BARCELONA

energy + urban form

Adrian Vickery Hill

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Cities are the crucible of human civilization, the drivers towards potential disaster, and the source of the solution to humanity's problems. It is therefore crucial that we understand their dynamics, growth and evolution in a scientifically predictable, quantitative way.

Bettencourt & West 2010

I knew I was going to take the wrong train, so I left early.

Yogi Berra

Mentors:

Meta Berghauser Pont
Chair Urban Design - Theory & Methods
TU Delft, Faculty of Architecture

Dominic Stead
OTB Research Institute for the Built Environment
Delft University of Technology

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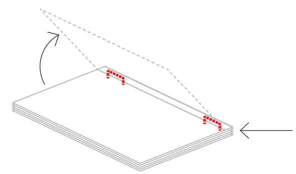
Front cover image: view south-east from Parc del Carmel



When printing, the layout functions best if stapled along the top margin.

EUROPEAN POSTGRADUATE MASTERS IN URBANISM

TU Delft

UPC

Foreword

Energy was by no means my initial interest, over the following pages I hope to explain why I ended up researching this topic and why I feel it is essential that urbanists in particular are more aware of energy consumption. My interest stretches back some time and has been a very personal experience in appreciating urban processes - I hope the following pages will put the research in context.

Coming from a sparsely populated urban area, I am one of many Australians taken by Europe's complexity and vibrancy. Many of us yearn for the richness of denser urban areas and for the atmosphere found in many European cities. Much the same can be said for other similarly urbanised regions – Canada and the USA for instance. Why? Is it due to the age of cities? Is it because of the extensive variety of monuments and architecture? Is it due to cultural richness? Is it because of the heritage and civic institutions? Is it because of the scale and design of European cities that feel intimate or comfortable? Or is it simply due to density?

Conversely Australian urban areas have qualities that are the envy of many Europeans; houses are luxuriantly spacious, urban areas are typically quiet and most homes are generally not far from generous stretches of open space. But I have often felt that these relatively new urban areas also come at greater cost – so why would denser urban areas be advantageous over sparser types?

My interest in urbanism began when trying understand why a decrepit part of my city's historic centre could never repel vandalism and anti-social activity regardless of the large sums ploughed into security and beautification. The city centre was compact and intimate and in my mind beautiful - yet something seemed imbalanced. I initially felt the community didn't find the area attractive or engaging. I felt it needed to be 'activated' so I decided public art or programmed events could be a solution. I also tried – but found myself ignorant of the bigger picture. At the same time almost every Australian city was refocusing on their odler urban centres and particularly exploring the the 'creative culture' in their laneways and derelict but intimate spaces - some very successfully (famously in Melbourne) others with less grace (such as in Sydney or Perth). I soon realised that my city was missing or had not harnessed many of the staples of a vibrant urban area; a resident population, a compelx mix of daytime jobs, a mix of shops and night-time activities, good accessibility and traffic speeds, conditions encouraging lower levels of car usage and many other details which I felt were far beyond my area of expertise.

This little exercise econcouraged me to look for the nuances of density and compact urban form – higher densities are relatively scarce in Australia and largely restricted to the old city centres. I felt there was much to gain from compact urban form but I could not relate what it was or how to translate these intuitions into improving the old CBD or the Australian context.

Arguments for and against compact urban form have been waged since the age of transportation, in the mid 19th century, when mobility allowed living and working to be practically distributed across then bloated urban areas. This in theory allowed incompatible land uses to be re-organised, for instance tanneries and iron smelters would separate from housing. But in many cases this strategy evolved into complete specialisation of city areas; inner cities focused on tertiary work, industry was sent to the periphery (regardless of whether or not it was noisy or polluting), housing areas contained little more than housing (supporting a new typology: suburbia). This is somewhat of an exaggeration however such simplifications / specialisations are now being observed to affect communities in complex ways.

We are entering an age where research (from medicine, economics, security to accessibility and mobility) is finding evidence of the 'holistic' benefits of well-mixed and compact or pedestrian oriented urban form. For example, obesity levels have been found to be greater in sparser urban areas by researchers such as Richard Jackson, Anne Vernez Moudon, Robert Frank and others. Certain types of compact urban form have been found associated with lower levels of crime due to passive surveillance and higher levels of pedestrian movement - illustrated famously by Jane Jacobs and Christopher Alexander. Infrastructure maintenance costs have been more recently resulting in pro-compact models – anecdotally American banks no longer favour lower density developments due to long-term loan security.

Compact urban form has been found to trigger a range of other benefits. For instance, use of collective transport systems is greater in dense and highly mixed urban areas as concluded by Robert Cervero and others – this correlation will be discussed throughout the research. Car dependence (but not necessarily car ownership) has likewise been found to be lower in compact urban areas. In addition, due to higher population levels, facilities such as schools can be located closer to users; Jackson has found that children who walk or ride to school have higher concentration levels than those arriving by car. It is clear that density or compact form does not simply attract these benefits – the design of the urban form is also critical. In other words, having certain facilities and a certain compact form does not automatically guarantee that an urban area will function effectively.

Compact form also attracts much criticism – which has been explored by many researchers and has not been the focus of this research. In fact sustainability experts have considered it difficult to simply favour dispersed or compact urban areas in terms of technical benefits (waste, embedded energy, storm water, sewage, self-sufficiency, more recently personal mobility amongst other themes). But often these measures have disregarded 'social-qualities'. Science often focuses on particular silos of knowledge, allowing generalisations to be made by placing low and high densities at two extremes without defining the qualities of either. In fact, it is clear that some high-density areas can perform similarly to low-density areas, for instance in terms of mobility demands, if the conditions of the density are not qualified. Regardless, the debate is highly emotional and conclusions depend largely on the researcher's interests and objectives; this research will therefore try to avoid such a discussion – and particularly avoid confusing terms such as 'sustainability'. The project does not seek to take sides on the density debate but rather looks at the qualities of density that best support low energy lifestyles, without factoring new high-tech solutions or social responses such as taking shorter showers, fulling recycling or growing one's own food. This research simply focuses on the intuitive use of urban form.

I initially felt mobility was the substance of modern cities and that it was largely responsible for a city's urban form and character. I felt collective transport would resolve many of the problems of our car dominated cities. But after considering it in greater detail, I realised mobility was a symptom and not the cause. Energy on the other hand is the substance of modern cities as we know them; without or with less energy, mobility systems would be very different and so would our cities. In addition much of my knowledge was based on the Australian context - one of a handful of countries that has been developed almost exclusively during the industrial age with industrial technology and energy. This sparse country has absorbed energy into its culture and urban fabric – how would such places survive if this type of energy were to be exhausted?

Energy is a highly complex issue – and one that will be a defining topic for global politics at least during the first half of the 21st century. It is also the symbol of modern urban life and we will reluctantly give up our high-energy lifestyles – it has become the most vital ingredient for progress and development, science and discovery, defence and communication, health and wellbeing, education and democracy. Yet as it is an abstract substance, few people truly understand how much of it is being consumed, or even where it comes from, or how utterly dependent we are on it. As residents of urban areas, we simply and ignorantly consume.

As I became interested in the issue of energy and cities, I realised that much of the investment in energy research is focused on transitioning current fossil fuel based technologies into new renewable alternatives. This transition will likely take many years to set in place. Yet many scientists, researchers and planners have indicated that it will indeed be very challenging (or impossible) to achieve the technical potentials of renewable energy due to cost, social resistance and complex vested interests. In addition, as much of the energy related research has some level of speculation, it is quite unlikely that a transition will occur unless we are faced with an inevitable decline in energy due to cost and / or availability. Such an event would also likely be sudden and have chaotic consequences.

I therefore became interested in the links between urban structures and energy consumption - I felt that urban form was a significant contributor to the way energy is intuitively consumed and some areas will be capable of tolerating greater variations in energy availability over others. I also wanted to have a better understanding of how cities as a whole consume energy. For instance will less energy mean a reduction in lifestyle qualities? In addition, as there is still speculation surrounding the significance of energy issues, it is difficult for energy to be the main objective of energy-based strategies. In other words, solutions to energy issues may be better resolved obliquely. This could be achieved by either significantly reducing overall energy costs or providing alternative conditions requiring less energy consumption.

There were a few limitations that provided some frustration during the project. As I began researching this case study on Barcelona, I quickly found that much of the necessary data is unavailable or presently unattainable. This was not unique for Spain but rather a statistical shortcoming (political or statistical) that researchers in this field will need to deal with. As Cevero and Kockelman (1997), in a paper referred to often throughout the research, noted the limitations of reaching associative conclusions (the existence of something is associated to the presence of something else with proven consequences) rather than causal hypotheses (reached through statistical analyses). As much of the data is inaccurate or too general, many of the conclusions arrived at during the project have also involved some level of assumption or speculation; in many cases conclusions made are not new and merely confirm those made by others.

I feel this project has achieved two things. Firstly it has been a very personal exploration into the relationship between energy consumption and urban areas, which opened my eyes to the reality of many popular assumptions. I hope others studying urbanism will be able to appreciate where energy is actually consumed – urbanists, planners and architects are often guilty of basing knowledge on the myths of energy consumption without studying the facts. In the past, energy assessment could be limited to the consumption levels of a single sector, such as housing or industry which often operated on very different fuel sources. As our society becomes increasingly electrified, the energy to cook our dinners will likely be the same energy fuelling our transport systems - this means energy markets are likely to become even more complex and sensitive to change.

The second is that this research has attempted to connect both technical and social data and tries to make some larger assumptions based on the urban system. It is here which I hope it will be beneficial for further research and I hope future investigations on urban energy consumption focuses more attention on the effects of urban form on energy consumption. Energy consumption clearly requires an understanding of urban systems in a broader sense, appreciating both the needs of consumers and the means to consume.

Adrian Vickery Hill
Rotterdam, 2012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Urban areas and energy consumption - what conditions are embeded in urban form that innately make us want to consume energy?

Figure 1/01 (previous page): *Via Agusta*
Figure 1/02 (above): *Passeig de Sant Joan*

1

Introduction

Overview
cities and their energy problems

Climate change, unstable world economies, dependence on global supply chains and dwindling fossil fuel supplies may result in sudden and dramatic socio-economic instability, leading to shifts in how urban areas are structured. Contemporary cities, established largely around stable supplies of materials and plentiful access to energy sources, will be seriously affected by sudden changes in supply particularly if technology cannot cater for consumption demands.

Energy is the base on which all modern cities are built, yet it is consumed almost unconsciously. Conventional forms of energy (fossil fuels) have been referred to as both 'friend' and 'foe'. The friendly side of energy is linked to almost all developments in contemporary society; from transport, to communication, industry, health and housing, to food, knowledge and technology and particularly to our unprecedented global population size. However, few cities or their hinterlands produce energy at sustainable rates or take responsibility for the consequences of the energy they consume such as contaminants / emissions, extraction processes or waste (Nordhaus 2011).

As the economics of energy production change due to scarcity of resources, changing climate and social pressures - the conventional policy approach, dictated by potential economic losses or reduction in growth, will focus on finding replacements to match current energy sources. Many critics however suggest this approach may not be practicable and energy reduction may be the most effective strategy (Mackay 2009; H. T. Odum & E. C. Odum 2006; Heinburg 2009). Upon entering the 'urban millennium' with half of the world's population now urbanised (UNFPA 2007), and with urban areas accounting for a large percentage of energy consumption, a number of energy related issues should be addressed by urbanists.

Urbanism can address two significant land use related energy consumption sectors; transport and buildings. Transport is one of the largest energy consumers (Mackay 2009). Density and transport-related energy consumption have been well documented, at least at a city scale (Newman & Kenworthy 1989). In terms of buildings, a signficant amount of energy is invested during construction (including materials, transport and the building process). Ongoing 'costs' related to urban form include inherent heating and illumination needs (Ratti et al. 2005). Energy demand in urban areas is also affected by the increasing affordability of appliances and the dramatic increase in energy consumption associated with the rise of ICT (Information Communications Technology) which has realtively little to do with urban form.

Urban energy consumption is not related simply to 'hard' or physical qualities of urban environments such as materials and insulation but also to 'soft' issues associated with how people use urban areas including density, accessibility and proximity to needs (Boyko & Cooper 2011). In this way, modern cities are built with an expected permanent supply of energy (electricity). This prompts the project's research question:

How would our cities tolerate sudden reduction in energy availability? What areas will be most suited to less energy and what changes will be necessary?

Energy use is often measured or compared in terms such as domestic energy consumption, rates / distance travelled, vehicle ownership, etc. But little is understood about how the immediate environments people work and live in influence consumption patterns. It is clear, however, that attitudes and habits are highly cultural and place based – depending on the distribution of living, work and recreation attractions. Therefore, how do environmental/place qualities reflect a city's energy demands? Can specific urban conditions be associated with energy consumption?

A sudden reduction in traditional energy supply will favour some urban areas over others and may create an economic shift favouring compact and efficient urban areas over dispersed ones, in apposition to recent trends in accessibility (Graham & Marvin 2001) that suit a high energy economy. As this research aims to show, some urban areas are expected to be able to support today's high quality of living while consuming significantly less energy. This however will require a long-term planning vision, integrating energy saving measures into urban form and urban planning.

This research will explore a number of Themes related to urban form and energy consumption – from density, place qualities and design, to amenities and diversity. Consideration will be made in terms of how urban areas may be modified or improved to quickly adapt to sudden reductions in energy supply.

Hypothesis

Readily available sources of energy have become so ingrained in contemporary society that it is hard to consider life without them. Indeed it is unlikely that we will divorce ourselves from the most accessible form of energy, electricity, in the short or medium term. Yet in the future overall supply volume will be in question.

As fossil-fuel energy sources are expended and supplies become riskier, and / or carbon production becomes limited at a global level, cities that have prepared for leaner energy demands will be significantly advantaged.

Based on energy conservation, compact and decentralised (in terms of services and employment) urban form with strong collective transport links is expected to be the most practical typology to deal with reductions in energy supply.

Effective strategies to develop such urban form may take an oblique approach to energy reduction by focusing on improving lifestyle qualities in to order reduce energy dependence. In fact energy may play a far more significant role in the future of urbanism and soon underpin social and aesthetic principles.

Method

This project will investigate energy and urban form through both empirical / observational research and a theoretical Futures Study[1] concluding in practical applications. A framework developed by Carl Steinitz will be adapted to the requirements of this project (Steinitz 2002).

Empirical research will help to consider how particular areas will be affected under different future conditions, suggesting the most effective ways to act. The Futures Study will frame strategies and help identify measures requiring further research. Case projects will be used to test strategies and to re-evaluate both the analysis and the scenarios within the foreseeable future.

With connections to systems thinking and organisational planning, popular in the 1970s-1980s, Steinitz's method is appropriate as it helps organise layers of impact related to energy consumption (Bertalanffy 1976; Ackoff 1989). It provides a framework for studying the larger context of energy consumption instead of predetermining issues such as mobility, embodied energy, thermal mass, industry etc and thus focuses on the elements that are most effective and have the greatest application potential. By distinguishing quantitative 'data' (such as consumption rates) from qualitative 'cultural knowledge' (user / social patterns), strategies can be identified that have the most significant

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[1] Futures Study will be capitalised in this document where the term refers to the Futures Study which forms part of this research.

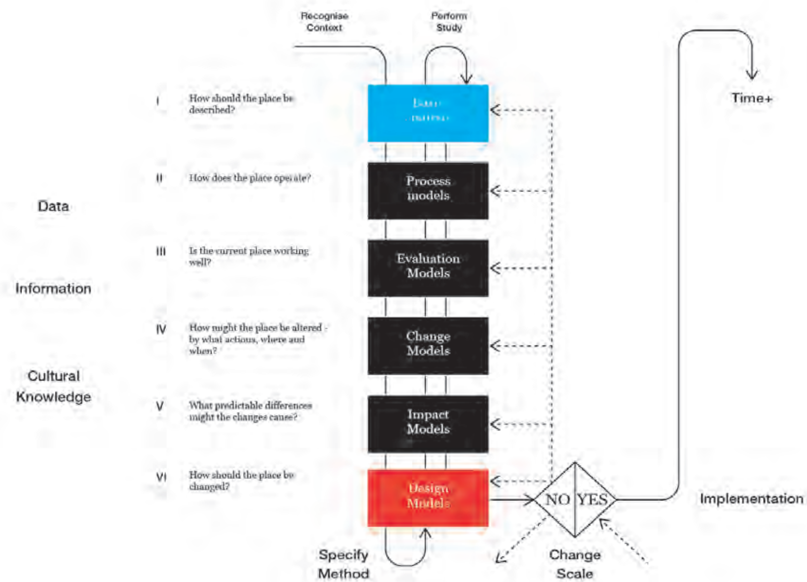


Figure 1/03: *Based on 'A Framework for Ecological Design' - Steinitz (2002)*

impact based on socio-cultural capacity. Accurate energy consumption rates, as will be explained later, are difficult to find so much of the research will be based on established research, confirmed through quantitative measures taken for each site.

Question	***Objective***
Tolerating sudden changes.	Analyse how urban areas consume energy. Identify indicators that can be used to read the 'fitness' or resilience of urban areas under leaner energy requirements. Develop a Futures Study based on a lower energy requirement. Qualify certain typologies based on their robustness.
Areas requiring attention.	Identify priorities based on the robustness analysis and the Futures Study. Determine importance of priorities.
Environmental / place qualities + energy demands.	Identify urban form characteristics that may contribute to high and low energy demands.
Strategies	Define an implementation process to create more robust urban areas

Chapter 2 offers an introduction to the theoretical concept behind energy reduction – at least why it is necessary to be prepared for such an occasion.

Chapter 3 will provide a basic analysis of a major urban area, Barcelona (I + II – as described in Steinitz's framework). ***Chapter 4*** will evaluate the city's energy performance by comparing sites within the metropolitan area – observing the 'fitness' of various typologies under comparable measures (III). Themes will be explored in terms of density, accessibility and proximity, diversity and building types. The Futures Study will then consider how changes may occur (IV) exploring the consequences of less energy. These deductive measures will be complemented with strategies based on both the performance and character of the place. A vision of the future will be then presented to frame the themes and the scope of the project. Finally examples, or 'design models', will be developed in ***Chapter 5*** in order to consider how to implement the strategies, test staging and to reflect how the Futures Study could be applied.

Objectives

The intention is to test the method identified earlier, based on certain generic themes related to urban form and energy consumption. The project will use Barcelona as a case study; however it is assumed such an approach and research method could be applied to many other urban areas.

Density and Urban Form

In the context of this research, two terms require clarification and distinction: density and urban form. Firstly density, as explained in Boyko and Cooper's extensive research, is a term that has been used freely and inconsistently (Boyko and Cooper, op cit). Density in the context of this research will be used as a study theme, referring to both the 'hard' / physical density and 'soft' / functional density.

Urban form specifically refers to the 'hard' density – which involves the container or the environment within which people live and work. It may consist of the amount of commercial space, the provision of car-parking, the size and fall of the streets, the availability of amenity and parks. But this does not offer any indication of how people relate to density. The 'soft' side of density involves habitation – it includes population density, income, mobility patterns and even use of public space. Therefore one of the study objectives involves identifying how urban form's physical / environmental qualities are linked to usage related energy consumption.

Research Themes[2]

Transport, housing and food have been found to account for a large portion of energy consumption; one study has found these factors contribute to 80% of direct and / or indirect environmental impacts (Holden & Norland 2005). There are four main sectors related to energy in Spain: transport, domestic, secondary industry and tertiary sectors. Secondary and tertiary energy consumption relate

[2] *Themes will be capitalised throughout the document where it refers to the five factors mentioned here: density, accessibility, proximity, diversity and building types.*

heavily to technology and supply chains – a complex and highly technical area of research which is largely outside the scope of the urbanist's expertise. Transport and housing will therefore be the focus of this study, as food and industry have a very different scope of research.

Transport contributes to over 40% of the total Spanish energy budget (less at a highly urban scale such as the centre of Barcelona) and is a far more complex area of research. Therefore the study will dedicate most of its attention on transport and mobility.

Housing contributes around 17% of the total energy budget in Spain. Residential energy consumption is generally distributed between heating, lighting and appliances – with median consumption averages calculated according to building type (IDAE 2010). Consumption, as will be shown, is more closely related to dwelling size than to income and building performance can be linked largely to age of construction.

Throughout this project, research will concentrate on five Themes that have been found to relate to energy consumption based on criteria framed within previous studies. The Themes are: density, diversity, accessibility, proximity and building types. They will be described in more detail and analysed in Chapter 4. The rationale behind selecting these Themes follows.

Cervero and Kockelman have linked 'density' and 'diversity' with mobility patterns (Cervero & Kockelman 1997). Density according to this study can refer to job and population density – but there are numerous other forms of density that, as will be shown, also affect significantly the performance of the urban area. Diversity involves the range of land-uses associated with a place.

