‘Greening’ the Cities

How Data Can Drive Interdisciplinary Connections to Foster Ecological Solutions

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Abstract

We are facing an urgent global environmental crisis that requires a reframing of traditional professional and conceptual boundaries within the urban environment. Complex and multidisciplinary issues need complex and multidisciplinary solutions, which result from the collaboration of many different disciplines concerned with the urban environment. A more integrated ecological perspective that recognizes the complexity of urban environments and resituates our ‘artificial’ or human-made world within its natural ecosystem can facilitate this shift towards greater knowledge exchange. C40 Cities case studies provide a framework within which to understand the disciplines and scales encompassed by ecological solutions, while projects at MIT Senseable City Lab and CRA-Carlo Ratti Associati highlight how data is used as a tool in driving ecological solutions. The artificial world of sensors, data and networks creates a bridge between the ‘artificial’ and ‘natural’ elements of our urban environments, allowing us to fully understand the present condition, connect city users and decision makers, and better integrate ecological solutions into the built environment.

Keywords

Ecological Solutions, Data-driven Design, Ecological Perspective, Urban Environmental Degradation, Artificial-natural

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Introduction

Cities cover only 1% of the earth's total land surface (Ritchie, 2018). Yet they are responsible for 76% of global CO_2 emissions, 50% of global waste and consume 75% of the world's natural resources (Organisation for Economic Co-operation and Development (OECD, 2020, 2020). These statistics would seem to imply a conflict between 'city' and 'nature'. Environmental degradation is one of the greatest impacts of urbanization. According to the C40 Cities organization, a global network of 97 cities committed to taking action on a broad range of urban environmental issues, cities must address loss of biodiversity, greenhouse gas emissions, water, air and soil pollution and the Urban Heat Island (UHI) effect in order to begin to reverse environmental degradation and consequently build resilience for the future (Attstrom et al., 2020). These issues present decision makers tasked with finding solutions with multi-scalar and multidisciplinary challenges and so the solutions require cross-disciplinary and cross-scalar knowledge transfer between stakeholders: citizens, planners, designers, scientists and technicians (Heymans et al., 2019). This means recognizing the connections between and consequences of urban activities at every scale: between disciplines, between users and city, and between the city and its landscape. There is growing agreement that we need a shift in work practices towards a more integrated and collaborative approach. But to enable this shift we also need a change of perspective on the human/nature relationship, as previously argued by practitioners and thinkers such as Ian McHarg, Timothy Morton and Janine Benyus (Benyus, 2015; McHarg & Steiner, 2006; Morton, 2018): an ecological perspective that recognizes human beings as just another species *within* the natural environment. Through this lens we can perceive the city as it is – an ecosystem, complete with its flows of energy, matter and information, living and non-living components, and their constant interactions and exchanges, from the micro to the global scale (Odum & Barret, 2005).

If these interactions and exchanges were visible to us, we might rethink the 'natural' versus 'artificial' perspective that seems to divide the city and its landscape, and that has been obscuring the environmental consequences of urbanization. Perhaps counter-intuitively, the digital revolution, which could be considered the epitome of artificiality, is providing us with the means to do this. Via new digital technologies, data-acquisition, data-sharing and data integration, are making the invisible, visible. Data can turn seeming chaos into legible patterns, can connect action and response and drive the feedback loops that ensure adaptability and resilience (O'Connor et al., 2019). On this premise, the design practice CRA-Carlo Ratti Associati has been exploring an architecture that 'senses and responds': using data to connect users and their environment; merging the 'artificial' and the 'natural' (Ratti & Belleri, 2020). By blurring this distinction and resituating our artificial or 'human-made' built environments within their 'natural' ecosystems, we as designers can begin to recognize the relationships between what were previously considered separate disciplines and scales, and so effectively implement 'green solutions'.

This article illustrates how 'green solutions' to environmental degradation can be applied using data as a tool to both understand the problems at hand, and better integrate solutions into the urban ecosystem. We begin by introducing C40 Cities as a practical representation of multi-scalar and interdisciplinary data-driven action that can help us define what 'green solutions' actually encompass. We then explore the use of data in sensing projects from MIT Senseable City Lab, which can be employed in better understanding some of the issues highlighted by C40 in a local context, and finally examine the Vitae building in Milan (IT) as an example of the integration of data and 'green solutions' in practice. Through these examples, the article also illustrates how data-facilitated connections encourage a broader and more balanced ecological approach to urban planning and design.

What are green solutions?

