Mark Deakin
Fiona Campbell
Alasdair Reid
Joel Orsinger

The Mass Retrofitting of an Energy Efficient— Low Carbon Zone

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Mark Deakin · Fiona Campbell
Alasdair Reid · Joel Orsinger

The Mass Retrofitting
of an Energy Efficient—Low
Carbon Zone

Mark Deakin
School of Engineering and Built
   Environment
Edinburgh Napier University Merchiston
   Campus
Edinburgh
UK

Fiona Campbell
Centre for Sustainable Communities,
   Institute for Sustainable Construction
Edinburgh Napier University
Edinburgh
UK

Alasdair Reid
Centre for Sustainable Communities,
   Institute for Sustainable Construction
Edinburgh Napier University
Edinburgh
UK

Joel Orsinger
Munich University of Applied Sciences
Munich
Germany

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Chapter 1
Introduction

demonstrating how urban morphology matters by reaching beyond the geometry of building design, construction systems and occupational behaviours and towards broader context-specific transformations

Recent studies of urban morphology suggest the planning, development and design of district centres have as much a bearing on levels of energy consumption and rates of carbon emission as either the layout of neighbourhoods, construction of "blocks", or use and occupation of buildings. In short, they suggest urban morphology matters. This book aims to reiterate this message by demonstrating how urban morphology matters. Not only with respect to either the geometry of design and construction systems, or occupational behaviours, that such studies draw particular attention to, but also with regard to a matter which they have hitherto overlooked. That is with regards to the potential which the planning, (re)development, design, construction, use and occupation of buildings, has to not only lower levels of energy consumption and rates of carbon emission, but global warming associated with climate change.

In meeting this aim and demonstrating how urban morphology does matter, the book shall build on a brief critique of the state-of-the-art on urban morphology, the geometry of design typologies, construction systems and occupational behaviours. Armed with the critical insights this offers, it shall go on to reground the subject via a case study analysis of recent attempts made by cities to reduce energy consumption and associated levels of carbon emissions, both by way of and through what has been termed: an active and integrated institutional arrangement. This institutional, integrated and active regrounding of urban morphology shall draw upon the experiences of a transformation taking place in the London Borough of Sutton known as the Hackbridge project: a mass retrofit proposal designed as a sustainable suburb with district centres, neighbourhoods and buildings, laid out and contextualised as an energy-efficient, low-carbon zone. That is by the institutionalisation of a mass retrofit proposal, which is actively integrated in an urban regeneration strategy, whose vision, district-wide master plan, programme of neighbourhood renewal and redevelopment of suburban housing estates, is in turn

capable of sustaining the ongoing transformation of Hackbridge into an energy-efficient, low-carbon zone.

Offering a context-specific analysis of how institutions can begin to actively plan for, integrate and sustain the development of energy-efficient, low-carbon zones, the case study draws particular attention to the type of baseline assessments needed to legitimate not only the strategic value of such arrangements, but their practical worth as measures able to meet the standards of environmental sustainability set out in the 2008 UK Climate Bill.

Urban Morphology

The article by Ratti et al. (2005) offers an account of why urban morphology, design, layout, texture and fabric matters via what might be best described as a coded critique of how the "building scientist" approaches the matter of energy performance, that is to say by way of and through a coded critique of the approach which assigns buildings a set of values to be read off by type of design, system of construction and occupant behaviour independent of their environment. For Ratti et al. (2005), it appears that such a scientific reading of the subject offers too narrow a perspective on the determinants of energy performance and for this simple reason, such a framework for analysis fails to explain the high degree of variance between the values assigned to them and those experienced.

Putting this right, i.e. explaining this variance in energy performance in terms of the gap between theory and practice, according to Ratti et al. (2005), means that we need to transcend the all too narrow perspective of energy performance which the building scientist offers and broaden it out so as to begin accounting for the complex environmental processes at play in such determinations. Ultimately, this means understanding the relationship that buildings have to their environment both by way of urban morphology and through the context-specific form which the design, construction, use and occupation of buildings take on. This is because for Ratti et al. (2005), urban morphology provides a critical insight into the context-specific form of the designs, construction, use and occupation of buildings that is currently missing and which limits what is known about energy performance. Focussing on the design, construction, use and occupation of buildings within the cities of Berlin, Toulouse and London, Ratti et al. (2005) find that variation in the consumption of energy by system and behaviour is something which cannot be explained by way of surface-to-volume ratios (STVR) alone, but through the relationship the passive to non-passive areas of their district centres, neighbourhoods, blocks and buildings also have to one another.

The Thesis

The background research to the study of urban morphology by Ratti et al. (2005) is based on March's (1972) analysis of building heat loss, Owens' (1986) extension of this study across house types and augmentation of the analysis by Steadman et al. (2003) to include the non-domestic sectors. All of this is in turn captured in Steemer's (2003) study of energy consumption within cities and relation this has to the density of buildings alongside their associated mobility and transportation networks.

Against this backdrop, Ratti et al. (2005) explore the effects of urban texture on energy consumption. This work is based on the analysis of digital elevation models (DEMs) in London, Toulouse and Berlin. In these studies, DEMs are stored in a 2D-Matrix with height values and processing tasks constructed by means of MATLAB software. Highlighting urban geometry, design, construction systems and occupants' behaviour as the "four parameters of energy performance", Ratti et al. (2005) loosen the grip buildings have on energy performance by way of and through an analysis of the form they take. In loosing this grip and highlighting all four parameters of energy performance, Ratti et al. (2005) draw particular attention to two urban morphology ratios whose geometric form set the parameters for the other three (buildings, construction systems and occupational behaviour).

The first ratio draws on the earlier research of March (1972) which arose from the question: "which shape should a building have to minimise heat loss?" For this model of building design, March (1972) assumes that its shape is perfectly rectangular, thermal transmittance is equal through all external walls and there is no heat transfer from the building to the ground. This is referred to as the STVR and value which is calculated by dividing the overall building envelope area (without ground area) by the volume. However, Ratti et al. (2005) suggest the STVR is not a very good indicator of energy performance, because only heat lost through the exposed building envelope is measured, while any gains from the use of natural ventilation and sunlight for heating and lighting purposes are ignored.

Taking the limitations of the STVR into account, Ratti et al. (2005) advance a second ratio that subdivides buildings into passive and non-passive areas. Here, passive areas measure the parameters of buildings lying within 6 m of the façade or within twice the ceiling height. These passive areas gain from natural ventilation and sunlight, whereas non-passive areas do not. The ability of buildings to use natural ventilation and sunlight is referred to as the *passive-volume-to-total-volume ratio* (PVTVR). This ratio offers another attempt to analyse the geometry of a building's energy performance, and its limitations are also drawn attention to. This is because passive areas can still be wasteful; for example, being mechanically lit their ventilation and glazing ratios may be very low, allowing heat loss through external walls and roof spaces to be greater than gains from sunlight.

Seeing that only an integrated energy model can overcome such limitations in the measurement of energy performance, Ratti et al. (2005) make use of the lighting and thermal method (LT-method) to calculate the annual lighting, heating,

Table 1.1 Data for London, Toulouse and Berlin (Ratti et al. 2005)

	London	Toulouse	Berlin
Ground floor area (m^2)	89,663	64,368	55,978
Unbuilt area (m^2)	70,377	95,632	104,022
Built volume (m^2)	1,221,499	966,768	1,042,199
Vertical surface (m^2)	174,757	174,888	119,698
Surface to built volume ratio (m^{-1})	0.216	0.248	0.169
Average energy consumption in passive and non-passive zones (kWh m/p.a.)	0.0683	0.0668	0.0731
Average energy consumption in passive zones (kWh m/p.a.)	0.0590	0.0599	0.0585
Average energy consumption in passive zones with optimum glazing ratio (kWh m/p.a.)	0.0554	0.0568	0.0550

ventilating and cooling values of buildings in terms of use/m^2. This model considers a variety of factors, including solar gains, shading of a neighbour's house (indicated by the obstruction sky view) and the degree of daylight that is either reflected from opposite facades (information about the orientation of facades is needed to calculate this) or which is directly received from the sun. The LT-method is applied by Ratti et al. (2005) to analyse the energy performance of blocks, neighbourhoods and districts in the cities of London, Toulouse and Berlin. The findings of these studies are held up as examples of how urban morphology has a bearing on energy performance when analysed in terms of both the STVR and PVTVR ratios for the "blocks, neighbourhoods and districts" of the building designs, construction systems and occupational behaviours under investigation. The STVR and PVTVR ratios for these case studies are set out in Table 1.1.

In another case study, Salat (2009) compares the urban morphology of Paris with the energy consumption of building designs. This analysis captures the impacts which the types of urban morphology factors listed below have on building designs, construction systems and occupier behaviours in terms of energy consumption and CO_2 emission.

- Mean and standard deviation of building height
- Mean and standard deviation of vegetation height
- Building height histograms
- Area-weighted mean building height
- Area-weighted mean vegetation height
- Surface area of walls
- Plan area fraction as a function of height above the ground surface
- Frontal area index also as a function of height above the ground surface
- Height-to-width ratio
- Sky view factor
- Roughness length
- Displacement height

- Surface fraction of vegetation, roads and rooftops
- Mean orientation of streets

In this case study, 96,000 residential buildings are analysed and four key components of energy consumption are calculated in accordance with the contribution they make to levels of CO_2 emission. The key components, derived from this case study, along with their factor contributions are set out below:

• Efficiency of urban morphology (e.g. density)	(1.8)
• Building design performance (e.g. shape, envelope area)	(2.5)
• Efficiency of construction systems (e.g. age of boiler)	(1.8)
• Occupants behaviour	(2.6)

Under this factor-component model, the city is represented as a homogenous entity where urban morphologic values, such as density, mobility networks and accessibility, are related to one another. Like Ratti et al. (2005), Salat (2009) sees the ultimate value of this model as lying in the ability it has to isolate the contribution urban morphology makes to energy performance when measured in terms of either the STVR or the PVTVR. In the case of Paris, the ratios calculated and drawn upon as measures of energy performance suggest the traditional, densely-built courtyards of this city have a good STVR and PVTVR. Good in the sense that unlike their modern counterparts, which are characterised as dispersed low-density developments and found in the suburbs of Paris, these designs, construction systems and occupational behaviours illustrate poor STVR and PVTVRs.

In view of the potential which exists for such large-scale assessments to save energy and reduce carbon emission by as much as 50 %, Bourdic and Salat (2012) stress that in order to capitalise on such virtues, save energy, reduce carbon emissions and sustain development, stakeholders need robust methods capable of assessing such possibilities. As they point out, many tools and assessment methods have been developed to improve energy performance. However, as they also go on to stress, most of these methods are still based on the building envelope and given stakeholders are now convinced the so-called building scientist approach is too narrow, these assessments need to be extended so energy performance analysis can cover the design, construction, use and occupation of both the blocks, neighbourhoods and districts of cities.

The reason why Bourdic and Salat (2012) reiterate this message is important because it throws some much needed light on what the calculation of the STVR and PVTVRs for London, Toulouse and Berlin offers in terms of energy performance. For what they offer is "proof of concept" and evidence as to the significance of urban morphology as a key component of energy performance. That is to say, as a key component of energy performance, which does not just matter, but should also be taken into account *alongside* the design layout, construction systems and
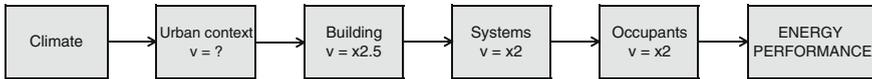
Climate		Urban context v = ?		Building v = x2.5		Systems v = x2		Occupants v = x2		ENERGY PERFORMANCE

Fig. 1.1 Factors that affect energy consumption in buildings (Ratti et al. 2005)

occupational behaviour components of any such determinations. For only in this way is it possible to not only account for the 20 % of energy performance which relates to urban morphology, but also account for other factor weightings that make up the remaining 80 % of the total measure.

This is perhaps why Bourdic and Salat (2012) go on to review the potential there is to integrate their morphologic model of energy performance with those adopted to assess layout, systems and occupant behaviour. For this purpose, the nested configuration of urban morphology is set aside and replaced by the "common six-step analytical grid" of energy performance first developed by Ratti et al. (2005) and augmented by Bourdic and Salat (2012) into an "assessment system" (Fig. 1.1).

This analytical grid is subsequently augmented to classify the types of "calculation tools" such assessment systems should adopt. This "grid of calculation tools" is then applied to review the strengths and weaknesses of these assessment systems. Here, bottom-up agent-based models are seen as underdetermined at anything more than the building scale (i.e. block, neighbourhood, or district), whereas the economic models are seen as too top-down and therefore overdeterministic. Likewise, energy–environment models are seen as being too aggregated, overly analytical and stuck in the diagnostic stage of development, that is to say, unable to provide any information on the intervention mechanisms which are available to improve energy consumption and carbon emission.

Turning to the morphologic models, Bourdic et al. (2012: 522) state these models:

> significantly differ from the three other types described above. While morphological approaches to quantify energy consumption and carbon emissions for the building sectors remain rare, two are analysed here: one is limited to the residential sector (ARUP 2007), the other to commercial buildings (Yamaguchi 2003). Both are based on a scale that is larger than the individual building and aim to account for the interactions between buildings. These are the only methods that explicitly consider the district or city as a whole, as opposed to the sum of the individual buildings.

As they go on to say:

> these models provide aggregations which take into account all the scales that constitute the urban fabric of buildings, blocks, neighbourhoods and districts. By using intermediate scales of aggregation, the loss of information in the process is structurally lower than with other models. They provide them an undeniable operationality to monitor the impact of energy performances on several scales.

This serves to capture the state-of-the-art on the types of building energy performance models drawn attention to by the likes of Ratti et al. (2005) and urban morphology approach to the fabric of buildings, blocks, neighbourhoods and districts highlighted by Salat (2009). However, it also serves to highlight the fact current state-of-the-art developments still leave the four main components of energy performance only loosely coupled, lacking any systematic integration. In responding to this challenge, Bourdic et al. (2012: 592–593) go on to advance an innovative system of indicators that in their opinion meet the call for multi-scalar and cross-cutting measures which encompass the intrinsic complexity of the situation. Based on this morphologic approach, new mathematical formulas are used to generate urban sustainability indicators. They suggest these indicators can assist with the comparison of urban projects by structuring them into techniques of analysis capable of assessing energy efficiency, alongside and in conjunction with the social and environmental components of urban development.

Table 1.2 captures the Bourdic et al. (2012) indicators, by type and triptych (sustainable urban development as the environmental, social and economic pillars) adopted to represent the morphology of city–districts. The urban morphology, typology and grids they present are said to be "exceptional" and of particular value because:

> while some governments are committing themselves to reducing energy consumption and carbon emissions, they need tools to measure the current performance of their cities, to find the levers to reduce it and to assess the efficiency of the actions engaged. This is why assessment systems play such a key role. However, cities are incredibly complex systems, made of components that can be identified using different point of views. Assessments based on single or simple metrics such as energy flows are insufficient to address the wider socio-ecological aspects of cities (ibid 592).

As they go on to say:

> Governments, citizens, urban planners, architects, property developers, as well as other stakeholders could use this system to understand better the interactions between forms and energy consumption, and to nurture a dialogue-based investigative approach. However, any attempt to use the indicators as absolute target values would be misguided. Doing so would fragment the whole urban concept into a series of technical targets, thereby losing the relation of the parts to the whole (ibid 593).

In their view, not being overdependant on indicators and *nurturing such a "dialogue-based investigative technique"* provides stakeholders with some latitude to account for the complexity of urban tissue. For in adopting such an approach, they propose the resulting indicators can then be *adapted to the specificity of projects by changing the variables to reach the structural objectives set. However, while nurturing such an approach, they also suggest the dynamic of urban form deserves to be set apart for purposes of analysis and approximated in a way that not only retains the three pillars of urban form, but which also realises this through an analysis of their interrelations.*

Table 1.2 Extract list of indicators (Bourdic et al. 2012)

Theme	Concepts of triptych	Indicator type	Name	Scale
Land use	Urban form	Intensity	Human density	D/N
			Building density	D/N
			Housing density	D/N
			Density of legal entities	D/N
			Job density	D/N
			Coefficient of land occupancy	D/N
			Subdivision intensity	D/N
		Diversity	Diversity of subdivisions size	D/N
			Diversity of land use (road network, built environment, courtyards, green spaces)	D/N
			Diversity of subdivision use (housing, offices, shops, public facilities, etc.)	D/N
Mobility	Urban form	Intensity	Surface occupied by pedestrian and bicycle paths	D/N
			Surface occupied by the road network	City/D
			Proportion of the road network dedicated to public transport	D
		Connectivity	Connectivity of the pedestrian/bike grid	D/N
			Connectivity of the car grid	D
			Cyclomatic complexity of the car grid	D
			Cyclomatic complexity of the pedestrian/bike grid	N
			Average distance between intersections (bike/pedestrian grid)	D/N
			Average distance between intersections (car grid)	D
		Proximity	Percentage of the population more than 300 m away from a public transport stop	City/D
		Diversity	Number of public transport modes accessible within 300 m	D

Table 1.2 (continued)

Theme	Concepts of triptych	Indicator type	Name	Scale
		Complexity	Scale hierarchy of the street network	City/D
Water	Environmental	Intensity	Hydrological intensity	D
			Impermeability of the land	D
			Intensity of water treatment: rate of waste collection and treatment	City/D
			Efficiency of water use	City
			Accessibility of drinking water	City/D
Biodiversity	Environmental/ urban form	Intensity	Proportion of agricultural surfaces	City/D
			Proportion of green fabrics	D
		Connectivity	Connectivity of green habitats	D
		Distribution	Distribution of green spaces (distance from an even distribution)	City/D
Equity	Socio-economic	Intensity	Proportion of jobs in relation to housing	D/N
			Proportion of social housing	D/N
		Diversity	Diversity of ages (structural distribution)	D/N/B
			Diversity of incomes (structural diversity)	D/N/B
Economy	Socio-economic	Intensity	Resource productivity	City
			Intensity of learning activities	D
			Job potential	D
		Diversity	Structural diversity of jobs	City
			Structural diversity of uses (shops, offices, housing, public buildings: schools, administrations, etc.)	City/D
	Urban form/ socio-economy	Proximity	Percentage of residents living less than x from a convenience store	D
		Distribution	Distance of the distribution of each district from the global distribution of shops, offices, housing or public buildings	City

(continued)

Table 1.2 (continued)

Theme	Concepts of triptych	Indicator type	Name	Scale
Waste	Environmental	Intensity	Proportion of recycled materials in the construction of new buildings	City/D
			Productivity of urban metabolism	City/D
			Intensity of greenhouse gas emissions per resident	City/D
			Intensity of emissions to produce wealth	City/D
Culture/well-being	Social	Intensity	Noise pollution	D/N
			Intensity of cultural activities	City/D
	Urban/social	Proximity	Proximity of leisure facilities	D
Energy and bioclimatic	Environmental	Intensity	Energy intensity per resident	D/N
			Surface energy intensity	D/N
			Proportion of local production	D/N
			Rate of renewable energy used	City/D
			Rate of energy reuse	City/D
	Urban	Form	Volumetric compactness	N/B
			Size factor	N/B
			Form factor	N/B
			Rate of passive volume	N/B
			Energy consumed for heating	D/N/B
			Energy consumed for air-conditioning	D/N/B

Note: City = city scale; D = district scale; N = neighbourhood scale; and B = block scale
Source Bourdic et al. (2012)

Critique

In light of this statement, it is perhaps a little surprising this is not what Bourdic et al. (2012) go on and do. For while advocating such a triple-bottom line approach to the sustainability of urban development, they instead adopt:

> *a thematic layout of the said inter-relations,* this being because *it makes the system easy to understand for the reader* (ibid: 593).

The semantics wrapped up in this turn of phrase and how they are made use of to justify the "thematic layout" set out is pivotal to the model of urban morphology Bourdic et al. (2012) advance and offers a good example of what role the *universal pragmatics of the life world* currently play, not only in the indicators this thematic itself layouts, but benchmarks it also sets. This is because the choices they make to privilege the urban over the sustainable, form over content, structure over system and advance this as a set of knowledge objects, as opposed to products, currently having some purchase over the environment, serve to highlight the critical nature of the relationship they have to the sustainability of urban development. For in making such choices, they fail to do the very thing which is expected of them; that is, make it easier to understand the contextual nature of the relationship between the design, construction, use and occupational components of energy performance.

This is because as indicators of the interrelations between the thematic, triptych and typology, what they are not only blind, but deaf to are the normative statements that need to be made about the should and would of any such actions and as a result fail to offer any benchmarks by which to get a sense of the task in hand, either as an image of what we should do, or as a symbolic representation of why any such action would be worthwhile. For not only are they blind to any vision of the enhancements needed to realise something of such a magnitude, but the scenarios required in order for any such improvements to overcome the current state of affairs as part of a transition to sustainable urban development.

Instead, every analytical effort is put into being diagnostic and understanding the entropy of the urban system they subject to examination, not gaining knowledge of how to reverse the trend whereby urban development degrades the environment and is ecologically destructive. Unfortunately, the entropy they search for within urban form does not either mark itself out for these reasons, or place such matters on the agenda. This is because here the object of the exercise is to capture the nature of the relationship between the three pillars of sustainable development, not realign them in favour of the environment. This is the truth of the matter because if "the system" is going to sustain urban development, then any such adaptation shall have to be "self-organising", evolving from within the so-called triptych. The problem with this is that nothing is offered to explain any such self-organising tendencies, so it is a mistake to think "the system" can sustain urban development either by way of, or through a programme, whose thermodynamic and constructal tendencies, ecology, exergy and entropy are able to generate innovations which themselves bear down

on the *wider energy, carbon, water, waste and mobility performances* culminating in the climate change we currently experience.

So where are the structural weakness in the triptych and types of indicators listed, the fault lines and fragilities? Well put quite simply in taking the form they do, the indicators quite literally fail to capture the materiality of the challenge sustainable urban development and climate change pose as a triple bottom line. For stripped and laid bare of any benchmarks, there is very little left for such a *wider data set and broader information system* to target and as a consequence material to gauge how close they are in reaching their goal. Here, it seems the warning Bourdic et al. (2012) make about how not to use indicators is so well made it ought to be turned against them, because this is in fact *the job of benchmarks* and norms they set. For the price we are asked to pay in not using benchmarks for the purpose they serve, i.e. as a means to baseline urban development, set environmental targets and climate change goals, is too high. This is because in asking that we either substitute indicators for benchmarks, or see them as one in the same, the data and information systems which are generated by the former, is not based on a sufficient *knowledge* of the latter. This tends to leave all concerned in the most unfortunate situation whereby they are left with an insufficient knowledge of the benchmarks to target and therefore *without the dialogue-based investigative technique to do anything but underpin the existing morphology* of an unsustainable urban development.

The stand-off which this unfortunate position produces is a situation whereby *everything stays the same*, urban development in terms of energy, carbon, water, waste and mobility is still unsustainable and does not lead to a set of performances that change climate in any positive way, and "business as usual" means benchmarks, and key performance indicators are both reduced to the status of little more than as set of tools. That is to say, as tools which hang on a workbench, ready for use as an *exception to the rule,* i.e. in the exceptional circumstances someone has the intelligence by which to cross all the interdisciplinary boundaries needed to benchmark *not only* the multi-scalar (block, neighbourhood and district scales) of environmental sustainability, *but* corresponding contextualisation of their urban fabric as the design, construction, use and occupational components *also* related to the economics of climate change adaptation strategies. Put in slightly different terms, in the exceptional circumstances, someone has the intelligence to cross the multitude of interdisciplinary boundaries needed to benchmark environmental sustainability and demonstrate how the key performance indicators this generates can be put to use. More specifically, can be put to use as the means for any such dialogue-based investigative technique to set the environmental standards by which to sustain urban development and climate change adaptation strategies that are needed to meet this requirement.

Drawing on earlier research, Deakin et al. (2002, 2007) and Deakin (2004, 2008, 2009a, b, c, 2011) suggest the only *possible way to break free from the vicious circle such techniques of analysis lock us into* is by creating a critical distance between the triple-bottom line of sustainable urban development that is sufficient to *uncover the relationship which the social needs and material realities of the environment in turn have to the economics of climate change adaptation*. Indeed, it

is possible to go so far as to suggest the lack of success the techniques of analysis currently have in both planning for and getting any purchase on either the indicators, or benchmarks of the textures and fabric behind such development and change, means we literally have to reground the subject and systematically go about securing both the real weight and true significance of the matter under consideration (also see Deakin et al. 2012a, b, 2013, 2014).

Synthesis

Figure 1.2 sets out the standard morphologic model first advanced by Ratti et al. (2005) and serves to reaffirm the relationship between climate and what are referred to as the four structural (context, buildings, systems and occupational) components of energy performance. It does this by overlaying the model with the components Bourdic and Salat (2012) and Bourdic et al. (2012) offer. Here, the application of the DEM to analyse the context is represented, along with the tools for analysing the buildings found within the respective forms, shapes and envelopes. This in turn draws attention to the themes that make up the systems and triptych (sustainable development) of their use and occupation.

Figure 1.3 develops this representation further. This begins by setting out the grounds for the interest in climate change and application of the morphologic models set out here as part of an adaptation strategy. Here, particular attention is drawn to the mass retrofitting of an energy-efficient, low-carbon zone as a sustainable suburb both by way of an urban regeneration strategy and through the visions, master plans and development scenarios such a transformation is based on. Moving from top to bottom, this in turn indicates the Lighting and Thermal Method (LT-method) is supplemented with a 3D rendering of the context grounded in ArchGIS technologies and Google maps. This represents a context that is underpinned by an analysis of the social needs and material requirements which such a demographic imparts on an information system, i.e. on an information system whose ecological, exegetic and entropic qualities support the physical form, shape and envelope of both the densities and mass of geometries which are placed under examination.

The next column in this representation draws attention to the tools available to indicate, benchmark and baseline the STVR and PVTVR of the blocks, neighbourhoods and districts under examination. This in turn leads to the themes (energy,
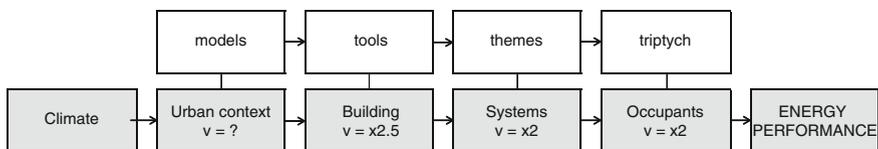

Fig. 1.2 Factors that affect energy consumption in buildings (adapted from Ratti et al. 2005)
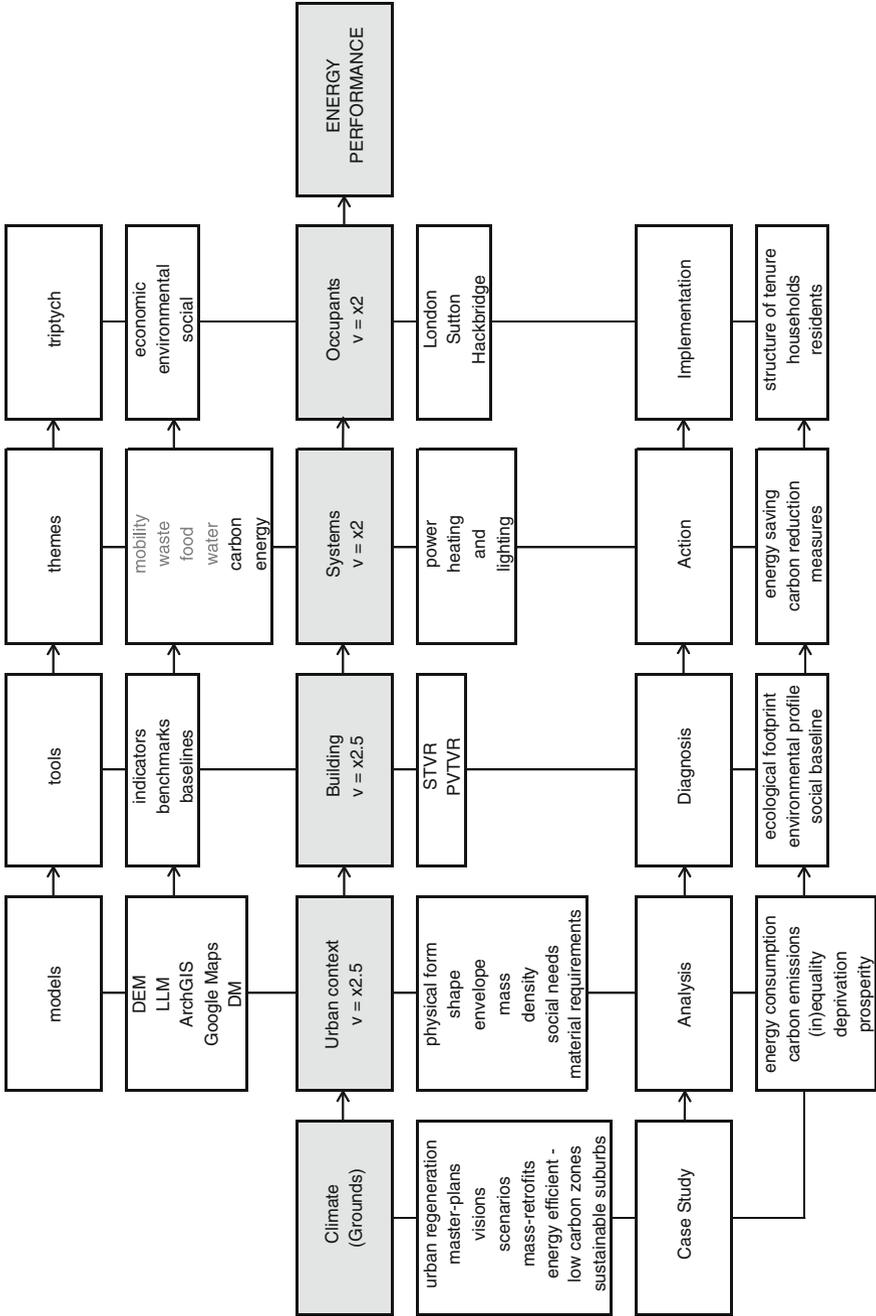
Fig. 1.3 Factors that affect energy consumption in buildings (adapted from Ratti et al. 2005)

carbon, water and mobility issues) linked to the thermal, lighting, power and heating systems central to mass retrofit proposal. The final column highlights the triptych in terms of the social, environmental and economic sustainability of those occupying this energy-efficient, low-carbon zone.