Accessibility and Proximityare also important factors that determine the reason for travel or the mode chosen for travelling (Talen 2011; Stead & Marshall 2001). Accessibility refers to the possibility of access, particularly through means of transport or communication. Proximity, conversely, involves attractions, destinations, services or amenities that are found near the resident reducing the need for transportation.

Finally as stated earlier, a significant amount of domestic (and tertiary sector) energy consumption is also associated with 'building types' and the technical qualities of the building Design (Ratti et al. 2005; Salat 2009). This Theme may be considered as being different to the other Themes, and regarded as urban 'fabric' rather than urban form (Álvarez 2010). However as this Theme is connected to the historical development of the city and to the robustness of urban areas under changing energy conditions, it will be considered as a layer of the overall strategy.

There are many other important issues which will be measured (refer to Appendix 2). Cervero and Kockelmen like Moudon and others find the Design qualities are also integral, including features of the urban areas such as trees, proportion of pedestrian areas and the design of the urban network (Moudon et al. 2006). Design qualities in this regard will be considered as indicators of energy consumption. It is clear there are 'social' factors associated with energy consumption connecting land use, travel patterns and income or socio-economic issues (Stead 2001). Income not only determines travel opportunities but is also associated with employment type and distance to work.

Relevance to current research

This project covers a range of topics within a number of fields of research related to energy consumption and urban areas. Associated research includes studies into urban form and density from both a physical and social perspective.

General research includes studies into walkable areas and 'sustainable' urban form (Moudon et al. 2006; Talen 2011), and transport and mobility and building technology, building form and energy consumption (Ratti et al. 2005; Salat 2009). Significant research has been undertaken in energy, mobility patterns and urban form – particularly in lower density urban areas such as North America, the UK and sites in Northern Europe (Stead & Marshall 2001). Research in Barcelona has focused on the costs of suburban development (Muniz et al. 2006). At a larger metropolitan planning scale, projects such as SUME (Sustainable Urban Metabolism for Europe) have investigated consumption patterns including energy consumption and mobility, comparing eight cities (SUME 2009). At a smaller scale, the linking of measures related to a wide variety of physical and social qualities and urban form is currently receiving attention (Salat & Nowacki 2011).

Barcelona is a city that has been studied at great length in terms of architecture, urbanism and transport but to a lesser extent in terms of energy performance at an urban scale. In principle Barcelona offers a model of planning that should cope well under a lower energy economy – this is a benefit when studying urban conditions that can identify 'best practice' when analysing other urban areas. Current planning policy in Barcelona and Catalunya focuses on compact urban form ranging from commercial strategies to urban settlement. The city itself has been praised for decentralising public offices, distributing administrative buildings and education centres across the city thereby encouraging mobility systems to be balanced and providing frequent demand throughout the day. However, road-building policy over the last 50 years has supported greater levels of private transport thus reducing the benefits of the city's compact urban form in terms of energy. Therefore this level of research is of relevance to Barcelona and the present debate behind urban energy strategies, which is currently overwhelmed by energy production or building technology rather than targeting strategies to deal with consumption patterns. Further to this, the municipality of Barcelona acknowledges energy savings as its main strategy to reduce C02 emissions by 2020 (PECQ 2011).

In Barcelona two organisations are heavily involved in researching 'urban metabolism' from a technical / engineering perspective (www.sosteniprac.cat accessed 05/11/2011) and 'urban ecology' from an ecological / environmental perspective (www.bcnecologica.net accessed 05/11/2011) however neither approaches the issues in terms of both urban form and social qualities. The Metropolitan Area of Barcelona (AMB), charged with reviewing mobility and environmental conditions, does include some research into mobility and energy consumption but energy is not a major focus. The Municipality of Barcelona also studies urban form and energy consumption at a municipal level however it is not in their competence to consider strategies for energy consumption related to urban form (Ajuntament de Barcelona 2011) – which will be described further in Chapter 3.

Scope + Limitations

Extent. The study area consists of the Metropolitan Area of Barcelona (Àrea Metropolitano de Barcelona or the AMB of Barcelona). The 'Law of the Metropolitan Area' was recently passed in 2010, becoming active mid-2011. This area is a reinstatement of the pre 1987 metropolitan area which now involves 36 municipalities collaborating on a range of issues including development, transport and the environment.

Scope. The Metropolitan Area of Barcelona will be the focus of the project, but the scope will remain directed at urban form to identify specific characteristics of urban areas. Specific strategies will be proposed; however an overall city masterplan will not be developed.

Mixed Use Urban Form. This project focuses on residential and mixed use urban form. As a large proportion of energy is consumed through mobility, this project focuses on how urban typologies may be able to support a greater mix of jobs and amenity aiming to reduce mobility. Other important urban energy related topics such as waste, water, work / industry, tourism and food production will not be covered. These are considered far more place specific and outside the urbanist's field of expertise.

Work Vs Play. While leisure related energy consumption is considered one of the largest components of Barcelona's mobility budget, it is also felt that leisure is the most dynamic component of society associated heavily with wealth and mobility making it hard to assess energy dependencies associated with leisure. Leisure is also very difficult to quantify. Data and statistics on work and home are far more readily available and can be quantified spatially.

Externalities. Places are linked by communications, trade of goods and movement of people and may include the embodied energy in materials and services that require energy. If a global energy crisis occurs then the implications will be shared universally. For example, the energy demands for food production may mean food not only becomes expensive but can be produced more cheaply in a city's hinterland – which may have a dramatic effect on the way the city operates. These externalities are highly complex and open to radical speculation. Although described within the scenario and important for planning, they will not be investigated in detail within this project.

Energy Production. Cities will need to take energy production seriously if they intend to become resilient. Energy production has been researched in detail by others such as David Mackay who considers not only the energy yield potentials but the social component attached to implementation (Mackay 2009). This is indeed a topic urbanism must not neglect but as energy production is a highly technical area of research (with future technology development a highly contentious topic), this project will not investigate renewable or metropolitan energy production.

Data. Limitations associated with availability of data affect the scope and precision of the analysis. As noted earlier, assumptions will need to be made in such cases, or based on established research. Accurate data on issues such as mobility and energy consumption may not be available but other measures can serve to provide an indication of consumption habits and confirm the literature. Certain consumption habits can also be assumed by other, socio-economic measures.

Analysis

Twenty two sites distributed across the city have been selected based on a mix of age, location, income level, density and accessibility. Each site will be analysed according to the quantitative measures identified and confirmed by a literature study. This project will provide an indication of average performance of each site in terms of the whole and will help identify priorities relevant to certain urban conditions.

Futures Study

How do we prepare for the future? Planning for the future requires a notion of what the future will look like under perceived circumstances. Evaluating future conditions helps establish criteria for analysing current conditions.

A Futures Study, developed in Chapter 4, will exclude technical solutions capable of solving current energy demands above and beyond the technology currently available. As will be explained, the focus of this research is on the implications of less energy, considering how this issue can be integrated into current urban planning.

As both gradual and sudden changes in energy availability have a relatively similar outcome, the Futures Study will look at the implications of the latter. Assumptions have been made that a 'gradual' decline would take in the order of 50-100 years to eventuate. A 'sudden' change would not replicate the 1973 oil crisis but would play out over a much shorter period of say 20 years. Based on this timeframe and on current trends, assumptions on energy demand conclude that renewable energy production will reach 30% of total Spanish energy requirements. The Futures Study also assumes 10% of today's demand will be from traditional sources in 2032. Therefore under these conditions, strategies will be developed to cope with potentially 40% of current energy demands.

The analysis will look at the four major energy consumption groups (transport, domestic, industry, tertiary / services) and consider how these groups will each be adjusted into the 40% energy budget. In this way the most wasteful forms of energy consumption can be targeted (personal transport for instance) while more important energy use can be protected (such as that required for food consumption).

Based on the readjusted energy demands, findings from the earlier analysis will be translated into three strategies involving mobility, density and building types.

Motivation - why Barcelona?

Energy could be analysed at a pan-metropolitan level – comparing various cities on a macro scale. But this would not explain 'soft' qualities or cultural habits associated with energy consumption and urban form. This study will focus on the performance of one city, Barcelona, but where possible make comparisons with other cities to gauge relative performance.

Barcelona, as noted earlier, is an example of a city that by its compact nature should perform very well in a low energy future. Therefore the findings may not offer radical innovations over what currently is standard practice. Nevertheless, the findings may help establish what is good practice. The city offers material for a rich case study on density as it contains a diverse range of clustered urban areas that can be easily catalogued in 'types'. As Manuel de Sola Morales put it, Barcelona could be considered a '…workshop in which ideas about urban form have been tested – some, as we have seen, remarkably successful and innovative…' (De Solà-Morales 2008).

Barcelona has areas with some of the highest population densities in Europe yet it also contains areas with very low densities within a short distance from the city's geographic centre. In addition, it contains areas with high land use mix, and others that are highly monofunctional. Therefore the city provides an interesting case for analysing energy consumption and a range of factors associated with density, accessibility and proximity, diversity and building types. These issues will be explored further in Chapters 3 and 4.

Another factor is containment. With metropolitan or city regions in some cases now agglomerating into 'urban' regions, it is hard to define where the limits of one area end or begin. Barcelona contains natural barriers that to some extent have limited its physical growth. While the city could be considered to extend for many kilometres along the Mediterranean coast, some geographical factors help define its limits away from the coast.

Barcelona is currently at a crossroad, making it an interesting subject for speculation. Having invested enthusiastically in both infrastructure and housing projects - most recently leading to serious property speculation and famously to a burst housing bubble - the city has entered one of its most dramatic economic crises in modern history. In a recent report analysing the economic status of 150 world cities, Barcelona was considered to have suffered the greatest drop in performance without signs of recovering (Metropolitan Policy Program - The Brookings Institution et al 2010). Unemployment is estimated at 20%, with 43% of younger age workers unemployed – the highest rates since the crisis started in 2008 and possibly in living memory (IDESCAT 2011). Across Spain, 700,000 new empty dwellings remain unsold – leaving the construction industry devalued and stagnant (The Economist, November 3, 2011). While this sets a sombre backdrop, it also provides an environment for change. The pattern of consumption, work, leisure and living prior to the recent global economic downturn is likely to change dramatically over the coming years.

After introducing a renewable energy scheme, Spain now produces almost 20% of its electricity needs (or a little over 10% of its total energy needs) through solar and wind generation while some regions (such as Galicia and Castile) produce between 50-70% by these renewable means. On the other hand, Catalunya, of which Barcelona is the dominant population centre, is a territory with 97.5% reliance on imported energy; the remaining 2.5% is derived through hydroelectricity. The energy demand relies predominantly on nuclear sources, supplemented by coal, gas and oil (refer to Chapter 3 for a more detailed analysis of consumption patterns). Changes in energy availability or price will therefore have a dramatic effect on Catalunya's economy and livelihood. With infrastructure funds scarce during one of the biggest economic downturns in living history, changing consumption patterns will be a more effective energy strategy than satisfying demand with large-scale local renewable energy infrastructure.

A number of qualities make Barcelona difficult for comparative studies. There are few other Western cities that are similarly compact and decentralised while sharing mild climatic conditions, which means that a number of factors should be considered before making comparisons with other cities. Barcelona's 'compact' decentralised character means that tracing commuter patterns is much more difficult than for monocentric working environments. In terms of climate, Barcelona provides an example for many Mediterranean cities and other cities with similar climate and latitude (for example a number of large urban areas in South America, west-coast USA, Australia, Southern Africa, some parts of the middle east and some parts of Asia).

Terminology

Refer to the section at the rear of this document for definitions of commonly used terms. A few terms used frequently include:

AMB – the managing authority charged with managing the Barcelona Metropolitan Area (Area Metropolitana de Barcelona). It involves three sectors: urbanism (Macrocumunitat AMB), mobility (EntidadMetropolitana de Transport) and environment (Mediambient AMB).

Barcelona, City, metropolitan area– the 36 municipalities within the Metropolitan area.

BCN – specifically the Municipality of Barcelona.

2

Energy Future

Overview

- A Futures Study based on a transition into a lower energy economy will be used.
- Some of the larger implications of a lower energy economy will be explained. This includes elaborating on a futures study prepared by Odum & Odum, titled 'A Prosperous Way Down' (2006). As will be explained, the Odums' study is provocative yet relatively vague, thus requiring some elaboration.
- This chapter will provide the basis for the analysis found in Chapter 3 and 4. It will be further expanded in Chapter 5 while establishing implementation straegies.

Introduction

Since the 1970s oil crisis, and as a result of the general scientific community's belief that climate change has been man-made, many energy transition studies have been considered. The studies assume changes to current energy sources ranging from technical salvation to apocalyptic energy scarcity. Essentially two questions stand out:

- Will there be a technical solution that can satisfy current energy demands?
- What will be the pace of change - slow or sudden?

Based on these two questions, four extremes can be established (refer to Figure 2/01): A) slow transition to new energy systems, B) dramatic technology improvements and over-abundance of energy (e.g. fusion or hydrogen become commercial), C) limited development of current technology followed by a slow decline or D) a relatively sudden scarcity of energy. This is just one of many approaches to energy futures[1].

This study looks at a future with less energy. As both A) and B) are likely extensions (or improvements) to current conditions, this research will not elaborate on them. Both C) and D) follow relatively similar outcomes, the variable being time. Clearly a rapid change would create more problems, so D) will remain the focus. This provides an opportunity to return to the main research question:

How would our cities tolerate sudden reduction in energy availability? What areas will be most suited to less energy and what changes will be necessary?

---

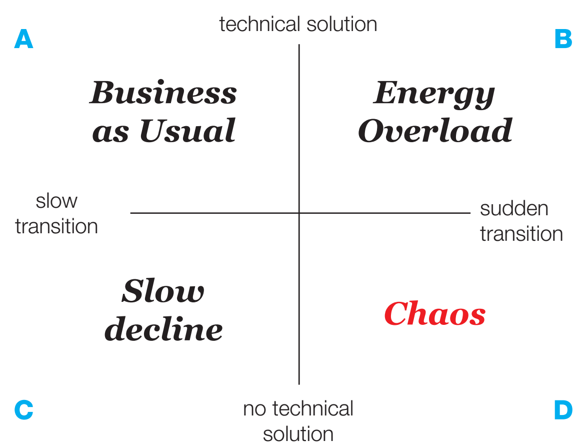
[1] *The range of scenarios varies considerably. Unfortunately the scope of this research does not allow for a comprehensive assessment of scenarios related to energy. For example, the 2050 EU Roadmap takes a 'tech-fix' approach, suggesting that despite increasing energy demands, an 80-95% reduction in carbon emissions can be achieved in 40 years time – indicating a radical renewable energy production challenge (European Commission 2011). This has been embraced by European Climate Foundation, proposing a pan-continental renewable energy network spanning to North Africa to address this demand (European Climate Foundation 2011). This strategy does not place emphasis on lifestyle changes – unlike scenarios such as the 2000 Watt Society (amongst many others) which proposes a policy driven cap on consumption (Stulz & Tanner 2011). Alternatively with current technology, and cultural objection to energy production technology existing demand will be difficult to satisfy (Mackay 2009; Heinburg 2009).*

Futures Study

Futures studies form the foundation of many approaches to energy planning. They offer a frame in which to plan. Within the context of this project, a Futures Study will be used to identify targets and the policy direction to be applied in the following chapter.

Zurek and Henricksin Figure 2/02, shows how the context of future planning becomes less definable based on time and changing knowledge. They suggest that longer term future planning should focus on how the decision unit (in this case Barcelona) fits within the decision context

Figure 2/01: *Scenario diagram*



(reduced energy availability). Certainly many variables will affect the outcomes of such a future and naturally a Futures Study on broad themes such as energy transitions will require significant generalisations or omit the significance of many complex interdependencies associated with energy use (Zurek & Henrichs 2007). As a single 'scenario' will be explored, the research will not enter 'scenario planning' but rather focus on studying possible 'future conditions' under certain circumstances; particularly less energy.

Future studies may involve either 'forecasting' (considering the outcome of current trends over a given time frame) or 'backcasting' (considering future conditions then establishing steps to arrive at that position) to define an implementation process. In some cases forecasting can be used to set foreseeable progressions, for instance the likely expansion of infrastructure, population growth or changing resource demands. Backcasting is much more effective at finding paths from abstract future conditions. Both forecasting and backcasting will be used to describe the outcomes of the Futures Study.

Futures studies, particularly scenario planning, was famously employed by Shell Oil in the 1970s, allowing the company to not only adjust to the 1973 oil crisis but to prosper. A futures study will now be considered involving a very different energy crisis.

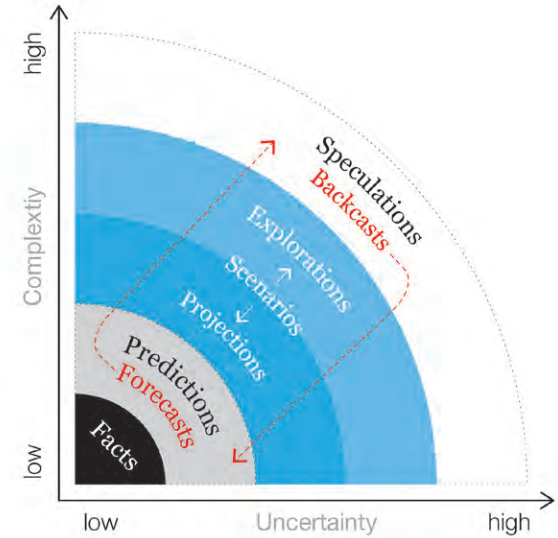


Figure 2/02: After Zurek and Henricks (2008).

Planning for a Downturn

Few future studies combine trends in global energy markets, global economy and increasing scarcity of other important materials. As explained by Nordhaus, energy economies are dynamically globally connected (Nordhaus 2011). This ranges from supply to cost. A downturn in global energy availability will have dramatic socio-political consequences.

A downturn in energy availability will not just be a production / consumption concern but will involve a major paradigm change. This will affect industry from communications and ICT to agriculture, health, transport systems, to mining and manufacturing and industries which many 'industrialised' nations have outsourced to the 'developing' world. Industrialising economies will also suffer considerably due to increased manufacturing costs. All levels and aspects of society will be subject to change.

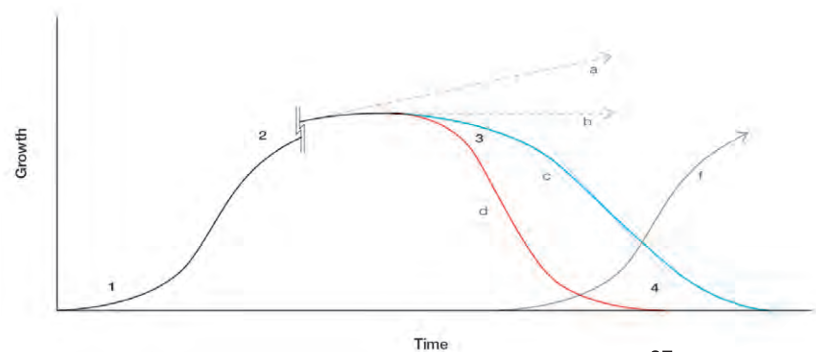
> *'Decisive changes in attitudes and practices can divert a destructive collapse, leading instead to a prosperous way down.'* (Odum & Odum 2006: 21)

Howard and Elizabeth Odum[2] developed a scenario dedicated to a descent (or 'decession') in both resource availability and economy - considering how to deal with a downward cycle without ending in a 'crash and restart' (H. T. Odum & E. C. Odum 2006). To avoid such a calamity, a 'prosperous way down' is proposed that superficially appears not dissimilar to the fiscal austerity savings measures that the Spanish are currently experiencing. However the emphasis of this transition is focused on quality of life standards.

Cycles, the Odums explain (refer to Figure 2/03), are evident in the natural world (annual growth cycles and animal migration, climate, etc) and throughout human history (technologies, businesses, economies, empires and civilisations). There are four particular stages in cycles as shown in the above diagram: 1) development and rapid growth, 2) climax and establishment, 3) descent with adaptations for less and finally 4) restoration without growth.

During the last century, the world witnessed, possibly for the first time in history, collective growth through global trade – driven, as the Odums explain, by a global energy economy. Financial models over the last 60 years have

Figure 2/03: *'The Pulsing Cycle' as described by Odum + Odum (2006)*



[2] H T Odum approaches energy from 'ecosystems principles' and an environmental perspective based on an environmental carrying capacity. This may be seen as contrary to other viewpoints that do not qualify a limit to resource extraction required to produce goods and technology depended on by modern society. The Odums' scenario is based on a reduction of resource extraction in general.

shown long term and a) steady growth making economies seem relatively stable however they rely on growth. Since the 2008 financial crisis, economies have grown little or have experienced b) relatively neutral growth. A change to a decline may take a c) slow or a d) sudden decline. A decline may now occur on a much larger scale than has been previously experienced.

