intergenerational ethics. We need to create the conditions for building collective intelligence, sense-making and even empathy rather than perceiving and treating tree maintenance as a centralised technocratic endeavour to be done by ‘others’.

7 Possible moments depicting the gift and care economy. From the left: merged back gardens host tree pruning festivals while trees send a blossomed flower image to neighbours. Park trees become the providers of shade, playful adventures and fruit pickings while residents can be notified when they lack water or their roots are constrained. Carless streets create new possibilities, from street parades or seed bombs treasure hunts, to the safe clearing of a littered meadow.

If this may seem abstract, we are already seeing such behaviours in practice. The Melbourne treemail phenomenon saw thousands of citizens send love letters to their favourite city trees, which became possible because the municipality created an open platform that gave a unique ID number to every tree in the city. The streets of Copenhagen will soon host communal fruit trees to reconnect residents with local vegetation and flora. Paris' 'permis de végétaliser' is unlocking distributed care for green infrastructure across the city, and Incredible Edible Todmorden has seen the very identity of a place change because of mass civic engagement with (edible) green infrastructure. As such, we know that it is possible for communities not only to plant trees to reach policy targets, but also to establish a whole new relationship with their ecosystem.

This could be taken much further — enabled by creative use of technology. What if a fruit tree could extend an invitation to gift its harvest? Or what if the water-stressed or disease-infected tree could trigger a message to ask for some extra human care? Trees As Infrastructure proposes to construct such communication channels, which is now technically possible. Natural Language Understanding algorithms using text, voice, and image recognition have advanced enough to trace human emotions and mental states. Similarly, we could develop a set of 'Natural Tree Understanding' algorithms that translate data gathered through sensors monitoring trees, to stimulate playful 'bonding' possibilities between humans and trees.



8 New York City Parks Council awareness campaign to incentivise citizen care and maintenance of street trees.

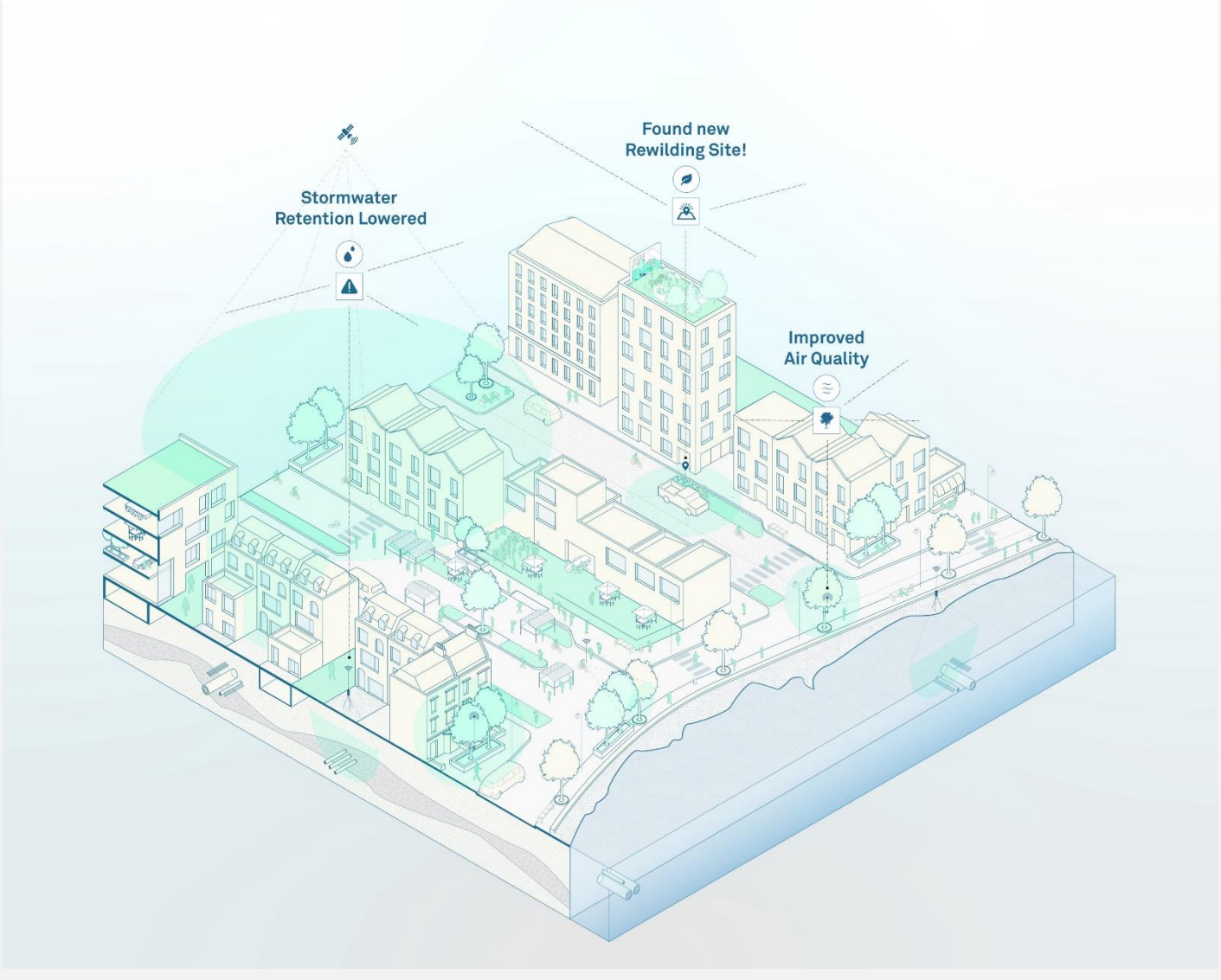
3 / Monitoring and evaluating success via the 'Internet of Trees'

