Brief note on 'Scale' for the UGEC Land use forecasting workshop

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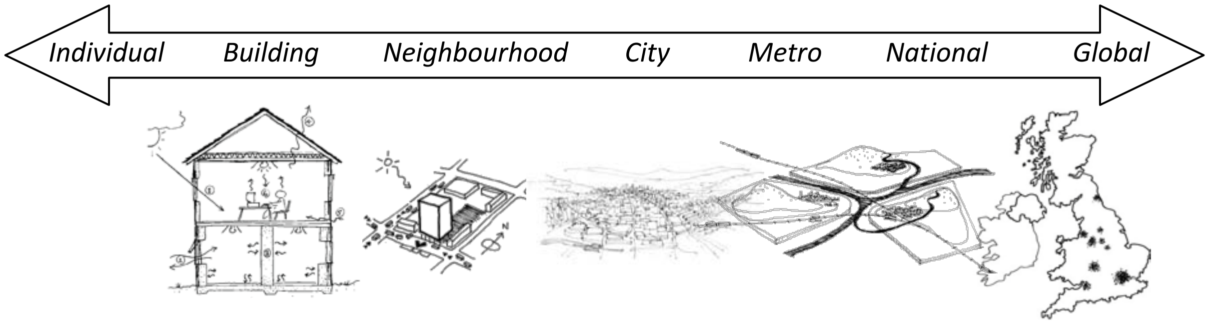
Land use is determined by the interaction in space and time of biophysical factors such as soils, climate, topography, *etc*., and human factors like population, technology, economic conditions, *etc*. These processes play out over a wide range of spatial and temporal scales.



For example, in the context of the urban heat, at different scales different components of the urban system become important: building materials have different thermal properties and subsequent implications for the heat island and roofs can influence airflow locally while the configuration of buildings and infrastructure within the wider urban area has implications for other impacts, such as wind and heat fluxes, flood risk and (waste) water management. Likewise, an individual's wealth and attitudes may shape their transport preferences, but they are also heavily mediated by existing landuse (*e.g.* service and employment locations) and the transport network(s) across the whole city or region.

A multitude of organizations collect vast amounts of data at varying frequencies and resolutions for a diverse set of economic, social, physical and environmental attributes of urban systems. Typically, 'indicators' provide the lowest resolution data. It is clear from the World Bank's Global Cities Indicator Facility (GCIF) and other initiatives that indicators do have a useful role in high level appraisal of priorities but must be interpreted with care and not relied upon exclusively for addressing more detailed policy and planning decisions. However, more detailed data from real time monitoring [1], community developed maps [2] and satellite observations [3] and models [4] is becoming increasingly available. Many cities will have long time records from censuses and weather stations, but more recently mobile phones[5] and social networking datastreams[6] may offer the 'bottom up' capacity to understand the urban 'pulse'. The potential for using this data in all parts of the world is growing as these technologies are rapidly taken up, meanwhile community initiatives for mapping[7], open source web-based platforms [8] and mapping organisations [9] should facilitate modelling studies to be more readily implemented in cities of all continents. From a 'top-down' perspective, remote sensing technologies such as airborne LiDAR and multi-spectral satellite images provide consistent views of a city's physical and biological form and composition[10,11].

In parallel to data at different scales are a range of modelling and simulation methods that operate at different scales, ranging from indicator-based analysis to full on simulation of urban dynamics[12,13]. Clearly, the amount of resource, in terms of data acquisition and analysis that is committed to informing sustainability policy should reflect the nature of the policy decision(s) being analysed. Planning policy frameworks tend to cascade from supra-national (*e.g.* European Union (and possibly global)) and National policy instruments that provide the framework and common understanding through spatial planning in cities to local design and operational decisions. Multiple scales of policy-making require a hierarchy of methods, data and detail of analysis appropriate to each level, examples of which are proposed in Table 1. Through fusing datasets from a diverse range of sources and exploiting their full potential by modelling and analysis, cities will maximise the evidence available to them to ensure more informed decision-making. Although a full range of data will not necessarily be available everywhere, as community initiatives and remote sensing data become more widely accessible, the higher levels of analysis should become feasible in the majority of locations. It is also crucial to note that even in cities with more sophisticated and established governance frameworks, many of the processes and drivers of land use change are informal. These informal processes can be even more significant in developing world nations.

Table 1 Hierarchy of methods, decisions they might be used to inform and the type of data and methods appropriate to the scale of analysis. Many data and models cross scales, it would be misleading to categorise.

↑ Increasing scales of analysis	**Decisions to inform**	**Data and methods sources**	**Methods**	Increasing resolution of monitoring and modelling ↓
	Benchmarking Nationwide assessment of sustainability in cities Identification of national priorities Planning policy and national directives *Regional and urban planning* Spatial development strategies Strategic assessments *Detailed design* Neighbourhood planning Infrastructure design Building design and orientation	Satellite observations Energy generation Rainfall, temperature monitoring Traffic and local air quality monitoring Airborne lidar and photogrammetry Property location and land use Population and demographic information Travel, energy, consumption and waste surveys Smart sensors and building air quality, energy and water monitoring Terrestrial and mobile laser scan Individual and mobile phone sensors	Indicator and checklists GIS overlays Global and regional climate model outputs Accounting tools Quantified modelling of risks and sustainability Integrated assessment models Urban metabolism Landuse and demand modelling Weather generators High resolution simulation and process models of selected urban functions Industrial ecology and life cycle analysis Engagement with individuals and community groups	

At each scale there are a range of relevant drivers, policy/decision-making agents; biophysical and human processes and opportunities for data acquisition. To be meaningful, drivers, decisions and processes need to be described, understood, and modelled at the correct scales. However, of particular importance is understanding the interactions across scales and between different processes which often suffers due to lack of data, or a sector led data acquisition strategies that fails to capture phenomena at sufficient resolution or their broader interactions.

Whilst land use modellers have recognised and are becoming increasingly talented at extracting value from existing data the emerging bottom up datasets still need to be better understood whilst the top-down datasets provide only limited value due to their non-urban focus. For example, AVHRR data has a high revisit time, resulting in up to a maximum of 4 scenes per day being acquired[14] yet some recent work we did in London[15] suggests that even this frequency is insufficient to understand the urban heat island. Sparse ground measurements and cloudy scenes compound this issue.

Ecological research in the USA has benefited from structured, place-based research programmes[16] such as that in Phoenix, Arizona. A similar *Long Term Urban Research* programme to address the challenge of sustainable cities would provide similar opportunities to improve our understanding of cities. This could build on a foundation of data that is already collected at a range of scales by the many stakeholders operating in cities. In many cities worldwide a first step will be to co-ordinate and structure the acquisition and archiving of data and to integrate modelling and analysis activities, before identifying gaps and where necessary commissioning new activity. Data could then be fed into a suite of urban models that can be used for emergency management or long term policy analysis, either for the city in its entirety or for different urban functions. To realise their full potential, these analyses must be visualised and communicated in many ways to satisfy the requirements of different stakeholders who will increasingly need to, and with appropriate tools be able to, interact collaboratively to address the challenges of land use management under conditions of global environmental change.

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