As explained, a downturn in energy and resources has a knock-on effect including impact on the general global economy, transportation, communication, population growth, industry, trade, food, culture and knowledge (Heinburg 2009; Mackay 2009; H. T. Odum & E. C. Odum 2006). In some cases technology could provide a fix, preserving current living conditions. In others it may mean revisiting now antiquated and regionally focused economies, smaller personal savings and disposable incomes, reduced mobility patterns, greater reuse of processed materials, greater reliance on hinterlands and more local manufacturing.

On an urban scale, personal mobility reduces dramatically and radically affects population distribution. Those areas that cannot connect to, or be easily connected to, decline. Other areas densify and make way for new urban conditions. Larger complex cities support further growth while smaller urban areas associated with specific industry return to their industrial bases or stagnate and contract.

Buildings are constructed to cope with less energy input - aspiring to be energy independent to avoid energy supply issues.

The economy shifts, with significantly less speculation around abstract markets. Incomes reduce and income ratios contract: capitalism evolves.

Approaching prosperity

A transition to a lower energy economy will not be easy as it means giving up certain energy intensive 'comforts'. Sacrificing living standards in exchange for long-term energy security is unlikely to be a popular policy without an impending or foreseeable crisis. By nature humans have an 'optimism bias' providing a sense that conditions are better than they may turn out to be (Sharot et al. 2007). How can we prepare for an energy crisis without the cues / triggers to identify the downward cycle? How far ahead do we need to prepare? Will preparing for a possible but uncertain future event impact a city's current economy?

Odum & Odum suggest that a 'Prosperous Way Down' will be an effective strategy to soften the blow of a downward cycle. It involves 'obliquely' integrating 'prosperity' into a concept for modern living (Kay 2010) – what Giddens similarly refers to as 'positive life-style bargaining' (Giddens

1996). The term 'prosperity' in this sense does not imply 'luxury' - on the contrary it means living happily with less. Therefore 'prosperity' refers to quality of life (focusing on health, wellbeing, education, safety, communication, knowledge etcetera) rather than standards of living (which primarily take income as a driving indicator). Such a vision involves finding both technical and social solutions that reduce consumption without impacting the quality of life established up until now.

The Odums have consciously omitted from their 'Prosperous Descent' scenario a tangible time horizon – they state that this is only clear retrospectively, after many consecutive contractions particularly in finance, manufacturing and agriculture. Time objectives will be further explored in Chapter 5.

Conclusions - relevant research issues

The Odums' 'Prosperous Way Down' scenario provides two messages for this project: a decline in energy will likely impact many issues outside of the control of urbanism however a strategy to soften the impact will be to reduce energy dependences through increasing 'prosperity' or quality of life values.

The scenario sets a larger context to the energy debate identifying how it is heavily linked to many other delicate issues such as finance, industry, food production and population, which may change directly or indirectly the future of urban areas. This regards growth and / or decline of urban areas, mobility and future economic conditions and helps frame this study.

The two focus areas of this research, mobility / accessibility and building performance, can be researched in terms of potential conditions in a low energy future as framed by the Odums. In terms of mobility a range of topics could be better understood: links to work places, accessibility to shops and basic attractors, proximity to public community environments, links to larger mobility systems. In terms of building types, basic consumption indicators are necessary – such as the condition of the buildings to deal with less energy.

As this research does not involve looking at energy production, self-sufficiency or energy independence will not be established – this requires a technical study at the building level.

As the Odums suggest, 'prosperity' or quality of life standards should be the focus behind change. A number of 'robustness' indicators based on this will be analysed in the following chapters.

3

Barcelona

I) Basic analysis: How should the place be described?

II) Process models: How does the place operate?

Chapter Overview

- This chapter will broadly describe energy consumption at the city scale to provide some context for the rest of the research.
- The chapter will report on how the city performs in terms of density, accessibility, proximity, diversity and building types. The chapter also attempts to place energy consumption into a historical context to consider what urban interventions or events may have allowed growth in energy demand.
- Where possible, comparative studies will be included to provide some context for how Barcelona performs.
- Although data presented within this chapter is not very detailed it will provide some context for further research in Chapter 4.
- The chapter ends with an overview of documents, plans and strategies related to the topic.

Figure 3/01: *The Barcelona Metropolitan Area (source: AMB 2011)*

Introduction

Energy consumption, as noted earlier, is highly place sensitive and relative to a range of socio-economic, historical and geographic conditions. Energy use in Spain is classified into four major categories; transport, domestic (residential), secondary industry and tertiary sector. This research will investigate both transport and domestic energy consumption. Mobility, as will be shown, is a function of many issues such as jobs, attractions / leisure, services, amenities and increased opportunities. Domestic energy consumption is seen as a function of building type and size of spaces.

General Stats

The study area for this project involves the 36 municipalities of the recently legislated metropolitan entity called the Metropolitan Area of Barcelona (AMB – ÀreaMetropolitana de Barcelona). The area includes a significant number of co-dependent municipalities, of which the municipality of Barcelona is the largest and most powerful. Often statistics purporting to represent the larger Metropolitan Area are confused with those of the Municipality of Barcelona (BCN) making the city appear more compact and pedestrian oriented than it is at a metropolitan scale (the following statistics from IDESCAT).

Size of metropolitan area – 636 km2 (BCN - 101.4 km2)

Population density, gross – 5060 residents / km2 (BCN – 15,991 / km2)

Population density, built area – 23,800 / km2 (BCN – 39,500 / km2)

Income – €15,121 RFD (Disposable Family Income – a standard measure of wealth in Spain) (BCN - €17,302)

Car ownership – 360 cars / 1000 inhabitants (BCN – 369 / 1000)

Energy consumption – 10.52 MW / hr / inhabitant (total energy consumption), 4.6 MW / hr / inhabitant (electricity consumption)

Current Energy Consumption – an Overview

As shown in Figure 3/02, energy consumption for the four main sectors, transport, domestic (residential), secondary industry and tertiary sector, varies significantly depending on the scale of analysis. At a state / national level, energy consumption consists of a relatively similar balance sheet (ICAEN 2007; Ministerio de Energía Turismo y Comercio 2010) with transport accounting for almost 37-40% of consumption followed by secondary industry with 31-34%, residential with 14-17% and finally tertiary sector with 10-11%.

At a city scale, values change considerably (Ajuntament de Barcelona 2011). As shown in Figure 3/02 at a city level domestic energy consumption doubles, the tertiary sector triples, while mobility and industry shrink to almost half – therefore over 80% of the energy consumption at a city level involves homes, movement and tertiary workplaces. Transport, domestic and the tertiary sector will be analysed in more detail in the following pages.

Mobility and energy consumption. Personal transport accounts for the highest amount of mobility related energy costs at a city level with almost 60% of all energy dedicated to cars and motorbikes. By contrast public / collective transport buses account for 14.5%. Private mobility patterns will be explored later in this chapter. A relatively smaller percentage of total transport consumption, 25.6%, is dedicated to freight, logistics and delivery vehicles (High / Mid / Light Devlivery Vehicles - HDV / MDV / LDV).

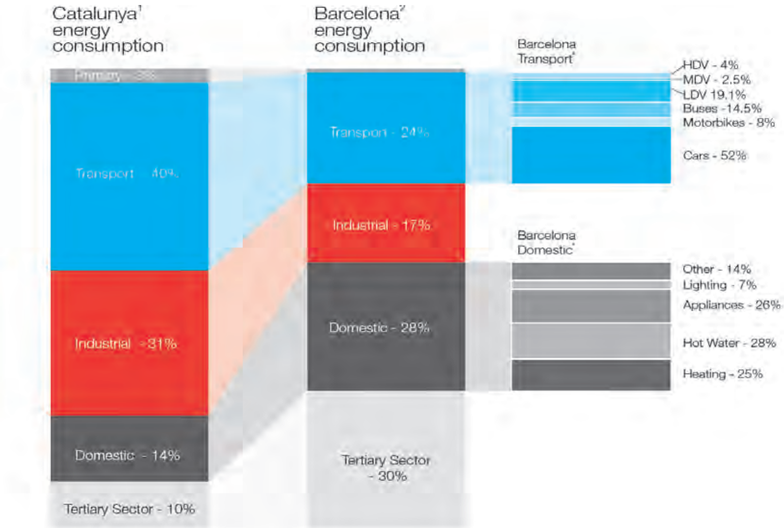


Figure 3/02: *Current energy consumption (PECQ 2011)*

Domestic energy consumption mix .The estimated domestic energy consumption mix largely involves heating and hot water, contributing to 50% of the overall mix. This amount is significant yet far lower than many northern European countries where heating can contribute to the equivalent of other domestic energy demands (Álvarez 2010). Generally domestic energy consumption is the sector that has made greatest growth in the last 15 years – with 50% increase from 4 GWh per capita in 1995 to 6 GWh most recently (Ajuntament de Barcelona op. cit.).

These statistics provide the context with which to study the historical development and existing performance of the city. The following pages will briefly present some the recent developments in the city that have links to how the city performs. City planning involves delicately balancing efficiencies through proximity and accessibility and as will be explained, many of these qualities have been embedded in the genetic composition of Barcelona.

Barcelona – a brief history of energy use

Barcelona, like many world cities, is situated on an unlikely and awkward site (Reader 2005). Its compact form emerges between two rivers (the Besós to the north and the Llobregat to the south) and between a steep coastal range and the Mediterranean. The city has survived since Roman times with an artificial and often silted harbour, a small and exposed agricultural area and a typically mercantile economy (Busquets 2005). Growing to be a significant industrial centre in the 19th and 20th centuries (competing with major centres in UK and Germany) it has no natural energy resources of its own.[1]

Links can be made between current energy consumption and the historical composition of the city reflecting how people live, shop, move and how buildings require lighting and heating. Robert Hughes, in his socio-political monograph, explains how Barcelona is three cities – each enclosing the previous (Hughes 1992).

> *On the perimeter, laced with ribbons of freeway, are the industrial suburbs that grew up in the post-1945 years of the Franco dictatorship; they are the products of unconstrained, unplanned growth in the 1950s and 1960s, stretching south to the Llobregat and north to the Besós rivers – a sprawl of factories and polygons, housing blocks for the hundreds of thousands of migrant workers who flooded Barcelona and decisively changed its social mix. Inside that is the big nineteenth-century grid of the Eixample, or Enlargement, which occupies*

Figure 3/03a: *The highly pedestrian oriented 'low energy economy' in the mid-19th Barcelona (Arxiu Historic de Barcelona 2012).*

[1] *With exception to seasonal hydropower which once ran some of its factories in the late 19th century.*

the coastal plain where the massif breaks away and slopes down to the Mediterranean: the New City, a repetitive carpet of squares with chamfered corners, slit by larger avenues, all laid out on paper in 1859 and mostly filled in by 1910. Then, inside that, where the grid meets the bay, you see the regular march of units break up, bunch into confusion, and become an irregular cell cluster from which older-looking protrusions rise: old square towers, Gothic peaks. This is the Old City, the Barri Gòtic, or Gothic Quarter. (Hughes 1992: 3-4)

These categories translate neatly into concepts of energy consumption. The three cities, regardless of current energy consumption, were designed and equipped for different kinds of energy and mobility systems - evident to this day; these will be further explored in Chapter 4. The three cities now consist of 1) the original ***low energy city*** developed during the Roman and Medieval periods which once survived with little solid fuel, followed by the 2) ***new energy city*** defined by Cerdà's Exiample and the agglomerated surrounding townships which have been adapted since the early days of electricity, and most recently 3) the ***high-energy city*** located on the periphery with sprawling industrial belts and pockets of monofunctional worker, commuter settlements and recent reformations.

New energy, new city

In 1848, the train arrived in Barcelona, connecting the city to the wider world of transport and technology. While combustion engines were being installed in small, typically family run factories throughout the city and adjoining settlements, the small cramped fortified city was not equipped for the dramatic industrial growth it would experience in the late 19th and 20th centuries (De Solà-Morales 2008).

One of Barcelona's most famous urban interventions was Ildefons Cerdà's 1859 city extension plan. Cerdà's new Barcelona is considered a work of great genius through its simple resolution of the many competing and complex demands of an urban environment. Not only did this plan

Figure 3/03b: *Cerdà's Barcelona - the new energy city, plan by Ricard Alsina Amils 1899 (ICC archive, accessed 21/12/2011)*

allow the city to grow but it allowed ordered growth to accommodate a range of new technologies such as personal motorised transport and the electrified tram network, carbon / electricity driven industries, public lighting and domestic electricity use. In fact Cerdà was an early proponent of the natural gas industry that emerged in the mid 19^{th} century which was accommodated in the Eixample grid (Arroyo 1997).

Cerdà established that a city should focus on two functions: nodes and connections. This according to network theorist Gabriel Dupuy, heralded the Catalan engineer as one of the innovators of modern network theory (Dupuy 1991). Cerdà's plan allowed the complexity of the formerly crowded gothic city to be transferred into the Eixample, while providing room for new energy based technology to fit comfortably within the growing city. Consequently with space for growth, demand also grew.

Chaos and Order - Recent development of Barcelona

In post 1939 Francoist Spain, Barcelona was hailed as one of the nation's industrial sweatshops, supporting what was later to be dubbed the 'Spanish Miracle'. From the late 1940s, the city grew rapidly through internal immigration. Unplanned residential and industrial polygons were consequently implanted haphazardly across the coastal plain. Development was distributed according to availability of land rather than proximity to mobility systems, services or

Figure 3/04: *The new energy city could accommodate many kinds of new transport (La Vanguardia Archive, accessed 13/01/2012)*

attractions. As de Sola Morales notes, 'Never before had so many decisions been made in so little time, nor the period between initial idea and laying the first stone been so short' (Morales 2008: 468). 'The Urgency Plan of 1957' ('El Plan de Urgencia de 1957') involved 900 hectares of land (around the same area as Cerdà's original Eixample), with the development of 127,000 dwellings – an approximate construction rate of 12,000 dwellings per year.

As will be noted in the following pages, this impulsive development during the 1950s and 1960s left many of these areas with little diversity, inadequate commercial space and few services while many areas remain relatively disconnected (De Solà-Morales 2008). In addition, worker housing initially connected to now decommissioned industry has meant that residents travel to similar types of jobs elsewhere, and often on the fringes of the city. These urban qualities have a fundamental impact on energy with little mixed use area, with a typically commuter work-force and with conditions oriented to private transport use. In addition most of these buildings were constructed before thermal insulation standards were legislated (in 1979) and therefore have thermal qualities similar or worse than those of much older types of buildings.

During this time, a second transformation ignited the increasing energy consumption: the development of new highways and the affordability of the car. The establishment of the Spanish national automobile company, Seat, made car purchase possible for the larger working class and shifted national transport policy towards private modes. Both roads and access to vehicles have had a positive effect on Barcelona's economy and significantly improved connectivity. However as will be shown later, connectivity has also allowed the city's reach to expand into the hinterlands well beyond the formerly compact centre and quickly instilled a car culture in Barcelona – thus creating significant energy dependencies that counteract the benefits of the compact urban form. These Themes will be explored in greater depth throughout this document.

Highway construction began in the 1950s, initially following the coast north and eventually connecting outlying settlements to the south and north-west. Further road building and infrastructure projects were implemented, yet it was not until the last quarter of the 20th century that the city was brought together as a metropolitan unit. In 1976, with the transition from the Francoist government, a comprehensive metropolitan plan was developed which has set the planning agenda ever since. Industry, port, mobility systems, tunnels, new urban areas, recreation areas, the orbital ring-road and many other large scale urban interventions have been developed over the last 45 years which have 'expanded' and 'reformed' the city (De Solà-Morales 2008; Busquets 2005). Supporting a previous statement, these transformations have brought prosperity to the city however through specialisation and improved accessibility

Figure 3/05: *Bellvitge, under construction in the late 1969 - one of many types developed during this period. (source - collection by Bagán Nebot, accessed 14/01/2012)* they have also resulted in significant increases in energy consumption.

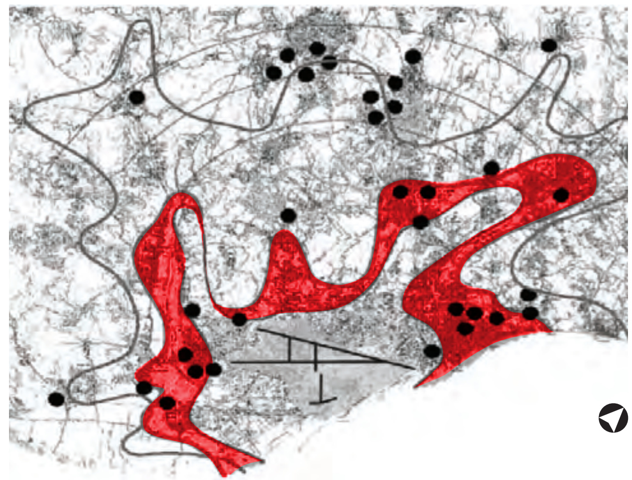
As Manuel De Sola-Morales and Manuel Herce explain, with the growth of highway development since the late 1950s, accessibility saw a radical shift in both policy and modal share towards the car (De Solà-Morales 2008; Herce 2009; Herce 2005). Satellite towns became within reasonable reach for daily commuters so urbanisations on the city's periphery offered both the comfort of exclusively low-density residential areas and access to city jobs and attractions. Herce's study on the accessibility (Figure 3/06) before and after the development of the city ring road prior to the 1992 Olympics shows how the city's catchment expanded creating 'new centrality areas' (Herce 2005).

With the new ring-roads, congestion was dispersed across the city to the new and less congested motorways. But over time car ownership has continued to grow and the once congested major roads in the city, such as Avinguda Diagonal and Gran Vía, have been re-saturated with equal to or greater levels of congestion (Herce 2009).

Collective transport between the centre and the new periphery, while available, has not been able to compete in speed, comfort or efficiency with the car thus making the city's periphery highly car dependent and consequently highly energy dependent. While typically low density development is associated with higher income, as will be explained in Chapter 4, the income density ratio decreases with distance from the centre (AMB 2011) confirming that some lower-middle income low density areas have little choice of collective transport and thus are compelled to use private modes (Coutard et al. 2009).

By contrast, since the 1980s the congestion and density in the centre has been recalibrated by expanding pedestrian areas, by slowing vehicle traffic in neighbourhoods and by creating access hierarchy, by reconfiguring public areas to provide increased public space that encourages pedestrians (with 36% of movements by foot) and most recently by improving the presence of bicycles through bicycle shar-

Figure 3/06: *As defined by Herce, new areas of centrality (in red) as a result of the ring roads built during the 1992 Olympics development (2005).*



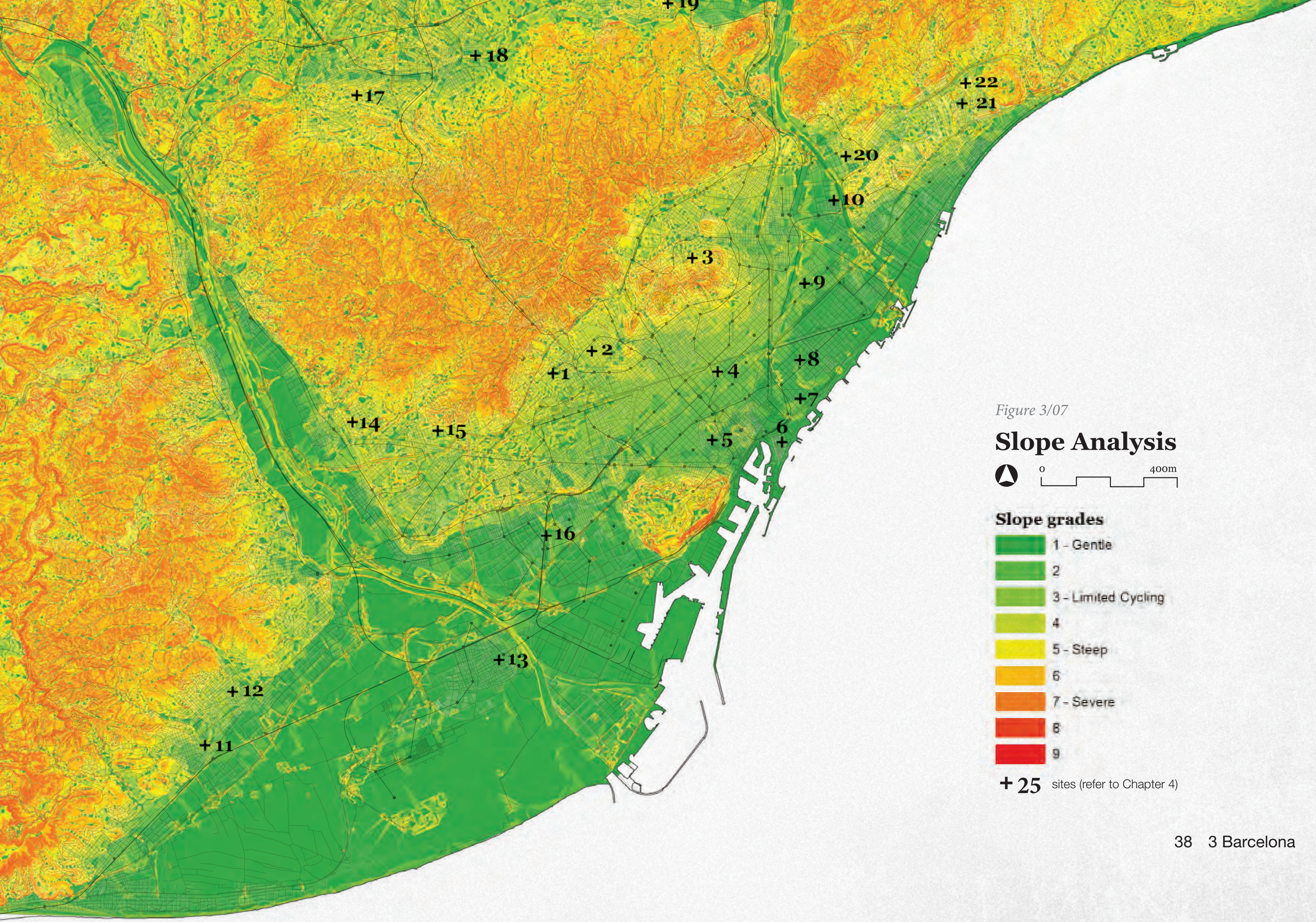


Figure 3/07

Slope Analysis

0 400m

Slope grades

- 1 - Gentle
- 2
- 3 - Limited Cycling
- 4
- 5 - Steep
- 6
- 7 - Severe
- 8
- 9

+25 sites (refer to Chapter 4)

ing and cycle lanes. These changes, as will be explored in the following chapters, have a positive effect on reducing energy consumption while improving the quality of life in these urban areas.