Under this rendering of the material lies a further level of case study analysis. This focuses attention on the diagnosis, action and intervention of urban planners, architects, designers and building contractors in Hackbridge and those promoted in the interests of securing the transformation of Sutton into a sustainable suburb.

The Book

In offering a critical synthesis of the research undertaken on urban morphology and broadening the subject out in the manner outlined, this book shall divide into five chapters.

The introduction *demonstrates how urban morphology matters by reaching beyond the geometry of building design, construction systems and occupational behaviours and towards broader context-specific transformations*. This chapter offers a critical insight into urban morphology and reviews the literature that makes up the state-of-the-art. Chapter 2 acts upon these critical insights and begins this process of transformation by setting out the grounds for the case-based reasoning reported on. It does this by *setting out the context of the transformation*. Chapter 3 turns attention to the *buildings subject to this transformation*. Chapter 4 integrates the previous chapters by way of *a case study into the thermal, lighting, power and heating systems of the blocks, neighbourhoods and districts*. It is by way of this case study and through the integration of thermal, lighting, power and heating systems it sets out, the book manages to break with the state-of-the-art and diagnosis this offers of energy performance in London, Toulouse, Berlin and Paris. This is done by examining the thermal, lighting, power and heating proposals of a mass retrofit proposal in the London Borough of Sutton and transformation of Hackbridge into a sustainable suburb. Chapter 5 *relates the prognosis that emerges from the integration of the thermal, lighting, power and heating systems making up the mass retrofit proposal back to the structure of tenure which exists within the residential property sector. This provides the means for this system-wide integration to assess the energy consumption and carbon emission of those occupying the blocks, neighbourhoods and district centres in the London Borough of Sutton.* Chapter 6 serves to conclude the study by reflecting on the potential mass retrofit programmes underway in Sutton and found in Hackbridge have to generate energy-efficient, low-carbon zones.

Chapter 2
The Grounds for This Study

setting out the grounds for the case-based reasoning reported on

The grounds for this study of urban morphology rests with research undertaken for the UK Engineering Physical Science Research Council (EPSRC) funded SURegen project, and desktop studies carried out to examine the institutional arrangements of mass retrofits within the residential sector of the property market (see Ravetz 2008). In particular, those institutional arrangements successful in not only making the case for mass retrofits, but also realising the "greater potential" they have to reduce rates of energy consumption and levels of carbon emissions in line with the standards of environmental sustainability laid down by the UK Government in the Climate Change Act 2008.

The case study this chapter advances as the grounds for the study attempts to bridge the gap that currently exists between energy consumption and carbon emissions by offering a sufficiently comprehensive analysis of the potential which mass retrofits in the housing sector have, to not only reduce energy consumption, but also to lower levels of carbon emissions.

As a suburb within the London Borough of Sutton, Hackbridge is home to approximately 8,000 people. The area is largely residential, and the housing comprises eighteenth century listed cottages, late nineteenth century terraced houses, inter-war semi-detached homes and BedZED, the internationally recognised development of 100 homes built to sustainable design principles in 2000.

In 2005, Sutton Council announced its commitment to move towards One Planet Living as a concept based around 10 sustainability principles developed by Bio-Regional. This is set out in the Core Planning Strategy BP61 as a:

> … key long-term target …to reduce the ecological footprint of residents to a more sustainable level of 3 global hectares per person by 2020 from the current "3-planet" baseline of 5.4 global hectares. To deliver this Vision, the Council is working in partnership with BioRegional to prepare a "Sustainability Action Plan" based on the 10 One Planet Living principles of zero carbon; zero waste; sustainable transport; local and sustainable materials; local and sustainable food; sustainable water; natural habitats and wildlife cultural and heritage; equity and fair trade; and health and happiness.

The Core Planning Strategy also states Hackbridge:

…will be the focus for a flagship sustainable [urban] regeneration project that brings about the renewal of the fabric of the area through environmentally innovative mixed-use redevelopment schemes.

The Urban Regeneration Strategy

In promoting this urban regeneration strategy, BioRegional have taken on the responsibility of managing the project and drafting a Sustainability Action Plan setting out how the renewal of the fabric shall be environmentally innovative in terms of the mixed-use redevelopment schemes their joint statement on One Planet Living sets out.

The Vision of the Master Plan

Under this institutional arrangement, a master plan has been commissioned from Tibbalds Planning and Urban Design. The vision which the master plan sets out, lays down the programme of renewal that is needed for such a (re)development to underpin the joint statement on One Planet Living and supports the transformation of Hackbridge into a "sustainable suburb." The Sustainable Suburb Charter, a voluntarily produced document complementing the plan's vision, programme of renewal and redevelopment, also draws out 13 additional requirements. These being to:

- create a local centre for Hackbridge;
- develop high-quality pedestrian and cycle routes;
- increase the amount of employment opportunities for local residents;
- meet the requirements of the area's population growth, via new schools, new health facilities, etc.;
- provide easily accessible green and open spaces;
- manage and maintain areas specifically for biodiversity;
- reduce the disparity in residents' life expectancy and obesity in general;
- achieve maximum energy efficiency "in all households, businesses and public buildings in the area";
- achieve a recycling rate higher than the average for London and water consumption rates lower than the national average;
- pilot parts of the South London Joint Waste Management Plan;
- establish a resource pool and evidence base for all forms of sustainability.

In this institutional arrangement both the master plan and Charter make explicit reference to the means by which to sustain the regeneration of Hackbridge in line

with BioRegional's "One Planet Living" principles. Here, particular attention is given to how a mass retrofit of the area's residential sector can generate lower levels of energy consumption and reduce the rate of carbon emission.

Review of the Energy Options Appraisal

The Energy Options Appraisal for Domestic Buildings, produced by Parity Projects in April 2008, sets out the "programme of work" for improving the energy consumption and carbon emissions of the housing stock. It assesses the levels of energy consumption and rates of carbon emission for the stock of housing within Hackbridge (as designated in the master plan). Brief attention is also given to profiling the resident community and referencing Census (2001) returns for the London Borough of Sutton. This analysis also details a number of energy efficiency measures that can be taken in order to turn the area under investigation into a low-carbon zone.

While all very useful, the environmental profile advanced in this report is found wanting for the reason the Energy Options Appraisal is unclear as to whether the benefits generated from the forecast levels of energy consumption and carbon emissions will be spread equally among all residents. The reason for this is simple: it is because in order to offer such an evaluation, it is necessary for the institutional arrangement supporting the regeneration i.e. between the London Borough of Sutton, BioRegional and members of the community as advocates of the Charter, to first of all "baseline" the social–demographic composition of Hackbridge. The second is to draw upon the results of this analysis as the means to assess whether the social–demographic composition of this "innovative environmental profile" has the capacity to carry the energy consumption and carbon emissions targets the "mixed-use redevelopment scheme" sets for the suburb. That is, assess whether this "innovative environmental profile" has the capacity to carry the energy consumption and carbon emissions targets which the "mixed-use redevelopment scheme" sets for the suburb and if this process of urban regeneration has the means to sustain them as an energy efficient—low carbon zone.

SURegen's Involvement

In seeking to fill these gaps in the existing appraisal, SURegen's involvement in the Hackbridge project has been defined in specific terms. In particular, it has been charged with the responsibility of *working with the institutional arrangement emerging from the urban regeneration proposal* and establishing the following:

- whether the environmental profile generated is capable not only of being baselined in sociodemographic terms, but also drawn upon as the means to evaluate whether the benefits of the mass retrofit can be spread equally among the residents;

- or if the distribution of costs emerging from the action is unevenly distributed across the structure of tenure within the housing market and whether this undermines the claims made about the environmental sustainability of the action.

What this specific terms of reference does is put an obligation on SURegen to supplement the technical knowledge of energy consumption and carbon emissions already in the public domain, with the sociodemographic data needed to inform those institutions participating in such regeneration proposals, not only whether the types of renewal and (re)developments they promote are legitimate in both technical and social terms, but if their demographic also champions the kind of environmental sustainability laid down in the principles of One Planet Living and Sustainable Suburb Charter everyone involved has signed up to.

The assumption underlying the types of profiling exercises found in the existing Energy Options Appraisal suggests they do legitimate actions of this type and, in turn, are effective in championing environmental sustainability. This is the assumption which the case study seeks to investigate, throw light on and in that sense, bring to the surface. Not for the reason SURegen wants to scrutinise their claims to legitimacy on technical grounds, but because under the institutional arrangements emerging to support such actions, the type of technical knowledge currently available is insufficient to answer the kinds of questions increasingly being asked of such appraisals.

In holding these assumptions up to scrutiny, it is anticipated the case study shall generate a number of insights into the possibility there is for examinations of this kind to not only fill the gap between the technical and social, but also take the opportunity their potential integration offers to bridge them. The kind of insights, possibilities, opportunities and potentialities, the authors wish to suggest are critical for all concerned to be aware of, for the reason they:

- start to reveal the complementary nature of the relationship between the technical and social components of such proposals, but because they also begin to show how the virtuous nature of this relationship may be realised;
- nor because the nature of this relationship may in turn be drawn upon to demonstrate how the type of collaboration inscribed into the institutional arrangements under examination, vis-a-vis, the visions, master plans, renewal programmes and redevelopment schemes, currently surrounding the mass retrofit proposals, can be constructive;
- but rather, because they offer the prospect for the institutional arrangement to build the type of consensus needed for the very (re)development schemes being designed to meet the requirement for the urban regeneration in question (i.e. generation of a suburban city-district, with associated neighbourhoods and blocks) to be environmentally sustainable.

The model of environmental sustainability this analysis draws upon can be traced back to Deakin et al. (2002) and Curwell et al. (2005). The technical components of the analytical model are set out in Deakin (2004, 2009), and the social–demographic

elements can be found in Deakin and Allwinkle (2007, 2008). In terms of the relationship such an institutionally grounded representation of urban regeneration has to environmental sustainability, this is reported on in Deakin et al. (2007), Deakin (2009a, b, c) and as part of an ongoing debate about the development of a community-based approach to the (environmentally) sustainable urban (re)generation of city-districts (Deakin 2009a, 2011, 2012; Deakin and Reid 2014).

Couched within this emerging debate on the sustainability of urban regeneration, the specific objectives of this examination into the mass retrofit proposal are to:

- develop an environmental footprint for the mass retrofit proposal based upon the profile of the urban form set out in the master plan and technical analysis of energy consumption and carbon emissions found in the Energy Options Appraisal;
- draw upon official statistical data currently available to analyse the social and demographic structure of the regeneration's environmental footprint to baseline the potential there is for the mass retrofit to transform Hackbridge into a sustainable suburb;
- use the outcomes of this social baseline analysis to review whether the energy-saving and carbon reduction measures can transform Hackbridge into a sustainable suburb and whether this is "achievable without burdening any residents with additional environmental cost."

Such an environmental profile is needed because currently neither the master plan, nor the Energy Options Appraisal is sufficiently grounded in what this examination shall refer to as an appropriate "area-based," vis-a-vis, "in situ" analysis. The first and second objectives set for SURegen's involvement in the project offer the prospect of such a contextualised analysis. The third uses the data generated from this predominantly technical analysis to review the sociodemographic evidence such a baseline offers to evaluate the proposition made about the costs and benefits of the environmental profile. Together the integration of the environmental profile and social baseline will offer the analytical means to establish whether the project is not just well grounded, or sure-footed, but if the type of environmental sustainability it champions is both fair and equitable.

Chapter 3
The Urban Context

setting out the context of this transformation

When reviewing the current literature available on mass retrofits, it soon becomes clear this is at best patchy in addressing the challenges the Hackbridge project sets in terms of the policy statements made by the London Borough of Sutton with respect to the vision, master plan, design and redevelopment strategy the sustainable suburb is based on. Indeed, in reviewing the literature currently available on mass retrofit proposals, it becomes all too obvious the models in question are based on the agency of architects, planners and designers and the capacity of their expert systems to align retrofits proposals with targets set to lower energy consumption and reduce levels of carbon emission. As such they lie in the first category of models criticised by Bourdic and Salat (2012) for not even meeting the robust standards of the building scientists they criticise, let alone those relating to the type of context-specific transformations they seek to usher in.

From this, it is evident the likes of Ratti et al. (2005), Salat (2009), Bourdic and Salat (2012) and Bourdic et al. (2012) don't see the movement back from the building component of energy performance models towards the context of the action (the urban planning, design and construction in question) as sufficiently scientific to stand as the means by which to move forward and systematically integrate them as assessment methods capable of saving energy and reducing carbon emissions. While it is the job of urban morphologist to fill this gap, they conclude the tendency to focus on the physical analysis of the form, shape and envelopes of building density and mass, only serves to leave the texture and fabric of this structure fragmented and in that sense incapable of being integrated into building systems able to save energy and reduce carbon emissions in the interests of climate change mitigation.

Diagnostic in nature, STVR and PVTVRs do not support such actions either. This is because an understanding of the structure is insufficient for the agents of change (urban planners, architects and designers) to act upon this context-specific knowledge and apply the expertise it offers to address the challenge in hand. This is because it is not so much the "step back" which in is put in question by the likes of Salat (2009), Bourdic and Salat (2012) and Bourdic et al. (2012) but the "step

down" into the very material capable of being assembled as the principle components of such an analysis. Indeed it seems the price we are asked to pay for basing urban morphology on the science of urban form, physics and geometry of their shapes, envelopes, mass and density, is too high, and the model needs to drill further down into the material capable of being mined for such assessments (Deakin et al. 2012, 2013, 2014).

This is why the urban morphology this book applies begins with the social baseline and not their so-called physical parameters. For it is the materiality of this demographic and not their geometry which make up the content of the urban form that both shape and envelop their mass as densities integral to buildings and systems their volumes in turn relate to. Switching emphasis from the physics of geometry and towards the social baseline of a given demographic has additional benefits. For one it introduces the question of equity into any such benchmarking of energy performance, and for another, it offers the opportunity to see much of what is otherwise left as a set of indicators, as material in its own right, with form and content which in turn gives rise to the shape that it takes on and envelops into.

This way urban morphology is given a social as opposed to physical and geometric basis and presented with the material needed to cross this boundary and inject the degree of transversal agency required to generate the type of dialogue between urban planners, architects and designers called for. That type of dialogue between urban planners, architects and designers which is called for because it provides the social and physical means to systematically integrate buildings, systems and behaviours into the structure of tenure they occupy within the blocks and neighbourhoods of city-districts. Of course any such integration in turn calls for a mode of representation able to overcome the limitations of the LED digital format advanced by Ratti et al. (2005). This shall be achieved by developing a 3D model of urban morphology. However, before assembling this model, it is essential to establish what geographic data is available and determine the accuracy of the information it is based on. Having established this, it then becomes possible to decide upon the level of detail the model is able to render.

CityGML introduces the so-called levels of detail (LoD) which describe different levels of representation. The classification is as follows (Open Geospatial Consortium, Inc. 2012):

- LOD 0—regional, landscape
- LOD 1—city, region
- LOD 2—city-districts, projects (with explicit roof structure)
- LOD 3—architectural models (outside), landmarks
- LOD 4—architectural models (interior)

Gröger and Plümer (2012) present the different LoD by means of a residential building (Fig 3.1).

The model built up for this contextualisation of urban form has been developed to LoD 1. The level of detail associated with Chaps. 4, 5 and 6 of the book transcend this and detail the morphological structure at LoDs 2, 3 and 4. This level of detail is needed because the form and shape of the buildings set out in Chap. 4
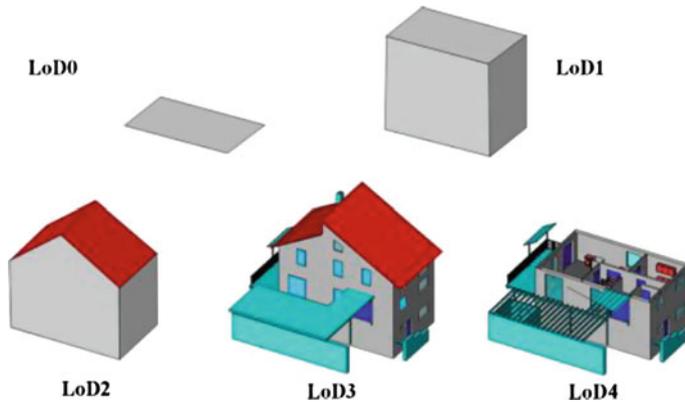
Fig. 3.1 Different levels of detail for residential buildings (Gröger and Plümer 2012)

are subject to systematic change which targets the consumption of energy within the internal envelope of the buildings and carbon emissions that are associated with the use and occupation of the modified structures (see Chaps. 4 and 5).

Using the workflow illustrated in Fig 3.2, the OSM data for the footprint of the mass retrofit proposal have been downloaded from the OSM Server as an XML file (Extensible Markup Language). The target area is shown in Fig. 3.3 and shows the OSM map of Hackbridge as it is presented online.

OSM is an open source project, and the accuracy and completeness of the data are not subject to general rules of quality management. Some building footprints, for example contain obsolete areas (e.g. garages) and other footprints are completely missing. To detect and adjust for such errors, the XML file was loaded in the Java OpenStreetMap Editor (JOSM) (Fig. 3.4). This editor displays the XML file with its different objects. With the help of satellite images provided by *bing* (Microsoft), the data for this case study was so adjusted. Every building block in the Hackbridge area (ca. 650 blocks in total) has been checked for completeness and positional accuracy. As satellite images sourced from JOSM can have a slight offset, they have also been adjusted with the help of GPS tracks provided by OSM volunteers. JOSM is designed as a user-friendly tool so that every OSM volunteer can make use of it without being circuitously instructed (e.g. easy editing of nodes via drag and drop).

With the help of the freely available ArcGIS Editor for OpenStreetMap, the edited OSM-XML file has been stored in a geodatabase and imported into ArcGIS.

The coordinate system in ArcGIS is determined as a UTM zone 30N projection. Two kinds of coordinate systems exist in ArcGIS. One is the group of global or spherical coordinate systems which measure spherical coordinates (latitude–longitude) from the earth's centre [e.g. World Geographic System 1984 (WGS84)]. The second group is the projected coordinate system which maps the earth's spherical surface onto a two-dimensional Cartesian coordinate plane, e.g. universal transversal mercator (UTM) projection (ArcGIS Resources 2012). Only projected
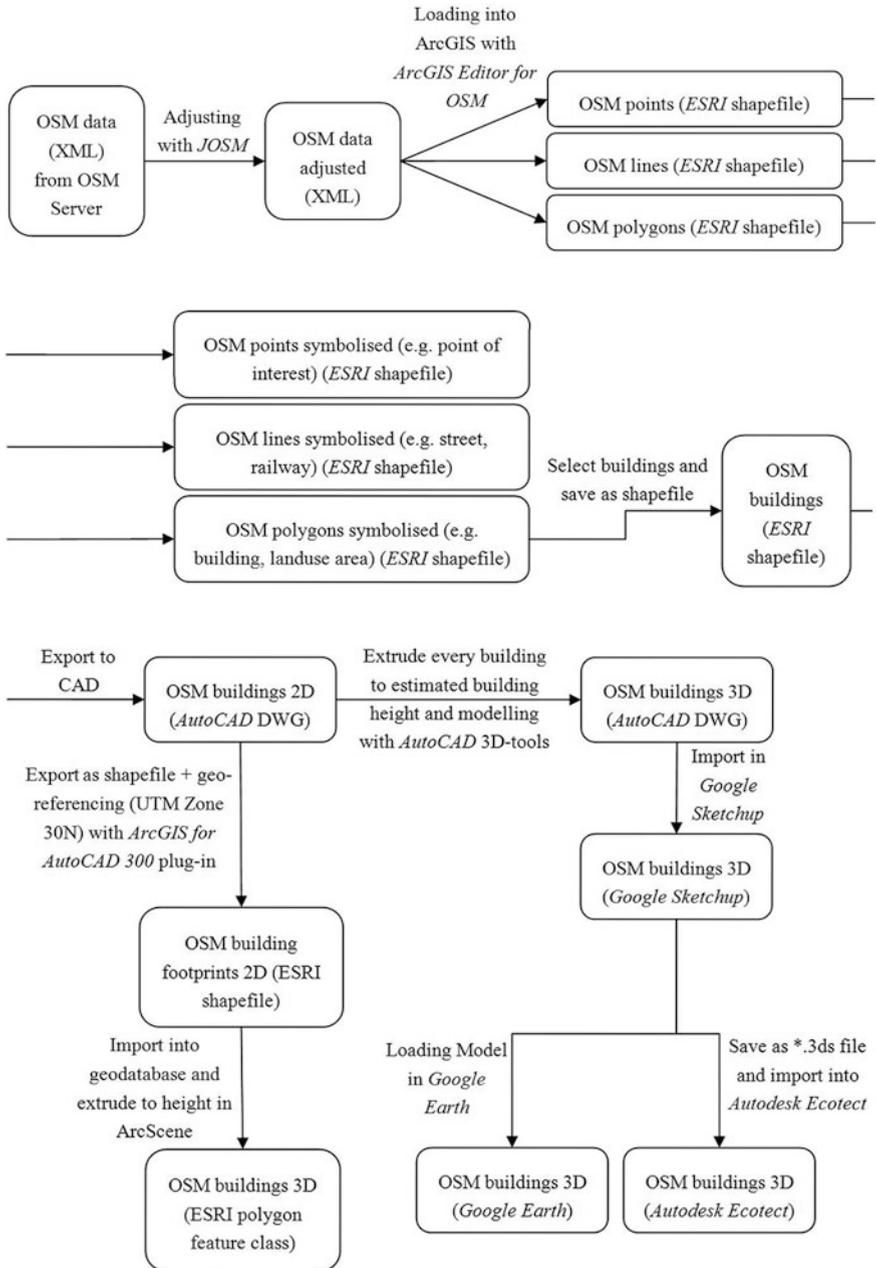
Fig. 3.2 A "float" diagram capturing the important processing steps in building the 3D model
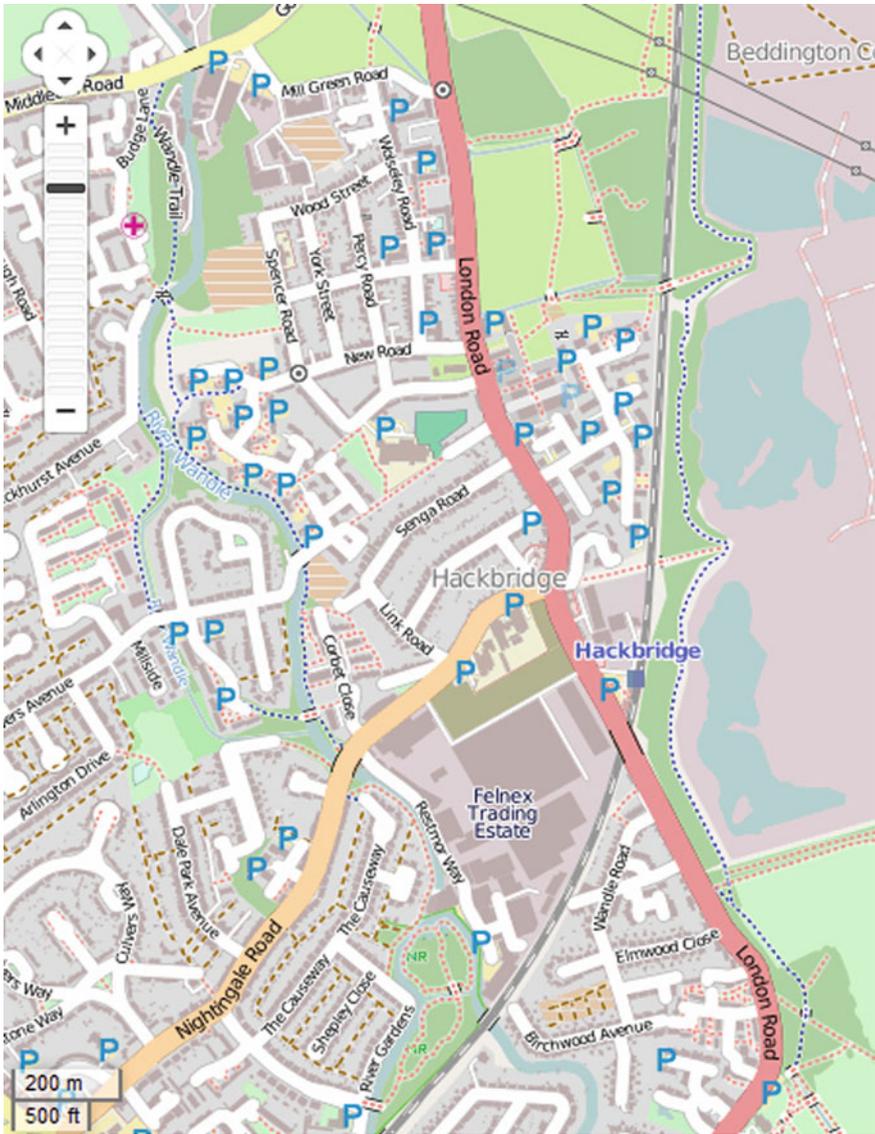
Fig. 3.3 Hackbridge in Open Street Map (www.openstreetmap.org 2013)

coordinate systems have the representative X, Y-dimension capable of enabling the proper calculation of values such as distance or area. As such configurations are an essential basis of the analysis and calculations of what follows, the UTM projection was chosen. UTM divides the earth into 60 zones, each with a width of 6° longitude. London and therefore the Hackbridge area is lying in UTM zone 30N.
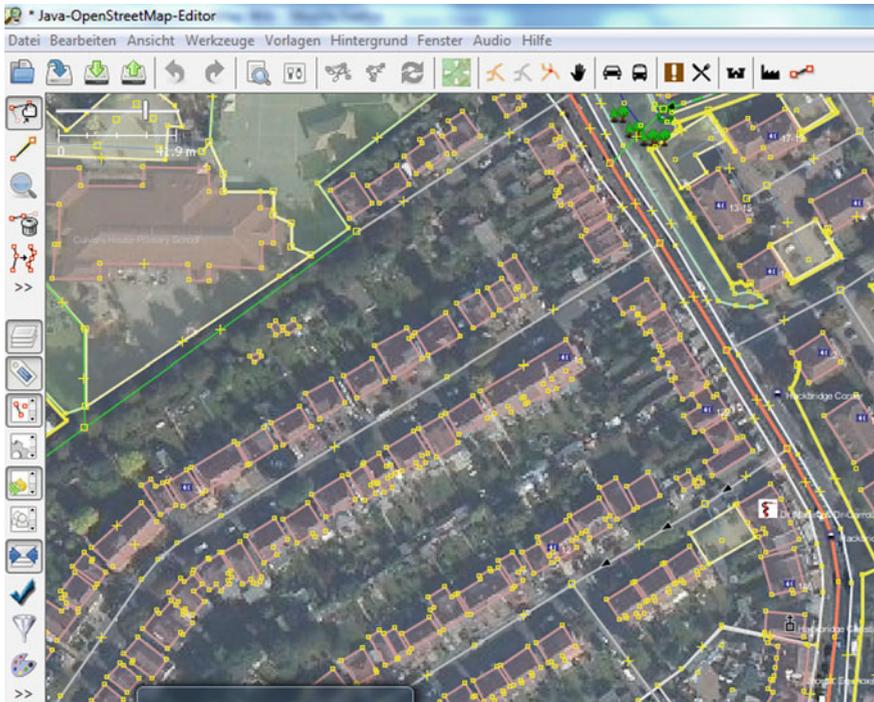
Fig. 3.4 Java Open Street Map Editor with an extract of Hackbridge (JOSM Software)

The ArcGIS OSM Editor provides:

- Download of XML data from OSM Server
- Loading of OSM-XML files
- Symbolising of OSM-XML files

During the loading process, OSM-XML files are automatically divided into three feature classes (point, line and polygon). Point features are points of interest or building points, the line features class contains elements such as streets or railways, and the polygon feature class contains elements such as land use areas and building footprints. However, these feature classes do not have the classifications and symbolisations presented in the original OSM online map. The ArcGIS Editor for the OpenStreetMap toolbox provides a "symbolise" tool which identifies, classifies and finally represents all three feature classes. Building footprints, for example, were identified with the help of this tool. For further work in AutoCAD, they were exported via the tool "Export to CAD." AutoCAD has also been used to build up the 3D model. This provides many tools for creating and editing 3D objects and even complicated structures can be modelled.