The term 'green solutions' carries the implicit assumption that 'green' is always good. However, this can strengthen the natural versus artificial divide and lead to a form of greenwashing, where 'natural' elements such as trees or plants are used in design as symbolic gestures, sometimes with little understanding of how they can affect the project (see Budds, 2020). Though vegetation in general can be one of the most effective solutions to urban environmental degradation, when applied without considering the effects within the larger system or across disciplines, vegetation can also lead to unintended consequences. The recent popularity in planting street trees as a climate change adaptation measure is an example. In some cities mass planting of street trees is believed to have contributed to a rise in human health problems due to severe pollen allergies: many cities use the male variety of certain species popular for urban planting since they are 'tidier' and produce only pollen, not fruit and seeds like their female counterparts (Hirschlag, 2020; Sierra-Heredia et al., 2018). Street trees, when planted in areas exposed to high levels of air pollution such as busy roads can also worsen air pollution as well as heat stress since the tree canopies can reduce ventilation and trap pollutants and rising hot air (Coutts et al. 2016). While we believe the use of urban greenery as a 'green solution' can make significant contributions to the overall ecological health of a site, as these examples suggest, addressing environmental degradation requires a more balanced and interdisciplinary understanding than the oversimplified emphasis on 'green' may produce. For this reason we suggest reframing the term as 'ecological solutions' to better reflect its scope.

There is a need, then, for a more interdisciplinary understanding of ecological solutions in design and planning. The C40 Cities organization is a good place from which to understand what the term could encompass at the large scale. While emphasizing climate action, C40 recognizes the complexity of environmental degradation and directs cities to address the sectors of Energy & Buildings, Transportation & Urban Planning, Food, Waste & Water, Air Quality and Adaptation and Implementation in their solutions (C40 Cities, 2021b). It focuses on providing quantifiable targets and facilitating knowledge transfer between cities, experts and citizens and emphasizes 'Measuring and Monitoring' as the first step in any initiative.

The projects presented in Table 1 provide a selection of solutions C40 cities have implemented to tackle environmental degradation. The projects presented are a result of a filtered search for green solutions within the C40 database of case studies and are reviewed for their specific outcomes as well as their overall contribution to the aforementioned issues (i.e., loss of biodiversity, greenhouse gas emissions, water, air and soil pollution and the UHI effect).

The strategies mentioned in Table 1 cover multidisciplinary solutions, implemented by private and public stakeholders, acting across multiple scales. They highlight the results of what can be considered 'ecological solutions,' effectively bridging disciplines, scales or domains. They range from the use of 'cool' materials on city roofs to alleviate the UHI effect as well as to reduce energy consumption, communication campaigns to reduce waste, the capture of landfill emissions for electricity production, renovation of street-level drainage systems to include nature-based drainage elements, and the use of vegetation in the form of green roofs, walls and planters. The Zero Waste project in Buenos Aires is an example of connecting stakeholders through top-down and bottom-up action. The project was able to reduce landfill by 78% in two years through a combination of government policy and a public communication campaign (*C40 Good Practice Guides*, 2016).

Another successful example of an interdisciplinary approach to addressing urban environmental degradation is Hong Kong's updated stormwater system: in redesigning its stormwater drainage system, Hong Kong was able to significantly reduce areas of high flood risk while also reducing freshwater consumption through combined policy interventions and a design that captured and treated stormwater for non-potable uses.

STRATEGIES	CITY	NAME	DESCRIPTION	RESULTS	ISSUE
Greening the building	Toronto	Eco-Roof Incentive Programme	Fees paid by developers under the cash-in-lieu policy of the Green Roof Bylaw make this project self-sustaining. Funding is granted for building owners to install green and cool roofs.	233,000 m^2 of eco-roof space (cool+green).[a]	● ○ ○ ●
	London	Greening the BIDs	The project has supported 15 green infrastructure audits; demonstration projects were partially funded to catalyst urban greening in central London.	1 million m^2 of new potential green cover, correspondent to 300 rain gardens, 200 green walls and 100+ ha of green roofs, and small-scale interventions such as planters and window boxes.[a]	● ○ ○ ●
Cool roof	New York	NYC °CoolRoofs Programme	The programme encourages and facilitates both private and public installations of cool materials on New York City's rooftops.	The programme has coated 626 buildings with a white, reflective coating, for a total of around 530,000 m^2 of rooftop. Buildings' cooling costs are reduced by 10-30%.[a]	○ ● ○ ●
Zero waste	San Francisco	Zero Waste by 2020	Policy initiative that aims to eliminate waste sent to landfill or incineration.	From 1990 to 2013, the waste diverted from landfill has increased from 35% to 80%; the recycling rate is 78%.[a]	○ ○ ● ○
	Buenos Aires	Municipal Solid Waste Reduction Project	Project to reduce waste sent to landfills by increasing citizens' awareness, as well as the realization of "Green Centres" and a Mechanical Biological Treatment plant.	The achieved disposal reduction was 44% in 2013, 78% in 2014.[a]	○ ○ ● ○
Landfill restoration	Wuhan	Project of Daijiahu Park	Transformation of a site of industrial waste in an urban park, with specific attention to water management and landscape.	Transformation of a previously polluted lake into a "green lung" for the city: greening rate of 91.8%, 80+ ha of public green space, 827 tons of CO_2 and 200+ tons of dust absorbed per year.[b]	● ● ● ●
	Johannesburg	Landfill Gas Project	Electricity generation from methane gas harvested from landfill sites.	CO_2 reduction of 1,813 tons in June 2018 (-13%).[b]	○ ● ● ○
Stormwater management	Hong Kong	Stormwater Storage Scheme	Expansion and improvement of the existing drainage, pumping and storage systems. Sustainability and ecology are included in the design.	Reduce areas of high flood risk from 90 (1995) to 6 (2019). Annual water savings of more than 240,000 m^3. Expected to increase to 3.4million m^3 with ongoing works.[b]	● ○ ● ○