Energy and Mobility

As noted earlier, energy consumption by the mobility sector at a state level (Catalunya) accounts for around 40% of total energy consumption (Ajuntament de Barcelona 2003). While this is less than the energy consumption for Spain as a whole, it is however almost 10% higher than average European levels of around 30%, making it one of the highest sectors for a European country (European Commission 2010). Transport related energy sources generally involve diesel or petroleum and some natural gas which currently does not interfere with domestic and industrial energy fuels, which is largely based on coal or nuclear (ICAEN 2007). This means that transport related energy prices and electricity prices have some independence. With growing attraction to electrical vehicles, increased electricity production will be required to cope with demand and will mean the transport sector will compete for the same energy sources as the residential and industrial sectors.

Analysis according to Theme

As noted in Chapter 1, five Themes (density, accessibility, proximity, diversity, building form) have been identified for further research. In many cases, issues overlap between the Themes; nevertheless the Themes provide a foundation for more detailed research and the content of each Theme will remain consistent throughout.

Density

Population densities. Population densities are naturally greatest in the centre where neighbourhoods (Raval, Eixample, Gotic, SagradaFamilia, Gracia) range from 30,000-50,000 residents / km2 to 10,000-20,000 residents / km2 in the denser settlements on the outer edges. Some population densities in low density areas drop to suburban densities with under 5,000 residents / km2 but such areas form a small percentage of the total area.

Population and Topography. Population density is often connected to topography. Higher population density areas are typically associated with flatter terrain (see Figure 3/07), located around former settlements on the alluvial coastal plane including Sants, St Adria, Nova Icaria, Poble-Nou, Badalona, Santa Coloma, El Prat, Gava, Esplugas, and El Hospitalet. These areas favour slow modes of transport: walking and cycling. Lower density areas are often found on steeper sites such as St Feliu, Les Planes, La Floresta, Pedralbes, Valldoreix and Can Güell. More recently devel-

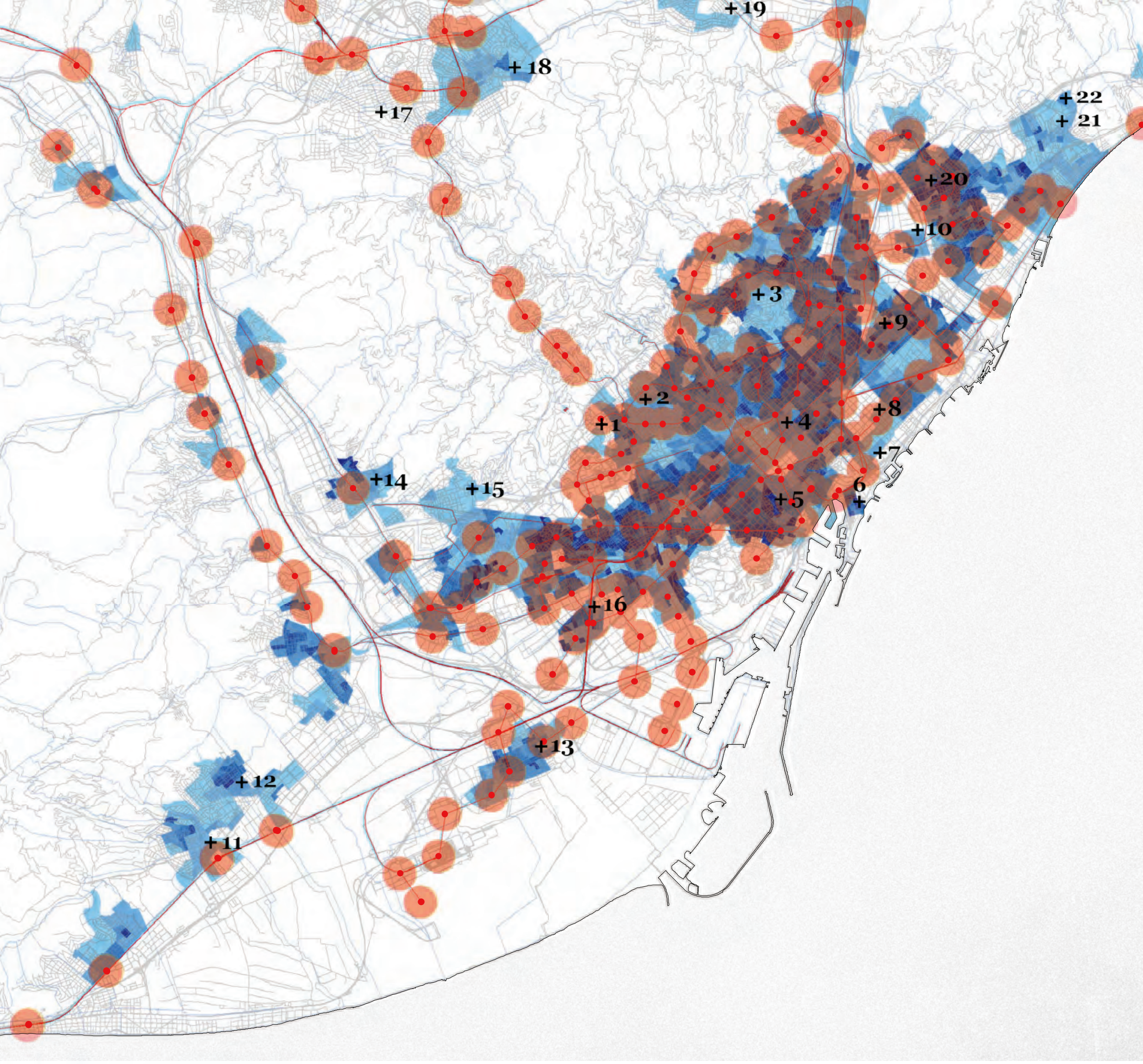


Figure 3/08

Catchments + Density

0 400m

400m catchment

Rail line

6000 - 14000

23000 -32000

42000 -53000

65000 -82000

110000 >

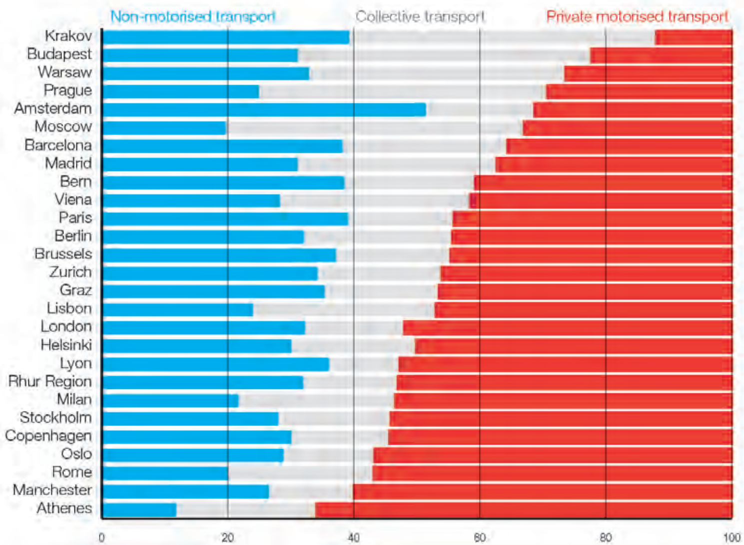
+25 sites (refer to Chapter 4)

oped areas with high population densities (yet supporting lower-median income groups) are located on very steep terrain to the north-west of the centre.

Accessibility

Mobility. The city contains a large and established rail network, consisting of a subway, metropolitan / regional rail and a tram system. As shown (in Figure 03/08), the network is accessible within walking distance to most of the population living in areas with over 5,000 residents / km2. This is an impressive accomplishment, with few other cities replicating this level of connectivity, station intensity and accessibility to the rail network (Parcerisa & Rubert de Ventòs 2002).

Figure 3/09: *Comparison of modal split in European selected cities. After a study by PTP in Miralles-Guasch et al (2008:122)*



Rail is a focus in this research as it is deemed one of the most efficient operational modes of transport in terms of energy consumption (see Figure 3/11). However, rail is a highly inflexible system while buses offer far greater opportunities for route adjustment.

Complementing this network, the city has an extensive surface bus network connecting both low- and high-density areas. While the bus system is heavily patronised with 380,000 rides per day (following behind the metro system with 613,000 rides per day), in some cases bus lines replicate the rail network - but are considerably slower (Miralles-guasch & et al 2008). Median bus speed is 19 km / h. Some inner city bus lines, notably the Diagonal, travel at 8 km / h at peak hour – only twice as fast as a typical pedestrian (PTP 2009).

Modal Split. The Municipality of Barcelona's modal split is fairly evenly distributed across the three main transport sectors: non-motorised, collective and private. Non-motorised traffic, at 38%, is almost exclusively composed of pedestrians with only 2% of movements covered by cyclists. But this is not consistent with other municipalities which all have a far greater predisposition towards private modes. As will be explained in Chapter 4, there is a strong link between mobility patterns and income, however residents of higher income areas within the Municipality of Barcelona are far more inclined to use collective modes compared those in high income areas outside the city.

Car ownership. Catalunya is considered to have one of the highest concentrations of highway per capita for a European region, but less than the total for Spain (Eurostat + PTP 2009). Road building largely occurred later than in most other European countries with large post-Francoist building schemes spanning the country. Car ownership since 1960 in Spain has grown by 9.3% annually while incomes have grown only 3.3% (Dargay et al. 2007). Vehicle ownership in the Municipality of Barcelona is 369 cars per 1000 inhabitants (with some neighbourhoods having under 250 cars per 1000 inhabitants) with a slightly lower number for the entire metropolitan area. Vehicle ownership in municipal areas adjoining major highways outside the city is higher with over 600 cars / 1000 (AMB 2011: 20). With greater levels of accessibility, cheaper and more tranquil living environments, the greatest increase in growth over recent years has occurred in commuter settlements adjoining the major highway routes with dependence on private mobility. As found by Olivier in Paris and London, these commuters, and particularly those from lower income groups, are also highly exposed to changing transport conditions (Coutard et al. 2009).

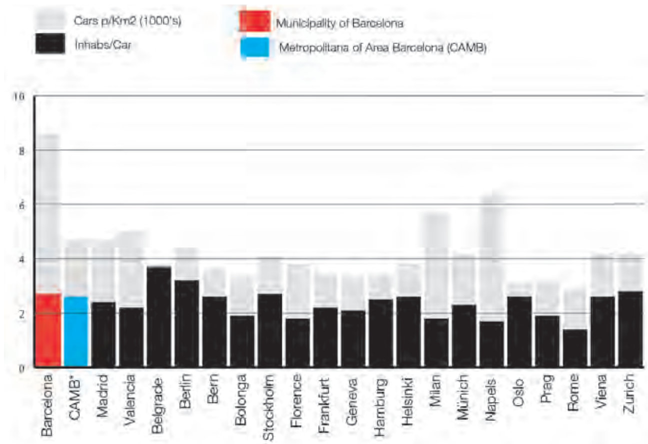


Figure *3/10 Car onwership comparision and cars per km2 (Ajuntament de Barcelona 2011)*

Considering Barcelona's high density (of both buildings and population), it is worth considering how density appears not to be a limiting factor in car ownership. As shown in Figure 3/08, while car ownership fits into the median - high range, it has a significantly higher number of cars per km^2 than any other city represented in this comparison. In other words, despite density, residents demand high levels of personal accessibility.

Non-motorised modes. Cerdà's Barcelona is considered a work of great genius through its simple resolution of the many competing and complex demands of an urban environment. A basic element of the plan is the democratic division of the road spaces. Typically 50% of the road space is dedicated to slower modes with the remaining 50% dedicated to motorised traffic. Cerdà's influence, expressed through generous footpaths, now extends into many other areas of the city consisting often of 30-50% of the total road carriage. This has allowed pedestrians to move freely and safely, while the city boasts a high percentage of trips made by foot - refer to Figure 3/09.

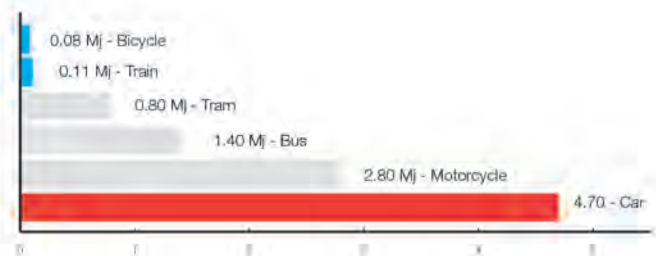
This segregation of pedestrian and motorised modes has not provided space for cyclists – who currently consist of only 2% of total movements and either compete for space with the slower pedestrians or the faster motorised modes. Neither space is suitable as the cyclist is perceived as a danger to pedestrians and as a nuisance in the faster moving motorised traffic. While some areas of the city are extremely steep, much of the densely populated coastal plain is relatively flat. Cycling has developed increasing support in recent times, but suitable strategies for its management have not been as forthcoming. The conflicting objectives between private collective modes and cyclists will be explained at the end of this chapter.

Regional energy consumption. Many assumptions can be made based on the consumption rates for Barcelona presented earlier. Mobility in the outer areas is however a significant source of energy consumption as residents travel long distances to work places in and around the centre, usually by private modes. A study by Banister and others found that a small percentage of the population could be regarded as consuming a large part of the energy budget creating an imbalance in demand for energy; this will be discussed in the following pages (Banister et al. 1997). Recent major growth has occurred along highway corridors which are also associated with high car dependency (AMB 2011). In addition, municipalities other than the Municipality of Barcelona tend towards low levels of collective transport use with over 80% of all work journeys made by private modes.

Proximity

Economic centres. Barcelona is a city that, superficially, does not have a Central Business District and thus operates through 'decentralised concentration' (Holden &Norland 2005), with a series of centres scattered throughout the greater urban area. Observed 'points of centrality'

Figure *3/11: This graph shows a comparison of typical transport modes for a low density city. Values for full occupancy of collective modes would further reduce these figures. Other factors are also not accounted for in this table such as maintenance and manufacturing costs (AGO 2002).*



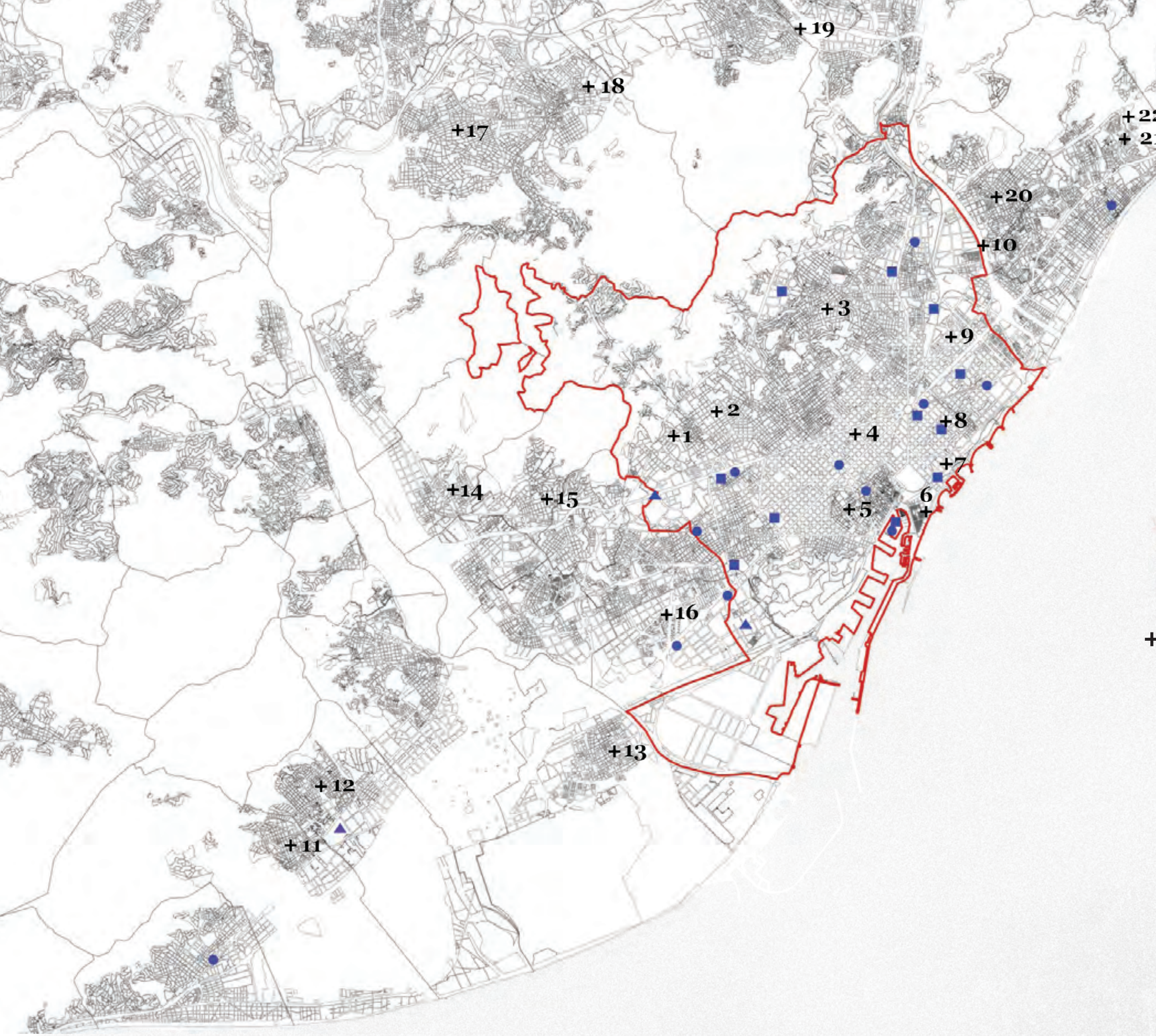


Figure 3/12

Centrality

Points of centrality, while dispersed acrosss the city, remain close to the centre and predominantly are located within the Municipality of Barcelona.

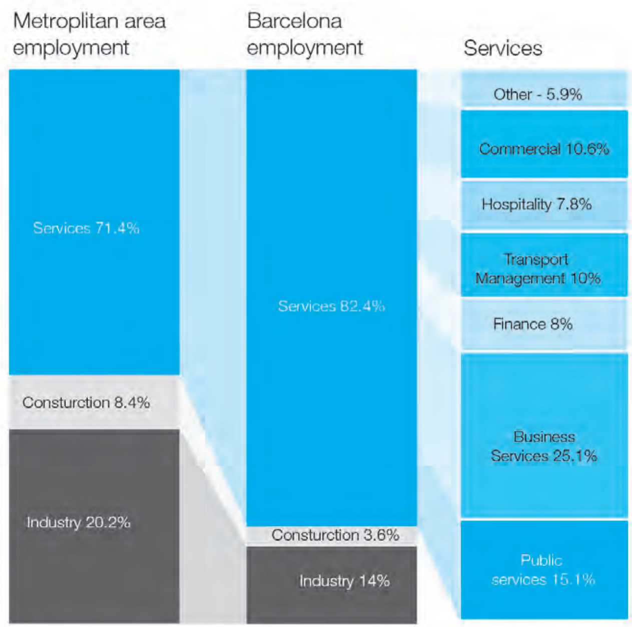
have been mapped on Figure 3/12 including areas identified by Herce (2005) and Barcelona Ecologica (2002) with other points added that are considered nodes of employment, business and / or other high activity. These points, as shown on the map, note that the major nodes have an attraction to the physical centre.