As a first step, all obsolete buildings not located within the Hackbridge case study area were deleted. Secondly, the building height of every building block
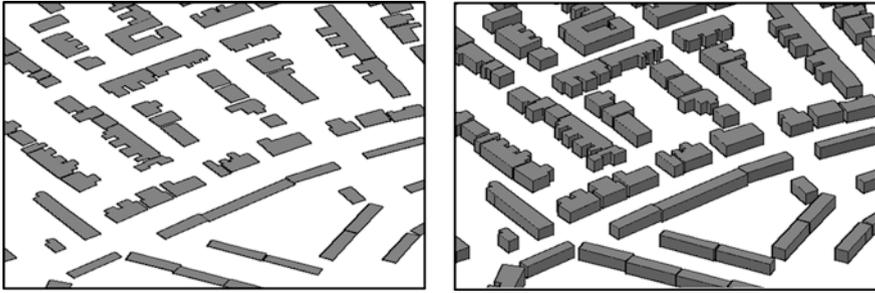
Fig. 3.5 *Left* building footprints. *Right* extruded building footprints
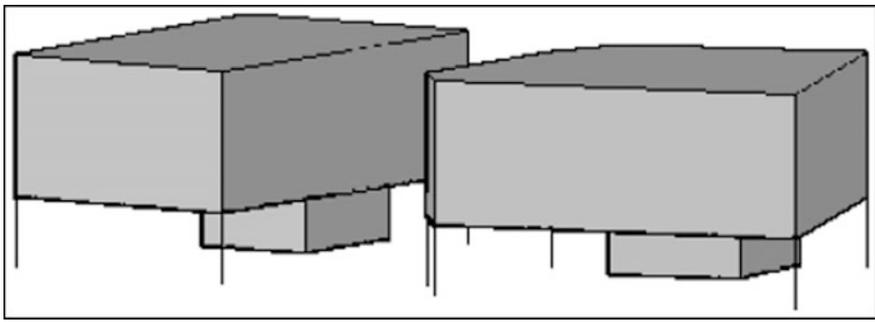
Fig. 3.6 Axonometric view of two buildings on Hackbridge Road which were modelled in more detail

(circa 650) was determined using Google Street View. The 360° panoramic view provided by Google renders it possible to identify the number of floors for each building block. For this model, a floor height of 3 m was estimated and then multiplied by the total number of floors in each building. Although this model was built up in LoD 1 and therefore roof shapes were not calculated, an approximate mean height of the roof was added to the absolute height of the buildings. The model is mainly a block model which means that the 3D building shapes are modelled by extruding each footprint to its estimated height (see Fig. 3.5). Only a few buildings were subsequently modelled to this level of detail (LoD 2) by taking obtrusive architectural elements into account. This is illustrated in Fig. 3.6. Varying roof heights within one building block were also identified and modelled. This is shown in Figs. 3.7 and 3.8.

This application produces a 3D city model representative in terms of building shape, envelope area and volume. Here, every building block is represented by a single 3D solid object. Figure 3.9 shows the whole 3D model with an axonometric view.

The finished AutoCAD 3D model was then used to calculate the envelope area and volume of the building blocks. Both figures are necessary to calculate the

Fig. 3.7 Axonometric view of three buildings with different roof heights on Green Mill Road

Fig. 3.8 Axonometric view of buildings on Hackbridge Road

Fig. 3.9 Axonometric view
of the 3D model of
Hackbridge

specific ratios of energy consumption and carbon emissions surfacing later on in this case study analysis. As AutoCAD 3D solids could not be 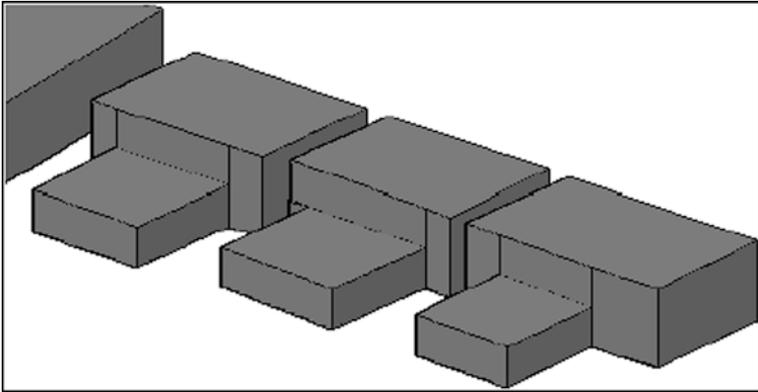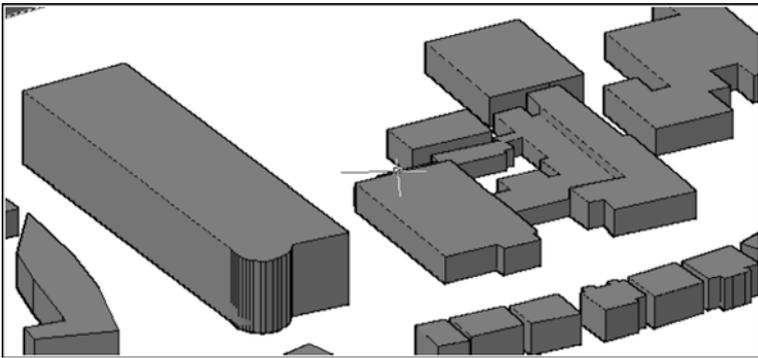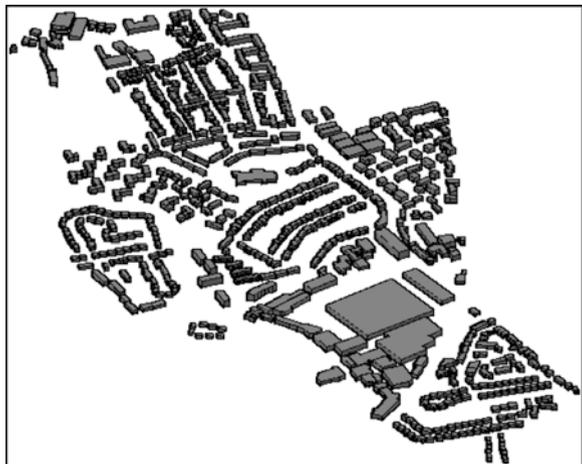exported, they were split up into single surfaces and classified into three AutoCAD layers. The first layer contains footprint polygons, the second layer captures all wall polygons and the third layer stores the roof polygons. With the help of *ArcGIS for AutoCAD 300*, the layers were saved as ESRI shape files. The coordinate system in AutoCAD was set to *UTM zone 30N projection* and imported into an ArcGIS geodatabase. The geographic coordinate system in the ArcGIS environment was determined again as *UTM zone 30N projection*.

For the purposes of spatial modelling and visualisation, the 3D application ArcScene came into operation. This desktop application provides many tools to analyse, edit and visualise 3D geodata. For example, footprint polygons can be extruded to a certain height. These heights must be existent in a so-called attribute table. Such tables contain information about features (e.g. shape area, coordinates and ID number). Attribute tables can be expanded manually by adding information (such as text or numbers) which are then allocated to an object. Calculations between different columns (fields) of an attribute table can also be undertaken. Since the imported building footprints exhibit no height information, they need to be connected with the respective roof polygons and their height information determined via a join connection. Join connections allow the connection of objects one feature class with objects of another using a field which is existent and identical in both data sets (e.g. "area" or "*x*-coordinate").

As most footprint polygons have the same area value as their respective roof polygons, the join was conducted with the usage of the field "area". Footprint polygons which belong to more than one roof polygon have to be allocated manually (e.g. when a roof was split up in areas of different heights in order to achieve a more detailed model). Having the height for each footprint polygon, the extrusion can be undertaken but also the volume and different ratios can be calculated for each building block.

Height data from the Shuttle Radar Topography Mission (SRTM) was then used to create a ground surface which serves as a base layer. All other layers are laid on top of this layer (Fig. 3.10). SRTM data are provided as GeoTiff files in the WGS84 geographic coordinate system with a 90-m resolution/grid size. The data is freely available online and is divided into tiles which cover the whole globe (Hackbridge tile: SRTM 36_02). The GeoTiff file was imported in a geodatabase as a raster file, transformed to UTM zone 30N projection and cut out for Hackbridge. Following this, contour lines (1, 2 and 5 m) were created in ArcScene. They function as input for processing a triangulated irregular network (TIN) (Fig. 3.11). Such a TIN is constructed by triangulating a set of vector-based geographic data (e.g. points) after a specific method. ArcGIS makes use of the Delauney triangulation.

Many different layers can now be created and added to the scene by laying them on top of the ground surface (TIN). Some layers are described as follows:

- streets (including different road categories)
- land use (e.g. wood and industrial)

Fig. 3.10 Satellite image as background layer, overlaid with OSM building footprints and OSM streets

- railway
- bus stops (as 3D point symbols)
- rivers
- highly zoomed Google Maps satellite pictures of the area (collected by taking screenshots. The single pictures were then stitched together with the use of Microsoft Image Composite Editor)

An axonometric view of the TIN overlaid with streets, rivers and extruded buildings can be seen in Fig. 3.12. Visualisation effects in ArcGIS, including 3D bus stops, 3D trees are also presented for the BedZed area in Hackbridge (see Fig. 3.13).

GIS can also be used to identify and analyse sociodemographics within small geographic areas, such as a neighbourhood or city–district. This level of analysis can enhance the early diagnostic phase of a regeneration programme, and the findings of such exercises can be used to support the:
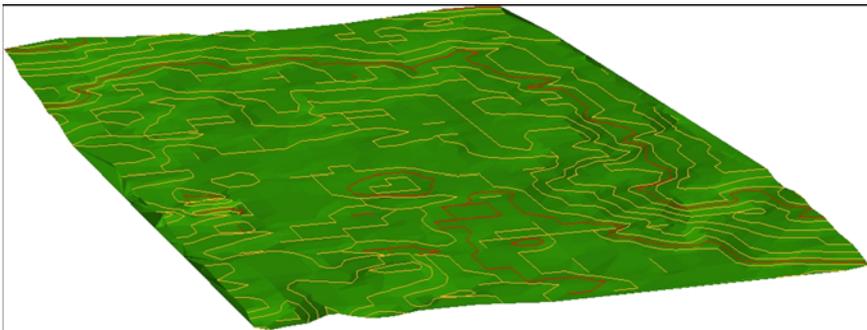

Fig. 3.11 TIN of Hackbridge with 2- and 5-m contour lines
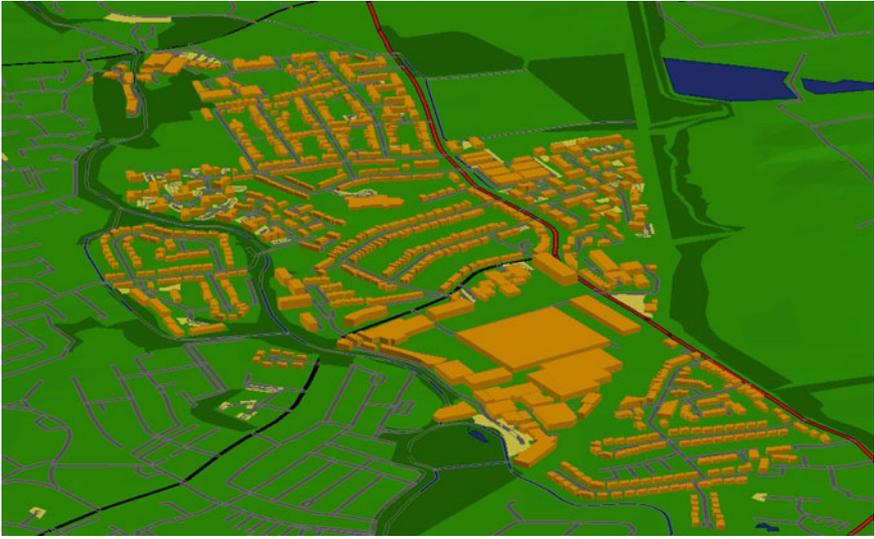
Fig. 3.12 Hackbridge with TIN, land-use layer, street layer, river layer and extruded building footprint layer
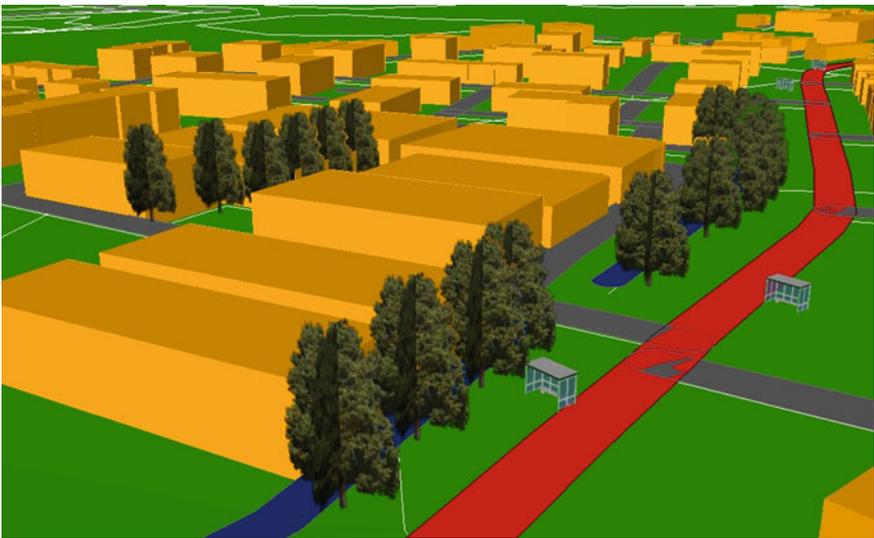

Fig. 3.13 Visualisation effects in ArcGIS, 3D bus stops, 3D trees presented for the BedZed area in Hackbridge

- effective targeting and coordinating of regeneration activity;
- identification of relevant policies and strategies at local and subregional levels;
- establishment of a set of baseline sociodemographic indicators;

However, it is acknowledged that such GIS-based analysis is often beyond the means of local authorities, SMEs and third sector stakeholders which participate in urban regeneration programmes. With these limitations in mind, this book sets out an alternative methodology for sociodemographic analysis without the need for GIS software. While such a statement may see counter-intuitive given the nature of the technical analyses set out so far in this chapter, it is done in the interest of illustrating how it is possible to capture, render and thereby represent the social–demography of a given area by use of free, publically available data and online information.

The first task in building the diagnostic components of such an analysis is to understand the standard geodemographic units for which data are available. The four basic units used in National Statistics (England and Wales) are shown in Table 3.1.

The two key units for neighbourhood or district-level analysis are output areas (OAs) and lower layer super output areas (LSOAs). OAs were developed following the 2001 Census by the Office for National Statistics: clusters of postcode units were grouped together using data from the Census returns to form areas that were "as socially homogenous as possible." Lower and middle super output areas were first introduced in 2004 as a means of providing stable geographical units between the size of an OA and a local authority. SOAs are thought to offer an improved basis for statistical comparison than, say, electoral wards as they are more similar in terms of population size.

LSOAs typically contain four to six neighbouring OAs and are generated automatically on the basis of population size. Middle layer super output areas (MSOAs) are developed across a two-stage process: initially generated automatically then later modified in consultation with local authorities. Both LSOAs and MSOAs adhere to existing local authority boundaries. The Office of National Statistics (ONS) recommend that SOAs should be used for data reporting and analysis as far as possible and suggest using the smallest possible areas for analysis. A number of the data sets relevant to the identification of an area's social–demography are available at LSOA level, the smaller of the two SOAs.

Table 3.1 Geographical units in National Statistics

Geographical unit	Minimum population	Mean population	Base units
Output area (OA)	100	300	Groups of postcodes
Lower layer super output area (LSOA)	1,000	1,500	Groups of output areas and constrained by the boundaries of standard table wards used for 2001 Census outputs
Middle layer super output area (MSOA)	5,000	7,200	Groups of lower layer super output areas and constrained by 2003 local authority boundaries used for 2001 census outputs
Local authority (LA)	n/a	n/a	(Set by the Local Government Boundary Commissions)

Fig. 3.14 Hackbridge
regeneration area

Fig. 3.15 Hackbridge by OA
and LSOA

In order to identify the relevant OAs and LSOAs in Hackbridge, a map of the regeneration area was developed using Google Maps, shown in Fig. 3.14. The ONS' Neighbourhood Statistics website features a "Map Viewer" tool: a "zoomable" map capable of displaying a range of boundaries. Figure 3.15 shows the OAs and LSOAs spanning the general Hackbridge area, as identified using the Map Viewer tool. Figure 3.16 shows the larger of the two units, and the LSOAs developed onto a Google Map which then allows for Fig. 3.15 to appear as an overlay, as is shown in Fig. 3.16. This enables the user to make an informed decision regarding the relevance of data from the LSOAs in terms of the regeneration area.

As the Hackbridge example shows, regeneration area boundaries rarely fit neatly within geodemographic boundaries. The most northerly LSOA in Hackbridge (Fig. 3.17, shaded in white) spans a large area out with the regeneration zone (shaded in red). With approximately two-thirds of the LSOA lying out with the regeneration area, it initially appears as though data from this LSOA would not support an accurate profile for the population within the red-shaded area. However, the Google map can be toggled to show a satellite image supported by the Google Streetview tool, enabling differentiation between residential properties, industrial sites and green spaces. A significant proportion of the most northerly LSOA covers green space, rather than residences, suggesting that sociodemographic data returns will offer a more accurate reflection of households within the regeneration zone than that initially appears. One of the LSOAs includes a very small number of residential properties within the regeneration zone. This can be seen in Fig. 3.17 on the lower left, the LSOA spanning Nightingale Road. As so few households within this LSOA belong to the regeneration zone, returns from this LSOA are not included in this analysis.

The process is repeated in order to identify the most appropriate OAs: a Google map is created to show the OAs across Hackbridge and then the outline of the regeneration zone is added as an overlay. OAs wholly out with the regeneration zone are excluded from further analysis. Those lying on the boundaries are surveyed using Google's zoomable satellite imagery and Streetview as previously described.

In developing a diagnostic area profile, there may be subjects of particular interest. Neighbourhood statistics produce an indicator catalogue which highlights those held within the national statistics website, the data sets where they can be found and the geographical units the information is available for. It is also possible to view Census area statistics at output area level using the Neighbourhood Statistics site. Results should be treated with caution owing to the fact that they represent a snapshot of 2001. The Census statistics include:

- accommodation type (reference code UV56)
- approximate social grade (UV50)
- distance travelled to work (UV35)
- household composition (UV65)
- housing stock (UV53)
- National Statistics socioeconomic classification (UV31)
- tenure—Households (UV63)

Fig. 3.16 Hackbridge by
LSOA

Fig. 3.17 The Hackbridge
regeneration area (*red*) is
superimposed on the impacted
LSOAs (Deakin et al. 2012)

For this exercise, household tenure data were used to show how owner occupation, private and social renting could affect the mass retrofit measures proposed under the Energy Options Appraisal.

The English Indices of Deprivation (EID) are the Government's standard measure of social status in England, last compiled in 2010, and the EID collate data, at LSOA level, within 37 indicator sets and then used to rank England's 32,482 LSOAs in terms of relative deprivation (where rank 1 is the most deprived and rank 32,482 is the least). The EID is calculated across 7 thematic domains:

- Income
- Employment
- Health and Disability
- Education, Skills and Training
- Barriers to Housing and Services
- Living Environment
- Crime

Data sets from the EID are available from Neighbourhood Statistics and the Department for Communities and Local Government. The data returns show relative deprivation and highlight any significant differences in economic status.

Based on this geolocated data, the social needs and material realities of this representation have been compiled using information from the English Indices of Deprivation 2007 and the Census 2001. This data has then been used to develop an innovative range of thematic chloropleth maps relative to the area specified in the master plan. The maps within this chapter have been created using Google's "My Maps" tool. "My Maps" is a free, online tool offering anyone with a (free) Google login, the opportunity to create map overlays and "mashup" thematic chloropleth maps. Google also offers users access to the Google Maps application programme interface (API) in order to combine their base data with other spatially referenced information. This, however, requires programming knowledge, whereas "My Maps" does not. The "My Maps" tool enables the swift production of thematic chloropleth maps (using the "Shape" tool) which can be redistributed, even edited, instantly, using the Google generated URL (unique to each map).

The London profiler (www.londonprofiler.org) uses the Google Maps API to build thematic chloropleth maps and demonstrate, among other things, returns from the English Index of Deprivation 2007. Although an innovative and useful tool in its own right, the London profiler returns are based around large areas grouped together; hence, local differences are impossible to discern. The Google Maps API does not supply or support the tools necessary to incorporate "a really aggregated data set" (such as the English Indices of Deprivation data), thus, requiring additional software development of the type outlined above. Given the remit of this sociodemographic analysis, Google's "My Maps" tool is fit for the purpose of quickly developing clear and accurate thematic chloropleth maps.

Here, Google's "My Maps" tool has been used in conjunction with the Office of National Statistics' Boundary Viewer in order to develop bespoke thematic maps at lower super output area and the smaller OA levels within Hackbridge.

Chapter 4
Buildings

the buildings subject to this transformation

The data that are used for this model have been extracted from the Energy Options Appraisal for domestic buildings in Hackbridge', commissioned by the London Borough of Sutton and Bioregional in 2008 (BioRegional Consulting 2008). In this study, the housing stock in Hackbridge is categorised by property type (terraced house, semi-detached house, maisonette and flat) and age (Pre-1918, 1918–1938, 1939–1959, 1960–1971, 1972–2000, 2001–2006, post-2006). Each combination (property type and age) has its own identification letter which represents the property group. B (i), for example is the category for terraced houses built pre-1918.

The Energy Options Appraisal divides the suburb into 20 areas in which residential property of approximately the same age and type are grouped together. For the purpose of this 3D model, the property types (house, semi-detached and flat) have been determined for every building block. This "block-based" analysis has been developed using Google Street View, scaled as either a neighbourhood, or city-district. This model also generates energy consumption and CO_2 emissions for each type of property within the block. While the original data found in the Energy Options Appraisal divides each property into sub types including "terraced ground floor" or "flat top floor," it was found that such a classification is not appropriate for this examination, as here it is building blocks, rather than properties which are the unit of analysis. Because of this, the mean annual energy consumption and CO_2 emissions for each type of sub group have been obtained and allocated to the respective classes. For example, a 1930 built building block consists of two flats, one ground floor flat and one top floor flat. The property group would be "C." Annual energy consumption of the ground floor flat would be 19,275 kWh/year and of the top floor flat would be 21,467 kWh/year. As property group C has six sub groups, the mean of all energy consumption and CO_2 emission numbers of these sub groups would be obtained and allocated to all C building blocks. In this way, the building block being used as an example would not be allocated to the mean value of the two flats only (20,371 kWh/year), but to a mean value of all six subgroups (18,901 kWh/year). This is a generalisation which leads to small differences of actual numbers.

As a final step, the households per building block had to be determined. This was realised with the usage of Google Street View in combination with data gathered from a street-based postcode search. This search displays all current households which are existent in a certain street. Such a combination of Google Street View analysis and postcode search leads to an accurate representation of household distribution.

By exploiting the model's potential, an analysis of energy consumption and CO_2 emission per occupant can be undertaken. The Energy Options Appraisal assumed that every property is inhabited by a four person family which heats the building in two distinct periods of the day. The London Borough of Sutton has information about the actual number of people inhabiting a household which are presented as a percentage to the total number of inhabitants in the Energy Options Appraisal. The inhabitants per household type (e.g. one person, family) were then calculated. These are listed below:

- One person (37 %)
- One family and no others, all pensioners (4 %)
- One family and no others, married couple households (30 %)
- One family and no others, cohabiting couple family households (15 %)
- One family and no others, single parent households (10 %)
- Other household (5 %)

These percentages have been multiplied by the total number of households in the model. This way the total number of each household type can be established. The allocation of the household types to the inhabitants was then realised with the help of a map which presents the social–demographic composition of Hackbridge (Geographers' A-Z Map Company Ltd. 2011).

As it is likely that such a classification is only a rough estimation of the actual occupation, the resulting distribution was adjusted. This was undertaken in a way suggested by the classification of Geographers' A-Z Map Company Ltd. (2011). By multiplying the adjusted number of occupants per household with the number of households per building block, the total number of occupants per building block could be estimated. To get the absolute and official numbers of occupants, the "*usual resident population*" data found in the UK 2011 Census (UK Census 2011) were used. This data is provided for output areas (OA) which are the lowest geographical level, the census numbers are available for. The inhabitants estimated by the census differed slightly from those numbers estimated by previous methods. The first calculated numbers of inhabitants per building block which then had to be normalised with the absolute numbers of the census. The normalisation of the inhabitants was undertaken as follows:

$$\text{normalised number of occupants per building block}$$
$$= \frac{\text{occupants per building block (Geographer's A-Z Map Ltd, 2011)}}{\text{total calculated number of inhabitants per OA}}$$
$$* \text{(total census numbers of inhabitants per OA)}$$

Having information about the absolute number of persons in each household, the energy consumption and CO_2 emission per person in a specific property could be estimated. It is the most accurate representation of actual energy consumption and efficiency as it considers the numbers of people living in a household. All model information is stored in an attribute table (Fig. 4.1).

Additional Software

In this chapter, additional software will be presented that have either formed a major part of the modelling process or which are useful for further analysis of the content this generates.

A useful software programme for simulation the energy performance of buildings is Autodesk Ecotect. This is a simulation and analysis software used to support the design of sustainable buildings. Here, solar radiation, shading or temperature and wind influences can be simulated for single days in a year.

Weather files for cities all over the world can be accessed, so allowing the local climate of a building's location to be considered. Ecotect is able to analyse energy performance of objects on a single building scale. It is a very powerful software programme which requires detailed input information (e.g. windows, reflecting surfaces and material of walls). For a group of buildings on an area-based scale (e.g. Hackbridge area), Ecotect can deliver accurate information about energy performance, but a lot work has to be undertaken to prepare all buildings in a way that best use can be made of the software's potential. For example, Ecotect could help to detect roof areas which are suitable for solar photovoltaic usage (accurate roof shapes are required) (Figs. 4.2 and 4.3).

Since AutoCAD 3D polylines are not supported by Ecotect, the direct import from a dwg/dxf file into Ecotect is not possible. The best solution is to import the dwg file into Google Sketchup and to transform it from there into a *.3ds file. Such a file format can be read by Ecotect and hence easily imported. Having the model in a Sketchup file format renders it possible to load the whole model into Google Earth (only locally viewable) showing the 3D model (Fig. 4.4).

Several attempts were subsequently made to integrate the Autodesk products Map3D, Architecture and Revit in the model visualisation process. Autodesk Architecture and Revit are powerful software programmes best used for projects with single and detailed modelled buildings. Map3D is a GIS and mapping application integrated in an Autodesk CAD environment, but lacks the ability to multitask such determinations. ArcGIS proved to be the most suitable software in terms of data interoperability, visualisation and editing performance. Autodesk Ecotect can be a very useful tool, but further research is needed to identify how groups of buildings can be properly integrated.