TABLE 1 C40 'green solutions' and related strategies for urban environmental degradation issues (source: https://www.c40.org/case_studies) Results updated at [a] 2016, [b] 2020.

Legend

- ● (dark) Loss of biodiversity
- ● Greenhouse gas emissions
- ● Water, air and soil pollution
- ● (light) Urban Heat Island

Thanks to the redesigned system, five of the city's rivers, previously polluted by their use as stormwater channels, are being restored to public use as parkland and planted with native vegetation, thereby contributing to biodiversity and human well-being (*C40*, 2020). Private/public funding mechanisms such as described in the Eco-Roof Incentive Programme help sustain these programmes, highlighting the shifting and necessary economic values essential to successful ecological solutions.

Sensing

The examples above highlight some of the cross-scalar and multidisciplinary solutions that can be implemented to address environmental degradation in cities. The solutions are supported by, and direct further action through, data acquisition, data-driven modelling, and data sharing and integration. Definitions of data vary according to the discipline, but broadly speaking, data are simply units of information, collected as observations or measurements (Australian Bureau of Statistics, 2021). Data acquisition begins with the human sensory system and is extended by new technologies that include environmental sensors, simulation software and wireless networks. This 'artificial' world of sensors, networks, data and software allows us to visualize and analyse large amounts of information so that we can begin to understand the complexity of the urban ecosystem. This information is key to understanding the issues to be addressed and the consequent effects of any interventions. In the context of the CRA and MIT Senseable City Lab sense/respond paradigm, sensing plays a major part in many of CRA and MIT Senseable City Lab projects. The following projects are examples of sensing applied across different scales to better understand specific urban issues related to environmental degradation.

City Scanner – data acquisition

City Scanner transforms everyday urban vehicles into sensing nodes that can inform planners and policymakers about the environmental conditions of their cities, including the C40 issues of air pollution, greenhouse gas emissions and the UHI effect. Examples of data collected include thermal conditions, sensors for particulate matter in the air, temperature and humidity, and accelerometers, which together can provide information about a wide range of urban concerns including those already mentioned, but also other important indicators like road quality (from vibrations detected by the accelerometer) or building energy efficiency (from thermal imagery) (MIT Senseable City Lab, 2018). Drive-by sensing can significantly improve the spatial coverage and time resolution of data collected, overcoming recognized limitations of stationary and remote sensing approaches (Anjomshoaa et al., 2018). The data collection campaign is performed by low-cost devices supporting multiple sensors, with little deployment requirements on the hosting vehicle (Mora et al., 2019). The sensing devices are installed on vehicles already present on urban streets, such as garbage trucks (Fig. 1a). The number of sensors can be optimized by studying street coverage using scheduled and unscheduled vehicles (Anjomshoaa et al., 2018). A web application provides a tool to navigate the resulting data (available at http://senseable.mit.edu/cityscanner/app; Fig. 1b)