The extensive re-landscaping of our cities will not be one continuous infrastructure, but consist of a web of urban forest micro-sites — private gardens, depaved sidewalks, green roofs, parks, redesigned squares, forgotten lands…collectively these will hold the distributed incrementally growing capacity to temper our urban climates. Each of these sites will host completely different habitats and morphologies. A rapidly growing number of software and tech tools are aiming to better map, monitor and evaluate the development of such diverse sites. Trees as Infrastructure proposes to leverage these technologies to build the *Internet of Trees* — a digital representation of our distributed green infrastructure. Multiple technologies analyse different datasets. For example, remote sensing can overcome intricate ownership structures by gathering and collecting data on multiple forest micro-sites. Geo-localised sensors and biosensors can link up local environmental data with each tree's microclimate, processing the tree's health in relation to its surroundings (from soil to air quality to biodiversity levels) and thereby its potential to generate ecosystem benefits.

Again, many of these ingredients already exist. Descartes Labs have developed a model to identify tree canopies across cities using satellite imagery, which could prove extremely helpful for municipalities in noticing possible trouble spots much faster than a traditional annual tree census. The governmental civic tech group in Taiwan has mapped 1500 potential sites to plant trees on Google Maps and is now planning to mediate with landowners to use their plots for the development of green infrastructure, while providing open information to support advocacy groups. Hise Scientific Instrumentation developed affordable precision dendrometers (springs resting on barks that sense and wirelessly report tiny changes in the environment to a cloud-based platform called the EcoSensor Network) allowing scientists and students to monitor a tree's health in real time and help predict their growth, thus its carbon sequestration ability. A forestry inventory company, Treevia, has developed another type of sensor, SmartForest, that among other things can detect early infections and pest attacks. U.S. Forest Service and numerous cooperators developed I-Tree, a urban

forestry management open source suite. Among its various applications, I-Tree Hydro+ is a standalone non-expert software designed to model the potential hydrological impact of urban vegetation (e.g. streamflow and water quality).

This emerging 'Internet of Trees' is essential in allowing various stakeholders to develop a sophisticated understanding of their green infrastructure, with technology likely to dramatically reduce the cost of obtaining, managing and sharing data. It is essential we build an open digital infrastructure, to ensure information remains open, accessible and fully interpretable to support ongoing civic involvement and innovation by a range of actors. Only then we will be able to see both the social and cultural movements of mass participation and care, and the rich data that we need to create a stronger evidence base.



9 Sensing architecture for the monitoring of multiple micro-sites and the evaluation of ecosystem, social and health benefits.

Broader Implications For Regenerative Scaling

A new Social Contract with 'Commons In The Loop'

As Garret Hardin famously described in 1968, we are in "in a shared-resource system where individual users, acting independently according to their own self-interest, behave contrary to the common good of all users by depleting or spoiling the shared resource through their collective action." Our commons are currently neglected, exploited, misused. The Trees As Infrastructure proposition is an example of how we might address our currently broken social contract through a series of technological and institutional shifts that can contribute to a change finance flows, the relationships between stakeholders, and our culture of living in cities.

There are, of course, bigger questions here: with rapid technological change, many of our governance mechanisms are becoming algorithmic. This risks further amplifying the Black Box Society and losing control over our commons by privatising knowledge and the capacity to act in our cities. Iyad Rahwan has put forward a proposition for a Society In The Loop (SITL) to embed the judgement of society as a whole in the algorithmic governance of societal outcomes. SITL supports the interaction between government and people, "negotiating the values of various stakeholders affected by AI systems" into an algorithmic social contract. This in turn opens a window onto a future where we can move beyond a human-centric approach: could technology enable us to embed not only the will of humans, but also the needs and 'will' of trees in our algorithmic governance? A 'Commons in the loop' approach might embed considerations about the state of our ecosystems that live alongside us into our algorithmic social and governance contracts.

10 Representation of Society in the loop Vs Commons in the loop social contract

What Next?