Table

footpoly

exact year	house flat maisonette	floors	HA	street	energy kwh p a with factor	CO2emission p a	family size
1890-1920	semi	1	HA3	Wood street	66482	8193	Cohabiting couple family households
1890-1920	house	1	HA3	Wood street	39000	10000	married couple households
1890-1920	terraced	2	HA3	Percy Road	291640	7419	Cohabiting couple family households
1890-1920	terraced	2	HA3	Seymour Road	174984	7419	married couple households
1890-1920	terraced	2	HA3	Wolseley Road	87492	7419	married couple households
1890-1920	semi	2	HA3	Wolseley Road	66482	8193	one person
1890-1920	house	2	HA3	Wolseley Road	39000	10000	one person
1890-1920	flat	2	HA3	Seymour Road	302416	5692	married couple households
1890-1920	semi	2	HA3	Percy Road	66482	8193	Cohabiting couple family households
1890-1920	terraced	2	HA3	Wolseley Road	116656	7419	married couple households
1930s	house	2	HA10	Senga Road	28000	8000	married couple households
1930s	house	1	HA10	Senga Road	28000	8000	all pensioners
1930s	house	2	HA10	Senga Road	28000	8000	all pensioners
1930s	house	2	HA10	Senga Road	28000	8000	all pensioners
1930s	house	2	HA10	Senga Road	28000	8000	all pensioners
1930s	house	2	HA10	Senga Road	28000	8000	all pensioners
1930s	house	2	HA10	Senga Road	28000	8000	all pensioners
1930s	house	2	HA10	Senga Road	28000	8000	all pensioners
1930s	house	2	HA10	Senga Road	28000	8000	all pensioners
1930s	house	2	HA10	Senga Road	28000	8000	all pensioners
1930s	house	2	HA10	Senga Road	54956	7321	all pensioners
1930s	semi	2	HA10	Senga Road	54956	7321	all pensioners
1930s	house	2	HA10	Senga Road	28000	8000	all pensioners
1930s	semi	2	HA10	Senga Road	54956	7321	all pensioners
1930s	house	2	HA10	London Road	28000	8000	married couple households
1930s	house	2	HA10	London Road	28000	8000	married couple households
1930s	terraced	2	HA10	London Road	82107	7300	Cohabiting couple family households

1 ◄ ► ►| (0 out of 649 Selected)

footpoly

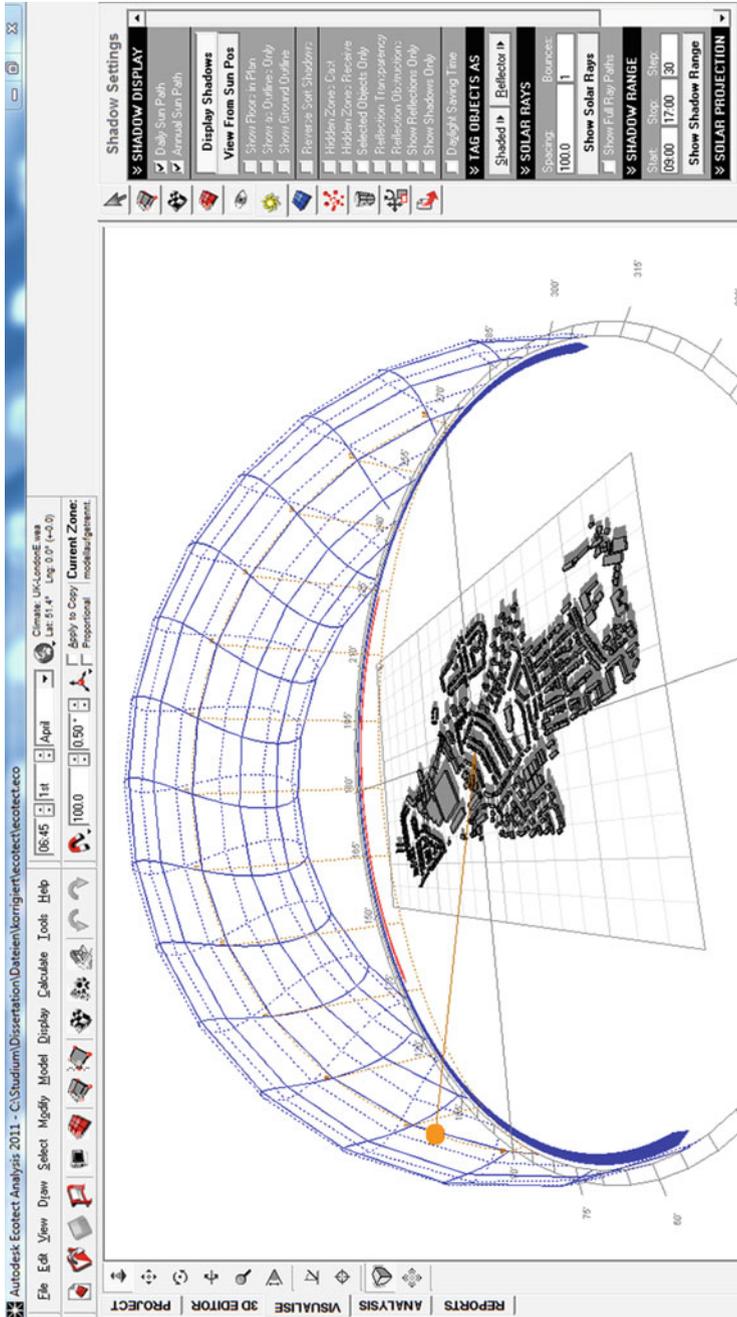**Fig. 4.1** Extract of attribute table containing all model information

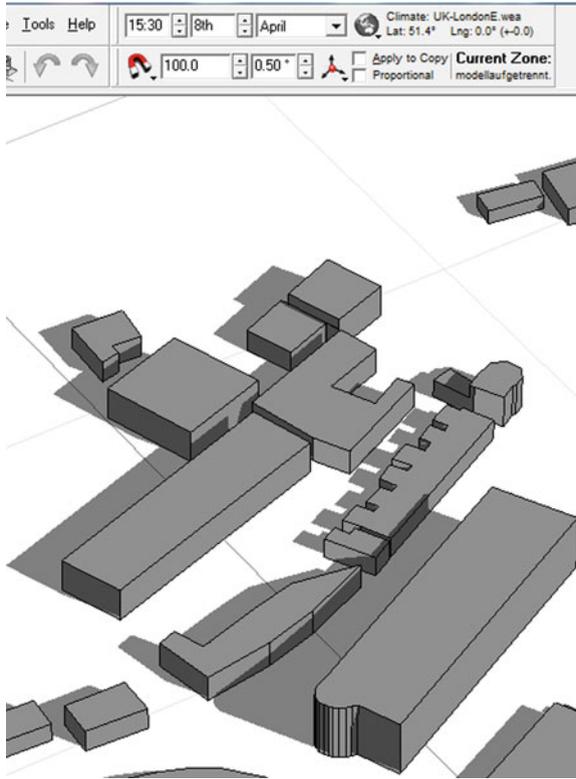**Fig. 4.2** Autodesk Ecotect with 3D model showing daily/annual sun path and shading

Fig. 4.3 Shading effects in Autodesk Ecotect and loaded weather file for London seen in toolbar

Fig. 4.4 3D model loaded into Google Earth

Quality Analysis of OSM-Data

The Ordnance Survey MasterMap data was chosen as the reference data set for the data quality analysis. It is the most accurate and detailed topographic data set available for the UK. Such data can be purchased from Ordnance Survey (OS) and are accessible via Digimap. Topographic—and network layers of MasterMap—are provided as GML 2.1.2 files. The data update frequency is every six weeks and its overall accuracy amounts to one metre. The data are structured in several layers and themes as administrative boundaries, buildings, heritage and antiquities, land, rail, roads, tracks and paths, structures, terrain and height, as well as water (Ordnance Survey 2010). The topography layer with its different themes is presented in Fig. 4.5. In addition, a very detailed integrated transport network layer (ITN) is contained in OS MasterMap. Road network information (e.g. road categories (A-road, B-road)) and road routing information is stored in this layer. These data make it possible to set up a routing network with ArcGIS Network Analyst.

With *ESRI Productivity Suite,* the OS MasterMap *.gml files could be transformed to ESRI shapefiles. Here, OS data sets are referenced in the British grid GCS_OSGB_1936 which is a transverse Mercator projection. After loading the OS MasterMap data in ArcGIS, there is an offset of over 100 m to the OSM data set which is referenced in the UTM zone 30N projection.

A transformation to the UTM coordinate system has been undertaken by using the projection tool "*British grid to UTM zone 30N England*" provided by ArcGIS. After transforming the OS MasterMap data, an offset of 2–4 m still remains. To achieve a more accurate result, the transformation was undertaken by a projection whose parameters were defined manually. A translation in *x* and *y* direction was conducted (−113.5 m in Y-axis direction and 20.8 m in X-axis direction)
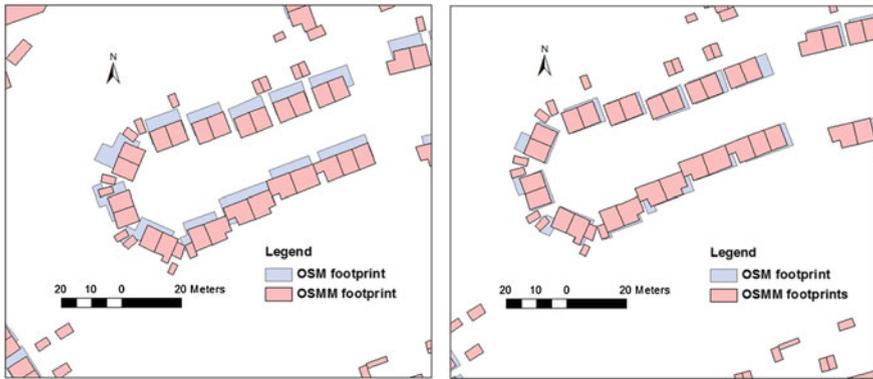
Fig. 4.6 *Left* transformation with predefined projection tool. *Right* transformation with manually defined projection

(Fig. 4.6). The data processing steps for the OSM data quality analysis are presented in Fig. 4.7.

In order to analyse the relative positional accuracy of OSM building footprints, these were intersected with OS MasterMap. As a result, the common areas of both footprints were determined and compared against the total area of the OSM. Two analyses of OSM footprints were undertaken. Firstly, the OSM raw data footprints (condition of data after downloading from OSM Server) and secondly, the adjusted footprints used for the 3D city model (adjusted by author with the Java-OSM editor) were intersected with OS MasterMap footprints.

OSM footprint raw data contain many ancillary buildings which were not used for the 3D city model. This explains the difference of about 17,000 m^2 footprint area between OSM raw data footprints and adjusted OSM footprints. OS Master-Map data also contain some outbuildings and, therefore, exhibit a greater footprint area than the adjusted OSM data used for the 3D city model (7,828 m^2 more footprint area). The coverage in percentage reveals that OSM raw data footprints (83 %) and adjusted OSM footprints (87 %) are of high quality in terms of positional accuracy and are, therefore, suitable as a 2D element of 3D city models. Adjusting OSM data in JOSM is very time intensive, and the results show the differences between OSM raw data and adjusted OSM 3D city model data are not very significant. However, by developing the model to the third scale (3D), such inaccuracies are multiplied and hence will carry more weight.

As OSMM data have an accuracy of 1 m, it is possible to determine the absolute positional accuracy of the 83 % of the OSM raw data footprints and 87 % of the adjusted OSM footprints, which cover the OSMM. For a more meaningful analysis in terms of absolute positional accuracy, the OSMM footprints were scaled by 1 m and intersected with OSM footprints. Now, 95 % of the OSM raw data footprints and 98 % of the adjusted OSM footprints are covered by the 1 m-scaled OSMM footprints and therefore can be determined as 2 m accurate (Table 4.1).
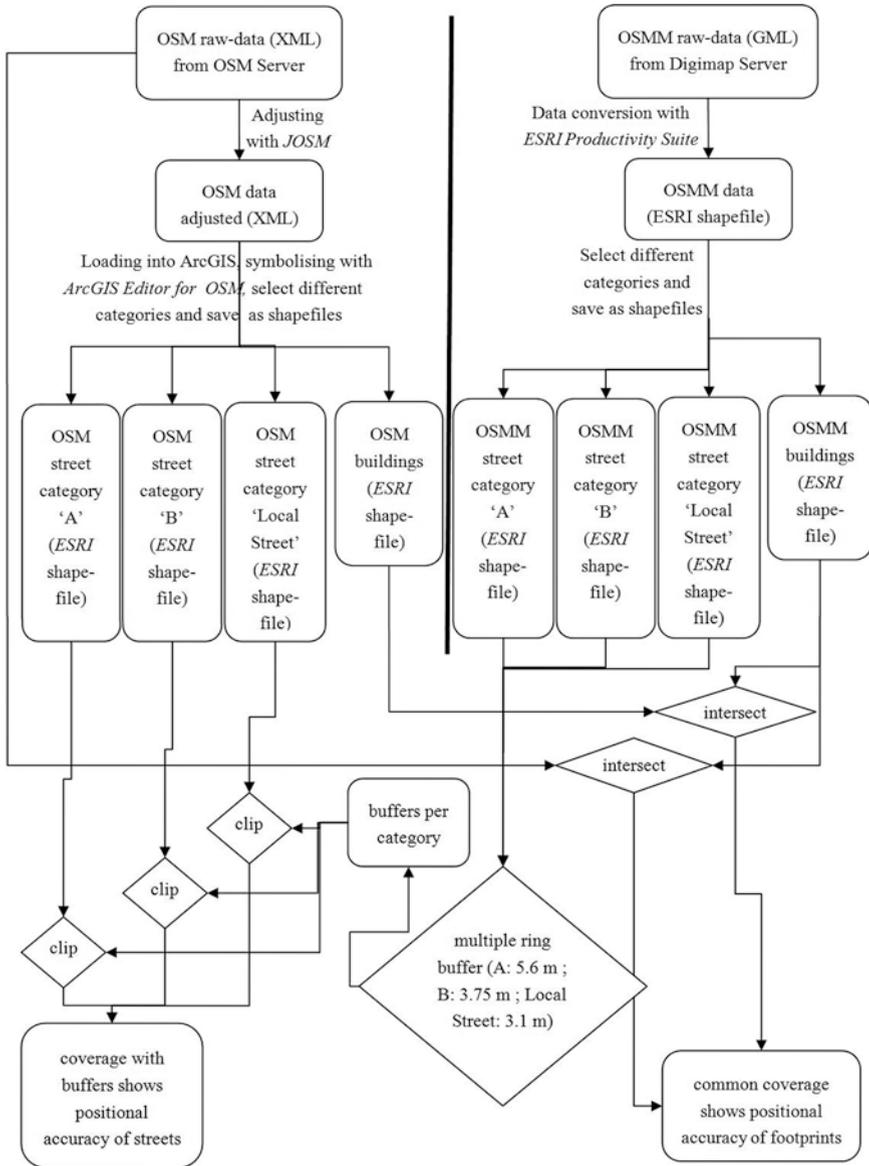
Fig. 4.7 Data processing steps for the OSM data quality analysis

The completeness of the building footprints is analysed by determining whether parts of the buildings or even whole buildings are either missing or are obsolete. First, the OSM raw data footprint area was compared with the total area of OS MasterMap raw data footprints. Comparing the total footprint area of OSM raw data within the coverage area with OSMM raw data footprints, a difference of 33,682 m^2

Table 4.1 OSM building footprint relative positional accuracy

	OSMM	OSM raw data	Adjusted OSM data
Total area footprints (m^2)	191,328	200,834	183,500
Coverage with OSMM (m^2)	–	167,152	159,072
Coverage with OSMM (%)	–	83	87
Coverage with OSMM (1 m scaled) (m^2)	–	192,425	179,920
Coverage with OSMM (1 m scaled) (%)	–	96	98

Table 4.2 OSM (raw data) building footprint completeness

	OSMM (raw)	OSM (raw)
Total area footprints (m^2)	191,328	200,834
Coverage with OSMM raw data footprints (m^2)		167,152
Difference "total OSM raw footprint area" to "coverage with OSMM raw data footprints" = obsolete footprint area (m^2)	–	33,682
Obsolete data (%)	–	17
Difference "total OSMM raw footprint area" to "coverage with OSMM raw data footprints" = missing footprint area (m^2)	–	24,176
Missing data (%)	–	13

(17 %) can be determined. This means that 17 % of OSM raw data footprint area is obsolete. Taking the total OSMM raw data footprint area and calculating the difference again—to the coverage area of OSM raw data footprints with OSMM raw data footprints—the result is 24,176 m^2 (13 %). This implies that 13 % of OSMM raw data footprint area is missing in OSM (Table 4.2).

Now, comparing both adjusted data sets in terms of completeness (if whole buildings are obsolete or are missing in OSM), it is possible to conclude that 99 % of the buildings in Hackbridge are mapped in OSM (Table 4.3).

The results of the comparison between OSM and OSMM building footprints for raw and adjusted data indicate the OSM footprints perform well in terms of

Table 4.3 OSM (adjusted data) building footprint completeness

	OSMM (adj.)	OSM (adj.)
Total area footprints (m^2)	179,119	181,632
Coverage with adjusted OSMM footprints (m^2)		159,067
Difference "total adj. OSM footprint area" to "coverage with adj. OSMM footprints" = obsolete footprint area (m^2)	–	22,565
Obsolete (%)	–	12
Difference "total adj. OSMM footprint area" to "coverage with adj. OSMM footprints" = missing footprint area (m^2)	–	20,052
Missing data (%)	–	11

footprint completeness. The comparison of adjusted OSM footprints with adjusted OS MasterMap footprints is an analysis which only highlights the features that are relevant for a 3D city model. Therefore, it indicates the quality and suitability of OSM data in terms of 3D city modelling. The results reveal that the adjusted OSM footprints perform better than the OSM raw data footprints in terms of footprint completeness and are therefore more suitable as a 2D element of the 3D city model. Editing OSM data in JOSM manually results in an improved completeness performance (especially obsolete OSM data can be detected and deleted). The footprint completeness is especially important when using the footprints for a 3D city model tasked with analysing building energy performance where figures such as volume and shape need to be calculated.

From these OSM footprints, it is possible to draw the conclusion that OSM raw data perform well in terms of positional accuracy (83 % coverage) and that manually adjusted OSM data perform slightly better (87 % coverage). With OS MasterMap as the reference data set and accuracy of 1 m, it is possible to note, that 83 % respectively 87 % of OSM data is positionally accurate within a 1-m range, and 95 % (OSM raw data) respectively 98 % (adjusted OSM data) is accurate within a 2-m range. The analysis, however, does not reveal the extent to which the missing 5 % (respectively 2 % of the footprint area) is inaccurate. The general completeness of OSM raw data performs well (17 % obsolete and 13 % missing footprint area), but focusing merely on the footprints (which are relevant for the 3D city model), the adjusted OSM 3D city model data perform better than OSM raw data (12 % obsolete and 12 % missing footprint area).

Overall, it is recognised that OSM data offers a suitably accurate 2D component of a 3D city model. A factor contributing to inaccuracies occurs when OSM footprints are measured from the top and therefore represent the shape of the roofs and not the exact footprint on the ground. It is believed that the roof shape is the same as the footprint shape. In cases of eaves, slight variances can occur to the actual footprints as they are existent in OS MasterMap. While this analysis only applies for the case study area of Hackbridge in the London Borough of Sutton, the results are also valid for bigger cities in Europe.

A second method to determine the quality of OSM data is to compare street networks with a specific reference data set. This method is commonly used and dealing with OSM data quality analysis. This study will compare OSM street networks with OS MasterMap street. To determine the relative positional accuracy of streets, the street networks of OSM and OS MasterMap are overlaid. An initial look reveals a good congruence performance (Fig. 4.8).

The relative positional accuracy has been analysed by using the method provided by Goodchild (2007), which stipulates that buffers are created around the reference street network to calculate the extent the tested streets are covered by these buffers. Streets are classified in their OS MasterMap road categories (A-road, B-road and local street) and will be compared to their OSM street category equivalent which visualises the OS MasterMap street network of Hackbridge underlain with a satellite picture (Fig. 4.9).

Fig. 4.8 Overlay of OSM street network and OSMM street network
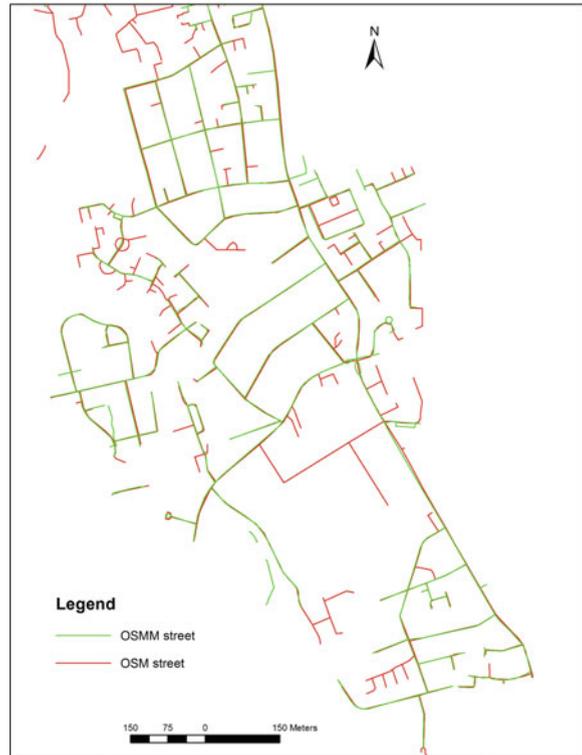
To enable a meaningful analysis, the OSM street categories had to be adjusted so that they can be compared to their equivalent OS MasterMap street category. OSM streets are categorised as either "residential" or "service" and had to be grouped to match the OSMM "local street" category. The buffer widths vary per street category and are adopted from Ather's work (2009). Ather (2009) took street width information from the House of Commons Hansard Written Answers (UK Parliament 2003). The road widths per street category and the derived buffer widths are presented in Table 4.4.

The different OSM street categories were then overlaid with the buffer of the respective OS MasterMap street category, and overlapping street passages were cut off by using the ArcGIS tool "clip." OSM street passages lying within a buffer zone are declared to be of good quality in terms of relative positional accuracy. Street passages lying outside a buffer zone are considered as inaccurate. A limitation of this method is that it does not detect the absolute distance error of a false position. Comparing the length of each OSM street category which lie within a OS MasterMap buffer zone, with the total length of the respective OSM street category, it is possible to draw conclusions about the positional accuracy of OSM street data. A-roads have a 100 % congruency with OS MasterMap data, and B-roads reveal 99 % congruency and local streets 94 % (see Table 4.5).
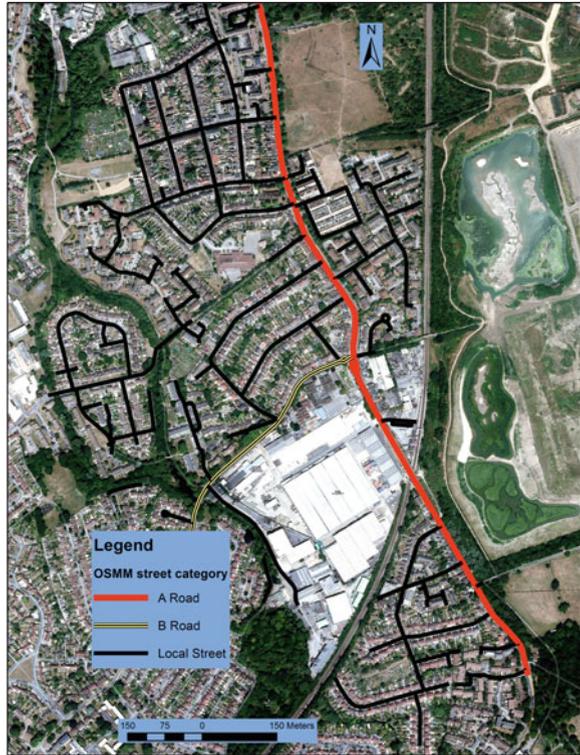
Fig. 4.9 OSMM street
network of Hackbridge

Table 4.4 OSMM street
categories with street and
buffer width (UK Parliament
2003)

	Street width (m)	Buffer width (m)
A-road	11.2	5.6
B-road	7.5	3.75
Local street	6.2	3.1

Overall, one can conclude that OSM street data are in general of high quality in terms of relative positional accuracy. This shows a clear trend is evident whereby congruency increases with the level of a street category.

However, the buffer method uses generalised measures which do not properly represent the actual street area. This method is still a good indicator for positional accuracy, but for a more meaningful result, a more accurate representation of the street actualities is necessary as a reference. In its topographical layer, OS MasterMap is accurate to 1 m. This "street area" will help to provide a more accurate analysis of OSM street data positional accuracy. Similar to the buffer method, OSM data were overlaid and cut with OS MasterMap street area. The congruent street passages characterised the highly accurate OSM street data. Results indicate that accuracy numbers are similar to those of the buffer method (A-road 94 %, B-road 100 % and local streets 92 % congruency). The 94 % congruency of A-roads do not

Table 4.5 Relative positional accuracy of OSM street network

|	OSM (m)	Congruency with OSMM buffer (m)	Congruency (%)	Congruency with street area (m)	Congruency (%)
Length A-road	1,849	1,849	100	1,745	94
Length B-road	563	560	99	563	100
Length local street	11,110	10,416	94	10,266	92

seem to fit into the trend, but in examining the reasons for this variation, OSM data was found to be highly inaccurate in a street passage in Hackbridge. After overlaying OS MasterMap with Google Maps satellite images, it was possible to identify the inaccurate data as being located on a street passage that leads over a bridge (Fig. 4.10).

Absolute positional accuracy of the OSM street data can be detected by comparing the position of street nodes with each other. Street nodes are mostly located in the middle of street junctions. Fifteen street nodes of OSM and their 15 equivalent street nodes of OS MasterMap were chosen randomly. Figure 4.11 shows four of these 15 junctions. By measuring the distance between the respective nodes, the mean distance error (4.1), the empirical variance (4.2) and empirical standard deviation (4.3) can be calculated.

$$\bar{x} = \frac{1}{n} \sum_{k=1}^{n} x_k \tag{4.1}$$

$$s^2 = \frac{1}{n-1} \sum_{k=1}^{n} (x_k - \bar{x})^2 \tag{4.2}$$

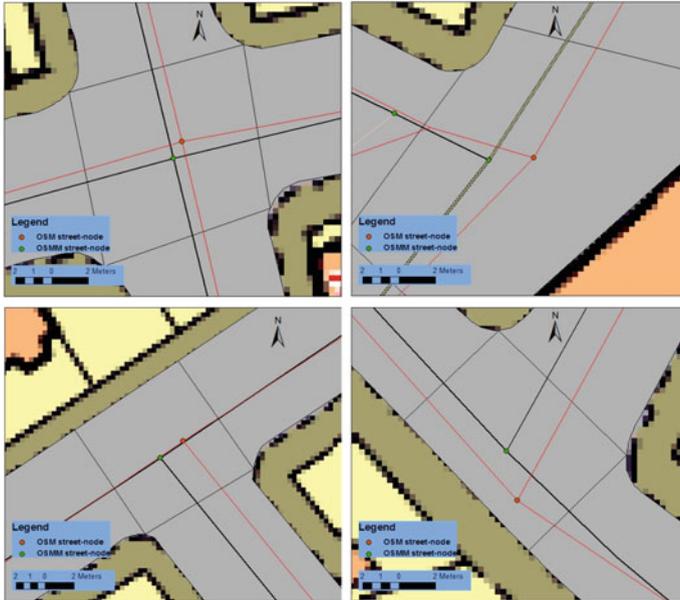**Fig. 4.10** Inaccurate OSM street (*red*) exceeds OSMM street area
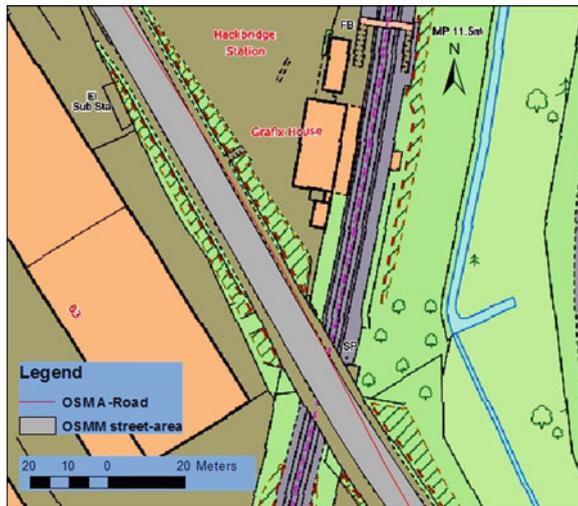
Fig. 4.11 Four of the 15 chosen junctions and street nodes used to calculate absolute positional accuracy of OSM data

$$s = \sqrt{\frac{1}{n-1}\sum_{k=1}^{n}(x_k - \bar{x})^2} \tag{4.3}$$

For the Hackbridge area, a mean distance error of $\bar{x} = 1.66$ m between OSM and OS MasterMap street nodes, an empirical variance of $s^2 = 0.55$ m and an empirical standard deviation of $s = 0.74$ m was determined. This reveals that OSM street data in Hackbridge are of very high quality in terms of absolute positional accuracy.