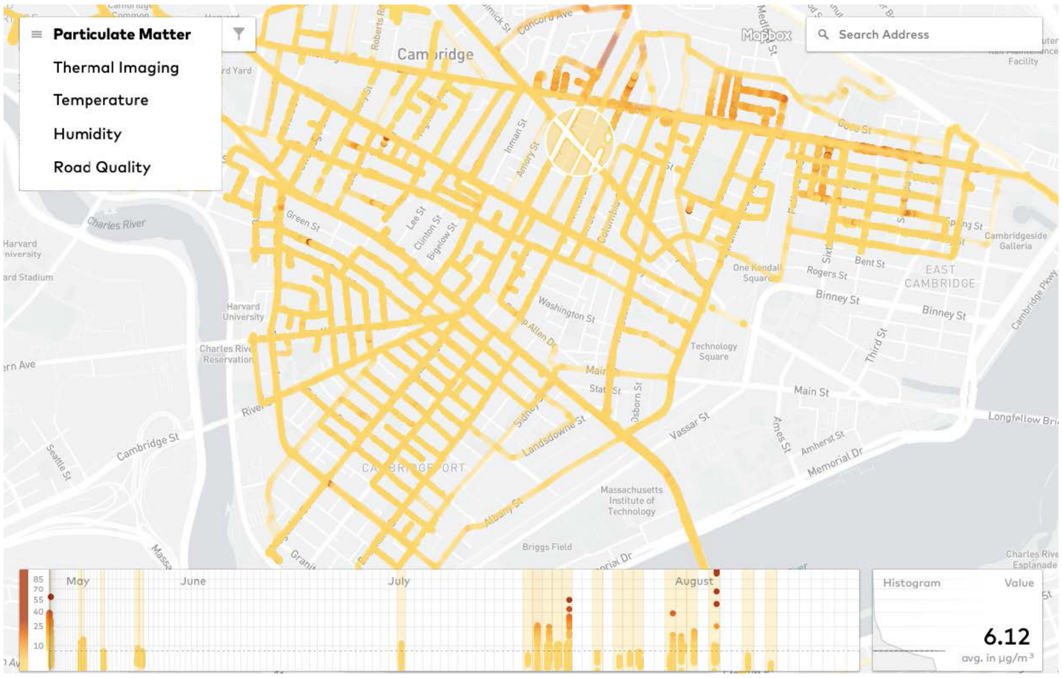

FIGURE 1 City Scanner: *Screenshot of the City Scanner web application (source: Anjomshoaa et al., 2018)*

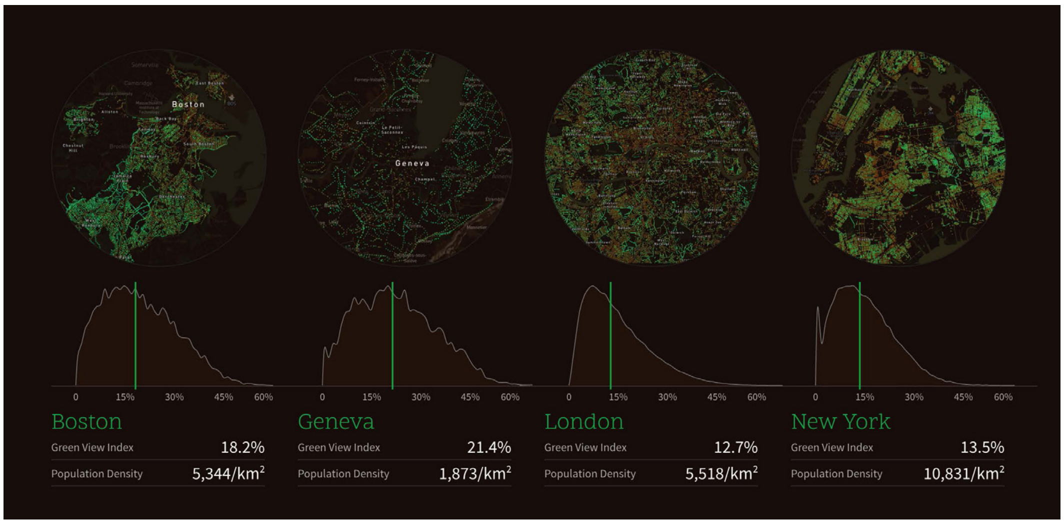

FIGURE 2 Treepedia maps showing the resulting green coverage and GVI comparison for four major cities (source: Zhu et al., 2020)

Treepedia – data integration and sharing

A second project is Treepedia which makes use of Google Street View (GSV) images to detect urban vegetation. MIT Senseable City Lab has developed this tool to measure and compare green canopy coverage in urban areas at street level. This allows urban vegetation to be assessed from the pedestrian perspective, which gives a fuller picture of the green coverage in the city and connects the citizen's experience of urban vegetation to planning on a larger scale (Li & Ratti, 2018). Specifically, GSV images are downloaded and processed to extract and visualize the amount of street greenery in an urban area; the proposed index (GVI

–Green View Index; Li et al., 2015) and the resulting maps (Fig. 2) provide not only a clear communication method to foster public awareness, but also form a valuable dataset on the presence of vegetation in the urban environment. The results can inform urban planners as well as citizens and are relevant to addressing all the C40 issues identified.