This blog has outlined a proposition for a series of interconnected technological-regulatory-accounting shifts to accelerate the ability of multiple stakeholders to play their part in increasing investment in (and care for) the green infrastructure of our cities. Each of the interconnected elements of this proposition can be further developed and tested in the context of specific cities and their challenges. We are currently further developing this portfolio of green infrastructure propositions, honing in on some of the institutional and administrative paradigm-shifts necessary for the development of Trees As Infrastructure. For example, we will aim to further develop the prototyping of multi-party smart micro-contracts for street depaving efforts and increasing tree cover, connected to outcomes-based investment models that can work at multiple scale levels (from neighbourhood-based to city-wide models). These experiments aim to improve long-established procedures of understanding, accounting for, and contracting our urban forestries. In doing so we can fundamentally rethink how humans and trees can flourish side-by-side at a time when multiple places around the world are recognising the importance of trees for the future prosperity and thriving of our cities.

We welcome cities to get in touch, contribute and be part of the green transition.

We would like to thank Andrew Gregson, Ban Yuan Chang, Ben Connor, Camilla Pandolfi, Carys Boyle, Dale Mortimer, George Collum, James Dalrymple, Jim Smith, Kate Raworth, Keith Sacre, Kieron Doick, Lorenzo Fassi, Marina Chang, Mary Stevens, Mathias Disney, Michelle Zucker, Naho Iguchi, Roger Barrowcliffe, Zoe Christo who supported the development of Trees As Infrastructure, via a series of workshops, interviews or informal reviews.

Trees As Infrastructure is one of a number of experiments developed by Dark Matter Labs, supported by EIT Climate-KIC. If you're interested in getting involved, or want to know more let us know @Dark MatterLabs.

This piece has been co-authored by Dark Matter Labs Tree Team: Aaron Gillett, Bulent Ozel, Carlotta Conte, Indy Johar, Joost Beunderman, Konstantina Koulouri, Oguzhan Yayla and Fang-Jui Chang.

References

Image 1 / Tree email sent through Melbourne's urban forest visual platform. Background image from: Cecile Benoist and Charlotte Gastaut. "Un Arbre une histoire". ACTES SUD junior.

Image 4 / Having a multilateral agreement enables us to address how a network of urban trees provides specific ecosystems and social benefits to each beneficiary and how these equate to cost savings to their operations. In fact the costs and benefits analysis over time may vary from one beneficiary to another. For example, in the diagram, both GP and Real estate developers could benefit from the cooling effect of street trees in the form of reduction in heating bills, however the rate at which the trees will cool the building will differ depending on their location. On the other hand, GPs will also benefit from the particulate matter levels reduction from street trees. In this case, the cost reduction will be related to the scale of the medical practice and the types of patients.

Diagram information references:

(**a**) There is up to a 24% reduction in particulate matter near a mature tree.

(**b**) More than 270 people are admitted to hospital each day because of asthma attacks. Of the £1.1b cost of treating asthma in the UK, at least £666 million is spent on prescription costs each year. Other costs include £160m on GP consultations, £143m on disability claims and £137m on hospital care.

© For every 5% of tree cover, stormwater runoff is reduced by 2%.

(**d**) Different species have different rates of transpiration (water passed from roots to leaves and evaporates into the environment through leaf pores) *Conifers* transpire 10–12% while *Deciduoud Trees* up to 25% of precipitation.(**e**) One tree with 25m2 tree pit will capture 26" of London's annual rainfall. For every tree with those qualities planted, Thames Water who currently pays £1.5 p/m3 could save £150 a year for every tree planted.

(**f**) Informed selection and strategic placement of trees and green infrastructure can reduce the UHI and cool the air by between 2°C and 8°C.

(**g**) Research has shown that temperature decreased nonlinearly with increasing canopy cover, with the greatest cooling when canopy cover exceeded 40%.

(**h**) Optimally positioned row of trees could help save up to 18% energy for heating office buildings and also help to enhanced pedestrian comfort.

Image 6 / This is a sketch representation of a digital ledger. The green infrastructure use case has been informed by the depaving project Grey to Green Guide V15. The future looking cost benefit calculation is made by an arbitrary non-linear hypothetical model inspired by a recent research on sustainable land management. Initially costs can exceed benefits. However, in the long-term individuals, communities, and the planet will exponentially benefit.

Image 8 / Stills of Street Tree TV spot produced by the New York City Parks Council. The moving images are accompanied by music and words: "Hey, have you ever seen a tree water itself?/ Run away from a dog?/ Jump over a motorcar?/ Call for help?/ No, it needs your help." (Avery Architectural & Fine Arts Library, Columbia University/New Yorkers for Parks) Excerpt From: Sonja Dümpelmann. "Seeing Trees". Apple Books.

Image 10 / Representation inspired by Ego to Eco meme.