Ather (2009) has used the buffer method to determine relative positional accuracy of OSM data in four London areas (total street length: 298 km). For A-roads, he examined an average accuracy of 89 % and for B-roads, an average accuracy of 76 %. His work did not cover the local street category. The results for the OSM streets' positional accuracy are slightly worse compared to those for Hackbridge which could be due to the larger analysed area. The Hackbridge area is much smaller than Ather's study areas and therefore, results are less representative than his study. However, this case study has used new analytical methods which, when combined with each other, lead to highly representative and accurate results.

To determine the completeness of OSM street data, a simple comparison of OSM street length to OS MasterMap street length was undertaken. By comparing the total street length of OSM and OS MasterMap data sets, a conformity of 77 % in

Table 4.6 Completeness of OSM streets

	OSMM (m)	OSM (m)	Length conformity (%)
Total street length	14,251	18,469	77
Length A-road	1,884	1,849	98
Length B-road	545	563	97
Length local street	11,353	11,110	98

length was identified. This shows a good quality of OSM street data in terms of data completeness. Differences can occur through different classifications and missing/obsolete data (e.g. tracks located within parking areas are included in the OSM street data set, whereas they are not in OS MasterMap data). OSM data of the Hackbridge area reveal an even higher total street length than OS MasterMap data. By examining the completeness of the different street categories, it is possible to detect that all three categories have almost the same result (ca. 98 %). This shows that OSM street data in Hackbridge are of high quality in terms of data completeness. It is also possible to conclude that OSM data completeness within bigger cities can perform better than purchased geographic data (Table 4.6).

The slight difference in length conformity of the B-road category can be explained by inconsistencies in data capture. This is especially the case when many untrained users gather geographic data for the same project. In this case, a street passage was uploaded twice, resulting in two street lines instead of just one. This inconsistency is located in the middle of a bridge (Fig. 4.12).

Fig. 4.12 Two OSM street lines
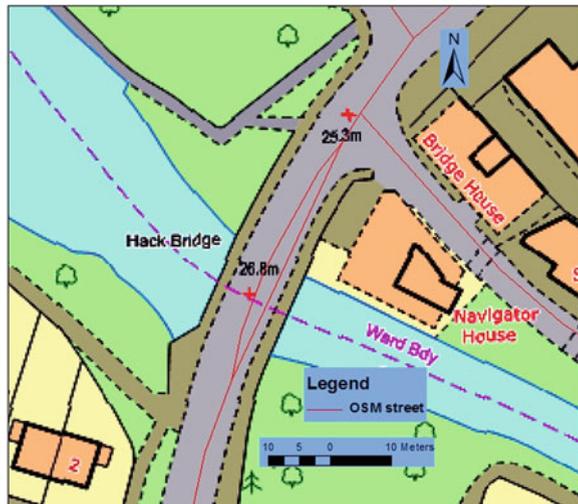
To determine an "a priori" accuracy of OSM data is very difficult, as many input parameters are unknown. OSM volunteers use different GPS receivers which can achieve different accuracies. GPS accuracies also depend on shadowing (trees or high buildings nearby), the degree of multi-way errors (e.g. how many signals are reflected from a wall), the constellation of the satellites' position or the influence of the Ionosphere. Another method to collect OSM data is the digitalisation of objects with the help of satellite pictures. Here, the accuracy is dependent upon the satellite pictures and the motivation of the volunteer. As some of these parameters are hardly measurable, the absolute positional accuracy of OSM data in Hackbridge could only be determined numerically by comparing OSM data with a reference data set whose accuracy is known (OSMM data).

3D City Model Analysis

The following shall draw upon this 3D city model to analyse the energy consumption and CO_2 emission from the area in question. Particular attention will be drawn to the impact of urban morphology on both measures. In general, it is seen that extreme values for the footprint shape length (accumulation of all footprint lengths), either for the footprint area or the volume, indicate a good energy performance (very high values) or a bad energy performance (very low values). However, considering merely single parameters is a very limited, so a combination of different values, expressed as a ratio shall be presented.

Presentation of Energy Consumption and CO₂ Emission

To relate urban morphology to energy consumption and CO_2 emission, it is essential to determine how energy consumption and CO_2 emission are defined. A starting point would be to take the total amount of energy consumption or CO_2 emission for one building block. This shows large buildings have the highest energy consumption and CO_2 emission levels. This is not surprising as such buildings comprise of many households and therefore multiply their energy demands and CO_2 emission by such magnitudes. Perhaps, a better way to represent energy performance would be to divide the total figures by a building's volume. With this measure, the energy consumption or CO_2 emission per cubic metre is calculated. This ratio is already a very good representation of energy performance (as an expression of energy consumption and carbon emission) as it considers a building as a 3D volume object. An even better and more holistic presentation would be to take the number of occupants per building block into account. Energy consumption and CO_2 emission in such instances might then be related to the

number of people producing such levels of consumption and rates of emission. However, a consideration of both figures (per person and per volume) is advisable as a building ought to be energy-efficient (per volume) but should also be used efficiently in terms of population density (per capita).

When comparing the energy consumption of buildings with their shape, it is possible to note that there is a relation to the shape-length-to-area ratio. This ratio indicates the relation between a footprint's edge length and its area. It is a good indicator for building energy consumption in the case of high and low ratios. Generally, buildings with a low shape-length-to-area ratio have high energy consumption per volume, whereas high buildings with high ratios have low energy consumption per volume (Fig. 4.13).

Shape Length

As *shape length* and *area* are 2D elements, it is possible to argue that a 3D scale is not needed in order to draw conclusions about the building shape with regard to energy consumption and CO_2 emission. However, by comparing buildings with the same shape-length-to-area ratios, it soon becomes clear differences in terms of energy consumption and CO_2 emission do occur. Table 4.7 and Fig. 4.14 presents a comparison between various blocks of residential properties in Hackbridge. This illustrates that by comparing object 147 with object 160, it is possible to show how energy consumption values between the two objects differ by 30 kWh/p.a., even though they have the same 2D shape-length-to-area ratio. This suggests such a ratio is not always a good indicator of either energy consumption, or carbon emission. The reason for the different performances for these two buildings can only be explained in relation to the significant difference in height (4 m). As such, another ratio must be found which considers also the third scale (height). The surface-to-volume ratio is such a ratio. The surface-to-volume ratio of both buildings differs by 0.1 and is considered a better indicator for energy consumption.

Surface-to-Volume Ratio

The surface-to-volume ratio of buildings of this model was calculated as follows:

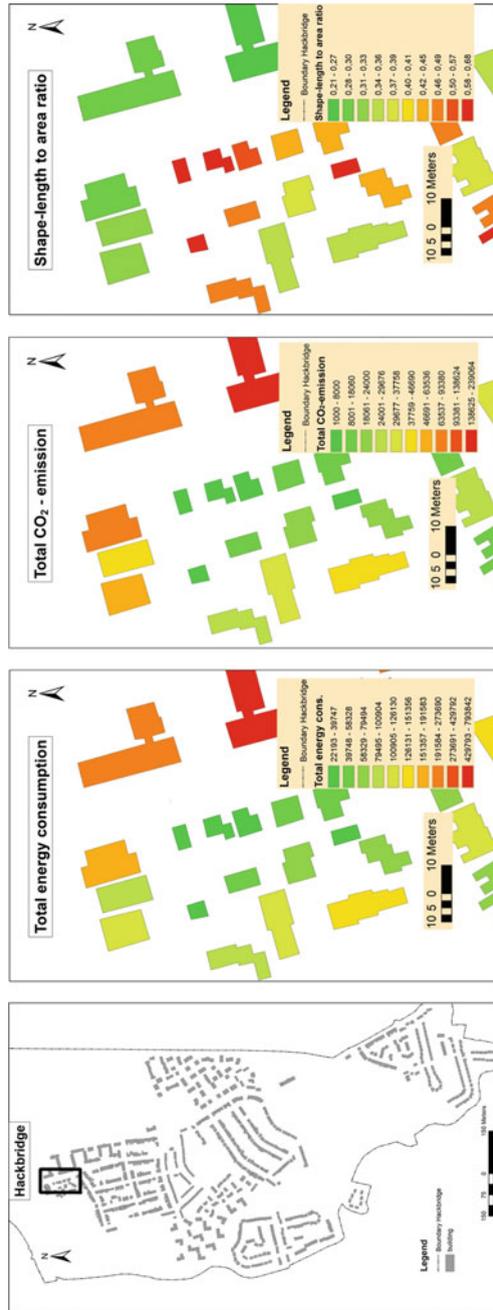$$STVR = \frac{\text{over-ground envelope surface}}{\text{built volume}} \tag{4.4}$$

Fig. 4.13 Shape-length-to-area ratio in Northern Hackbridge

Table 4.7 Comparison between shape-length-to-area and CO_2 emission

Object ID	Height	Shape-length-to-area ratio	STVR	Energy_per vol (kWh/year)	CO_2 per vol (kg/year)	Street
157	5.5	0.40	0.58	133.16	35.21	Kingswood Drive
239	6.5	0.39	0.55	62.03	17.04	Furlong Close
147	9	0.29	0.40	70.94	30.51	Foxglove Way
160	5	0.30	0.50	102.20	27.02	Furlong Close
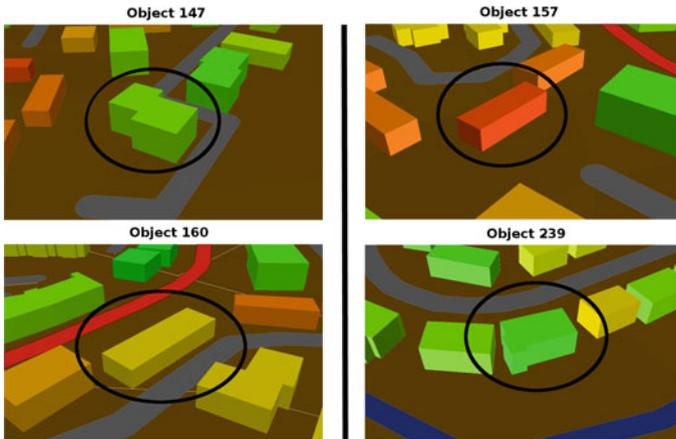
Fig. 4.14 Comparison between shape-length-to-area ratio and energy consumption. Colour indicates energy consumption (from *green* = low to *red* = high)

with:

$$\text{over-ground envelope surface}$$
$$= \text{area}_{\text{footprint}} + \left(\text{lengths all edges}_{\text{footprint}} * \text{height} \right) \tag{4.5}$$
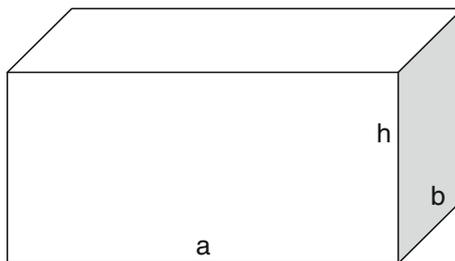
Having a cuboid building shape with the footprint-edges "a" and "b" and with the height "h," the formula for the *surface-to-volume ratio* would be:

$$f(a,b,h) = \frac{2ah + 2bh + ab}{abh} \tag{4.6}$$

This formula assumes that heat loss only takes place through the over-ground building envelope area and not through the ground. The smaller the ratio, the less is the heat loss through the building envelope area, meaning that the perfect building shape is the highest volume together with the minimum envelope area. With any such increase in built mass, the growth of the envelope is quadratic, while the increase in volume is cubic. This means, the higher a built mass, the better the STVR. In order to calculate a perfect shape, the volume and the ground area has to be defined as constant to render it possible to solve the extremum problem. For clarity, this mathematical calculation was divided into two steps. First, the perfect 2D shape and second, the perfect 3D shape were determined. Calculations were undertaken with the help of the math software *Maple*.

The formula to calculate the area of a rectangle is:

$$A = a * b \tag{4.7}$$

The perimeter of a rectangle amounts:

$$P = 2a + 2b \tag{4.8}$$

As A is constant, it is possible to solve (4.7) for a and insert this in (4.8) to get (4.9):

$$P(a) = 2a + \frac{2A}{a} \tag{4.9}$$

Now, the minimum edge lengths to equal the constant area "A" have to be calculated. Therefore, (4.6) needs to be derived with respect to "a" (4.10), zeroised (4.11) and dissolved for "a" (4.12):

$$P'(a) = 2 - \frac{2A}{a^2} \tag{4.10}$$

$$0 = 2 - \frac{2A}{a^2} \tag{4.11}$$

$$a_1 = \sqrt{A}; \quad a_2 = -\sqrt{A} \tag{4.12}$$

As a_2 makes no sense as a measure of length, the result for a is $\sqrt{A}$. The second derivative of P with respect to "a" is positive (4.13) so a_1 is a minimum.

$$P'(a) = \frac{2A}{a} > 0 \tag{4.13}$$

Inserting "a" into (4.7) and solving the equation for b, it equals $\sqrt{A}$. The perfect shape for a rectangle to achieve the area A with a minimum edge-length is therefore a quadratic one.

In the second step, the minimum overground envelope surface for a constant volume and a quadratic ground area needs to be determined. The formula for the overground envelope surface is:

$$S = 2ah + 2bh + ab \tag{4.14}$$

The volume is calculated as follows:

$$V = abh \tag{4.15}$$

V is set as constant, so (4.15) can be solved for "h" and insert in (4.14):

$$S = 2a * \frac{V}{ab} + 2b * \frac{V}{ab} + ab \tag{4.16}$$

As the ground area is quadratic "b" equals "a" and be substituted with "a:"

$$S = 2a * \frac{V}{a^2} + 2a * \frac{V}{a^2} + a^2 \tag{4.17}$$

Summarised it is as follows:

$$S(a) = \frac{4V}{a} + a^2 \tag{4.18}$$

To determine the minimum overground envelope surface for a constant volume and a constant ground area (4.18) needs to be derived with respect to "a" (4.19), zeroised (4.20) and dissolved for "a" (4.21):

$$S'(a) = -\frac{4V}{a^2} + 2a \tag{4.19}$$

$$0 = -\frac{4V}{a^2} + 2a \tag{4.20}$$

$$2V = a^3 \tag{4.21}$$

Equation (4.15) is now to be inserted in (4.21):

$$2a^2h = a^3 \tag{4.22}$$

And (4.22) solved for h:

$$h = \frac{a}{2} \qquad (4.23)$$

The perfect shape for a minimum overground envelope surface for a constant volume and a constant ground area would therefore be half a cube, cut horizontal in the middle. The geometrical shape with the lowest surface-area-to-volume ratio would be a sphere.

Comparing the *surface-to-volume ratio* with energy consumption per capita, it is noticeable that the STVR is a better indicator for energy consumption than the shape-length-to-area ratio, especially for very small or very large buildings (Fig. 4.15).

But for some houses in Hackbridge, the STVR provides little information about a building's energy performance. This indicates that there must be other morphological parameters which influence energy consumption and CO_2 emission in addition to the heat loss through outside walls (indicated by the STVR). This assumption is backed up by the second comparison shown in Table 4.7 between object 157 and object 160. For while here the STVR is almost the same, both buildings exhibit significant differences in energy consumption and CO_2 emission (Fig. 4.14).

Passive Volume-to-Volume Ratio

For this energy related ratio (passive volume-to-volume ratio), all areas located within a 6 m distance to exterior walls of a building have to be determined. With the help of the ArcGIS buffer tool, buffers of 6 m length were drawn on each side of building footprint polygons. The buffers were exported to AutoCAD, and the buffer lines located outside the footprints were deleted. With the help of AutoCAD 3D tools, the buffers were then extruded and cut with the existing building solids. Figure 4.16 shows a building solid (green) with the respective buffer solid (red) in AutoCAD.

The buffer footprints were exported back to ArcGIS and joined to their equivalent footprint polygons. Since buffers differed from building footprints in terms of area and x-coordinate, they had to be joined manually. As most building blocks in Hackbridge exhibit edge lengths of less than 12 m only a few of them contain non-passive areas. Having been able to determine the area and height for each buffer the passive volume-to-volume ratio could be calculated for each building block. Figure 4.17 shows the buffer zones in ArcMap.

Ratti et al. (2005) consider the PVTVR as a better indicator for energy consumption and CO_2 emission than the STVR. Hackbridge reveals a high percentage of passive volume which results from the suburban character of this area. Single edges of the footprints seldomly exceed the required 12 m to form a non-passive
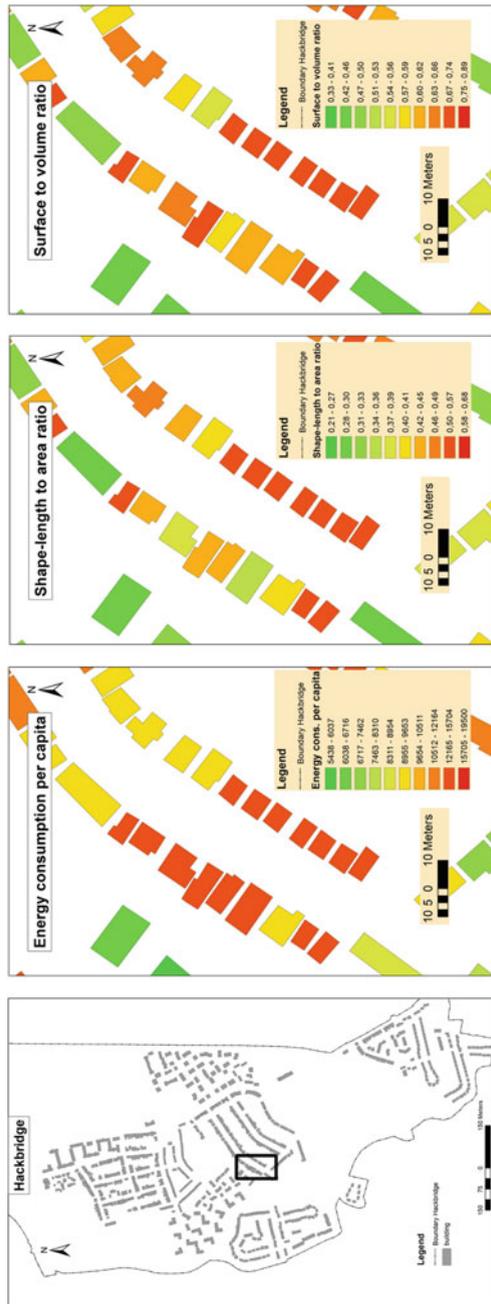
Fig. 4.15   Shape-length-to-area ratio and STVR in Northern Hackbridge

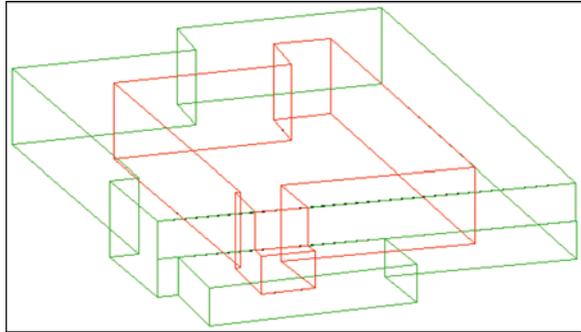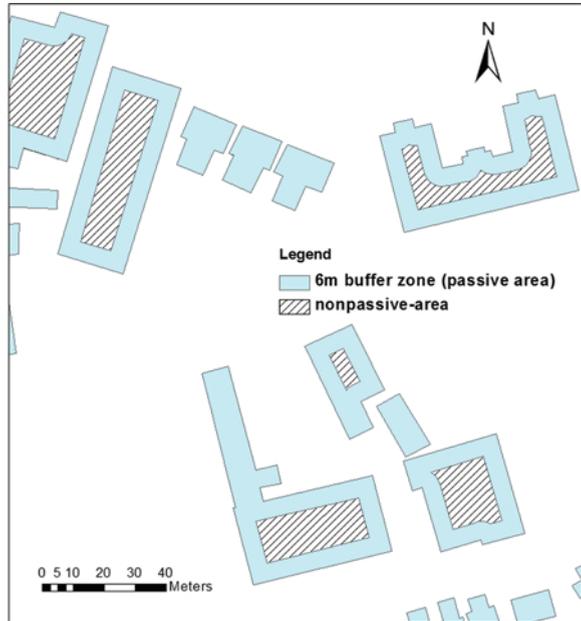**Fig. 4.16** Building solid (*green*) and buffer solid (*red*) in AutoCAD

Fig. 4.17 Six metre buffer zones and passive and non-passive areas

zone (25 out of 555 blocks exhibit non-passive zones). This is in contrast to the case studies of Ratti et al. (2005) and Salat (2009) carried out in the centres of European cities, characterised by large building blocks (see Fig. 4.18).

As urban morphology considers not only the built volume, but also empty spaces (Salat 2009), the empty spaces between footprints were also calculated for this examination. Haq (2011) highlights that inner city green empty spaces can help to decrease building energy consumption. They function as a heat absorber in summer, while keeping warmth and absorbing cold winds in winter. Both effects help to lower the buildings' energy consumption and rates of CO_2 emission. Green areas also reduce air and noise pollution in urban areas (Haq 2011). Buildings in Hackbridge surrounded by green empty spaces reveal a lower than average energy
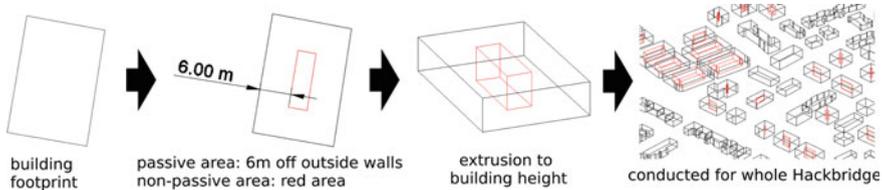
Fig. 4.18 Construction of passive and non-passive volumes

consumption and CO_2 emission. The average empty space between buildings in Hackbridge is five times higher than empty spaces in the centre of London, Toulouse, Berlin or Paris. However, the input data of this case study are insufficient to detect the full impact of empty spaces on a city's energy consumption and CO_2 emission.

The SVTR, PVTVR and empty space values for Hackbridge are presented in Table 4.8. This sets out the mean energy consumption and CO_2 emission for Hackbridge (suburb), London (centre), Berlin (centre) and Paris (city). Such figures are not available for the work of Ratti et al. (2005). In considering the coverage of these three studies, it should be noted that Salat's (2009) study area (the whole of the Paris metropolitan city-region) covers a much greater area than either the study from Ratti et al. (2005), or this examination of Hackbridge. In Ratti et al. (2005), the study areas are small metropolitan inner city residential areas within large building blocks. Although the ground floor areas of the Hackbridge case study and those of London, Toulouse and Berlin are similar, there is a significant difference in unbuilt areas which differ by a factor of five. Hackbridge has a typical suburban morphological structure which is shown by having five times more unbuilt than built areas. The study areas in London, Toulouse and Berlin all reveal a higher proportion of built volume and have less ground floor area than Hackbridge.

These differences in urban morphology are mirrored by the STVR and PVTVR. The mean STVR for Hackbridge (0.488) is much higher than for the inner city areas of London (0.216), Toulouse (0.248) and Berlin (0.169). This indicates the buildings within Ratti et al.'s (2005) study areas are more vulnerable to heat loss through exterior walls than buildings in Hackbridge. However, in terms of the PVTVR, Hackbridge's residential buildings reveal a much higher potential for using natural ventilation and day/sunlight (99 % passive area) than either the Ratti et al. (75 %) study of London, Berlin and Tolouse, or Salat's (2009) examination of Paris (82 %).

The mean energy consumption of ground floor residential buildings (m^2) in Hackbridge (539 kWh/m^2/y p.a.) is twice as high as such of Paris (247) and London (253). Berlin shows the lowest level of energy consumption (144). However, while this tends to suggest scale does in fact matter and Paris offers evidence as to the existence of "economies in scale," it should be noted Salat (2009) only considers heating demand for his energy and CO_2 calculations, whereas the energy and CO_2 calculations for this predominately suburban case study also consider the

Table 4.8 SVTR, PVTVR and empty space values

	Inner city-district neighbourhood			Suburban city-district	Metropolitan city-region
	London	Toulouse	Berlin	Hackbridge	Paris
Dimension of study area (km²)	~0.03	~0.03	~0.03	~1.7	~105
Ground floor area (m²)	89,663	64,368	55,978	91,778	67,000,000
Unbuilt area (m²)	70,377	95,632	104,022	481,803	38,000,000
Built volume (m³)	1,221,499	966,768	1,042,199	616,839	580,000,000
Vertical surface (m²)	174,757	174,888	119,698	209,411	
STVR	0.216	0.248	0.169	0.488	
PVTVR [%]	77	84	61	99	82
Unbuilt area ratio	0.785	1.486	1.858	5.250	0.567
Energy consumption (kWh/m²/year)				539	247
CO_2 emission (kg per capita)				2.796	0.338

consumption of energy serving all thermal, lighting, power and heating demand. This perhaps goes some way to explain the marked difference in energy consumption and in particular, CO_2 emission between Paris and Hackbridge. For as can be seen, energy consumption in Paris seems to cause significantly less CO_2 emission than in Hackbridge. The explanation for this however may rest as much with the source of the supply than with the value of analysing the urban morphology of cities at such scales. This is because in Paris nuclear fuel makes up a significant contribution to energy supply and consumption is less dependent on energy sourced from fossil-based fuels, such as coal, oil and gas, all of which lead to a higher rate of carbon emission.

Building Age

Building ages are also an indicator of urban morphology, as blocks with the same building age often exhibit similar performances. For example, buildings in Hackbridge which were constructed after 1990, reveal a high percentage of empty spaces around them and have a small STVR (due to high building blocks). Buildings in the northern part of Hackbridge are mostly built in the early twentieth century, are more densely developed and exhibit a high STVR (due to small convoluted buildings). Therefore, comparing building age with energy consumption/CO_2 emission helps to draw conclusions about the morphological structure of energy consumption and CO_2 emission. Figure 4.19 presents energy consumption per capita for each building age group.
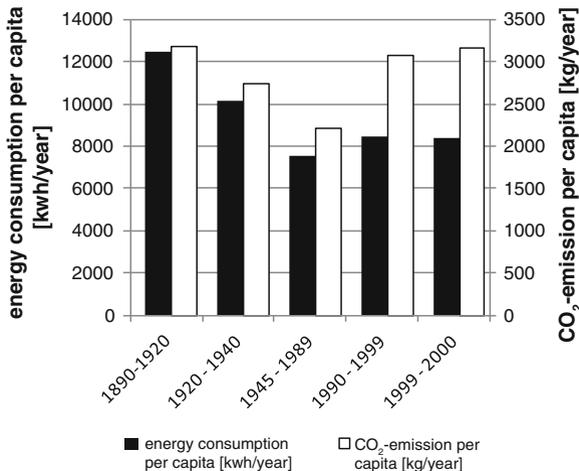

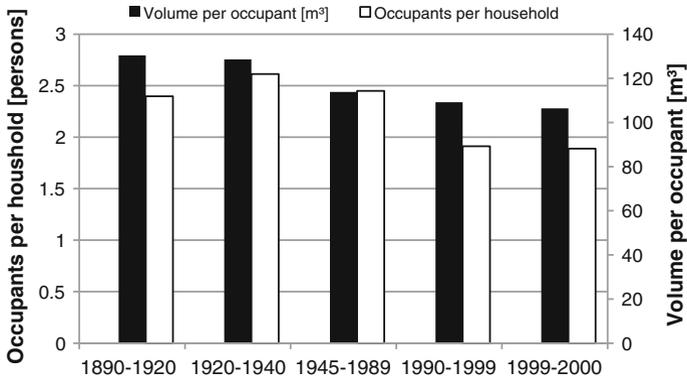**Fig. 4.19** Energy consumption/CO_2 emission per capita for each building age

Fig. 4.20 Occupants per household (persons) and volume per occupant (m^2)

In analysing Fig. 4.19, it is possible to observe that energy consumption per capita decreases in the range of buildings built between 1890 and 1989. After 1989, the level remains fairly consistent. As the energy consumption per built volume shows the same trend, it can be concluded that new buildings are generally more energy efficient than older buildings. This appears to have very little to do with either their STVR, or PVTVR, but explained in relation to the tendency for newer buildings to benefit from better insulation and more energy-efficient systems than older buildings. By considering CO_2 emissions, it is also noticeable that such values are not as dependant on the building age as level of energy consumption. For if we focus attention on new buildings, the level of CO_2 emission is about the same when compared to older buildings. This is because CO_2 emission is mainly affected by the use of electricity as a source of energy. As every household has a washing machine and a fridge which needs electrical power, this issue seems to be more dependent on the size of households than on the building age. Energy consumption still influences CO_2 emission as trends in Fig. 4.19 indicate, but this trend is interrupted for properties built after 1990, which suggests that people living in newer buildings (in this case mostly flats) have a higher level of demand for electrical power, which in turn helps explain the corresponding CO_2 emissions that are observed.