Solar Cities - Data-driven modelling and data sharing

From roaming sensors to street-scale imagery, to large-scale urban modelling, Solar Cities maps the annual irradiation across a city's urban surfaces (Fig. 3) with the intention of providing a tool to 'support local governments in strategising urban developments and provide decision making support for energy harvesting initiatives' (MIT Senseable City Lab, 2021). By facilitating the use of clean energy in the form of photovoltaics, which can also double as passive shading, it addresses C40's identified issues of greenhouse gas emissions and the UHI effect. The project quantifies just one relationship – solar potential (Wh/m^2) – but considers it across the entire city, from 'rooftop to street level'. It can pinpoint which building facades have the greatest energy potential, allowing cities to make more efficient use of resources, and provides a visual resource to aid city planners, designers and decision makers in understanding the energy potential of their city as well as how future developments might impact that potential.

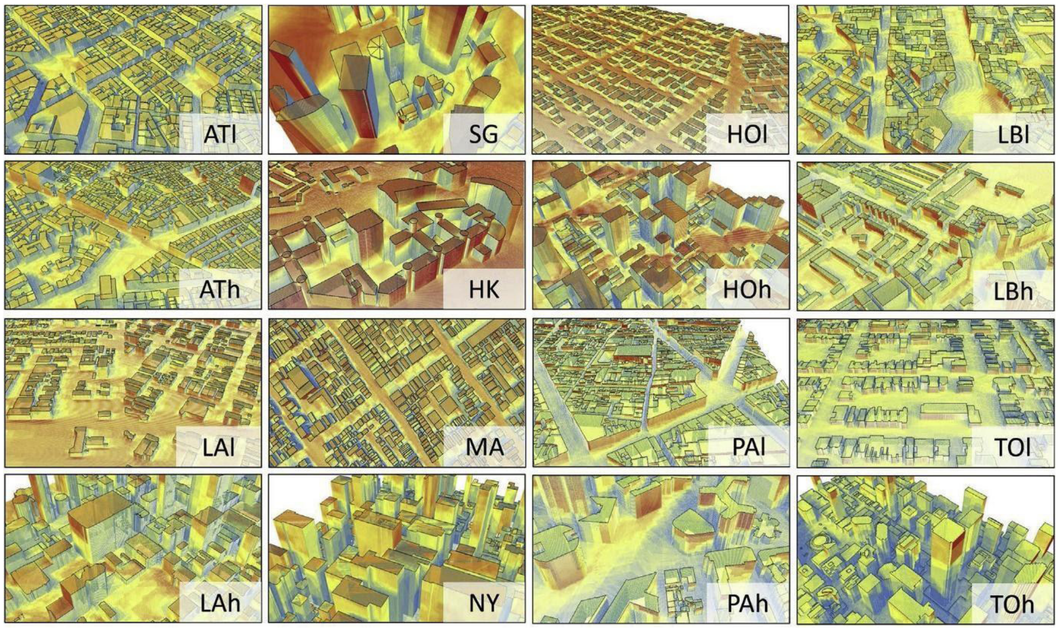

FIGURE 3 Solar Cities: analysis of annual solar irradiation across urban surfaces in sixteen study areas (source: MIT Senseable City Lab, 2020)

Responding

Sensors and the resulting data analysis allow us to simultaneously 'zoom' in and out, spatially and temporally, on the urban ecosystem, highlighting patterns and relationships between different urban issues. From this extended perspective, we gain the more nuanced understanding (and justification) that we need to address the complex problem that is environmental degradation. Backed by this data-driven knowledge, initiatives like C40 can provide pressure and support from 'above' to implement interdisciplinary and multi-scalar work that comprehensively addresses environmental degradation. At the same time, small projects that address these issues at a local scale provide valuable examples of how designers can apply data and the related technology to implement ecological solutions when supported by initiatives like C40.

Reinventing Cities, organized by the C40 Cities Climate Leadership Group, is a competition that seeks to bolster sustainable and resilient building developments in underutilized areas of cities across the globe (C40 Reinventing Cities, 2021b). The C40 framework – distilled in the Reinventing Cities challenges (available at https://www.c40reinventingcities.org/en/professionals/guidelines/) – calls for projects that provide solutions to environmental degradation at the single building scale. By uniting multiple scales, disciplines and stakeholders in the pursuit of those shared goals it also encourages an ecological paradigm that is as necessary as the technology employed in the projects in addressing environmental degradation. The winning projects highlight a broader 'ecological' approach to design, where every project involves specialists from multiple and diverse fields, as well as private and public stakeholders to address the specific environmental challenges identified by C40.