Workplaces. Workers travelling out of or into the Municipality of Barcelona have almost doubled since 1986, showing that the city has become far more polycentric. This also shows that levels of mobility are increasing as jobs are being (re-) distributed throughout the city (Ajuntament de Barcelona 2011: 61).

Is a distribution of jobs across the city a good or bad strategy in terms of energy consumption? As most to work trips are made by private modes (particularly trips tangential to the centre), distribution of jobs throughout the larger metropolitan area would only encourage greater levels of private transport use – unless the collective transport system was faster, cheaper and / or more comfortable.

Employment type. As noted in Figure 3/13, in excess of 80% of the employment within the Municipality of Barcelona is service sector oriented while other employment areas such as construction and industry play a much smaller role. These averages change significantly outside the Municipality of Barcelona, where the service industry has a decreasing role relative to distance from the city centre. This is an interesting detail for relationships between jobs and mobility, as improving communications technology could make workplaces more flexible (Ajuntament de Barcelona 2011: 61).

Figure 3/13 *Major employment areas (Ajuntament de Barcelona 2011: 59)*



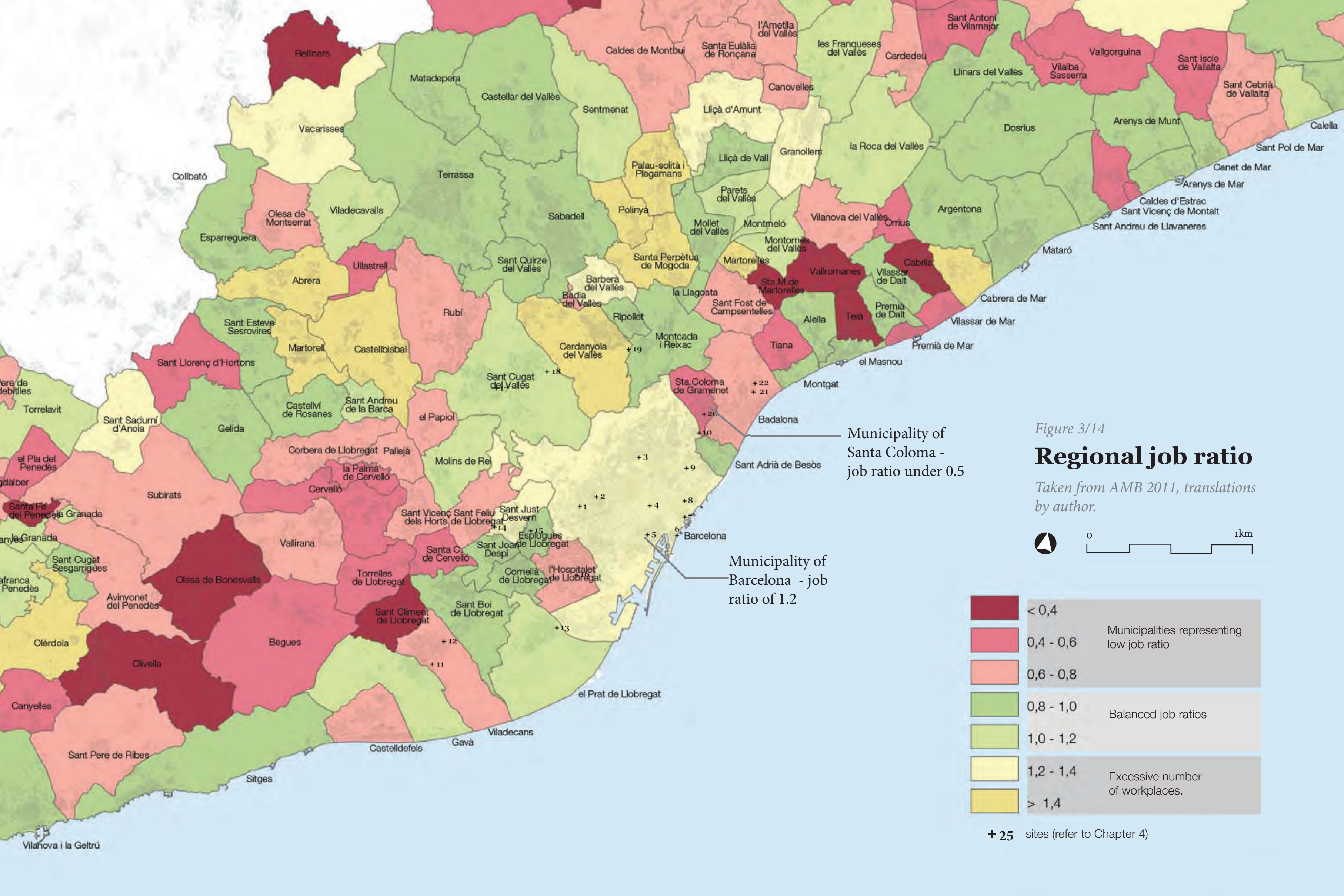


Figure 3/14

Regional job ratio

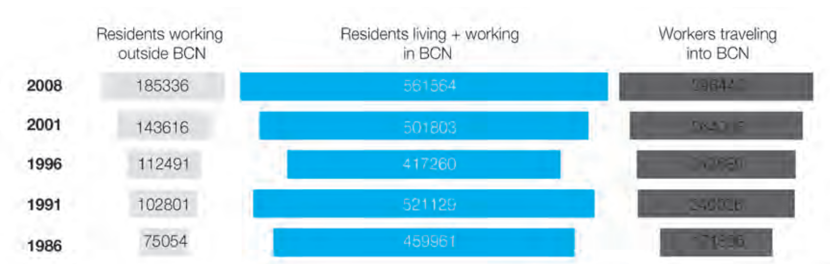
Taken from AMB 2011, translations by author.

Employment self-sufficiency. As indicated by Cerdà over 150 years ago, Barcelona is a city characterised by movement – particularly travel to work. It is worth noting that prior to the availability of collective modes of transport, workers lived close to their jobs. As the city grew and as industry relocated, workers had to travel to jobs rather than live near them. In fact, dramatic changes have occurred only in the last 30 years, with municipal self-sufficiency on average reducing from 85% to 50% indicating a significant increase in longer distance travel to work; in this time the number of municipalities with a 'self-sufficient' job-ratio has dropped from 89 to 41 (AMB 2011). This coincides with the construction of the metropolitan ring-road, as Herce noted, allowing significantly higher opportunity to access the city.

As can be seen in Figure 3/14, few municipalities provide jobs for their own residents. While many municipalities provide almost as many jobs as there are local workers, few municipalities have all the right jobs. On average only approximately 20% of residents work within their municipality. Barcelona, partially by virtue of size and economy, is also the most self-contained. How would this situation change if there was a change in mobility trends? If mobility costs increased, would people be more inclined to seek work nearby?

It should be noted that the motive to travel does not equate to travel distance or time travelled but rather to travel desire. As shown in Figure 3/12 (municipal job ratio), most trips have multiple purposes. For example one will mix a work journey with a trip to the shops before returning home. If friends, services, leisure and other destinations are nearby, then this will have a significant affect on mode choice. If users have access to vehicles, options and distances increase dramatically and the vehicles are likely to be used.

Figure 3/15: *Major employment areas. Ajuntament de Barcelona 2011: 59*



Diversity

Travel Motive. While travel to work and centres of study create stable daily mobility demands, they form less than 20% of total travel motives. In fact travel motives for non-work purposes such as shopping, entertainment and sport are just as high.

Municipal Diversity. At a metropolitan scale, municipal self-sufficiency as defined by the AMB (refer to Figure 3.14), has shown highly 'self-sufficient' municipalities are

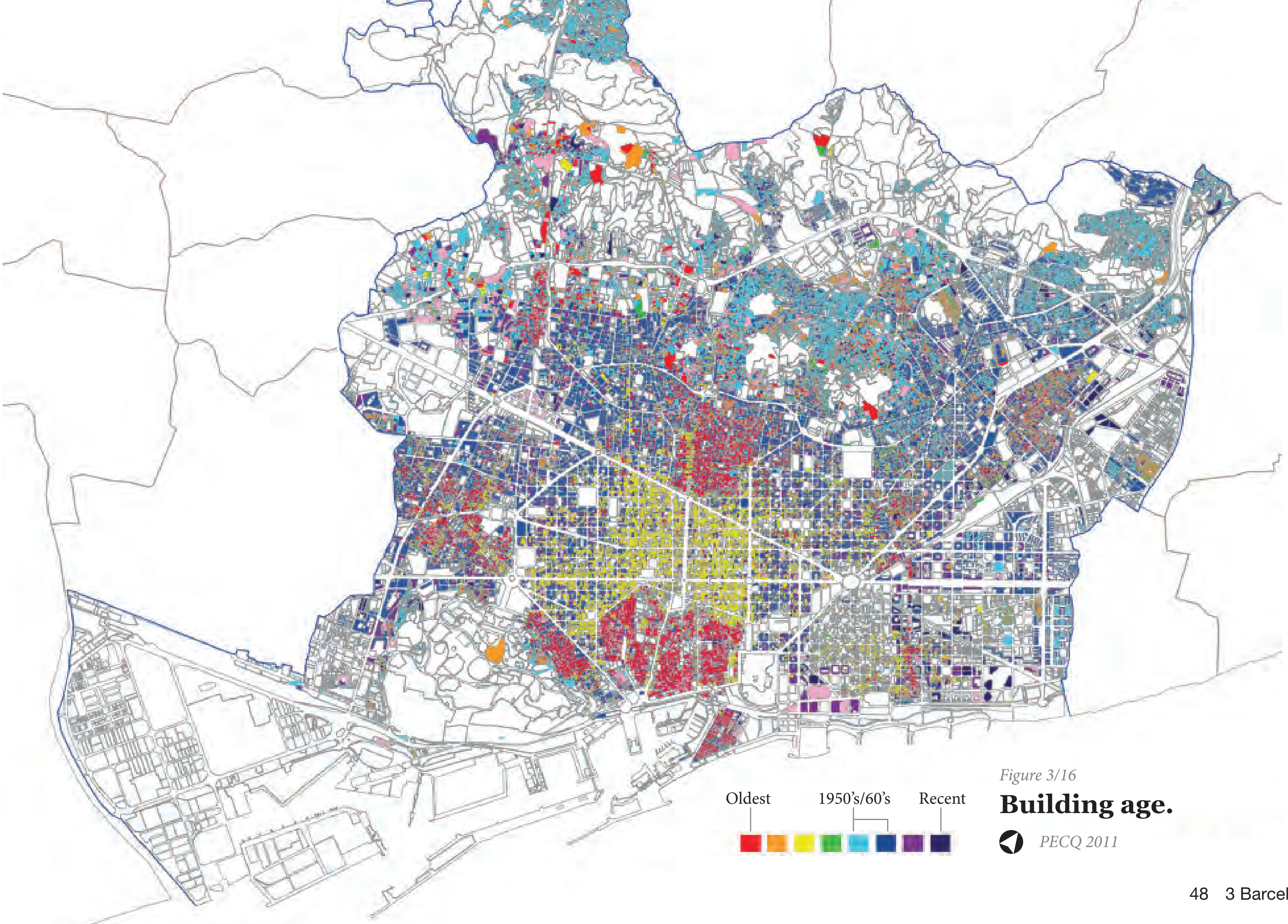
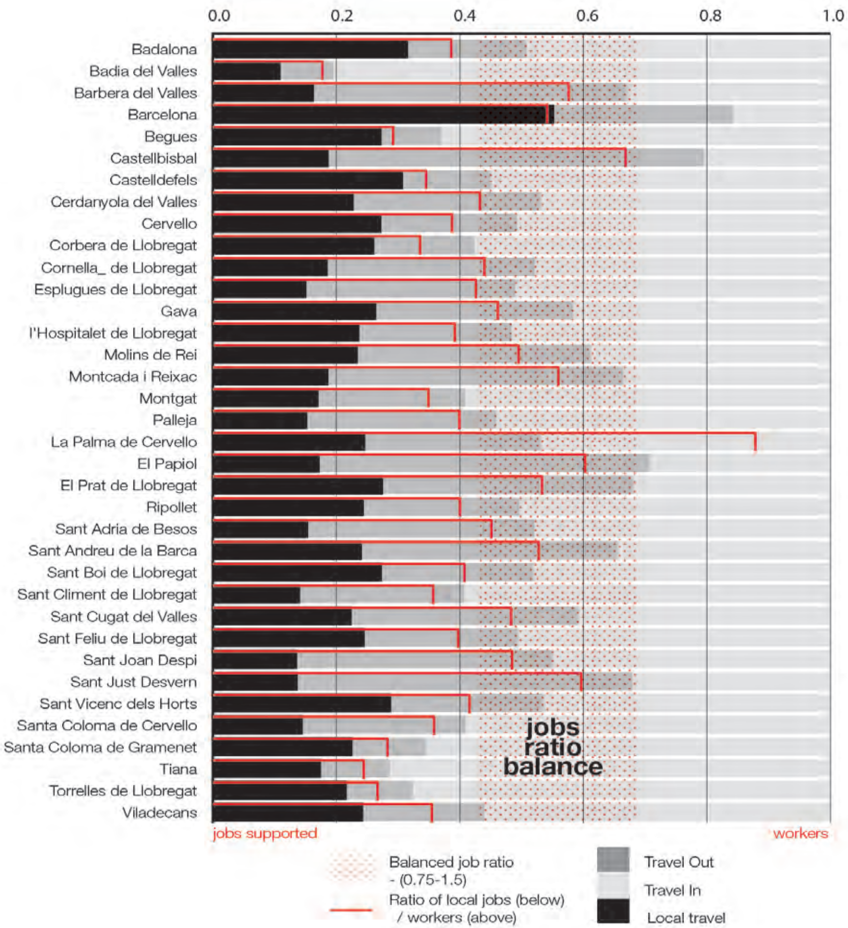


Figure 3/16

Building age.

PECQ 2011

Figure 3/17: *Job ratio versus job location in terms of the municpal travel data. EMQ 2006.*



located at long distances from the Municipality of Barcelona. This indicates that many workers who live in municipalities surrounding the city centre commute towards the centre or other municipalities for work purposes.

Diversity at the block level. Barcelona's urban blocks typically are very complex and dynamic organisms, often containing many of the amenities required for daily lives – from grocery shops and bread shops to kindergartens, community centres, bars and cafes, health facilities, commercial space and sometimes small parks. This situation is particularly noticeable in many of the blocks developed in the Eixample. During the rapid 'Urgency Period' building boom, much of this complexity was discarded or lost; building programs were simplified and commercial space (or the provision for interstitial unplanned uses) was eliminated. As will be shown in Chapter 4, this is significant for energy consumption as it means residents are forced to travel to access their basic needs. In addition, spaces for jobs - commercial space - is largely non-existent.

Amenities and population density. As will be investigated in the following Chapters, some locations within dense urban areas lack amenities or facilities that people need in their daily lives. One of these is public open space. A measure researched in Chapter 4 is provision of open space. For instance, some inner city areas contain as little as half a square metre of public open space per resident within a 400m distance. While seemingly trivial, these issues may encourage residents to travel to obtain these fa-




cilities, thus the benefits of high population densities for low energy may be reduced (Holden & Norland 2005).

While these inner-city areas are better suited to a low-energy future, due to proximities, mobility patterns may be creating dependencies which might not be appropriate under low energy economies. For instance, would current levels of public space be suitable or become saturated if residents were to be less mobile? If saturation occurred, how long would it take to make the changes necessary to develop suitable public space?

Building types and Energy in Barcelona

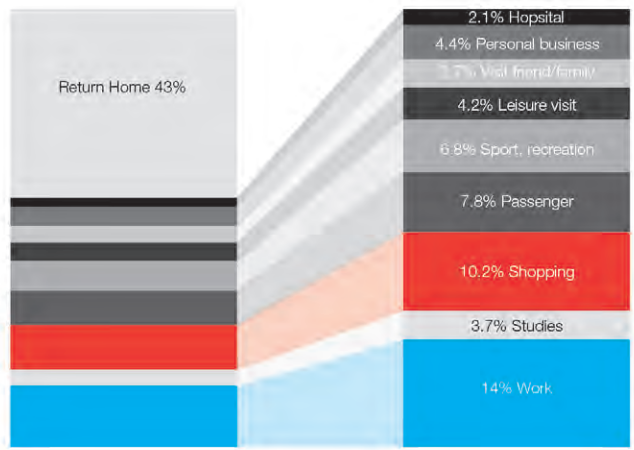
Buildings and energy demand. Buildings have an inherent energy demand associated with heating, lighting and functionality appliances (lifts, water systems and electronics) that can change depending on the type and age of the building. Typically building ages (see Figure 3/16 can be associated with building trends, building types and materials (Ajuntament de Barcelona 2011).

Figure 3/18-22 (previous page): *Four typical building types found in Barcelona. Raval (far left) performs badly in terms of thermal energy consumption but by virtue of size, consumes relatively little. The Eixample (second from left) similarly is badly performing yet have larger dwelling areas. Bellvitege (third from left) was built before thermal heating laws. Villa Olimpica (right) performs best thermally but worst due to appliances and embeded technology. All photos Bing Maps (accessed 14/01/2012)*

The age and type of buildings have important roles to play in terms of thermal mass and heating. Artificial temperature control, as noted at the beginning of this chapter, is the largest single demand of domestic energy. Lighting and appliances are generally not large consumers of energy however the growth in ICT during the last 15 years is associated with the large growth, almost 50%, in energy demand during that period.

Many old buildings (pre 1930s) were traditionally built with thick walls, tall narrow windows, with external blinds or shutters; they are well prepared for passive cooling dur-

Figure 3/23: *Travel Motives in Barcelona (AMB 2011:37). This involves travel but not length of journey.*



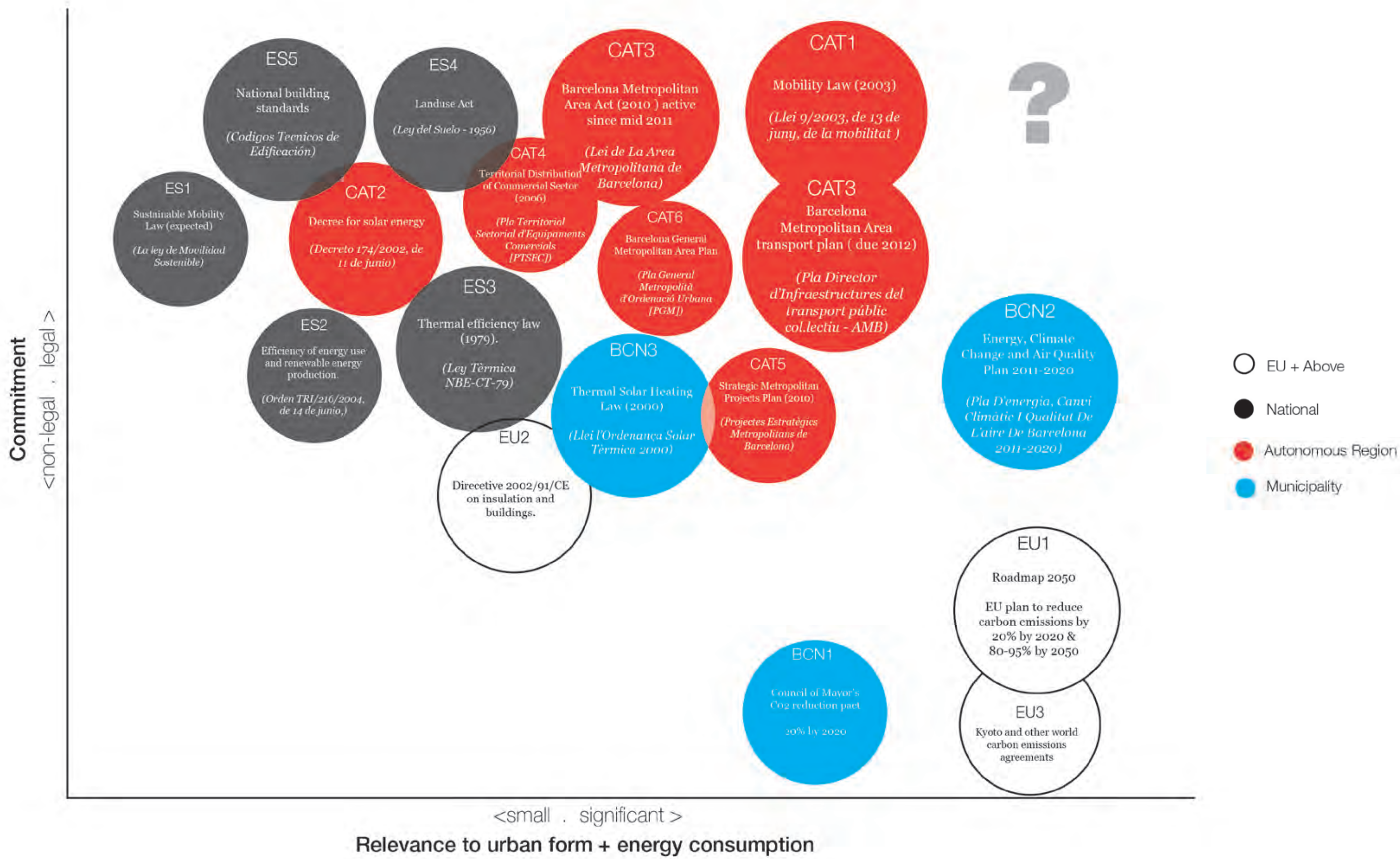


Figure 3/24 - Comparisons chart, showing significance in terms of urban form and energy consumption ing warm summers (particularly those in the Eixample). On the other hand these older buildings are poorly insulated and perform badly during the cooler months. While these older buildings often require greater levels of heating, many lack energy consuming technology associated with modern buildings such as lifts, central climate control, surveillance technology and comprehensive lighting.