By comparing population density (built volume per occupant) with the average number of occupants per household, one can see that the trend is developing to a higher population density and a lower number of occupants per household. This emphasises the development in urban areas where large building blocks are built which consist of many small flats (Fig. 4.20).

Property Type

This section compares property types (house, semi-detached, terraced, flat) with energy consumption and CO_2 emissions per capita (Fig. 4.21), per volume (Fig. 4.22), and per household (Fig. 4.23).

In terms of energy consumption, it is possible to conclude the statistics per capita and by household follow a clear trend. In both cases, houses are the worst performer; semi-detached and terraced houses are in-between and flats perform the best. This is because houses have in general a higher energy consumption since
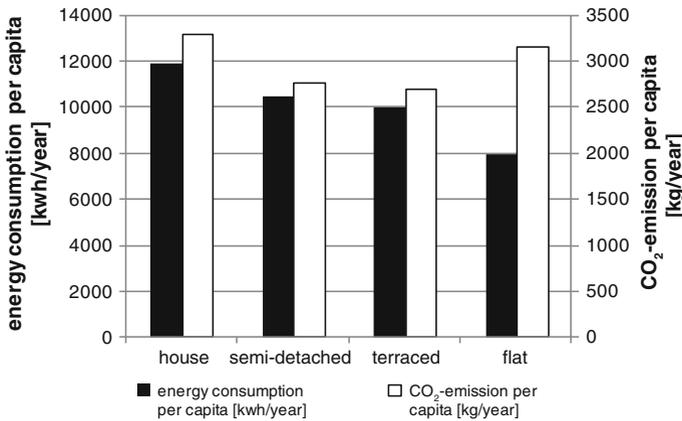

Fig. 4.21 Energy consumption/CO_2 emission per capita for each property type
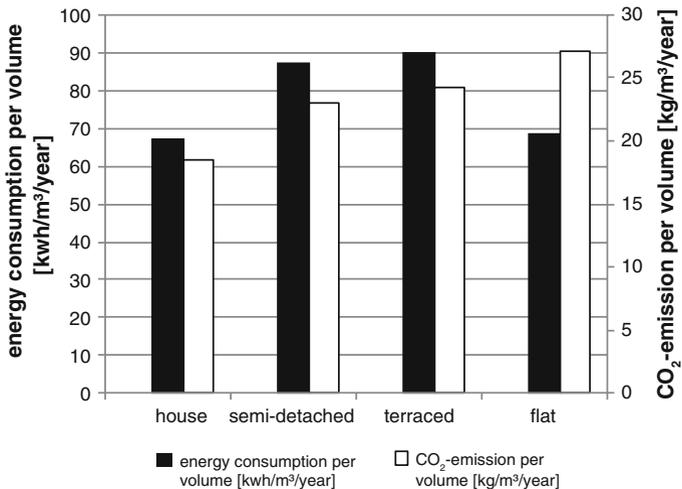

Fig. 4.22 Energy consumption/CO_2 emission per volume for each property type
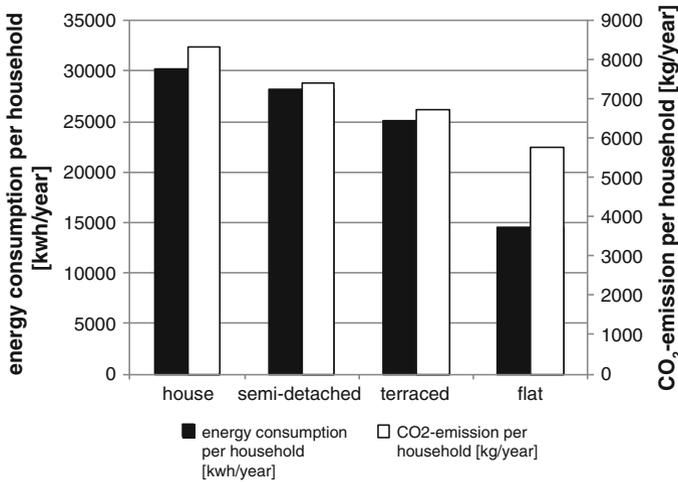
Fig. 4.23 Energy consumption/ CO_2 emission per household for each property type

there are no common walls, unlike for example; semi-detached houses. In addition, houses in the case study area are sometimes inhabited by only two occupants. These factors contribute to poor energy performance per capita and household. Breaking these factors down to smaller property types, shows this is the same for semi-detached houses and terraced houses or terraced houses and flats.

This indicates houses in Hackbridge are mostly aged between 1890 and 1940, and flats are built after 1990. This fact is another factor for the energy performance difference of both property types, as newer buildings are mostly built to a higher level of energy efficiency than older buildings. Looking at energy consumption per volume, houses perform better than semi-detached and terraced houses. Despite houses having high energy consumption figures, their built volume has a higher impact on energy consumption. This raises the question as to why flats, characterised by low building volume, still perform better than houses.

The CO_2 emission follows the trend of energy consumption in all three graphs, so energy consumption (generally caused by heating demand) has a high impact on the actual CO_2 emission. Similar to the comparison of building age to CO_2 emission performance, flats are again an exception. The CO_2 emission level stays relatively high for new build property types. Due to better insulation and more efficient systems (hot water boiler etc.), energy consumption for heating is mostly low, so the reason for high CO_2 emission lies in a high level of electrical energy demand (e.g. for electrical devices or electric heating). As flats are mostly located in big building blocks, their PVTVR is often low, and therefore, the potential for using natural ventilation and day-/sunlight is also lower. This leads to a higher electrical energy demand caused by mechanical ventilation and artificial lighting.

Visualisation Potential of the 3D City Model

Having the building stock as a digital representation in a 3D vector format enables a visualisation of several energy consumption and CO_2 emission themes in one map. Figure 4.24, for example shows the STVR by means of colour (red = high
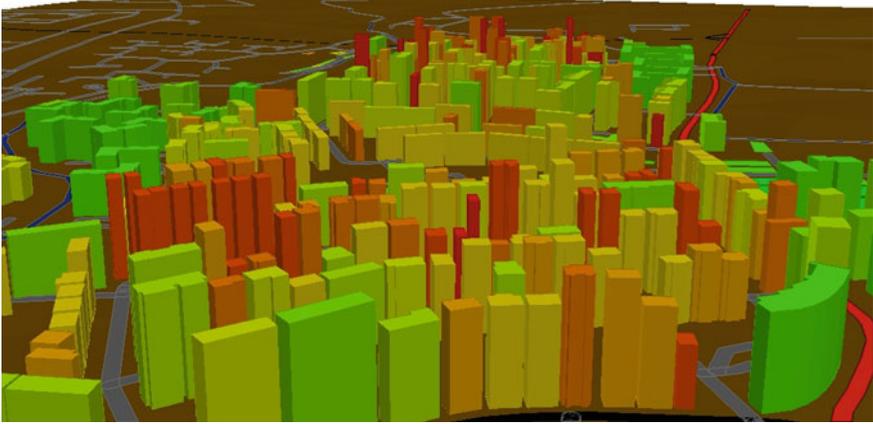

Fig. 4.24 Area of Northern Hackbridge presenting energy consumption per capita (visualised by height of extrusion) and the STVR (visualised by colour: from *red* = high ratio to *green* = low ratio)
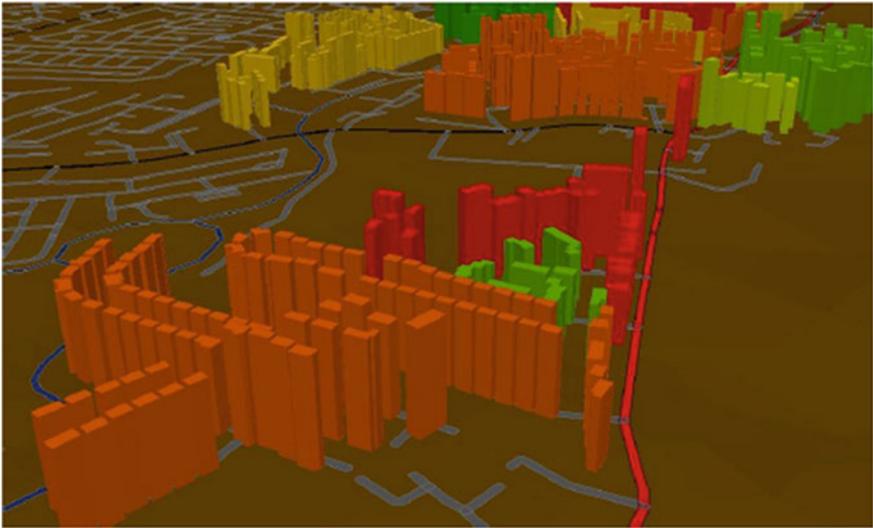

Fig. 4.25 Building age in southern Hackbridge displayed by colour (*green* = new build; *red* = old build) and by extrusion height (CO_2 emission per capita)

ratio; green = low ratio) and the energy consumption per capita (the higher the extrusion of building blocks, the higher its energy consumption value). Another example is shown in Fig. 4.25 which displays the building age of buildings in southern Hackbridge by colour (green = new built; red = old building) and the CO_2-emission per capita by the extrusion height.

As can be seen, the newer built building blocks (green) exhibit a lower CO_2 emission per capita value (visualised by lower building height) than older buildings (orange and red).

As presented, a 3D city model can be a powerful tool to visualise different thematic issues at one time. In regard to the Hackbridge project, it can help to make, for example the occupants aware of actual energy consumption and CO_2 emission of their homes. The Energy Options Appraisal (2008), also includes the costs and benefits of different energy saving measures for the Hackbridge building stock. Integrating these values into the model allows the occupants to get a visual impression of the cost and benefits related to such measures and how any potential energy savings and carbon reductions may also reduce their ecological footprint.

Chapter 5
Systems

a case study into the power, heating and lighting systems of the blocks, neighbourhoods and districts

What follows extends the previous chapter on buildings by systematically integrating the thermal, lighting, power and heating components of the retrofit proposal it serves to highlight the significance of. In particular, it provides an account of how to set the baseline needed to confirm the relative underperformance of buildings and improvements that can be made to the fabric of buildings which the case study relates to. Again this draws upon the Energy Options Appraisal and translation of this assessment into the STVR and PVTVR ratios deployed here as baseline calculations for the context-specific urban forms making up the fabric of the building designs rendered by way of and through ArcGIS software. However, in drawing upon this 3D city model as a means to systematically integrate the construction systems as key components of the assessment, the case study does not reduce energy performance to a mere head count, i.e. a measure of energy consumption and carbon emission to a per capita ratio, but instead bases this on the social-demographic structure of the environmental profile relevant to such an evaluation.

This is because it is these units of analysis that provide the means by which to capture something more meaningful about the situation in hand. That is to say, capture how it is possible to dispense with mere headcounts and assemble the material necessary to not just analyse, but act upon the results of any such diagnosis by intervening in the relationship between energy consumption and carbon emission. What-is-more intervene in such a way and by this, we mean, with the weight necessary to reset the parameters of these respective performances, as part of an on-going recalibration of both their extent and scale. Indeed in a way which has the weight of force needed to bear down on the said values and thereby meet the requirement for any integration of thermal, lighting, power and heating systems to lower energy consumption and reduce carbon emissions.

The intervention in question is what makes up the grounds for this book and as such looms large over the contextualisation of the specific urban form it takes on, itself captured and thrown much needed light on in the previous chapter. What this chapter wants to stress and therefore place weight on, is that being an intervention of this kind, it not only takes on a physical form (expressed in technical terms) but

which also manifests itself as a body of knowledge lodged in the institutions charged with the responsibility for promoting any such development in line with the vested interests of the social groups they in turn represent. This, we suggest, is an innovation of particular significance because it shines a light on yet another morphological factor, equally if not more important to those already drawn attention to. Those morphological factors not only important in setting the context of such actions, but the parameters of the very measures able to align buildings with the systems capable of driving the types of development and change searched for.

The factor we refer to is known as an "institutional arrangement" and in that sense a sociodemographic structure whose text, fabric, stocks and flows of materials and very existence as an environmental profile is lodged in the structure of tenure regulating the residential property sector. By this we mean environmental profiles, whose stock and flows of materials are critical to account for because their configuration, either leaves the structure of tenure in the residential property sector locked into an inefficient level of energy consumption and excessive emission of carbon, or with the means able to break free from such situations. If we quickly refer back to the ratio previously reported on for London and Paris, we can see that in comparison with the current institutional arrangements which make up the grounds of this case study, they exhibit an environmental profile very much locked into the inefficient and excessive and whose adverse effects in terms of global warming and climate change are tendencies to be reversed.

The possibility of reversing this tendency is what the urban regeneration process making up the grounds of this book's case study in mass retrofit is designed to do. In setting out this form and laying down its content, this chapter shall suggest the all too illusive integration of the buildings' thermal, lighting, power and heating systems, pivotal in realising any such resolution of energy consumption and carbon emissions, is not just predicated on a series of physical, but sociodemographic parameters, whose range and extent are just as equally significant in setting levels of consumption and rates of emission as anything else. In the previous chapter, it was only possible to hint at this by foregrounding the social-demographic as a stage to play-out the full weight and significance of, as institutional bodies staking a claim to the proceeds of such actions, not only for their scientific and technical value, but practical worth, as the enhancements such improvements map the possibilities of.

Why is this important? Well because it goes some considerable way to provide the critical building blocks needed to systematically integrate the physics of such analysis with the geometry, shape, form and content able to fill in the holes left in the previous attempts made by the likes of Ratti et al. (2005), Salat (2009) and Bourdic and Salat (2012) and Bourdic et al. (2012) and begin evaluating such performances as part of an environmental sustainability assessment.

Ratti et al. (2005) and Salat (2009) probably provide the best accounts on the current state-of-the-art on this matter, Ratti et al. (2005) with regard to London, Toulouse and Berlin and Salat (2009) for Paris. The significance which this has for the assessment of environment sustainability is a matter that has subsequently taken up by Bourdic et al. (2012) and reviewed in the first chapter of this book.

With Ratti et al. (2005), the effect urban morphology has on energy performance is calculated through a process of factor substitution and measurement of the effect this replacement of a building component (in this instance window glazing) has on consumption. The average effects on the energy consumption of the passive areas of the building subject to this assessment are marked: up to 50 % and the equivalent of an 8 % overall saving. While notable, the problem with this particular determination of the "average energy consumption in passive zones with the optimum glazing ratio" in terms of kWh p.a. is that such a replacement of a component does not add up to even a light retrofit package, never mind the type of deep retrofit which is currently under consideration in this case study. The other problem is that neither do retrofits limit the type of interventions they take on to morphological-specific components. Being more widespread, they tend to cut across the other categories of buildings, systems and occupational behaviours and therefore extend beyond the boundaries of the DEM model and LT calculations this performs. This in turn means that in terms of modelling performance, the application of the DEM model and LT calculations such a measure is based on, is currently limited to one morphological component and the evidence replacement glazing provides.

This perhaps goes some way to explain the reduced significance which the DEM and LT instruments take in Salat's (2009) assessment. For here, the assessment is not so much by component but for "heating energy" consumption across building types. Being forced to crossover into the domain of building physics and systems analysis, this assessment is unable to rest on predetermined theoretical values, but must instead make use of empirical data as some sort of supplement. However, saying this, it is also evident the exercise is equally singular in nature, as in this instance the evaluation is of "heating energy" and made on the assumption all other parameters (thermal, lighting and power) remain the same. For only in this way the assessment is able to measure how the difference in energy consumption and carbon emission can be explained by difference in building typology. Here, the difference is marked and as much as 33 %.

While this does give the impression of being a much more significant case study, covering as it does not just a neighbourhood, or city district, but metropolitan city-region, it still nevertheless begs the question: how to realise the energy saving, carbon emission reductions and efficiencies low-carbon zones have the potential to deliver? The answer to this is perhaps: by replacing the less efficient typology which relate to the buildings of the nineteenth century with those of the late twentieth. That is to say, by nothing less than a demolition of the buildings which currently make up the typology in question and replacement of them with a programme of new build. In that sense, by doing nothing less than a demolition and replacement of the equivalent stock with a new build programme, which replaces the old with the new, rather than by way of and through a retrofit which adapts the old to meet the standards of the new.

We suggest this alone serves to illustrate the choice offered is a false one and for the simple reason: while the first factor substitution (the widow replacement) is technically possible, the latter (demolition and renewal) is socially controversial. We also suggest this false choice exposes something more significant. That is, the

instinct there is to keep energy performance assessments within the strict confines of urban morphology and on a theoretical basis, yet need to loosen the tight grip this has over the method of evaluation where attempts are made to demonstrate the much larger (in terms of both scale and volume) savings and reductions which can be practically founded. This in turn culminates in a situation whereby any such loosing of the tight grip urban morphology currently has over the assessment of performance, means doing two things: exposing any evaluation to the building and systems scale of analysis and tightening up on the authority needed to execute the types of enhancements such improvements in performance also require. So, it might be said that whereas morphological-based assessments tend to preserve theoretical integrity and trade this off in terms of any potential savings and reductions, the other method of evaluation (buildings, systems and occupancy based) swaps theoretical purity for practicality, only to find other perhaps even more insurmountable problems (of both scale and volume) still tend to stand in the way.

For us the particular problems that DEM- and LT-type performance assessments cause those which are interested in using the context-based model as a basis for any such evaluation, rest with the following:

- the 2 dimensional representation of DEM rendered as volumes, with scale, mass and weight, are inadequate for the LT model to capture both their form and content, something that in turn becomes particularly noticeable when levels of energy savings and reductions in carbon emission have to be represented in terms of the volume of kWh saved/m^2 and reductions in tons per capita, respectively;
- capturing these savings and reductions in terms of volume in turn necessitates a "level of detail" (LoD) that shifts their rendering from LoD 2 and up to 3–4. For not only is it impossible for LoD 2 to calculate changes to the volumes in question, but also for LoD 3 too. For this, only extends to components (for example: windows and glazing) making up the external fabric of buildings. Something which in turn necessitates that LoD 4 be available to capture any impact such modifications have inside the built envelope and to fabric, be they either component-based, or founded on a more extensive set of system-wide developments.

While it is all too easy to dwell on the details of these methodological challenges, it is sometimes best to try and cut through them by appealing to one of the key drivers behind the assessments and by this we mean performance itself. For if we make a relatively simple comparison that does fall within the bounds of practical reason, it soon becomes clear the respective savings of 8 and 33 % reported on here, are of a lesser magnitude than the 60 % figure currently being claimed by retrofit proposals. This is why the following shall offer an assessment that adopts the ratios previously drawn attention to as indicators of what is environmentally unsustainable and then go on to assemble the means by which the baselines these in turn set, can begin to benchmark instances whereby the levels of performance do provide an indication of where all due pressure ought to be brought to bear. This offers an important insight into performance, because "building such a system of assessment"

strikes at the heart of what Ratti et al. (2005) previously referred to as merely the variance associated with and circulating around the normative standards of an abstract average. Here, we instead take up the theme of variance, not so much as a technical issue offering an indication of what might be referred to as a virtual absence of any meaningful normative standards by which to either set things by, or mark them up against, but instead as an indicator of the various inequalities that are associated with such measures.

Substituting inequalities for variance in turn has quite a dramatic effect, because it takes the point of emphasis away from technical matters to do with the quantification of measures, their scales and magnitudes and shifts the focus of attention instead towards the more subjective properties of the situation under investigation. That is away from the technical relationships between the physical spaces of urban forms (their geometry and shape) and towards something not only less abstract, but equally more concrete and real. By this, we mean the social structures these spaces in turn relate to and enter into the design and construction of as the textual means by which the human tissue of this fabric goes about meeting the underlying needs and material requirements of the environments. Those needs and material requirements are equally important in supporting the various performances of the residential property sector.

In methodological terms, we account for this substitution by starting with the given and in this instance, the environmental profiles of the residential property sector whose textual means and human fabric are embodied in the mass retrofit proposal. That is to say, with an account of how this material subdivides into the types of residential property which exist in the given structure of tenure. This is done in the interests of setting the baseline for the environment that these profiles currently relate to and benchmarking the likely enhancements and potential improvements that can flow from the types of alterations to the stock of housing which this points towards. We then go on to assess the impact of acting upon the enhancements and improvements such environmental profiles offer and retrofit proposals have to not only bear down on levels of energy consumption and rates of emission, but perhaps more importantly on the inequities of the existing structure of tenure when viewed in terms of the economies associated with the resulting distribution of costs and benefits.

This social base-lining also serves to captures and gives a name to the innovative qualities of this study. As an assessment exercise, this baseline is perhaps sufficiently unique to represent the defining feature of the case study. For it provides us with another point of reference by which to view the retrofit proposal and one that can be used to explore, study and gain a critical insight into the social-demographic qualities of such measures. As such the exercise does not so much start with a search for the normative performance standards, but instead commitment to begin working with the existing, well established, securely grounded and stable set of measures currently available to assess how the communal spaces of these environmental profiles meet the social need for and material requirements of energy efficient-low carbon zone. In this instance, a sociodemographic set of measures that draw upon these baselines as a set of benchmarks by which to evaluate the

impact of the environmental enhancements and improvements that changes of this kind have on levels of energy consumption and rates of carbon emission. We suggest that only in this way can the question of equity remain something which lies at the heart of the matter. This is because it is only in this manner, i.e. as a sociodemographic measure, can the matter of equity and environmental justice remain absolute and of overarching significance for the benchmarking of such enhancements and improvements represented here in terms of energy consumption and carbon emission.

The Environmental Profiling

This profiling exercise subdivides the stock of residences into the six house types previously referred to and is used to calculate the potential energy savings and carbon emissions reductions generated from the range of retrofit options (see Fig. 5.1).

The second set of columns in Fig. 5.1 illustrates the potential energy and CO_2 reductions if all the recommendations outlined within the report are taken up. In the event all measures are installed it forecasts that there shall be a 56.0 % reduction in energy consumption and 51.2 % fall in CO_2 emissions when compared to 1990 levels.

Tables 5.1 and 5.2 list the cost of the works needed for the retrofit to lower the levels of energy consumption and reduce carbon emissions. In some cases, alternatives are provided, such as in the proposed thickness of loft insulation. Both figures highlight these alternatives in italic.

Table 5.1 lists basic thermal measures assumed to be adopted by a high proportion of households without the need for professional assistance. These measures can be carried out immediately. The DIY percentage listed is the envisaged
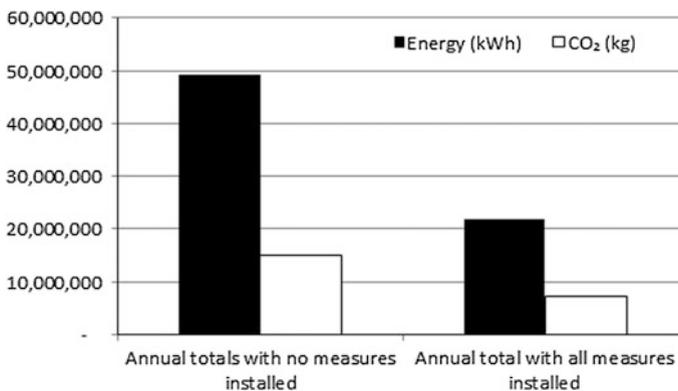

Fig. 5.1 Potential energy and CO_2 reductions. Data sourced from the Energy Options Appraisal (Deakin et al. 2012)

Table 5.1 Cost of basic measures

Measure	DIY (%)	Professional (%)	Existing grants available	Total cost
Loft insulation—300 mm	40	60	Subsidy included	£481,387
Loft insulation—400 mm	40	60	Subsidy included	*£569,936*
Draught proofing	75	25	None	£414,132
Turn heating from 18 to 17	–	–	None	£0
Boiler for one hour less per day (controls required)	–	–	None	£0
Energy saving light bulbs	100	0	CERT	£165,599
Efficient appliances	100	0	None	£599,922
Total				**£1,661,040**
Average cost per household				**£691**

Data sourced from the Energy Options Appraisal (2008) (Deakin et al. 2012)

capability of residents to fulfil this requirement. Implementing such measures will cost on average £691 per property.

Table 5.2 lists those thermal-plus measures which are mostly out with the capability of households and instead require professional installation by qualified

Table 5.2 Cost of more complex measures

Measure	DIY (%)	Professional (%)	Existing grants available	Total cost
Secondary glazing	25	75	None	£1,463,056
Solid wall insulation (internal)	5	95	None	*£6,328,197*
Solid wall insulation (external)	5	95	None	£5,709,127
Under floor insulation	5	95	None	£1,281,581
Heat exchange ventilation	100	0	None	£1,556,069
Cavity wall insulation	100	0	Subsidy included	£265,607
Double glazing	100	0	None	£4,093,861
Triple glazing	100	0	None	*£5,018,332*
Boiler replacement	100	0	None	£973,792
Solar water heating (with scaff required)	100	0	£493,200	£5,512,950
Solar water heating (no scaff required)	100	0	£493,200	*£4,608,990*
Solar voltaics	100	0	£3,082,500	£4,946,103
Total				**£25,802,146**
Average cost per household				**£10,737**

Data sourced from the Energy Options Appraisal (2008) (Deakin et al. 2012)

Table 5.3 Average cost per household

	No. of households	Average cost per household	Total cost
Hackbridge study area	2,403	£11,429	£27,463,887
Hackbridge study area: owner occupied (73 %)	1,754	£11,429	£20,046,466

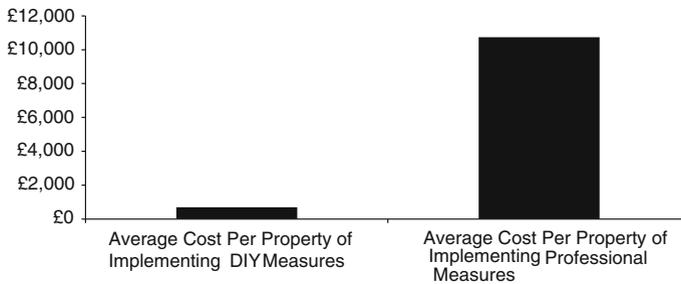Data sourced from the Energy Options Appraisal (2008) (Deakin et al. 2012)

Fig. 5.2 Average cost of DIY and professional measures. Data sourced from the Energy Options Appraisal (Deakin et al. 2012)

personnel. Implementing such thermal, lighting, power and heating measures will cost on average £10,737 per property.

Table 5.3 shows the total cost of implementing all the proposed measures to be £27,463,186. With an average of 73 % owner occupations, the cost of the implementing such measures within this sector is £20,046,466 or £11,429 per property within the study area (Fig. 5.2).

In accordance with the terms of reference laid down for the retrofit, the said costings are limited to those items of expenditure incurred by households in the owner-occupied and private-rented sector. Households in the social-rented sector are not factored into this costing and do not to form part of the retrofit proposal.

Hackbridge by House Type

This profiling exercise goes on to identify six house types within the boundaries of the regeneration footprint: House Type B; House Type C; House Type F, House Type I, House Type J and House Type L. Variations within House Type F appear to be based upon dwelling size rather than any significant difference in design so the "subtypes" within this group have been aggregated for Fig. 5.3.