Vitae

Our case study Vitae (Fig. 4 *Vitae*, 2019), designed for the C40 Reinventing Cities competition, involved 14 partners from a range of disciplines including design, energy engineering, agriculture, psychology and education. The project lead, Covivio, is a real estate developer, while CRA acted as architect and project manager and Habitech as environmental expert (C40 Reinventing Cities, 2021a).   Vitae's environmental aims are twofold: to address the identified C40 challenges in a concrete way, but also to encourage a (re)connection between city and 'nature' for users by building on the theory of Biophilia – the innate link humans have with the natural environment and other living organisms (see Edward O. Wilson's Biophilia theory (1984)). This more intangible goal, like the more technical goals, is supported by data and the artificial 'realm'.

FIGURE 4 Rendered image of Vitae design proposal for C40 Reinventing Cities Competition (source: Vitae Presskit, available on https://www.c40reinventingcities.org/data/sites_134e6/fiche/39/projects_memo_-_vitae_-_milan-_serio_f9b88.pdf)

Vitae is designed as a combined private/public building providing office space, research centre, public green space and urban agriculture within an area of Milan currently in the process of transforming from an industrial to an 'innovation' district. The project began in 2019 and has just entered the construction phase, but the design process itself highlights several ways in which data was used to advance the C40 goals. The following highlights some examples of how data was used in the design process to facilitate an integrated, interdisciplinary design approach as well as to support the implementation of vegetation, which is key to Vitae's ecological approach. Figure 5 shows how data acquisition and data-driven modelling were used to help connect project stakeholders during the design phase as well as to merge various building disciplines to address the C40 challenges.

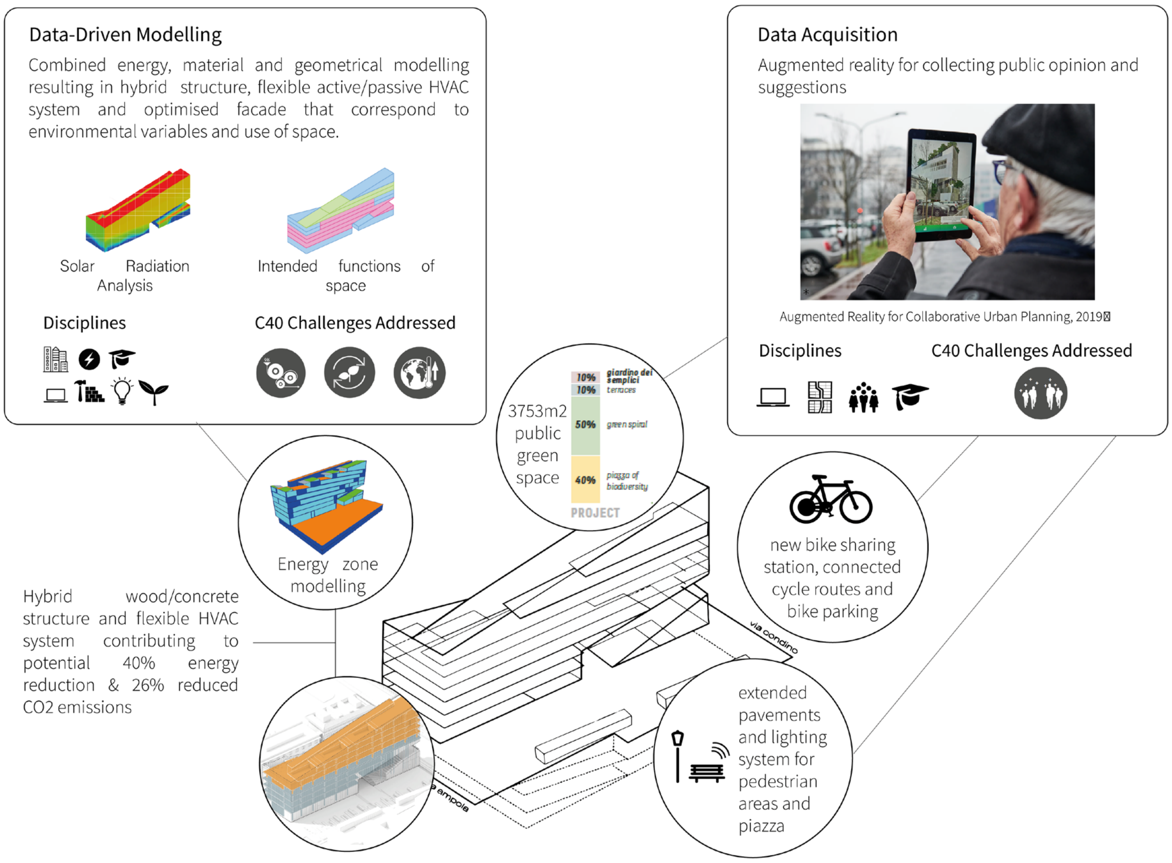

FIGURE 5 Data in the design process, based on Vitae Technical Report, Phase 1, 2019