Dwellings built after the 1930s, and particularly during the building boom in the 1950s and 1960s, were built economically and at great speed. While there is no single building type representative of this period, compared to the earlier buildings they typically had larger windows, thinner walls and particularly larger spaces. This last detail, the size of space, is a critical variable that will be further explained in the following chapter.

The most recent buildings, constructed since the 1979 thermal mass legislation was passed, are the best insulated. However the increased mean dwelling size and modern technology have made these buildings more energy intensive with their lifts, lighting, electronic control systems, security, temperature management and other energy consuming devices.

The following map identifies areas according to age / most recent renovation showing that buildings have largely remained unchanged since construction (Agencia de Energia de Barcelona 2007).

Current plans + strategies

There are a number of documents and plans that have some relevance to urban energy consumption yet none specifically target energy consumption in relation to urban form (refer to Figure 3/24). Only the PECQ addresses energy considerations yet it is limited in its scope of action (Adjuntament de Barcelona 2011). The Catalan mobility law significantly requires new development to be associated with collective mobility.

Energy related strategies EU / Global scale. Global agreements such as the Kyoto Protocol and EU level carbon reduction objectives have driven heavy Spanish investment into renewable energy technology. This policy is connected most significantly to energy production rather than reduction.

The European Union has promoted energy efficiencies, particularly since the recent proposal of a 2050 Roadmap for reducing carbon emissions by 80-95% (European Commission 2011a). This policy aims to achieve a 20% emissions reduction by 2020. The national Spanish government looks as if it will achieve this target if growth continues. After significant investment and subsidies in renewable energy infrastructure, almost 10% of the national energy needs are produced through renewable sources (European Commission 2011c).

Finally EU standards have been set for mobility, appliances and in some cases construction materials and techniques – which have either direct or indirect energy outcomes.

National level. As noted earlier, Spain has been very active in promoting renewable energy production. In addition, a mandate set in 2010 to achieve 20% renewable energy includes a 2% annual energy reduction objective. In addition at a national level, there are a number of laws that inherently influence energy consumption.

A document stipulating control over the function of urban areas is the Landuse Act – defined nationally and enacted at a municipal level (Ley del Suelo,1956). This document may have some role in defining functions or limitations for urban areas. It may provide limitations on increasing density and diversity.

Another more limited yet significant policy is available at the building level for new construction. A standard on insulation and thermal mass resulted from the 1973 oil crisis. At a national level the Technical Building Code (Codigo Tecnica de Edificación 1979) determines building standards for new construction including passive standards (thermal and lighting). Neither standard affects the large amount of older building stock constructed before the 1960s building boom that has not been recently redeveloped / renovated. Therefore large portions of the city do not and need not comply with current passive standards that significantly reduce heating and lighting demands.

Autonomous Regional Level. Catalunya has a number of policies and plans related to urban energy consumption. The Catalan mobility law (Llei 9/2003, de 13 de juny, de la mobilitat) is considered a first in Europe. It stipulates that each municipality with a population over 50,000 must have an active mobility plan, reviewed every five years. Barcelona's collective bicycle scheme (Bicing) is considered an outcome of this law. This plan concerns efficient mobility solutions and demands that all new development must be associated with an existing mobility plan. While the plan provides priorities for pedestrians and collective modes, it does not target private mobility which is a highly protected topic.

A second document of significance for jobs and development is the PTSEC (Pla Territorial Sectoriald'Equipament sComercials, 2006). This regulates the management of new commercial land releases. While this plan aims to retain the compact nature of urban areas in Catalunya by distributing new commercial land to areas that lack it, the plan caps new commercial floor space giving incentives to develop large Greenfield sites over infill.

Barcelona region scale. With municipalities depending largely on development to subsidise budgets, non-core management initiatives (such as energy related issues) depend largely on the size of the municipality and its ambitions. There is a significant benefit in having a metropolitan level government take responsibility for coordinating trans-municipal issues.

Two additional documents of significance affect the metropolitan area. Firstly the Barcelona General Urban Area Plan (Pla General Metropolitàd'Ordenació Urbana [PGM]), released in 1976, remains an active masterplan for the city with ongoing revisions. It focuses on major infrastructure policy for mobility systems, industry and urban expansion. The second is the recently enacted Metropolitan Area Law (Lei Área Metropolitana de Barcelona, 2010). This law reinstates the law of 1987, allowing the metropolitan area to be governed more comprehensively which is particularly important for issues such as energy which cannot be easily contained within municipal boundaries. The law has brought together three organisations charged with coordinating mobility, the environment and development. The law is yet to be properly enforced however it offers hope for greater collaboration and management of collective metropolitan issues. A recent report has been developed in preparation for a new metropolitan infrastructure plan, making some links between mobility and energy consumption (AMB 2011).

Municipality of Barcelona. The Municipality of Barcelona (Ajuntament de Barcelona) contains the largest area, capital, land value and population (1.6 million) of the 36 metropolitan areas constituting the AMB. The municipality takes an active role in improving the performance of its urban area and developing plans, studies and laws, which are not replicated across other municipalities. The 2011-2020 'Plan for Energy, Climate and Air Quality' (PECQ) is a comprehensive document which covers a diverse range of energy consumption related issues and would provide an ideal portrait of energy use if extended to the metropolitan area (Ajuntament de Barcelona 2011). In this document, energy consumption has not been analysed at the block level due to a lack of data – which unfortunately exposes the analysis to criticism in terms of the accuracy of precise consumption rates.

An initiative at a Municipal level has been the mandatory installation of thermal solar hot water heating on all new or renovated buildings. The Municipality also conducts an annual mobility survey providing an insight into mobility processes otherwise not covered by census data or the annual metropolitan level mobility reports.

The Municipality of Barcelona has also stated that its main strategy for minimising carbon emissions is through reduction rather than financing renewable energy.

Figure 3/24 + 25 - *Potential deadlocks: a community space above, paid for by the carpark below - will this make it hard for municipalities to divorce themselves from car ownership?*

Deadlocks + Institutional Challenges. While plans and strategies that provide incentives to improve energy consumption exist, there are other things that work against this process. As described by Loorbach, 'deadlocks' in transition processes or 'path-dependency' due to commitments that have already been determined demand that urban areas retain current levels of energy consumption or current mobility patterns (Loorbach 2010). Two examples of this involve parking and cycling.

As municipalities are required to fund much of their own public works and amenities, many smaller municipalities have developed creative ways of paying for their public spaces and community facilities (Miguel Cuellas, personal conversation, former project architect with the Municipality of Gavà, 2010). A common funding strategy involves a Public Private Partnership between the municipal landholder and private car parking developers; by providing the land, developers build the public space in return for long-term (20-30 year) lease of the car-park. As will be discussed in the following chapter, car ownership has been found to have greater association with energy consumption than density (Mogridge 1985).

The second example involves the cycle network. As noted earlier, the Municipality of Barcelona, amongst others, has a vested interest in the smooth operation of both the metro and bus network. The growing attraction to cycling is encouraged by almost 200km of bicycle lanes and the established public bicycle sharing, Bicing (www.bicing.cat), have seen a spike in cycling throughout the city; however the numbers remain modest at around 2% of all movements. Firstly, while wanting to promote the image of cycling, the city remains badly equipped for cyclists with a discontinuous and illogical cycle network. In addition, the city is under pressure by car lobbies not to reduce road space. Secondly and most significantly, the growth in cyclists comes from former public transport users, therefore improving cycling is not reducing the amount of private mobility throughout the city (Ricardo Riol, PTP, personal conversation, 2009). Complementing this attitude, the AMB have shown that an objective to increase use of collective transport will require lowering both non-motorised and private modal share (AMB 2011: 72).

To deal with these issues, Banister and others have discussed strategies for 'de-coupling' issues attached to energy consumption and those working fundamentally against it (Banister 2000). Strategies to will be investigated in Chapter 5.

Figure 3/26: *Autopista de Montserrat, one of the great mobility corridors, quickly and efficiently cutting through the Collserola Range and linking the centre to Sant Cugat and other settlements further west while expanding Barcelona's physical reach. This kind of infrastructure also provides a challenge reducing energy dependence.*

Chapter Conclusions

Generally based on this brief analysis, it has been shown that two of Barcelona's largest energy consumption sectors are transport and housing – and these are affected by a range of peripheral issues such as employment patterns, income and mobility opportunities.

- Employment areas have spread further and further apart with a relatively small number of municipalities housing their own work-forces. This change is associated with greater levels of accessibility by private transport. While a large accessible workforce may provide an economic advantage for the city it also depends heavily on mobility infrastructure – and in this case typically private mobility infrastructure. A collapse of the mobility system will likewise have significant economic impacts.
- Rail has been shown to be one of the most energy efficient modes of collective transport. The metropolitan area contains a significant number of rail stations within pedestrian catchments (400m) and stations cover most of the city's population with densities greater than 5,000 inhabitants / km2. In addition, higher population density throughout many parts of the metropolitan area, associated with gentler topography, show an opportunity for non-motorised modes.
- Car use to work and general car ownership (considering density) is considered very high relative to other urban areas.
- Large portions of the metropolitan area contain buildings which consume significant amounts of energy as a result of inherent design and construction inefficiencies, while other buildings demand energy because of the extensive technology they contain.

Until now, the city has been explored abstractly in terms of performance without delving into the particulars of urban form. The following chapter will take the findings from this chapter and explore how particular urban areas perform.

4

Analysis

III) Evaluation Models: Is the current place working well?

Overview

- Chapter 3 has provided an overview of how Barcelona performs as a metropolitan unit in terms of issues related to energy consumption.
- Performance will be evaluated through mapping and statistical data. Data has been compiled based on measures (refer to Appendix2).
- These measures will be correlated according to each of the five Themes (density, accessibility, proximity, diversity, building form) to identify trends and the performance of each according to relevant issues.
- Sites will be reviewed in terms of their energy dependence (rather than energy consumption) and potential robustness as a result of less energy.
- Finally, maps will be used to determine where else the identified trends may occur throughout the city.

Introduction

The details studied so far in Chapter 3 showed a broad and relatively imprecise assessment of energy consumption in terms of mobility and building types. While this kind of assessment is suitable for judging broader issues, some details can be 'obscured' unless understood in terms of the places and environments in which people live. While building types are relatively easy to assess (based on building age and dwelling size), mobility patterns are not.

As will be shown throughout this chapter, population density and energy efficiencies are highly linked. Naturally, population density alone must be supported by a wide variety of other factors that make it both amenable to residents and also used by residents - provision of attractive public areas for instance.

Energy consumption also depends on a range of other social factors such as income and car ownership. This currently allows choices for living locations, work travel and recreation – but it also creates energy dependencies which some urban areas will likely to be able to transition from easily while others will be left exposed.

Assumptions can be made based on analysing the qualities of urban environments to understand which will best cope with change and which will require remediation.

Summary of Site Selection Criteria

Twenty two sites were selected representing variations on the Themes noted earlier. The objective was to find exemplars that could provide a cross-section of each individual Theme, determining a 'performance' scale. Control factors include:

Types. Firstly a range of building types was selected based on criteria established by Berghauser-Pont & Haupt and Salat (Berghauser Pont & Haupt 2010; Salat 2011). Urban types selected included: freestanding single residential dwelling, free standing collective, continuous non-enclosed, continuous low and continuous high.

Density. Mix of high population density and density based on the Spacemate (Berghauser-Pont & Haupt 2010).

Income. Sites cover a range of income groups at a district level for the municipality of Barcelona or municipality level for all other municipalities. Wealth and income have been found to be heavily linked to energy consumption and particularly associated with private modes (Stead & Marshall 2001; Muniz et al. 2006).

Mix of locations, both in the centre and periphery of the Barcelona metropolitan area. Sites selected on the periphery included high and low levels of accessibility to collective transport.

The Themes will be further explained throughout this chapter.

What to Measure

Measures used to evaluate sites have been linked to research based on empirical studies, or research referring to empirical studies. Refer to the Measures table (Appendix 1) containing the name of the measure, research and data source, metric and scale of study for each of the measures. The source of a number of the measures will now be explained.

Research on mobility and urban form by Cervero and Kockelman defined three particular themes referred to as the 3Ds; density, diversity and design (Cervero & Kockelman 1997). This study uses factor analysis and census travel diary data, focusing on 50 sites distributed throughout the greater metropolitan region of San Francisco with sites both near the CBD and on the outer fringes. Measures used in the study include: income, population density, age, gender, employment density, land-use, distance to major roads and collective transport (including timetables), on-street parking and presence of street trees. This study provides a relatively comprehensive collection of measures, associated particularly with mobility. Many of these measures will be used in this research however aggregating some of the measures Cervero and Kockelman used such as gender and age - a more comprehensive study dedicated to social characteristics would consider these details. A measure the authors have not been specific about is density – referring in their case to population and job density.

In an audit of research regarding density and mobility, Stead & Marshall identify a number of common research topics (Stead & Marshall 2001). Many of these were noted earlier by Cervero and Kockelman,including also the importance of connecting socio-economic measures, land-use patterns and income. This may involve the number of cars per household, distance from the city centre, size of household, education and employment type, job ratio and employment density and pedestrian environments.

In a study by Moudon and others researching walkable neighbourhoods, based on random phone interviews and bivariate / multivariate analyses, measures including both attractors and detractors for walkers and non-walkers were used. Measures including population density, block size, commercial attactions (shops, supermarkets and particularly food venues) and land-use mix were used to find correlations with walking (Moudon et al. 2006).

As described by Berghauser-Pont & Haupt (2009) and Boyko & Cooper (2011), density is a theme often subject to generalisation. A more precise measure of physical density and urban form involves combining the occupied area or Ground Space Index (GSI), the gross floor area or Floor Space Index (FSI), the complexity of streets or the Network (N), the floor Levels (L) and finally the pressure on open space based on GSI and FSI using the Open Space Ratio (OSR).

The building type related to energy consumption has been investigated by Alvarez and the Municipality of

Barcelona. Both studies use relatively generic categories based on types; typical solar access and typical heating demands based on typical construction techniques and average energy consumption (Álvarez 2010; Ajuntament de Barcelona 2011).

Data

One of the biggest issues with energy consumption is that energy remains a largely abstract concept. Similarly publicly available data on precisely how it is consumed at detailed levels, is scant. An alternative method using indicators of energy consumption will be used. Cervero and Kockelman, as mentioned earlier, note the technical limitations with making associative rather than causal hypotheses. Unfortunately causal links between energy consumption and urban form will remain associative until data is freed. This leaves many aspects of the issue as being relatively speculative.

Data on energy is available at two levels: at a city level (Municipality of Barcelona) and at the regional scale (the Catalan Institute of Statistics, IDESCAT, and the Catalan Institute of Energy, ICAEN). Neither data set is precise enough to explain consumption patterns at a neighbourhood or block level. However they both provide a useful indication of the largest energy consumption sectors (as identified in Chapter 3). Some assumptions based on mobility patterns and general energy consumption will need to be made to fill in the gaps.

National census data (the latest - 2001) is available at the 'infra-municipal level', the most detailed level. The census areas are defined by population numbers and therefore in some parts of the city the infra-municipal census area may enclose a city block or in other areas an entire municipality. The census contains no data directly related to energy consumption but does contain other useful data including population density, education level, types of buildings, amounts of car-parks, type of work etc.

The Catalan Institute of Statistics (IDESCAT) has collected data at a municipal level on many of the measures used in this study. Data available includes statistics on income, modal share (for work and education), and employment (and unemployment). In some cases this data is quite useful but it is imprecise when looking at municipalities containing a number of extreme types such as high and low density, and high and low income.

The Catalan state government (Generalitat) commissions a general mobility survey (EstudiMobilitatQuotidiana or EMQ) for municipalities with over 50,000 inhabitants; the last survey was published in 2006. The Municipality of Barcelona (BCN) contains a much more precise database available through municipal records and a series of regular performance surveys. Very precise data is available for a range of measures such as population density, car-parking, liveable area, car ownership etc. At the block or neighbourhood level data is also available at a neighbourhood scale for income and a district scale for mobility. In some cases, databases will be normalised to establish approximations on actual values. For example, by comparing education levels and dwelling sizes available from the 2001 national census, approximate values can be derived for income in municipalities where municipal data is too vague.

Analysis Method

Measures will be analysed according to the most relevant Themes, including: density, accessibility, proximity, diversity and building form.

The research will use a range of graphs, tables, maps and diagrams to correlate data and draw findings. Generally all the sites will be evaluated while only outstanding sites, where comparisons and conclusions can be made, will be discussed in detail.

Graphs and Diagrams

Generally, as values between measures can be very different, data will be adjusted to reflect a ratio scale. This involves making the highest value of a certain measurement equal to 1, then adjusting all other values as a percentage of this. The results of two or more measures can in this way be compared regardless of the absolute value, allowing

Figure 4/01: *List of the measures taken at each of the 22 sites, showing how measures can be correlated for analysis.*

connections / links to be made between indicators such as open space, car ownership and distance to the city centre.

Where possible, maps will be developed through GIS data to locate other regions sharing similar conditions throughout the city.

Measures description table
refer to Appendix for the completed table

The following pages involve an overview of each of the twenty-two case study sites – comparing some of the measures found in the Measures Table.

	Measure	Why	Research	Data	Metric	Research scale
	GSI	Land occupancy / building density	Berghauser Pont &Haupt 2010	GIS / maps	-	Fabric
	FSI	Gross floor area	Berghauser Pont &Haupt 2010	GIS / maps	-	Fabric
	OSR	Indicator of demand for open space	Berghauser Pont &Haupt 2010	GIS / maps	-	Fabric
	TARE	Neutral public space	Berghauser Pont &Haupt 2010	GIS / maps	-	Fabric
01	Population density		(Ratti et al 2005)	2001 Census / Municipal	Pop/km	Block/ Census
02	Urban Characteristics	Energy assessment	(Salat 2009)	IDESCAT + calculations	kWh/m2	BCN
03	Income	Income heavily associated with energy consumption	(Stead 2001)	IDESCAT 2008 Municipal census + 2010 BCN census	% of average wage Catalunya = €16,555 BCN = €16,900	Municipal/ BCN district
04	Age of buildings	Embedded energy and insulation	(Ajuntament de Barcelona 2011; Álvarez 2010; Salat 2009)	2001 Census	% age group: 30<, 30-60, 60>	Census area / BCN block
05	Commercial space	Potential job / work / shops	(Cervero & Kockelman 1997)	Mapping, 2001 Census	% ofgroundfloor area	District
06	Access to shops	'Walkability'	(Moudon et al. 2006; Cervero & Kockelman 1997)	Municipal GIS, online mapping + site study	Supermarkets	400/1000m radius
07	Schools	Mobility	(Moudon et al. 2006)	Catalan education dept online map	Number within 1000m	1000m radius
08	Entertainment	Mobility	(Moudon et al. 2006; Cervero & Kockelman 1997; Stead & Marshall 2001)	Municipal GIS + site study	Number + Variety (IE type of venue)	400/1000m radius
09	Education level	Work type		2001 Census	% of population	Census area
10	Modal share	Use of PT, use of vehicles	(Cervero 1998; Mees 1999)	2006 IDESCAT /AMB Mobility survey	% share private, collect, walking	Municipal / District
11	Connectivity	To transport systems	(Ohnmacht et al. 2009; Stead & Marshall 2001)	Online maps	Distance/time from the physical ctr by both private and collective modes (Pl. Catalunya)	Block
12	Service level	Accessibility / competition with private modes	(Mees 1999)	Timetables	Approx number of services p/hr	Most regular service
13	Pedestrian environments	Attraction to walking – extends pedestrian range	(Moudon et al. 2006)	Site study	- Footpath / street width - qualitative	District
14	Open public space	Recreation	(Cervero & Kockelman 1997)	Mapping	Size, quantity and amount perperson	400m radius
15	Vehicle ownership - Car, M'bike/scooter	Option to drive	(Stead & Marshall 2001; Cervero & Kockelman 1997)	2001 Census, 2010 BCN Census	Vehicles/1000	Census area
16	Car parking - On / Off street	Incentive to use private modes	(Stead & Marshall 2001; Cervero & Kockelman 1997)	2001 Census, mapping, 2010 BCN Census	Parking total + per capita	Block / Census area

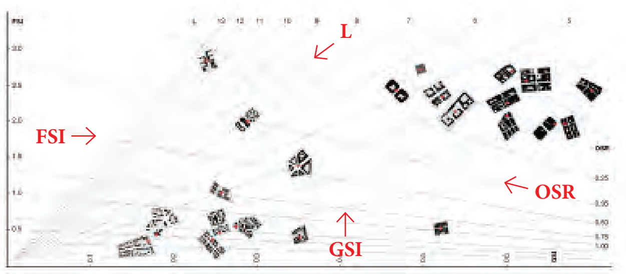
Analysis of Physical Density

As noted earlier, to qualify types density in terms of urban form, sites will be assessed based on their physical density as defined by Berghauser-Pont and Haupt (op cit). This includes measures such as the Ground Space Index (GSI) or footprint and Floor Space Index (FSI) or gross floor area. For smoother results, the 'fabric' level is assessed which involves taking averages across various 'islands' or blocks.