Here, Hackbridge is identified as having a high proportion of housing stock built post-1972 (39 %) and are likely to already have cavity insulation already installed. Similarly, those properties built pre-1939 (23 %) are likely to have been built with solid single skin external walls and therefore unable to receive cavity wall
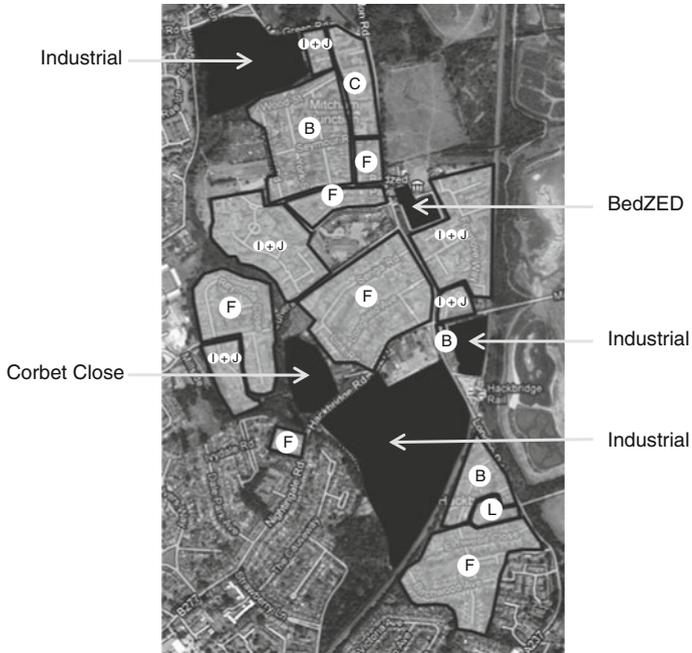
House Type	Construction Date	No. of Properties	% of Housing Stock
L	Post 2001	57	2
I+J	1972-2000	872	37
F	1939-1959	913	38
C	1918-1938	121	5
B	Pre 1918	440	18
		2403	100

Fig. 5.3 House type by location (Deakin et al. 2012)

insulation. The appraisal suggests that remedial works targeted at the older housing stock will deliver the greatest improvements, however, concedes the necessary works are often more invasive and costly (Fig. 5.4).

Figure 5.5 shows that, in general, the older house types use more energy than the newer property types. While energy consumption in Type B dwellings is highest, Type L homes consume the least energy. Similarly, it can be seen that the older housing stock (Type B, Type C and Type F) has a higher rate of CO_2 emission than the newer properties. This is demonstrated in Fig. 5.5 by Type B (pre-1918) dwellings, which feature the highest rates of CO_2 emission and Type L (post-2001) producing the lowest rates.

The maps in Fig. 5.6a, b present a more detailed picture of energy consumption across the housing types. These have been collated using data from the Energy Options Appraisal to indicate energy consumption and consequent CO_2 emissions.

Figure 5.6 is arranged according to the groups of similar housing stock identified in the appraisal then coded according to their consumption of energy and emissions
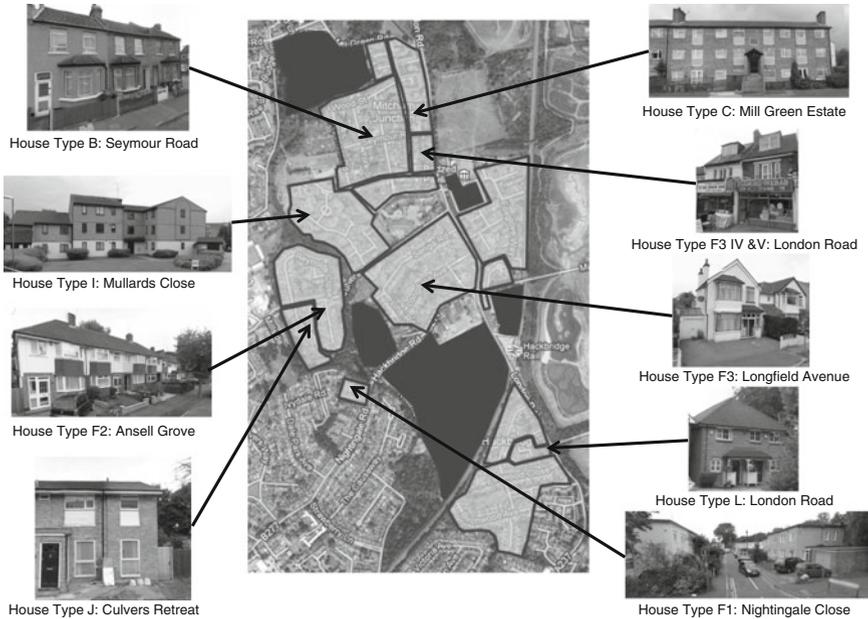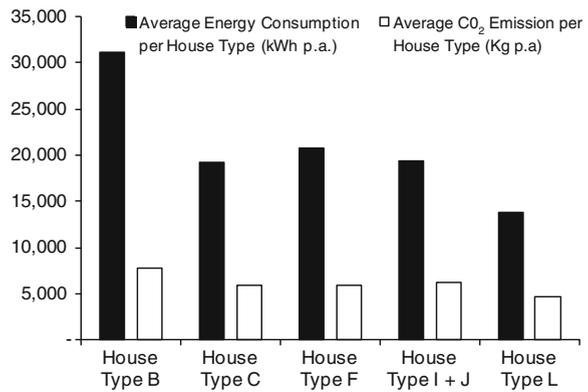
Fig. 5.4 House type by location—images (Deakin et al. 2012)

Fig. 5.5 Average annual
energy consumption per
house type (kWh p.a.) and
Average annual CO_2
emissions per house type (kg).
Data sourced from the Energy
Options Appraisal (Deakin
et al. 2012)

of CO_2. Figure 5.6a demonstrates pockets of high-energy consumption (shown in
dark grey) to the north and again in areas to the south. Similarly, pockets of low-
energy consumption can be seen across the map, in the north, where social
deprivation is highest, and in the south, where it is lowest. This also shows the CO_2
emissions. The method of calculating CO_2 emissions has been arrived at by mul-
tiplying the energy consumption by conversion factors of 0.43 per kWh of elec-
tricity used and 0.18 per kWh of gas. The highest emissions (7,500–8,000 kg CO_2
per annum) can be found in the north of the study area.

Fig. 5.6 a Energy consumption (kWh p.a.) and **b** CO_2 emissions (kg p.a.). Data sourced from the Energy Options Appraisal (Deakin et al. 2012)
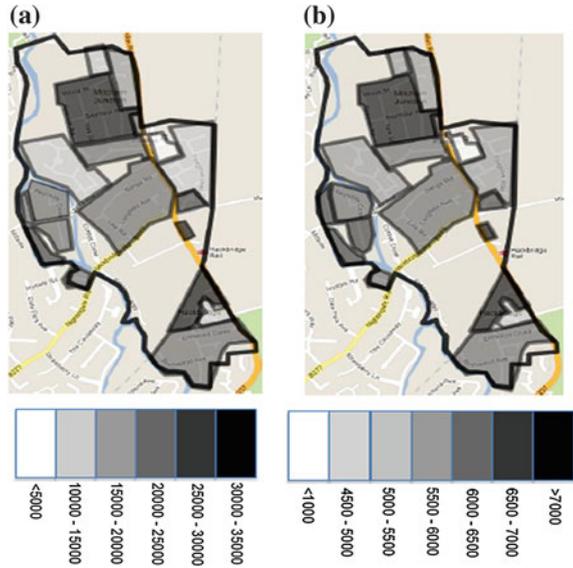
Social

The maps draw on data returns from the Census 2001 and EIMD 2007 (adapted from data supplied by the Office for National Statistics and sourced under the Open Government Licence v.1.0). The base unit for census data release is the output area—a cluster of adjacent postcode units incorporating approximately 312 residents. The base unit for the EIMD 2007 is the lower super output area (LSOA): these are built from groups of 4–6 OAs and constrained by the wards used for the 2001 census outputs. LSOAs incorporate approximately 1,500 residents.

The outline for Hackbridge has been prepared using the Google "My Maps" function (see Fig. 5.7a). The second map has subsequently been prepared showing the outlines of the LSOAs spanning Hackbridge (identified using ONS Boundary Viewer and as shown in Fig. 5.7b). The map of the study area has been superimposed upon the map of the LSOAs to confirm appropriate coverage (see Fig. 5.7c).

Classification of Social Groups

The standard measures of social deprivation in England are the English Indices of Deprivation (EID), produced by the Government and compiled in 2007. These provide a ranking system whereby small geographical units, known as LSOAs, are rated against 37 indicators and then ranked in relation to one another. LSOAs are home to approximately 1,500 people: there are a total of 32,482 LSOAs in England.
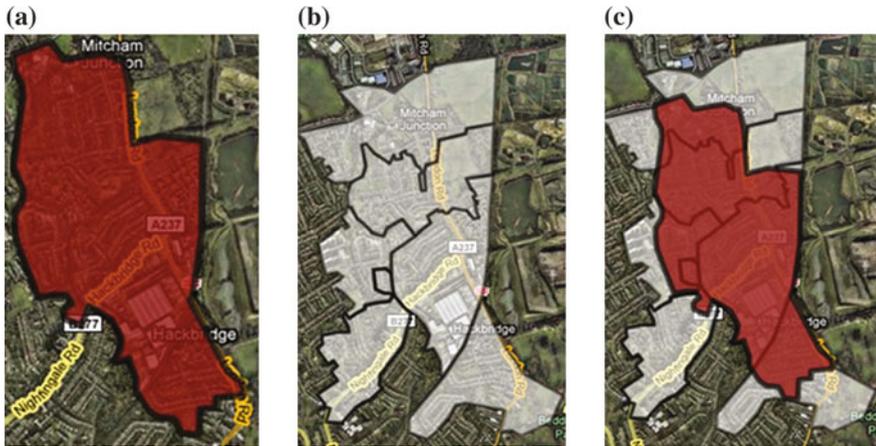
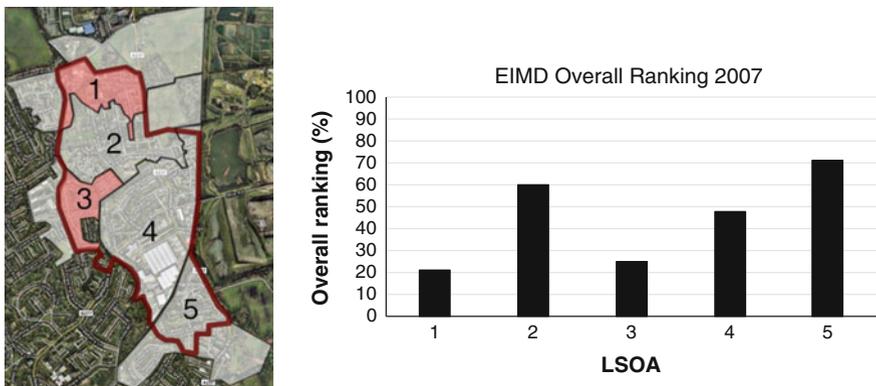**Fig. 5.7** Hackbridge by LSOA and study area (Deakin et al. 2012)

Fig. 5.8 The overall deprivation ranking by LSOA (*1–5*) (where 100 % is the least deprived in England) (Deakin et al. 2012)

As the LSOAs are ranked comparatively, rank 1 indicates the most deprived LSOA in England and rank 32,482 the least deprived in England.

The LSOAs within the Hackbridge study area (outlined in black) have been numbered from 1 to 5 and are shown in Fig. 5.8.

As Fig. 5.8 illustrates, Hackbridge is home to a large population who rank in the 50 % *least* deprived in England. For the purposes of this study, each LSOA has been labelled from 1 to 5: areas within the 50 % least deprived in England are labelled 2 and 5. However, Hackbridge is also home to a population amongst the 25 % *most* deprived in England—in the area labelled 1—with an overall ranking of 6,768 (where 1 is the most deprived and 32,482 is the least deprived). A second LSOA is ranked at the 25 % mark; this is the small area labelled 3. However, as

Fig. 5.8 indicates, care must be taken when interpreting data returns for Area 3 as only half of the surface area is included within the Hackbridge study area (outlined in black). In total, three LSOAs, with an approximate combined population of 4,500, are home to people within the 50 % most deprived in England.

In order to better understand these figures, it is important to consider each of the areas covered by the Indices in turn. The Indices of Deprivation 2007 were calculated across 7 domains: Income; Employment; Health and Disability; Education, Skills and Training; Barriers to Housing and Services; Living Environment and Crime.

Deprivation Across the Domains

Figure 5.9 demonstrates deprivation ranking in the five LSOAs within the study area. These are labelled 1–5. Findings from each domain are as follows:

- the Income domain is designed to identify the proportions of a population experiencing income deprivation, with particular attention to those reliant upon various means-tested benefits. None of the LSOAs within the case study area fall within the 10 % most income deprived in England; however, two of Hackbridge's LSOAs are ranked within the 20 % most deprived (Areas 1 and 3) and one is ranked within the 30 % most deprived (Area 4). The actual score given to each LSOA represents the area's income deprivation rate. This means that:
  - Area 1: 32 % of residents can be described as income deprived;
  - Area 3: 30 % of residents can be described as income deprived;
  - Area 5: to the south of Hackbridge station, only 9 % of residents are income deprived
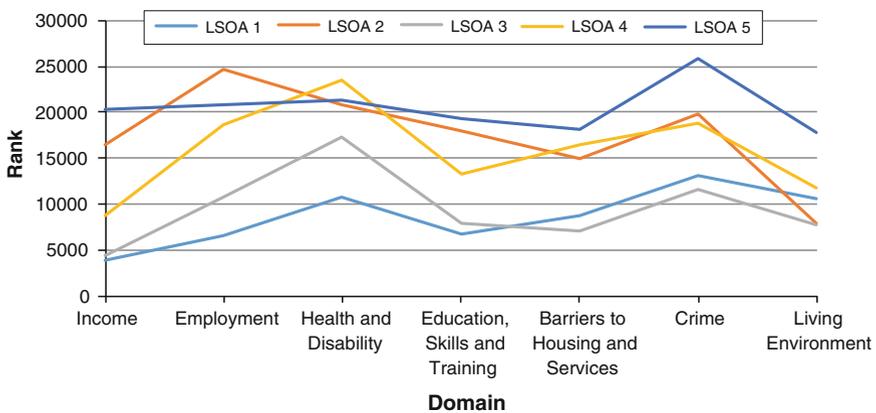

Fig. 5.9 English Indices of Deprivation (2007) ranking by Domain (where a ranking of 32,482 is the least deprived in England) (Deakin et al. 2012)

- the EIMD 2007 conceptualises employment deprivation as "the involuntary exclusion of the working-age population from the world of work". The highest rate of employment deprivation in Hackbridge is 15 %, seen Area 1. This is in the 30 % most deprived areas in England. By contrast, the area immediately south of this LSOA (Area 2) has an employment deprivation rate of 5 %; amongst the 20 % least deprived in England.
- the Health and Disability domain measures morbidity, disability and premature mortality in each given area. Area 1 is the most health-deprived, ranking within the 33 % most deprived in England. Area 4 ranks within the 28 % least health-deprived in England.
- the Barriers to Housing and Services domain is calculated over two subdomains: geographical barriers and so-called wider barriers, which includes issues relating to the affordability of local housing. Area 3 is the most deprived within the study area and is within the 22 % most deprived in England.
- the Education, Skills and Training domain measures deprivation in educational attainment amongst children, young people and the working-age population. Area 1 ranks at 21 % most deprived in England; its high ranking is owing to the low rate of young people entering higher education (HE) each year. Area 3 ranks at 25 %, again largely due to its low HE progression rate.
- the Crime domain measures the rate of recorded crime for 4 major volume crime types: burglary, theft, criminal damage and violence. The EIMD 2007 proposes that this domain represents "the risk of personal and material victimisation at a small area level". In this domain, Area 3 is ranked within the 36 % most deprived and Area 1 within the 41 % most crime deprived. Area 5 ranks in the 20 % least deprived in England, in terms of crime.
- the Living Environment domain is, in fact, calculated over two subdomains: indoors and outdoors. Indoors, the domain identifies deprivation by measuring housing in poor condition and houses without central heating. Outdoors, air quality is measured across several parameters and the number of road traffic accidents involving injury to pedestrians and cyclists is incorporated. In terms of Living Environment deprivation, both Areas 2 and 3, rank within the 24 % most deprived in England.

From these measures, a pattern can be seen emerging in the area's EIMD overall rankings: two pockets of relative deprivation to the north and west of Hackbridge, with relative prosperity to the south of the study area. These measures of deprivation are, in turn, compounded by the health, housing, education, crime and living environment rankings.

Structure of Tenure Within the Housing Market

Figure 5.10 illustrates the structure of housing tenure within the study area. As the data returns in this instance are at output area level (the smallest unit of spatial analysis), it is possible to include a sixth area: a section of 127 households. The data

Fig. 5.10 Housing tenure in Hackbridge. (2001 census, standard area statistics—England and Wales)
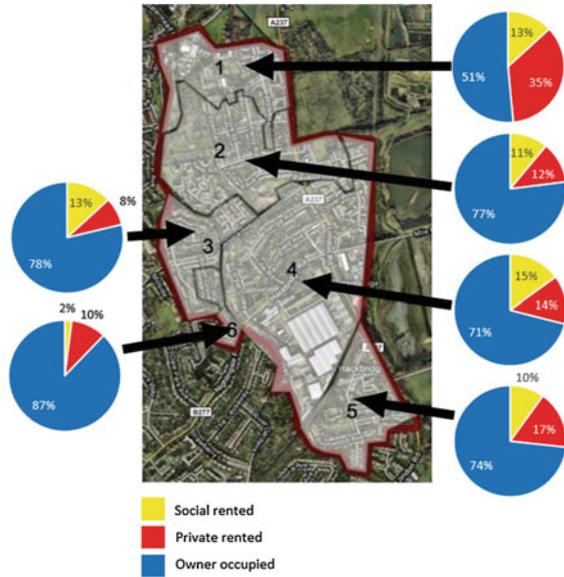
returns (at output area level) have been shown within the LSOAs (numbered 1–5) for the purposes of clarity. As Fig. 5.10 shows, owner occupation in Hackbridge is above the English average of 68.72 % in all but one area. Social-rented accommodation is below the average of 19.26 % in all areas, and privately rented accommodation exceeds the average figure of 8.80 % in all areas but one.

Chapter 6
Occupational Behaviour

> *relating the prognosis that emerges around the integration of the thermal, lighting, power and heating systems making up the mass retrofit proposal back to the structure of tenure which exists within the residential property sector. This provides the means for this system wide integration to cover the occupiers of the blocks, neighbourhoods and district centres of the London Borough of Sutton*

Table 6.1 relates the area-based energy consumption and carbon emissions to the STVR and PVTVR ratios for measuring consumption and emissions and goes on to cross reference these against the structure of tenure across the respective LSOAs for Hackbridge. These figures are in turn used to calculate the energy savings and carbon reductions for the respective retrofit options under consideration by the London Borough of Sutton. This is captured in Tables 6.2 and 6.3. Table 6.2 captures the energy savings for both retrofit options: the thermal and thermal-plus options. This is then repeated for the carbon reductions this also generates (Table 6.3).

As Figs. 6.1 and 6.2 indicate, the level of energy savings and reduction in the rates of carbon emission are noticeable across all LSOAs. For the thermal option, this type of retrofit results in a 25 % energy saving, whereas with the thermal-plus option the savings are as high as 65 % (Fig. 6.1). In terms of carbon reductions, Fig. 6.2 indicates the thermal retrofit option reduces the rate of carbon emission by 25 % and as much as 50 % for the thermal-plus option. In terms of tons per household, the thermal and thermal-plus retrofit options have the potential to reduce the emissions from 6 to 4.5 and 3, respectively.

Figures 6.3 and 6.4 relate the sociodemographic data set out in the last chapter to the environmental profile and offer a transversal analysis of the retrofit proposal's impact upon the occupiers of the residential property. This is achieved by the way of an area-based analysis, linking levels of energy consumption and carbon emissions to the structure of tenure and the connection this has to the housing market. As an area-based analysis, this assessment of consumption and emissions by structure of tenure draws upon data profiled from LSOA's 1 and 5. The reasons for focusing attention on these areas are as follows:

Table 6.1 Energy consumption and CO_2 emissions by LSOA

	LSOA 1	LSOA 2	LSOA 3	LSOA 4	LSOA 5	Total
Energy consumption total (kWh/p.a.)	6,733,319	14,644,009	5,576,413	13,140,448	8,079,019	48,173,208
CO_2 emission total (kg/p.a.)	1,904,109	4,684,583	1,657,453	4,002,471	2,176,338	14,424,954
Households	295	741	321	601	318	2,276
Energy consumption/mean household	22,825	19,762	17,372	21,864	25,406	
CO_2 emission/mean household	6,455	6,322	5,163	6,660	6,844	
Mean STVR	0.59	0.53	0.53	0.55	0.56	
Mean PVTVR	99.96	99.90	99.99	99.73	99.81	
Owner-occupied	150	571	250	427	235	1,633
Social-rented	107	89	31	84	53	364
Private-rented	38	81	40	90	30	279

Note The figure of 2,276 households is less than the previous figure of 2,403 (see Figure X). The reason for this can be found in the fact the first figure is taken from the Parity Report (2008) and the latter is drawn from the MyStreetFinder software used to generate the 3D city model. For the purpose of this occupational analysis, the following shall draw upon the figure generated from MyStreetFinder

Table 6.2 Energy saving by LSOA

	LSOA 1	LSOA 2	LSOA 3	LSOA 4	LSOA 5
Current energy consumption (kWh/p.a.)	6,733,319	14,644,009	5,576,413	1,314,048	8,079,019
Retrofit(s):					
1. Thermal	1,357,437	2,952,232	1,124,205	2,649,114	1,628,730
2. Thermal-plus	2,413,222	5,248,413	1,998,586	4,709,537	2,895,521
Maximum energy savings	3,770,659	8,200,645	3,122,791	7,358,651	4,524,251

Note Thermal-plus equals: thermal, power, heating and lighting

Table 6.3 CO_2 reductions by LSOA

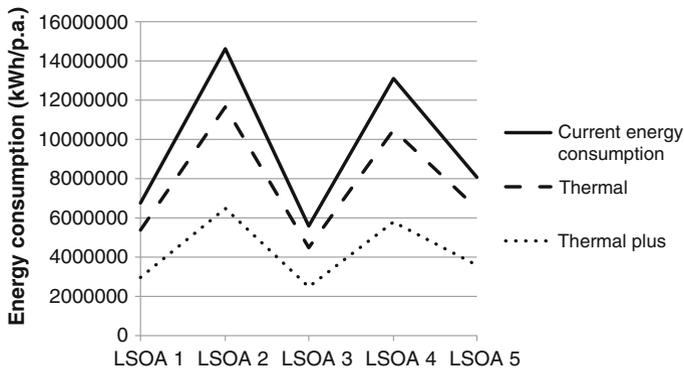|	LSOA 1	LSOA 2	LSOA 3	LSOA 4	LSOA 5
Current CO_2 emissions (kg/p.a.)	1,904,109	4,684,583	1,657,453	4,002,471	2,176,338
Retrofit(s):					
1. Thermal	378,727	931,764	329,667	796,091	432,874
2. Thermal-plus	592,368	1,457,374	515,634	1,245,169	677,059
Maximum CO_2 savings	971,096	2,389,137	845,301	2,041,260	1,109,932

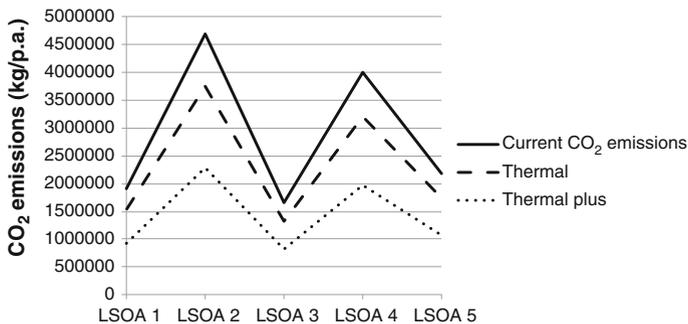**Fig. 6.1** Energy saving by type of retrofit

Fig. 6.2 CO_2 reductions by type of retrofit

- LSOAs 1 and 5 provide measures of the most and least deprived areas within the urban regeneration footprint. Here, Area 1 is the most deprived with a ranking within the 21 % most deprived areas in England, whereas Area 5 has a much lower ranking within the 29 % least deprived;
- while roughly similar in terms of building type, age and levels of consumption and emissions, the social-rented sector is prevalent in Area 1, whereas in Area 5, the owner-occupied and private-rented sector are the main sectors of the housing market;
- such an area-based analysis provides evidence to suggest which type of tenure consumes the least or most amount of energy and relationship this, in turn, has to the levels of emissions from the residential property in question.
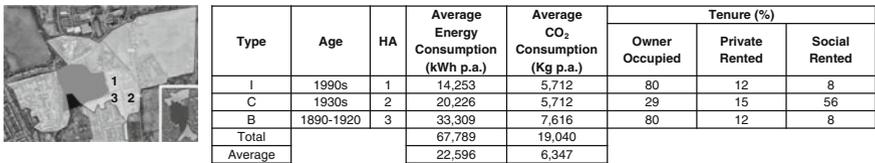

Type	Age	HA	Average Energy Consumption (kWh p.a.)	Average CO$_2$ Consumption (Kg p.a.)	Tenure (%)		
					Owner Occupied	Private Rented	Social Rented
I	1990s	1	14,253	5,712	80	12	8
C	1930s	2	20,226	5,712	29	15	56
B	1890-1920	3	33,309	7,616	80	12	8
Total			67,789	19,040			
Average			22,596	6,347			

Fig. 6.3 Profile of housing, energy consumption and tenure within the most deprived area of Hackbridge (LSOA 1) (adapted from Deakin et al. 2012)

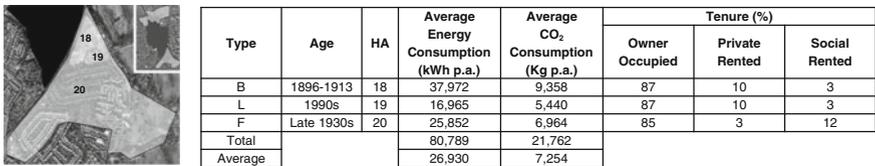| Type	Age	HA	Average Energy Consumption (kWh p.a.)	Average CO$_2$ Consumption (Kg p.a.)	Tenure (%)		
					Owner Occupied	Private Rented	Social Rented
B	1896-1913	18	37,972	9,358	87	10	3
L	1990s	19	16,965	5,440	87	10	3
F	Late 1930s	20	25,852	6,964	85	3	12
Total			80,789	21,762			
Average			26,930	7,254			

Fig. 6.4 Profile of housing, energy consumption and tenure within the least deprived area of Hackbridge (LSOA 5) (adapted from Deakin et al. 2012)

Notes on Figs. 6.3 and 6.4:

1. "Type" refers to the housing model applied in the Energy Options Appraisal (see Fig. 5.3: House Type by location).
2. "Age" refers to the approximate year of build, as designated in the Energy Options Appraisal. Under this, "HA" refers to the designated localities of similar housing stock in the Hackbridge Study Area, as detailed in the Energy Options Appraisal. Under this analysis, twenty areas of similar housing stock are identified and used here to capture housing stock within the lowest-ranking Lower Super Output Area (EID 2007) and the highest-ranking LSOA.
3. Energy and CO$_2$ data have been taken from the Energy Options Appraisal.
4. "Tenure" data have been taken from the Census 2001 at Output Area level.
5. The HA (areas of similar housing) are smaller than Output Areas; therefore, exact counts for each area of housing cannot be provided. The percentages shown represent a best-fit analysis at Output Area level.

Figure 6.3 illustrates the relationship between the building type and age of construction by housing area (HA) 1, 2 and 3, levels of energy consumption and carbon emissions for the same, split across the structure of tenure. As this illustrates, HA 2 is predominantly social-rented in terms of tenure type and has an energy consumption rate of 20,226 kWh/p.a., 2,370 kWh p.a. or 10 % below the overall average for the owner-occupied, private-rented and social-rented sectors of the housing market in LSOA 1. Figure 6.4 goes on to illustrate the same relationships for HAs 18, 19 and 20 in LSOA 5. Here, the structure of tenure is predominantly owner-occupied and private-rented, and the average energy consumption is 26,930, 565 kWh/p.a., or 8 % higher than the average for LSOA 1.

Figure 6.5 illustrates that LSOA 1 (HAs 1, 2 and 3), located within the 21 % *most* deprived in England, has the lowest levels of energy consumption and LSOA 5, situated within the 29 % *least* deprived in England (HAs 18, 19 and 20), the highest. Figure 6.6 also illustrates the levels of energy consumption within the 21 % most and 29 % least deprived LSOAs (1 and 5, respectively) and shows how they are split across the social-rented, owner-occupied and private-rented sectors. Within the social-rented sector of LSOA 1 (HA 2), it illustrates the average level of consumption to be 22,596 kWh p.a., whereas in LSOA 5 (HA 18, 19 and 20), this is shown to be 26,930 kWh p.a., or 16 % higher for the owner-occupied and private-rented tenures.