Data Acquisition

During the design phase of Vitae, an augmented reality tool (Fig. 5) developed by a team of researchers, software developers, social and environmental psychologists and business strategists was used to stimulate communication between the public, designers and other stakeholders as well as to gather data on their views and suggestions to further inform the design (Augmented Reality for Collaborative Urban Planning, 2019). The software, capable of running on a tablet, computer or smartphone, allowed users to visualize the various design options on site, in real time; to rate different aspects of the project; and to submit their own suggestions and drawings. The interaction facilitated through the 'Experience Vitae' trial was an example of how data can encourage feedback between users and designers of the space, merging the two roles. The top priorities identified during the community consultation, which included accessible green space, integration with the surrounding neighbourhood, security and access, are strongly represented in Vitae's design. By opening the design process to the wider community, these tools provide a means to connect to the wider context of the site and encourage integration with the existing 'ecosystem/neighbourhood'.

Data-Driven Modelling

Digital models addressing multiple elements of the project including programme, facade, structure, vegetation planting scheme, and the heating, ventilation and air conditioning (HVAC) system allowed the project team to combine and test these elements in different design scenarios providing insights into the interactions between project elements that might otherwise be too complex to comprehend. The temporal dimension was also made more visible; so that changing demands based on future scenarios could be tested and considered in the design. Modelling allows designers to see and compare the effect of different project iterations on chosen metrics such as embodied energy, energy production and use, daylighting or greenhouse gas emissions. In Vitae, the team combined energy modelling with different programme scenarios to understand the varying energy needs of the flexible programmes within the building, resulting in a radiant HVAC ceiling system that allows for variable thermal zones corresponding to the particular use of a space at a given point in time. These flexible systems also allow for passive air conditioning when an active system is not needed. Another outcome was the proposed hybrid structure that corresponds to the intended programme, with concrete used for office spaces and wood for living spaces, resulting in reduced carbon footprint.

Vegetation as an ecological solution

Vegetation in Vitae contributes to many of the Reinventing Cities Challenges (Fig. 6) highlighting the interdisciplinarity of ecological solutions. The project aims to integrate vegetation into the project rather than considering it as an optional 'add on'. This is made possible through the collaboration with relevant experts including botanists and the agricultural associations that were involved in the design process (Fondazione Politecnico, 2020), as well as through modelling to provide detailed information on site conditions including climate, shading patterns, water availability and local vegetation. Importantly, sensors and connected networks will allow for automated and adaptive maintenance that monitors the health and physical needs of the natural elements and communicates with machines or humans depending on the need and resulting response. This is essential to the successful integration of vegetation within a large project like this as highlighted by the case study referenced in the definition of ecological solutions (Budds, 2020). By designing it into the project at an early stage, vegetation can provide multiple services to the project: contributing to the management of predicted future heat stress and flood risk, which were identified as important adaptation issues to address for the site (C40 Cities, 2021b); providing green space, the majority of which is publicly accessible, thereby addressing one of the main concerns identified during public consultation; an urban vineyard, hydroponic greenhouses and traditional vegetable gardens, which will allow Vitae to serve as a test bed for urban agriculture research as well as to provide produce for the planned on-site café that will in turn support the continued maintenance of the gardens. Through these functions, jobs are created, connections are made to the surrounding neighbourhood and knowledge about food production and the impacts of climate change on natural systems is disseminated.

The role of Biophilia

Both technical/scientific knowledge and an ecological perspective are needed to turn the information that data can provide into solutions. Vitae encourages not just technological solutions but also a more subliminal recognition of the connection between humans and their natural environment. This recognition is important in addressing environmental degradation as it emphasizes the real and sometimes unmeasurable value of our natural environment, even within the city. An example is the improved tolerance we have for high temperatures in urban spaces when vegetation is present – the increased 'naturalness' can significantly improve both user's physiological *and* psychological adaptation to high temperatures as well as reduce stress levels, illustrating the existing connection between humans and 'nature' (Nikolopoulou and Steemers, 2003; Shanahan et al., 2016). These more qualitative benefits are only recently being recognized as important aspects of reintroducing nature within the city and highlight the need for a deeper understanding of the 'natural' elements in our urban ecosystems. Vegetation and the associated interactions that Vitae provides, can allow us to (re)acquire information or 'data' on our relationship with the natural environment as well as natural processes and the services they provide. This can help improve our understanding of humans existing *within* the ecosystem and thus generate a more ecological perspective that can support more comprehensive solutions to environmental degradation. The knowledge gained from data acquisition, integration and sharing through our artificial devices is essential to addressing urban environmental degradation. So, too, is the knowledge gained from our own ability to sense the world around us. Vitae seeks to build on this 'natural' sensing and, together with the artificial sensing network that makes the implementation and maintenance of vegetation possible, to contribute to both the Reinventing Cities Challenges and a more ecological perspective.