GSI and FSI will be plotted using the 'Spacematrix' Diagram (Figure 4/02a), which includes two other measures; the average number of Levels (L) and the pressure on open space relative the FSI and GSI shown through the OSR value. GSI and FSI calculations:

$$GSI = \frac{B_X}{A_X} \qquad FSI = \frac{F_X}{A_X}$$

Figure 4/02a: *Spacematrix diagram plotting GSI and FSI which helps define the 'physical density' or urban form.*



Below: analysis of density *after Berghauser-Pont & Haupt (op. cit.). The following diagrams are an interpretation of how physical density was measured in this project - refer to Berghauser-Pont & Haupt for a more comprehensive explanation.*

Figure 4/02b (right): *The area used in the study includes the entire block (or blocks) including the associated road area, up to the road centre-line. Only the built area is used for the calculation.*

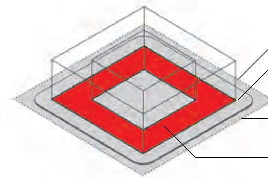
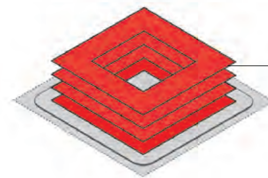


Figure 4/02c (right) + 4/02d (below): *All private courtyards and/or gardens are included in the overall area. In this sense, both Figure 4/03c and 4/03d may have relatively similar FSI and GSI values.*



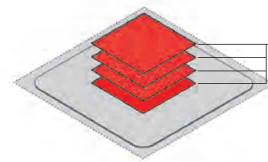
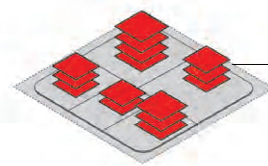


Figure 4/02e (right): *The overall gross floor area is taken, so the calculation is irrespective of significant variations in levels or size or individual lots. Other measures will account for these details.*



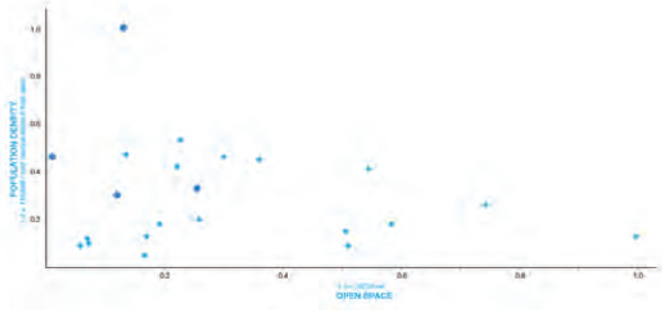


Figure 4/02f (above): *A typical plot graph showing anonymous values - this graph may be considered to show the relative 'performance' trends between two measures.*

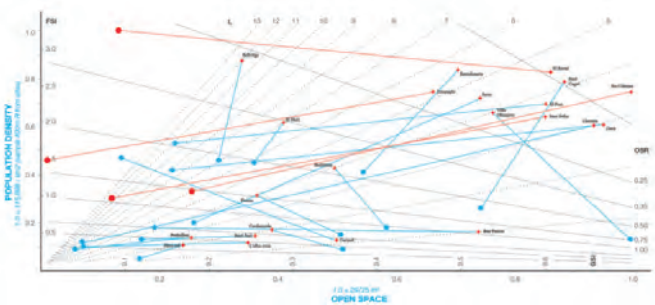


Figure 4/02g (above): *Overlaying the physical density diagram with performance within those areas. This will help identify links between physical density and other measures of density or energy consumption.*

Other Diagrams

In some cases to further analyse urban areas in terms of physical density and other associated indicators, the Spacemate graph will be overlaid with an X/Y plot graph (see Figure 4/02f and Figure 4/02g), showing how certain areas perform in terms of physical density and performance. With these links established, urban areas can be mapped using GIS data.

A second method for comparing 'performance' measures is by using normalising data on a graph. In this case a 'radar graph' (known also as a 'amoeba graph') will be used to overlay data that uses very diffrent values yet follow similar trends. For instance vehicle ownership (measured in cars per 1000 inhabitants) can be compared to income (measured as a percentage of an average). Data is normalised by taking the greatest value as 1 and all lesser values as a percentage of 1.

Figure 4/02h (below): *A radar graph comparing five distinct measures.*

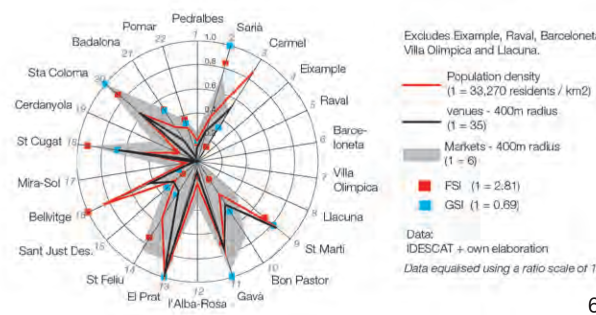


Figure 4/03:

Site Locations

0 400m

Badalona 21
Barceloneta 06
Bellvitge 16
Bon Pastor 10
Carmel 03
Cerdanyola 19
Eixample 04
El Prat 13
Gavà 11
l'Alba-Rosa 12
Llacuna 08
Mira-Sol 17
Pedralbes 01
Pomar 22
Raval 05
Sant Just Desvern 15
Sarià 02
St Coloma 20
St Cugat 18
St Feliu 14
St Martí 09
Villa Olimpica 07

Photo source:
Google Maps, accessed 14/01/2012

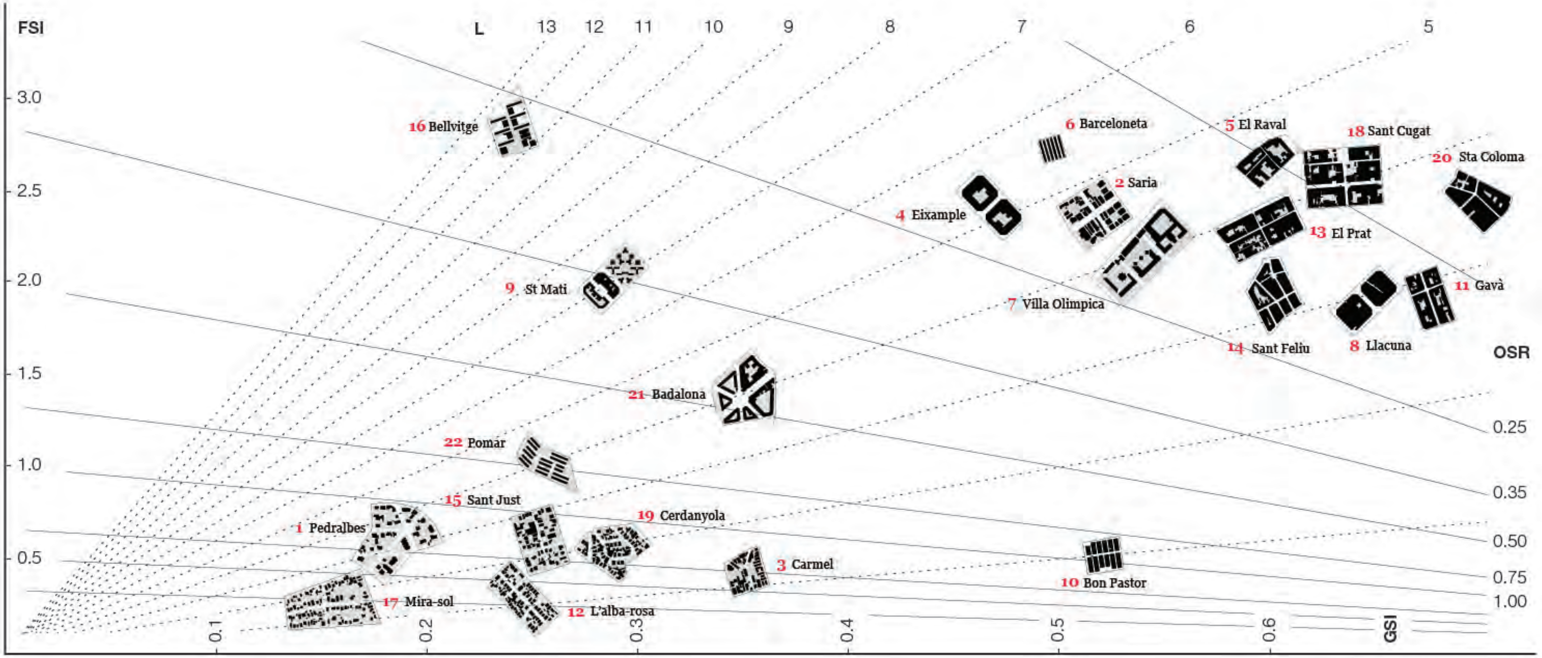


Figure 4/04: Spacematrix, physical density *as defined by Berghauser-Pont & Haupt (2010)*

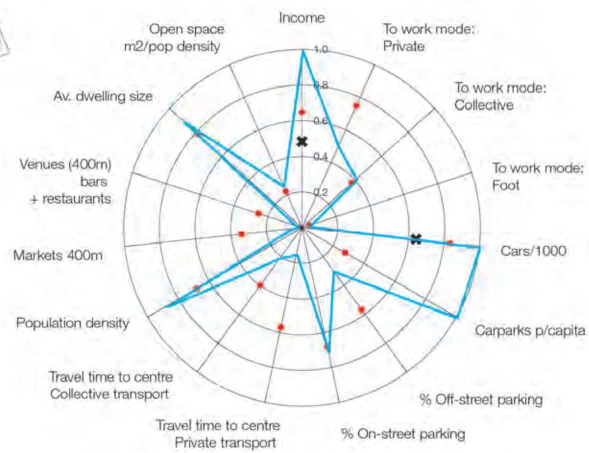
In the following pages:

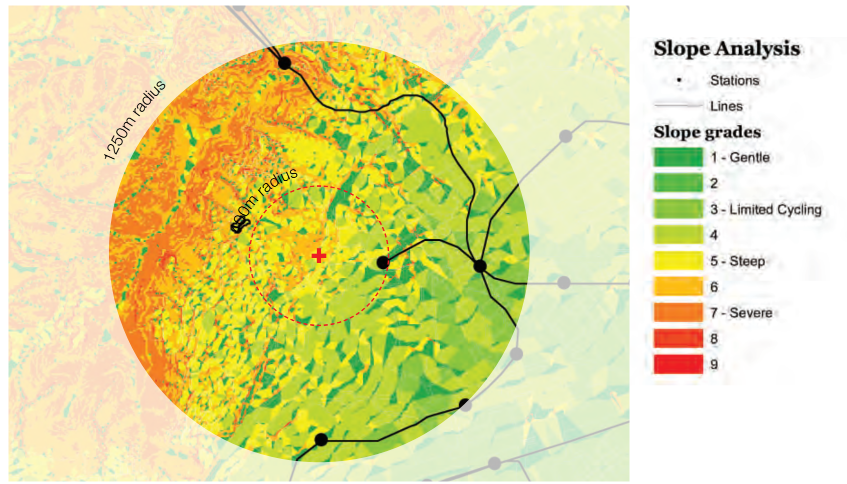
- ✖ Metropolitan average
- ● Average
- —— Site performance

01 Pedralbes

This area was originally developed around the convent of Pedralbes and other associated sites owned by the church – hence the high number of local schools. With large free-standing housing sites with low building density and in proximity to the centre, the area is associated with the city's executives and high income earners. Despite its low density and steeper topography, it contains access to a train station but otherwise contains little diversity and little access to any other land use but schools and housing. The site not only represents the highest number of car parks per capita but also the highest car ownership - measures found to be related significantly to the high income. Despite the aparently high income, the dwellings are not significantly larger, on average, than a number of other areas with lower incomes - which suggests possible issues with data.

Area (m)	*66200*
Lots (m)	*48700*
Coverage (m)	*11000*
L	*2.5*
GSI	*0.17*
FSI	*0.42*
OSR	*2.01*
Tare	*26%*
N (/m)	*0.022*
w (/m)	*92*
b (/m)	*13*

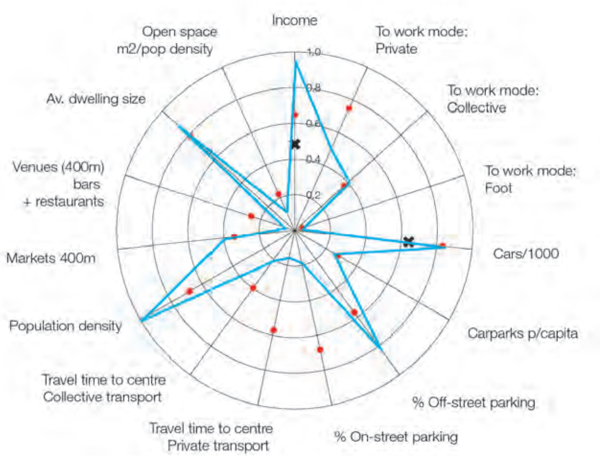


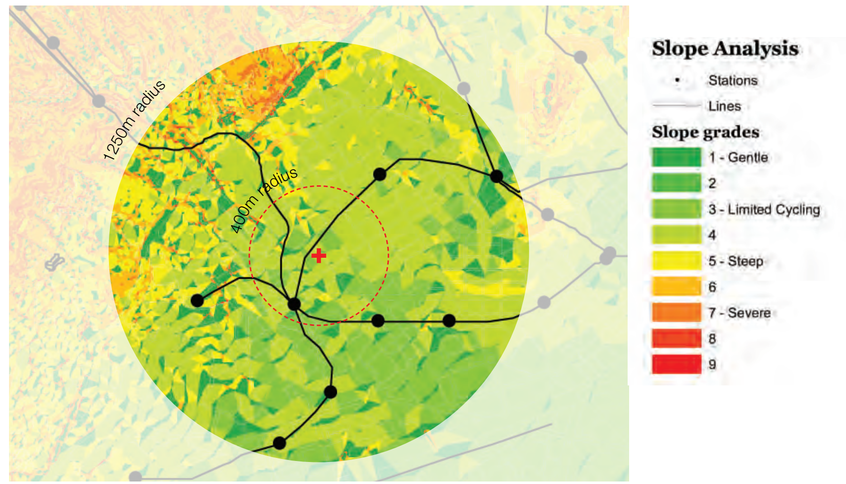


02 Sarià

This area is representative of higher physical density (associated with densities such as Barceloneta, Villa Olimpica and Eixample), but comparatively low population densities - associated with higher incomes and larger mean dwelling sizes. It shows the potential densities high income will tolerate. Like neighbouring Pedralbes, this area has a high number of cars and high incomes. Despite the physical density, it has a high number of supermarkets but a low number of entertainment venues. Slope offers a significant challenge cycling and non-motorised modes. Connectivity to collective modes is adequate but not heavily depended on as private mobility in this district is highest within the Municipality of Barcelona.

Area (m)	48600
Lots (m)	36759
Coverage (m)	25269
L	4.6
GSI	0.52
FSI	2.39
OSR	0.20
Tare	24%
N (/m)	0.018
w (/m)	110
b (/m)	14

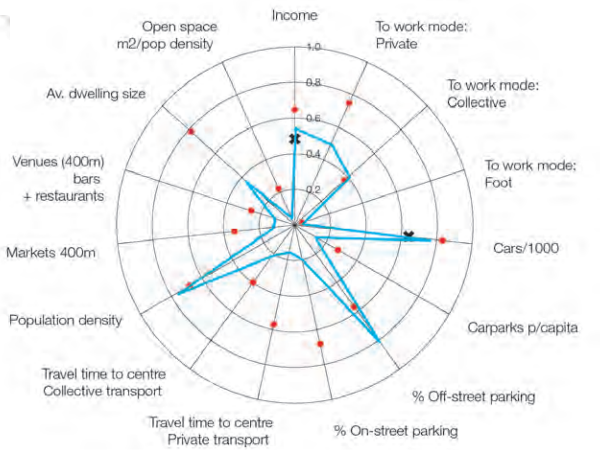


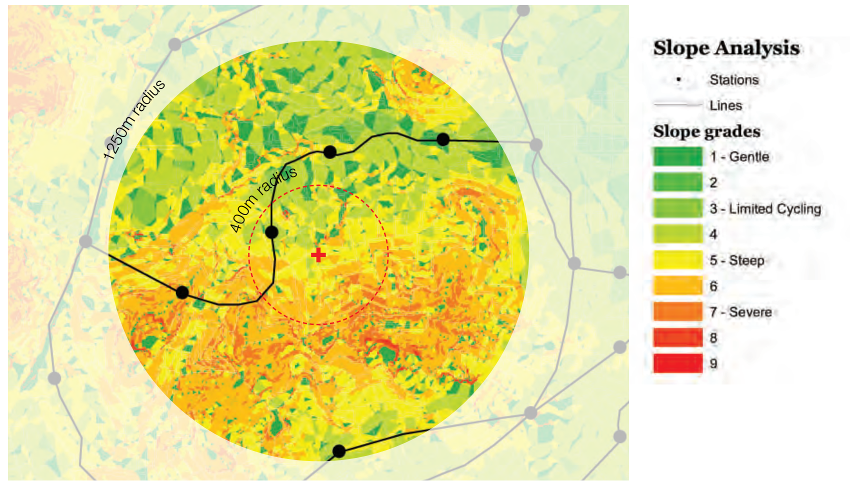


03 Carmel

This area consists of some of the last land to be built on during the building frenzy in the late 50's and 60's. This area was relatively unplanned and many sites began as squatter's settlements – and mixed with steep topography it contains a number of odd characteristics. It has been slowly modified to include schools, occasional community spaces, shopping streets and parks - all of which have been creatively retrofitted. While the site has a moderate population density and accessibility to collective transport (both metro and bus), it represents far greater car ownership than other similar sites. This may be related to the lower availability of services and attractions found in this perdominantly residential area.

Area (m)	*23600*
Lots (m)	*19600*
Coverage (m)	*8000*
L	*1.2*
GSI	*0.34*
FSI	*0.41*
OSR	*1.63*
Tare	*17%*
N (/m)	*0.024*
w (/m)	*82*
b (/m)	*7*

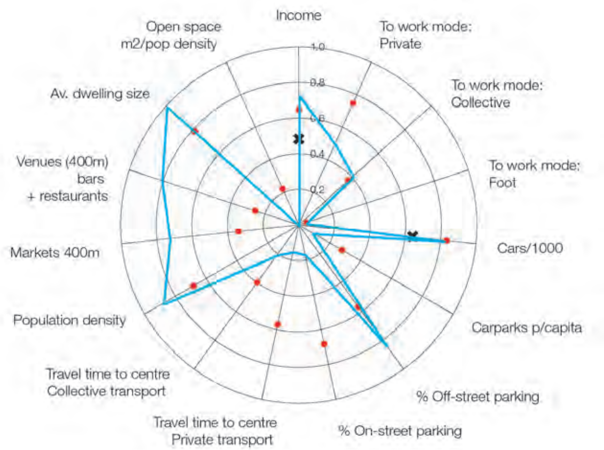


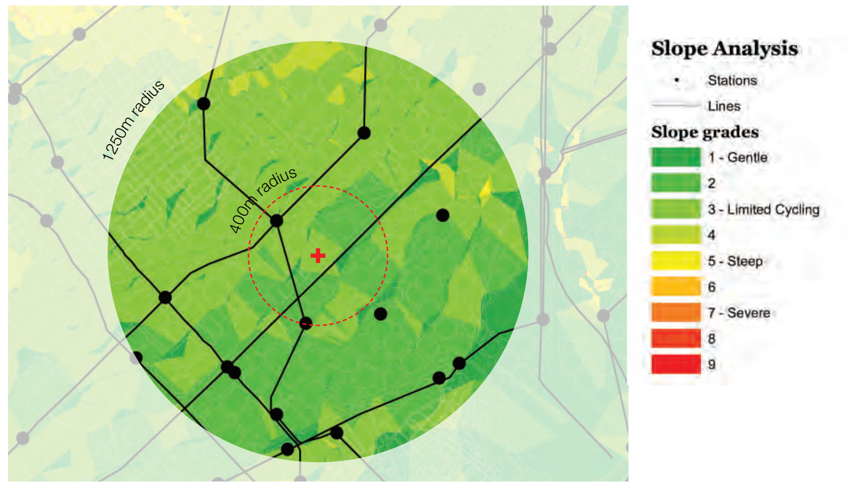


04 Eixample

The Eixample square city block is emblematic of Barcelona's modern urban planning. Cerdà's contemporary rectangular block, despite being radically different from the adjoining medieval layout, now contains both a slightly lower population yet similar physical density to the older city. Albeit many residual improvements established in Cerdà's plan (such as lighting, mobility, air circulation etc..) a number of critical detail omitted from the original plan is communal/public space - which is some of the lowest found in the city. Likewise, roads surround most of the city's blocks leading to considerable air and noise pollution (some of the loudest residential locations in Europe) and thus resulting in significant concerns with living qualities. There are also a high number of cars per capita despite generally low numbers of carparks.