As the CO_2 emission levels are similar for both LSOAs 1 and 5 (HAs 1, 2, and 3 and 18, 19 and 20), they are not seen as warranting such an area-based analysis.

Reflecting on the terminology deployed by Ravetz (2008: 4482), it is evident the Hackbridge project offers a particularly good example of a response to the "perceived need for more integrated and active institutional arrangements towards the strategic management of the housing stock". As an exercise in realising the potential of mass retrofits, it is to be commended for providing a good example of how to progress beyond the state-of-the-art and be strategic, visionary and masterful in planning a programme of renewal whose redevelopment is not predicated on demolition and new build, but adaptation and renovation of an existing use. That is,

Fig. 6.5 The relationship between deprivation and energy consumption in LSOA 1 and LSOA 5 (Deakin et al. 2012)
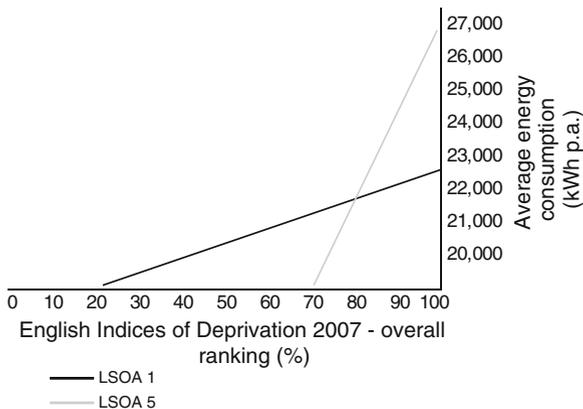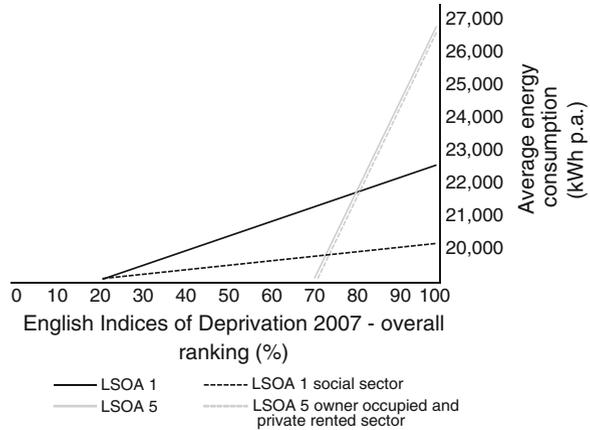
Fig. 6.6 The relationship between deprivation and energy consumption in the social and owner occupier (including private rental) sectors (Deakin et al. 2012)

based upon relatively small-scale, low-cost adaptations of existing buildings whose value lies in the capacity, such modifications have to reduce energy consumption and lower the levels of carbon emissions. The Energy Options Appraisal produced by this exercise should also be commended, if only for the reason this report offers the evidence base to underpin such actions and support them as viable implementation strategies.

The fact this project has now started to integrate the energy consumption and carbon emissions generated from the commercial and industrial sectors of the property market also serves to highlight the progressive nature of the renewal programme and redevelopment scheme it advances. Not least because in cutting across these sectors, it no longer restricts itself to the adaptation and continuous use of the existing housing stock, but also covers the energy consumption and carbon emissions of the new build components of the commercial and industrial property market covered by the regeneration strategy. As embodiments of One Planet Living Principles and the Sustainable Suburb Charter, the institutional arrangements between Sutton Council, BioRegional, Parity Projects and other organisations emerging from the Hackbridge project are also commendable, not only for the reason they assemble the resources to programme this renewal and redevelopment, but because they also piece together the means to implement it.

Saying this, the underlying issue, which this case study analysis has with the Hackbridge project, relates to the environmental profile the mass retrofit proposal advances. This is found wanting because the appraisal is not clear as to whether the benefits generated from the forecast rates of energy consumption and levels of carbon emissions will be spread equally among all residents. The reason for this—we suggest—is simple: in order to clarify the distribution of benefits generated, it is necessary for the institutional arrangement supporting the regeneration i.e. the London Borough of Sutton, BioRegional and members of the community who have signed up to the Charter, to first of all "baseline" the social demographic composition of Hackbridge. Then, to draw upon the results of this analysis as the means to

assess whether this "innovative" environment has the capacity to carry the energy consumption and carbon emissions targets, the "mixed-use redevelopment scheme" sets for the transformation of Hackbridge into a sustainable suburb.

Defining the terms of reference and specific objectives of SURegen's involvement in the Hackbridge project, our "baseline assessment" has also gone some way to overcome the methodological challenges currently surrounding any analysis of the distributional benefits such redevelopment schemes generate. This has been achieved by:

- assembling the footprint forming the boundary of the project's environmental profile;
- mapping the footprint by building type, age and number of residential units;
- analysing the footprint's:

  – energy consumption and carbon emissions by building type and age;
  – energy-saving and carbon reduction measures by building type and age,
  – their consumption, emissions, savings and reduction measures, by location within the boundary of the environmental profile;

- evaluating the cost of implementing the measures proposed in the Energy Options Appraisal.

This has established that housing built pre-1918 on average consumes 56 % more energy and emits 41 % more CO_2 than houses built post-2001. This establishes the older housing stock is the worst performer in terms of energy consumption, and such housing is also the most costly to improve. House Type B, identified as the oldest of the 6 house types and subsequently the worst performer, makes up less than 20 % of the housing stock. Indeed, the same calculation shows that a high proportion of the stock within the regeneration footprint comprises house types which can be considered relatively new. Indeed, as much as 39 % of the housing stock was only built post-1970 and already contains many of the measures proposed their contribution towards the transformation of Hackbridge into a sustainable suburb shall be marginal.

The sociodemographic baseline of this study area has, in turn, been compiled using data from the English Indices of Deprivation, 2007 and 2001 Census. The results of this analysis have been aggregated at Lower Super Output Area level, and the overall ranking of these areas shows a mix of relatively deprived and prosperous residents. Two of these areas, home to approximately 3,042 people, are ranked within the 25 % most deprived in England. By contrast, another two LSOAs, home to approximately 3,271 people, are ranked within the 40 % least deprived in England. One LSOA is also ranked within the 30 % least deprived. Expanding this sociodemographic baseline to include data on building type, age, levels of consumption and emissions across the structure of tenure within the housing market, it has been possible for the analysis to cross reference the rate of energy consumption and level of carbon emissions within these areas to the structure of tenure.

The value of such sociodemographic analysis lies in the opportunity it offers the master plan, programme of renewal and (re)development scheme to:

- provide an area-based analysis of the urban regeneration's mass retrofit proposal that is location specific in terms of the environmental profile which it builds;
- get beyond the tendency for the environmental profiles constructed by such reports to take on a purely technical nature;
- overcome the methodological challenges that such exercises pose by supplementing such technical analyses with the social demographic information able to integrate data previously overlooked;
- use the aforesaid as a means to take a fresh look at the retrofit through an analysis that is not overly reliant upon the technical efficiencies of the consumption and emission targets supporting the environmental profile, but social equity and environmental justice underlying the structure of tenure and which the housing market is based upon.

Together these analyses offer critical insights into the distributional assumptions underlying the mass retrofit and supporting the transformation of Hackbridge into a sustainable suburb. In particular, those about the degree to which the project's alignment of both their social and technical components provide a baseline *as much equitable as efficient*. That is, as much equitable as efficient and based on a structure of tenure within the housing market, which is sufficiently balanced for the environmental profiles this develops to support the transformation of Hackbridge.

We appreciate this transversal analysis of the impact differs markedly from other such analysis of occupant behaviours, for example Salat (2009). This is because unlike the other case studies, here, we do not have to concern ourselves with the so-called rebound effect, whereby reductions in the annual costs of energy consumption are either met with increased purchases of the commodity from the public, as in this instance the networks supporting the distribution of power do respond to market signals. This is because with this case study, the supply of power across all of the house types, irrespective of the tenure, is metered and met by the occupier, and in that sense, fed back into the system which serves to resource it. Instead, what we experience in this particular instance is something that might be better referred to as more of a "pre-bound" effect, relating not so much to either the buildings, or systems of integration, but structure of tenure which distributes the costs and benefits of retrofit proposals in relation to the disposable income of the occupants, and in that sense, between the income-deprived and those occupants which are otherwise classified as privileged. This is because for the purposes of our analysis, the question is how this division of income systematically "builds in" and in many respects reinforces an inequitable distribution of costs between the wealthier and poorer social groups in the residential property sector, in particular between those in the housing market whose tenure is owner-occupied, social or private-rented.

The results of this transversal analysis in turn indicate that it is the former which serve to gain from the proposal, while the latter are left in a situation which offers them little benefit. The difficulty with this outcome is that, while it is those households in the owner-occupied sector that contribute most to the levels of consumption and rates of emission, they are not in any way shape or form compensating the members of either the social or the rented sector for what is in effect

their "good behaviour", when it comes to energy consumption and carbon emissions. In light of this, it might even be possible to say the incentive mechanisms the market operate in the pricing of fuel, consumption of energy and emission of carbon are in some way perverse. For as this assessment indicates it does not compensate those whose consumption of energy to light, power and heating their homes is efficient nor does it for those households who contribute least to "public bads" such as carbon emissions.

For us, this unfortunate situation is in many ways the natural outcome of superimposing another set of technical criteria on the social demography of a given environmental profile. In this instance, the environmental profile of residential property within the owner occupied and private rented sectors of the housing market. That is to say, the outcome of a decision not to include any sectors of the housing market i.e. social-rented residential properties that fall into the most efficient level of Standard Assessment Procedure (SAP) ratings and to prioritise those which have low scores as part of a drive towards energy efficiency, irrespective of any questions such carbon emissions may raise as to the equity, vis-a-vis social justice of such environmental actions.

Chapter 7
Conclusions

reflecting on the potential mass retrofit programmes underway in Sutton and found in Hackbridge have to generate energy efficient-low carbon zones

The grounds for this book rests with research undertaken for the UK Engineering Physical Science Research Council (EPSRC)-sponsored SURegen project, and desktop studies carried out to examine the institutional arrangements of mass retrofits within the residential sector of the property market. In particular, those successful in not only making the case for retrofits, but realising the "greater potential" they have to reduce rates of energy consumption and levels of carbon emissions in line with the standards of environmental sustainability laid down by the UK Government.

Reviewing the literature available on mass retrofits, it soon became clear this was at best patchy in addressing the challenges the Hackbridge proposal sets in terms of the policy statements made by the London Borough of Sutton with respect to the vision, master plan, design and redevelopment strategy this sustainable suburb model is based on. Indeed, in reviewing the work on mass retrofit proposals, it becomes too obvious the models in question are based on the agency of architects, planners and designers and the capacity of their expert systems to align retrofits proposals with targets set to reduce energy consumption and reduce levels of carbon emission. As such, they lie in the first category of models criticised by Bourdic et al. (2012) for not even meeting the robust standards laid down by the building scientists they criticise. That is to say those criticised for not giving sufficient attention to the context-specific nature of the transformations they seek to usher in.

It is evident the case study material set out in this book goes some considerable way to build on the current state-of-the-art on building energy models captured by the likes of Ratti et al. (2005) and morphological approach to urban texture, the fabric of buildings, blocks, neighbourhoods and districts of cities. Keeping the four main structural components of energy performance highlighted by Ratti et al. (2005), Salat (2009) and Bourdic and Salat (2012) and Bourdic et al. (2012) alike, this serves to underpin the digital technologies employed in the DEM model and supports the LT with a 3D representation that enriches the visualisation of the material which is under consideration. It also manages to augment this by supplementing the physical

analysis of urban form, shapes and envelopes, with the social needs and material realities of the demographics making up the built environment and tools (indicators, benchmarks and baselines) able to capture the STVR and PVTVR of the said baselines and environmental profiles benchmarked as indicators of the transition to a post-carbon economy.

The value of this rests with the way the case study overcomes the diagnostic limitations relating to the topographical dimensions of such physical determinations and achieves this by drawing upon the opportunities this 3D model offers to extend the social needs and material realities of the demographic thematically, thereby integrating the institutional structure of energy consumption and carbon emissions into the normative standards of the power, heating and lighting systems. Normative standards of thermal, lighting, power and heating systems that likewise underlie the triptych and support the behaviour of occupiers in terms of what they not only add to the environmental sustainability of such developments, but performance, which the emerging post-carbon economy and what this in turn contributes to meeting the climate change adaptation targets set by government.

In transcending the determinism of previous ventures into energy performance measurement and climate change adaptation targets, it bases such calculations on the social needs and material realities of the demography making up the (in) equalities, deprivation and affluence of energy consumption and carbon emissions. The (in)equalities, deprivation, affluence, levels of consumption and rates of emissions that make up the social baselines and environmental profiles and which are benchmarked as the indicators of a post-carbon economy. Baselines, benchmarks and indicators that in turn articulate into the structure of tenure regulating the behaviours of those occupying the residential sector, the levels of performance and climate change adaptation targets which this sets.

This study has also presented the phenomena of Volunteered Geographic Information and highlighted its increasing significance in the context of geographic data. Data from OpenStreetMap, as the most highly structured profile of Volunteered Geographic Information, has been analysed in terms of suitability as a 3D city model in LoD 1 and LoD 2. The reference data sourced for such purposes are the highly accurate and official Ordnance Survey MasterMap data. Different analytical methods have also been adopted which demonstrate that OpenStreetMap data are of high quality in Hackbridge and that OSM footprints are very suitable as the 2D components of a 3D city model. However, further analysis has also shown that 3D height information is not widely available for OSM and geodetic measurement techniques (e.g. photogrammetry, LiDAR) which are needed to gather such information.

The methodology for building up the 3D city model has also been presented and the suitability of different software in terms of 3D modelling and solutions for data interoperability demonstrated. Data has successfully been fed into the 3D city model to analyse how urban morphology effects energy consumption and therefore CO_2 emission of buildings. Different ratios have been calculated, analysed, presented and compared with the intention of showing to what extent urban morphology effects energy consumption and CO_2 emission. Connections between

urban morphology parameters (such as shape-length-to-area ratio, surface-to-volume ratio, passive-volume-to-volume ratio, empty spaces, and building age and property type), levels of energy consumption and CO_2 emission have also been demonstrated with the help of the 3D city model. This demonstrates that an accurate 3D city model can be built up at little expense using volunteered and open source geographic data, and this in turn has the potential to be enriched with further (geographic) information and become an even more powerful tool (e.g. through combining OpenStreetMap footprints with photogrammetric or LiDAR measured roofs and Autodesk Ecotect sunlight/shading analysis to calculate the potential for photovoltaic solar systems).

A particular quality of this city model is the connection to the as-built 3D vector geometry of buildings it offers to other attributes (e.g. annual energy consumption, the annual CO_2 emission or the building age). Having all this information available in one 3D model renders it possible to determine connections between the 3D geometry (such as built mass, volume, shape, footprint area and height), energy consumption and CO_2 emissions. Such a 3D model can be published online via a GIS Web Service, so that citizens can view their 3D homes and calculate how much money they save per year or how their ecological footprints decrease by implementing energy saving measures.

The institutional arrangement which has been chosen to demonstrate the strategic value of this 3D city model offers a particularly good example of a response that has been made to move beyond the state-of-the-art and underpin the vision of urban regeneration with a master plan itself capable of supporting a programme of renewal and redevelopment by way of and through the adaptation and renovation of property within an existing use. This has in turn served to highlight the retrofit's proposal to improve the energy efficiency and carbon emissions of existing housing stock and to thereby make the settlements undergoing this process of transformation into a more sustainable place to live. The baseline analysis has, however, thrown light on a number of problems associated with the environmental profile of the retrofit proposal. These are as follows:

- housing built pre-1918 on average consumes 56 % more energy and emits 41 % more CO_2 than houses built post-2001;
- the older housing stock is the worst performer in terms of energy efficiency, as well as the most laborious and costly to improve;
- within the regeneration footprint, this type of housing makes up less than 20 % of the housing stock. Nearly 40 % of the housing stock has been built post-1970 and is already benefitting from many of the measures proposed to save energy and reduce carbon emissions;
- almost one-third of Hackbridge residents live in areas which rank within the top 15 % most income-deprived in England, renting their homes from the Local Authority, Registered Social Landlords, Housing Associations or the private-rented sector. Homes in the social-rented sector have been shown to consume less energy and to emit less CO_2 than other housing types of a similar age in Hackbridge. Indeed, using the Government's Standard Assessment Procedure

(SAP) for the energy rating of dwellings, the local authority housing in question is shown to outperform the national average ratings across all dwelling types.

Given that the current policy on the retrofit excludes the social-rented sector, the assumptions made about how such a flagship "low-carbon zone" can be developed at no additional environmental costs to residents prompts a number of questions. This is because in its current form, the commitment to the mass retrofit may be seen as *divisive* in terms of the actions it lays down for improving the energy efficiency and carbon footprint of the housing market. The reasons for this being:

- the most income and employment-deprived residents live in social-rented accommodation which already exceeds national standards in terms of energy performance;
- the least deprived members of the community tend to secure their accommodation from either the owner-occupier or private-rented sectors of the older, less energy-efficient and the highest carbon-emitting dwellings;
- while the former are excluded from any benefits, the retrofit may generate in terms of energy savings and carbon reduction, the latter are targeted, not only because they are the worst offenders (as occupants of the older stock), but for the reason that occupants of newer owner-occupied and private-rented housing are also some of the least "worst offenders".

This becomes particularly clear if we summarise the potential benefits of the greater energy efficiency and lower carbon emissions associated with the Hackbridge project. As with the existing proposal, housing situated within the social-rented sector shall be excluded from the retrofit and remain with an energy efficiency and carbon emission rating of 75 % (Band C rating). While under the retrofit proposals covering the owner-occupied and private-rented sectors of the housing market, the 50 % improvements in energy efficiency and carbon emissions for this sector are not only forecast to improve their standing from Band E to C, respectively (69–80 %), but holdout the prospect of meeting the targets set under the UK's Climate Change Act for 2020.

This tends to leave the occupants of the social-rented sector in the same situation they were in before the Climate Change Act 2008 came into effect. For improving the overall standing of the owner-occupied and private-rented sector, this sector of the housing market is likely to be left in a situation whereby the mass retrofit measures introduced under the auspices of the Hackbridge project end up leaving the most income-deprived groups in a somewhat precarious situation, that is, with the status of currently being the best in their class (for rates of energy performance and levels of carbon emissions, respectively), but stuck in a situation which is tantamount to "fuel poverty".

This also suggests that using the structure of tenure to draw a clear line between what sectors of the housing stock are eligible to participate in the benefits of mass retrofit projects is inappropriate, not only on the grounds which their programmes of renewal are divisive and socially inequitable, but for the technical inefficiencies which redevelopment schemes of this kind also generate. In their current form, the

measures adopted to champion the virtues of environmental sustainability fail to adequately demonstrate where retrofits can best perform as energy-efficient, low-carbon zones. That is where they can best perform as energy-efficient, low-carbon zones and which in both technical and social terms are equally capable of being administered at no extra environmental cost to the very communities their emerging institutional arrangements are designed to serve.

This clearly demonstrates that the structure of tenure does not offer an appropriate means to baseline mass retrofits associated with the regeneration strategies, visions and master plans under consideration, as it is not only divisive, but also out of balance with the demands which transformational actions of this kind place on communities to deliver energy-efficient, low-carbon zones at no extra environmental cost. The findings drawn from this case study tend to suggest that it is not tenure which should be used as the basis for the retrofit, but the type, age, rates of energy consumption and levels of carbon emissions themselves. For in terms of the measures currently being drawn upon to transform Hackbridge into a sustainable suburb and champion environmental sustainability, such a basis would:

- be more *inclusive*, capable of cutting across the structure of tenure and integrating the housing market based on levels of energy consumption and carbon emissions, that is, capable of not only realising the potential which the owner-occupied and private-rented sectors have to increase levels of performance from Bands B to C, but the possibility there is to do likewise and draw upon this to *shift the ratings of the housing stock within the socially rented sector from a C to B Rating and use this as a means to begin addressing the 80 % post-2020 targets;*
- treat all social groups—the most and least deprived—equally, and in terms of the potential, each type of tenure offers any retrofit proposal to save energy and reduce carbon emissions;
- allow the retrofit to prioritise those types of housing, age groups and tenures with the greatest potential to be both socially equitable and technically efficient in meeting such targets;
- focus attention on the worst offenders and maximise the environmental benefits such energy-efficient, low-carbon zones offer society without either excluding the strongest upholders of such standards from the exercise altogether or running the associated risk of downloading the cost of any such actions onto the weakest and most vulnerable groups, least able to afford them. Those who simply cannot afford not to be included in such actions: not only because of the contradictions which this exposes in the programmes of renewal and redevelopment schemes that currently support mass retrofit proposals of this kind, but for the reason such exclusions also tend to bring the status of the master plans and visions of urban regeneration into doubt.

These findings are in clear contrast to Salat (2009: 606) who states:

A comparison of three urban blocks typologies in Paris – the traditional 19th century urban block, the modernist high-rise block of the 1960s and the contemporary urban block of the 1990s – reveals the combined effect of building from and construction technology on the required energy of this building stock for heating. Thus, the better insulated urban block of the 1990s required less than one third of the heating energy than the traditional masonry urban blocks and less than 22 % of the free-standing high rise blocks. The multiplicative factor between the extreme cases being 4.5 (including 1.8 for morphology and 2.5 for building physics). At the larger scale and by neutralizing the impact of construction technology (as shown above), the greater efficiency of the dense courtyard blocks appears more clearly. This shows the interest in separating the factors of urban morphology and building typology as well as enlarging the scale of the observation.

While it is not exactly clear what Salat (2009) means by the statement: "*by neutralizing the impact of building technology*", we find the suggestion these figures demonstrate the "greater efficiency" of the dense courtyard blocks and "*show the interest in separating the factors of urban morphology and building typology*" counter-intuitive for a number of reasons. Logically, the only way this "separation" can work is if you take it to mean the separation of the urban block from technology and substituting the traditional urban block with the post-1990s technology of the contemporary era. To do this would logically assume a separation of the urban morphology from the construction technology as otherwise, the factor substitution in question would not be possible. While this line of reasoning does serve to highlight the potential urban morphology has to lead the way in the drive to greater efficiencies, this is only because the footprint it maps out extends beyond the block and therefore offers something greater in terms of scale, volume and mass, but as Salat's (2009) examination of energy consumption in the urban blocks of Paris itself goes to demonstrate, much of this is contingent on the systems embedded in servicing the buildings. In this instance with the power, type of heating systems and, to a large extent, how the occupants of the residential property behave in relation to their consumption of energy and carbon this emits in meeting thermal comfort thresholds.

The point we want to make is that contrary to what is assumed, it is not possible to separate them i.e. technologies from embedded systems, out for anything but analytical purposes and even then only on the assumption they are going to be integrated back with one another. For otherwise, you run the considerable risk of not merely separating them out from one another as either "dimensions" or "planes of existence", but leaving both of them as little more than fragments of the very geometry, physics, shapes and forms the analytical grid is trying to bring together under the name of urban morphology.

We also suggest there is a higher ontological question at stake here because any such separation is based on an understanding of the world which not so much cuts across, but perhaps "hacks into" the objects of knowledge they suggest urban morphology may rightfully lay claim to. What we mean by this is that rather than separating out the morphological components and illustrating their significance as something which needs to be brought back into the fold, it is instead left stranded. That is to say, not only stranded waiting to be brought back in, but very much out in

the cold when looked at against the harsh realities of where all the energy in question is currently being expended.

We suggest this unfortunate situation arises because the whole argument in favour of the morphological approach still remains—in scientific and technological terms—overly dependent not so much on the thermodynamic and constructal tendencies, ecology, exergy, entropy and fractal geometry which make up the complex (invariant) structures (in this instance, highly structured, resilient and adaptive systems), as the images and symbols more common to see deployed as an aesthetic whose geometry serves to mimic nature. In this instance, an aesthetic geometry serving to mimic the cultural heritage of traditional urban blocks and legacy of environmental determinism that still continues to overshadow the real significance of the potential which this holds out for the "contemporary era". That potential which we would suggest this approach still does much to "hold out on" because while focussing on the urban condition, as an aesthetic on the virtues of environmental restoration, these economies still fall someway short of an informational exegesis whose entropy rests on a circular metabolism able to institute such values at the level of social need, let alone take on the real task of allowing any such escalation to shape and give form to the materials required to meet them. That is to say, meet them by giving shape to the form of the material needed for the fabric of the built environment and multitude of social, environment and economic relationships which this highly structured, resilient and adaptive system in turn cultivates, requires in order for any technique of analysis to integrate them, not only at the level of the block, but street. Integrate them, not only at the level of the block, but street and as the very place where their morphology is built out as the content of those spaces such a topography prepares the ground for.

In the case study set out in this book, the relationship between the block and street is cultivated not through the images and symbols of aesthetics, but the information technology and computational power open source software has to represent such communications. In particular with the power it has to process the voluntary contribution digital data loggers make to capture the textual elements and fabric of these communications as part of a bottom-up social movement. In particular, as a bottom-up social movement contributing to the diffusion of digital mapping, itself capable of rendering all the contextual-based forms of intelligence needed to service a real-time visualisation, not only of either the street or block, but the building envelope as environments at LoD 4.

This aside, our major concern over the separation is that in focusing attention on urban morphology, it may not merely serve to highlight why it is an important factor in the equation, but cast a shadow over the possibility which there exists for such an emerging group of experts to be just as divisive as the "building scientists" whose "physics" they are particularly critical of. In this instance, for the very reason, the former seems to have no moral obligation, nor have any ethical compulsion to "pay-back" what has been taken away as part of some re-integration. Indeed, contrary to Ratti et al. (2005) and Salat (2009), we would suggest this "return to the fold" is imperative for the ecology, exergy and entropy which they open up a debate on and something that ought not be foreclosed, but left open. Not

just because it would be "fair minded" but for the following reason: the critical relationship that needs to be sustained is not so much between urban morphology and buildings, but the context in which they develop as systems of thermal, lighting, power and heating capable of being integrated into the institutional structures of housing provision. Those institutional structures of housing provision whose tenures are just as equally important in setting the level of energy consumption and rates of carbon emission resulting from this.

While Salat (2009), Bourdic and Salat (2012) and Bourdic et al (2012) clearly recognise the significance of such institutional structures and how they operate to effect energy consumption and carbon emissions, they are not so much given any particular weight, as merely "factored in". This is because every effort instead is invested in avoiding any such dialogue and putting as much critical distance as is possible between them and the morphological. So much so they almost pale into insignificance when the former is placed against the latter.

Comprehending the relationship between them in this way, i.e. at the scale of social need, rather than space and as a matter concerning the demography, not topography of sustainable urban development, also begins to change the perspective of the energy performance model Ratti et al. (2005) and Salat (2009) sketch out. For rather than seeing the components as loosely coupled along a horizontal plane, here they are configured more as critical blocks in the building of a vertical "factor adding" model, wherein neither one is capable of being separated from the other without the whole structure of energy performance (as we know and have come to understand it) collapsing in on itself. The precept for this, of course, is not to limit the model to an analytical grid, but to comprehend the geometry, physics, shape and form of the structure it builds as having not so much a natural as organic texture, fabric and ecology of what might be termed an "energetic magnitude".

Only in this manner can the act of mass retrofits sustain the development they institute by being an integral part of what this builds as opposed to isolated from it. Otherwise, all the geometry of urban morphology can offer is the insight that STVR ratios cannot help with any such actions and the PVTVR ratio is merely able to indicate which blocks would benefit from the systematic modifications and alterations to the thermal, lighting, power and heating needing to be integrated as a material requirement of the programme. In short, they provide very little, either in terms of an analysis or diagnosis, let alone anything else which serves to approximate a process of implementation. This is because such techniques of analysis are not only specified at too high a level of abstraction, but also scale of granularity far too course to be of value. The paradox here is that while Salat (2009) suggests urban morphology has the potential to half energy consumption and carbon emissions alike, in the case of London, Toulouse, Berlin and Paris, not only are the measures (STVR and PVTVR) adopted too remote to capture the weight of this, but approximate these values in conjunction with the mass of the buildings which the evidence drawn from the Hackbridge project indicates has the potential to improve energy performance by as much as 60 %. As much as 60 % before factoring in any further contribution changes in occupant behaviour may also make to energy consumption and carbon emissions.

While it is appreciated the changes that Salat (2009) refers to as the "rebound effects" of occupant behaviour could just as much undermine any such improvements as support them, with the structure of tenure regulating residential property in this particular housing market and inequitable distribution of costs and benefits it is shown to uphold, such an outcome is only considered possible if the price of fuel does not act as the economic standard upon which to base the consumption of energy and emission of carbon.

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