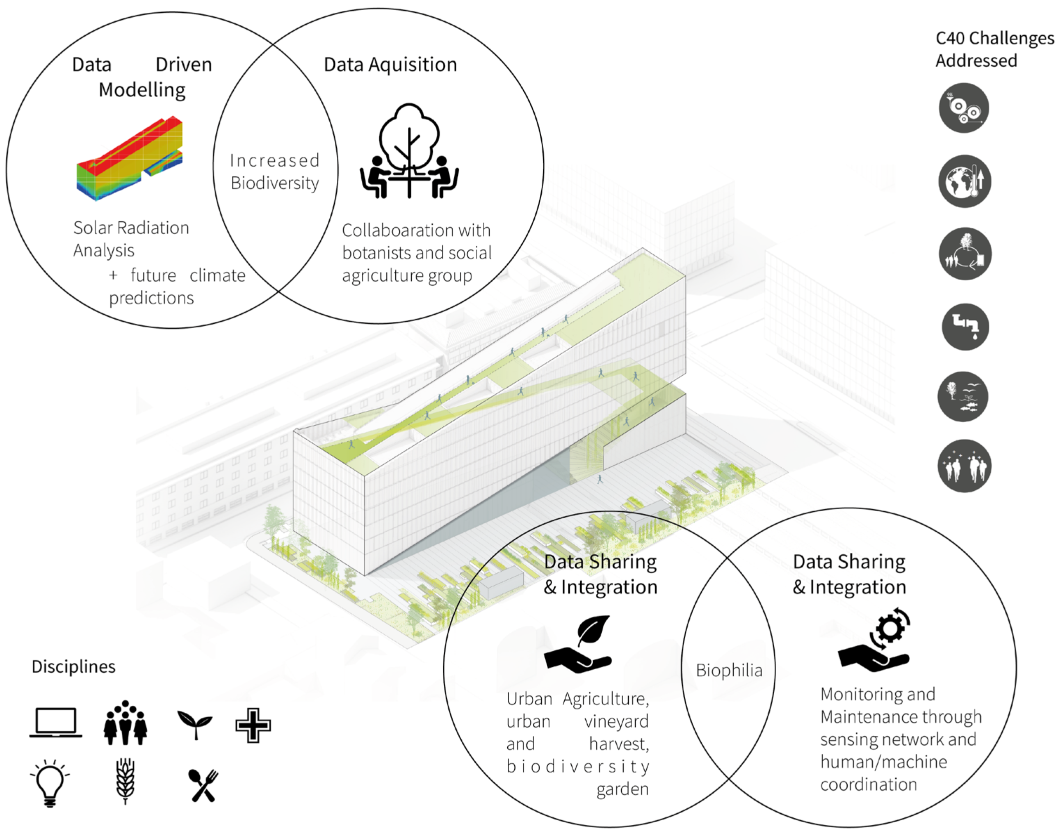

FIGURE 6 Vegetation in Vitae, based on Vitae Technical Report, Phase 1, 2019 (Vitae, 2019).

The value of data lies in how it is applied. We now have the possibility to collect and analyse vast amounts of data. However, to advance effective ecological solutions, the knowledge that data can provide must be understood and applied across the many disciplines, stakeholders and scales involved in urban environments. The C40 Cities case studies highlight the broad range of disciplines and scales encompassed by ecological solutions. Sensing projects, such as those mentioned above, make the complex web of connections in cities visible and pinpoint specific issues, driving a more ecological perspective in urban design and planning and supplying cities with the knowledge from which they can build solutions. Vitae is an example of this shift in perspective in action. It was conceptualized as a living organism within the wider ecosystem, utilizing both natural and artificial elements to integrate ecological solutions. This was the result of inputs from a diverse range of sources concerned with the urban environments, facilitated by the 'artificial' world of data. Ultimately data can drive a redefinition of the limited and problematic 'natural v. artificial' perspective that has contributed to our present crisis, leading to *ecological* solutions that match the complexity of the issues we face.

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