Area (m)	*36000*
Lots (m)	*25400*
Coverage (m)	*17000*
L	*5.2*
GSI	*0.47*
FSI	*2.46*
OSR	*0.21*
Tare	*29%*
N (/m)	*0.015*
w (/m)	*135*
b (/m)	*22*

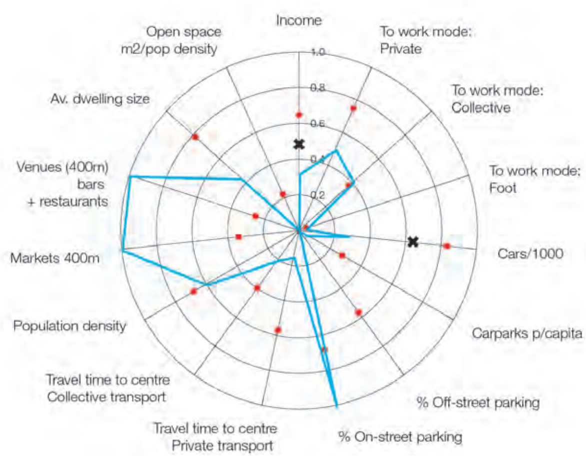


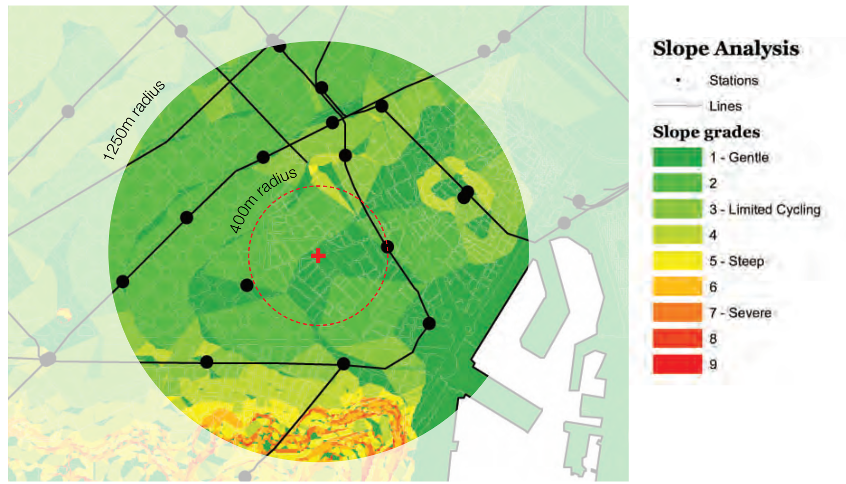


05 Raval

The oldest site covered in this study – the final and most structured extension of the medieval city. This area notably contains one of the highest immigrant levels, the highest densities (with some blocks exceeding 120,000 inhabitants / kilometre) and some of the lowest incomes. It also a vibrant mix of uses on the block level and building level with commercial space typically occupying the ground and second floors. The area contains very little public space and very low numbers of cars which means public space is often saturated. Fortunately with its extremes, it is also extremely central, making most basic needs within walking distance. In addition, the area is extremely noisy (generally from cars, trucks and motorbikes), which is a taxing cost to pay for the benefits of its compactness.

Area (m)	*25400*
Lots (m)	*19600*
Coverage (m)	*15700*
L	*4.3*
GSI	*0.62*
FSI	*2.66*
OSR	*0.14*
Tare	*24%*
N (/m)	*0.022*
w (/m)	*90*
b (/m)	*11*

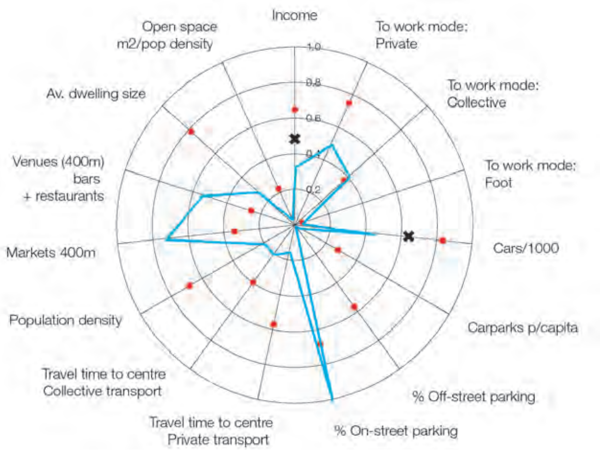


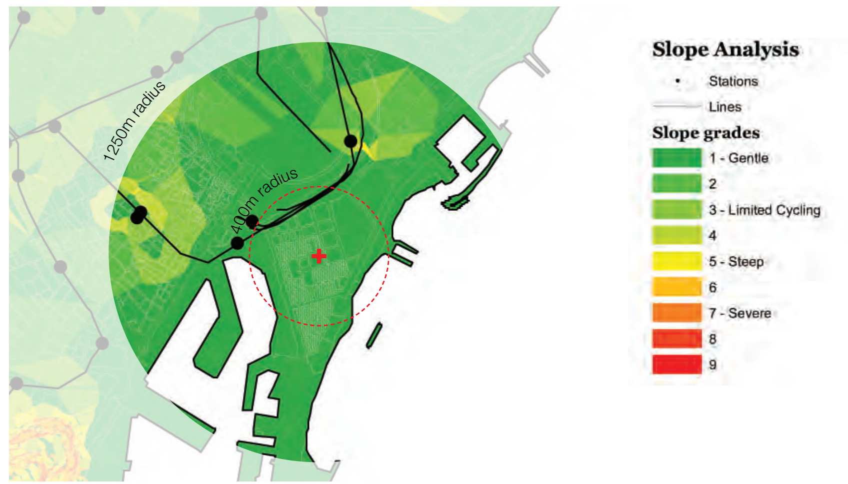


06 Barceloneta

This site represents a unique metropolitan form within the city. The site was laid out by military engineers, and therefore does not follow the courtyard typology typical across the rest o the city. It is dense, compact and relatively self-sufficient, served by a high number of venues and markets which are typically located along the end of the long rectangular blocks at the points of intersection and not within the blocks. With narrow streets, motorised traffic is slow as the streets innevitably become shared space - the high level of pedestrian activity could also be associated with the neighbourhood's robustness. As it is located next the popular park areas along the foreshore it has a relatively high amount of accessible public open space. The lower income levels are also connected with significantly lower levels of schools and cars per capita. There are also very few car parks per capita which may be connected

Area (m)	*8600*
Lots (m)	*4300*
Coverage (m)	*4200*
L	*5.4*
GSI	*0.49*
FSI	*2.64*
OSR	*0.19*
Tare	*50%*
N (/m)	*0.076*
w (/m)	*26*
b (/m)	*8*

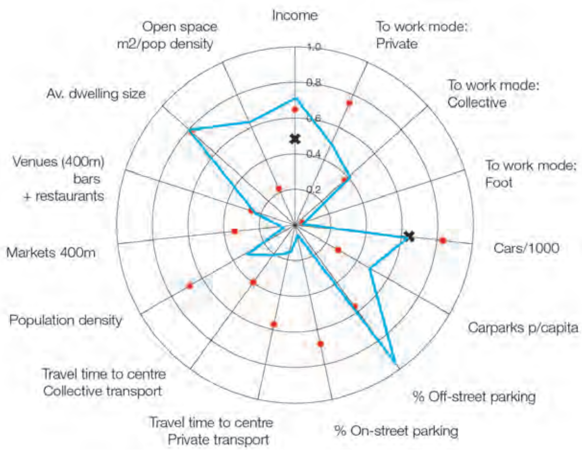


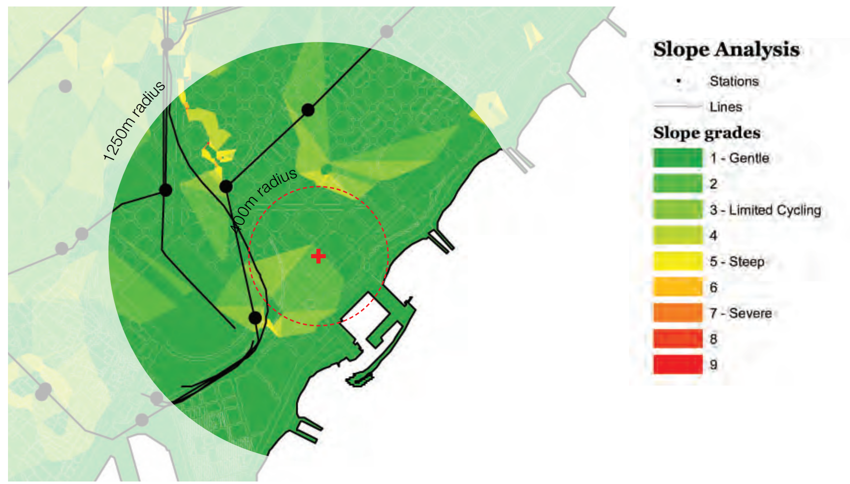


07 Villa Olimpica

The 1992 Olympic Games triggered a significant development program across the city, much of which had been planned in the 1976 metropolitan plan (PGM 1976). The site shows an evolution in urban planning. Firstly it returns to the GATPAC 'super-sized' block from the 1930's, expanding Cerdàs 113 x 113 to much larger proportions. Then memories of Cerdà's unrealised integrated open space has been integrated but over-compensated here – with large tracts of relatively underused parks. In addition lessons learnt from the Urgency Period show how these projects include a much greater mix of functions; shops, offices and residential yet the low population density and the large spaces make it feel empty and lifeless, largely oriented towards car use.

Area (m)	*76800*
Lots (m)	*43700*
Coverage (m)	*40500*
L	*4*
GSI	*0.53*
FSI	*2.11*
OSR	*0.22*
Tare	*47%*
N (/m)	*0.013*
w (/m)	*160*
b (/m)	*44*

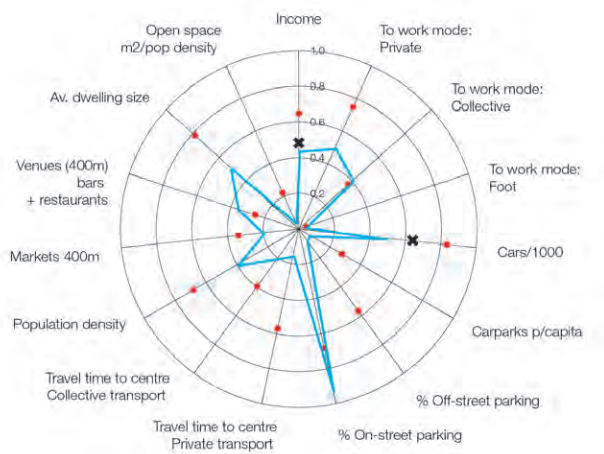


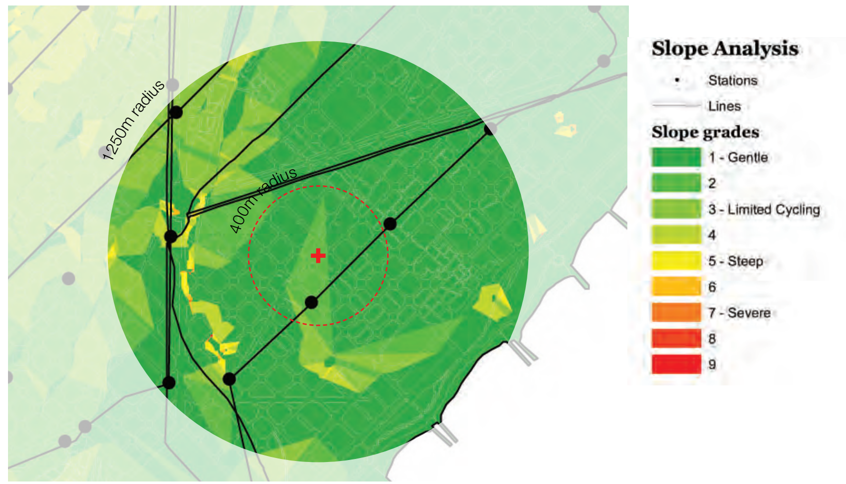


08 Llacuna

Llacuna offers a taste of the pre-Olympics industrial development. In this case the area contains a complex array of functions which seem to neither compete or compliment each other. There are car-yards and mechanics, schools and day-cares, occasional workers bars and hip 'underground' nightclubs, decommissioned industry and new commercial areas, housing and warehouses, car-yards and empty lots. The urban area is currently in transition with the BCN 22@ plan implemented over ten years ago. While the area is mixed, the proportions of mix favour the daily work conditions, therefore on weekends or in the afternoon, the area becomes still and lifeless. For this reason it does not support rich variety of shops and essential services.

Area (m)	*36500*
Lots (m)	*24400*
Coverage (m)	*23900*
L	*3*
GSI	*0.65*
FSI	*1.96*
OSR	*0.18*
Tare	*33%*
N (/m)	*0.015*
w (/m)	*136*
b (/m)	*25*

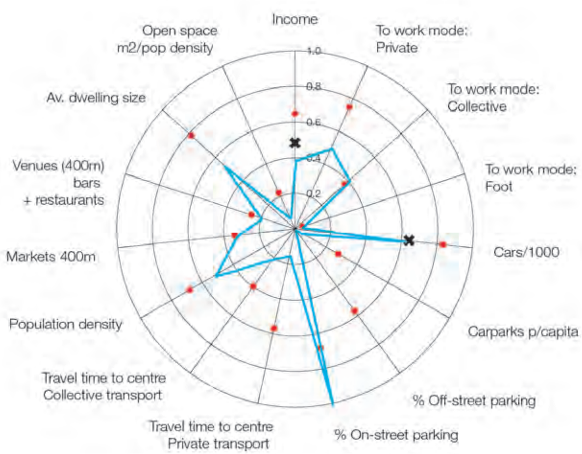


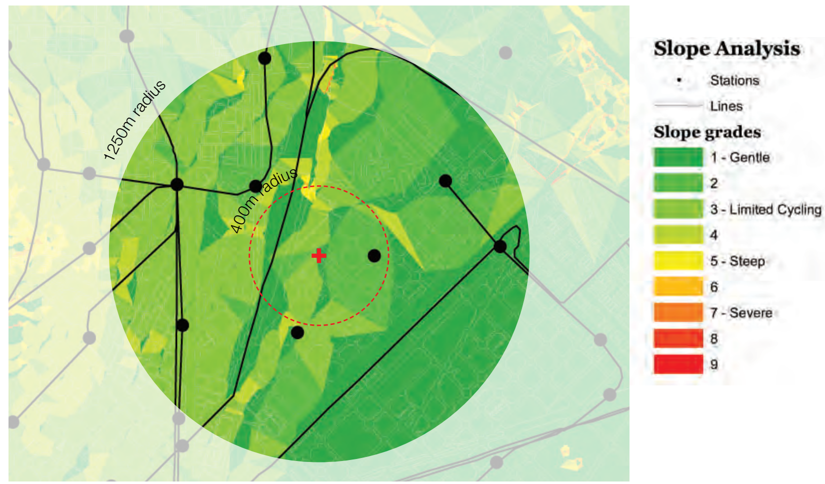


09 St Martí

As Manuel de Sola Morales explains, this development is one of the more complex projects developed during the Urgency Period. Cerdà's typical square block has been dissected into smaller forms that do away with the central courtyards with some open space and commercial areas on the ground floor. One of the criticisms of this and the adjoining sites is the limited level of complexity. As most blocks in this area were developed as single units, they do not display the richness of inner city sites, while supporting similar population densities. Without this complexity, incomes are relatively flat and the area serves largely as a 'bedroom neighbourhood' - therefore residents are inclined to travel outside the neighbourhood for work. Schools are well accounted for but other shops and essential services are relatively lower.

Area (m)	36800
Lots (m)	23000
Coverage (m)	10700
L	7
GSI	0.29
FSI	2.04
OSR	0.35
Tare	38%
N (/m)	0.018
w (/m)	110
b (/m)	23

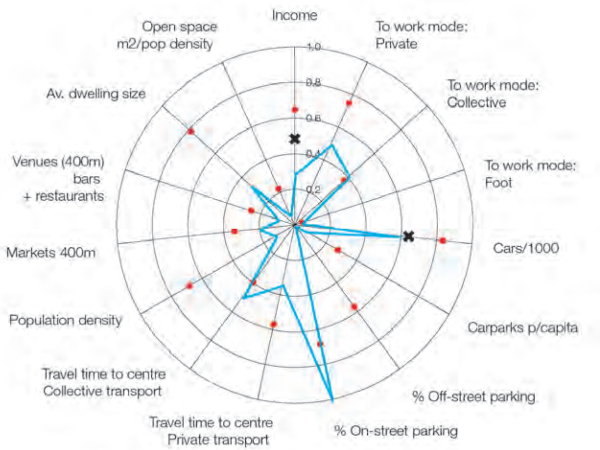


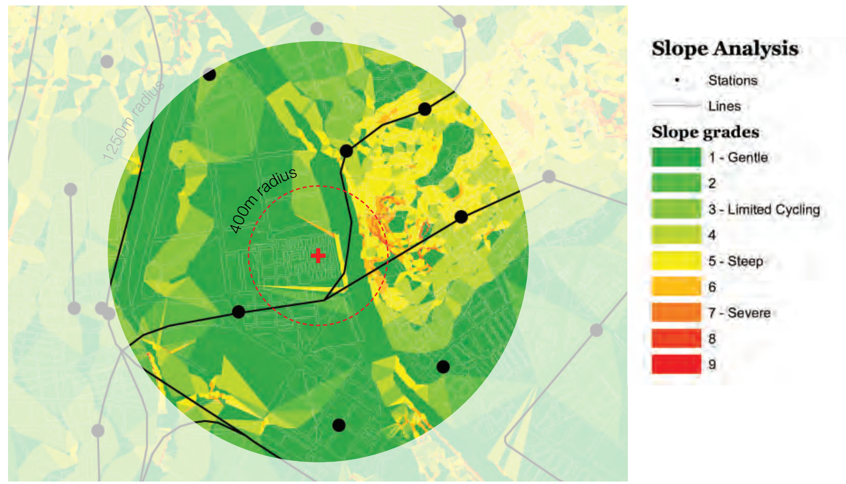


10 Bon Pastor

This type was selected as it displays an exotic urban form not common elsewhere. This is one of the first worker's 20th century housing projects located then on the fringe of the city attached to the former factories adjoining the Besos. Considering the scale and intensity of construction, this site has a relatively high population density – possibly attributed to the modest design with small rooms. The site contains little in the way of open space, no mix of land uses (in the immediate context) and low-income levels. It also has median car ownership which is odd considering the low income level and despite its proximity from the centre with connection to two metro lines.

Area (m)	*19400*
Lots (m)	*10600*
Coverage (m)	*10000*
L	*1*
GSI	*0.52*
FSI	*0.52*
OSR	*0.94*
Tare	*45%*
N (/m)	*0.074*
w (/m)	*27*
b (/m)	*7*

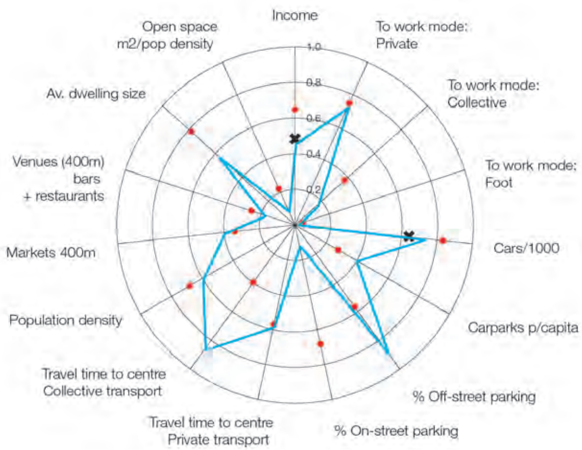


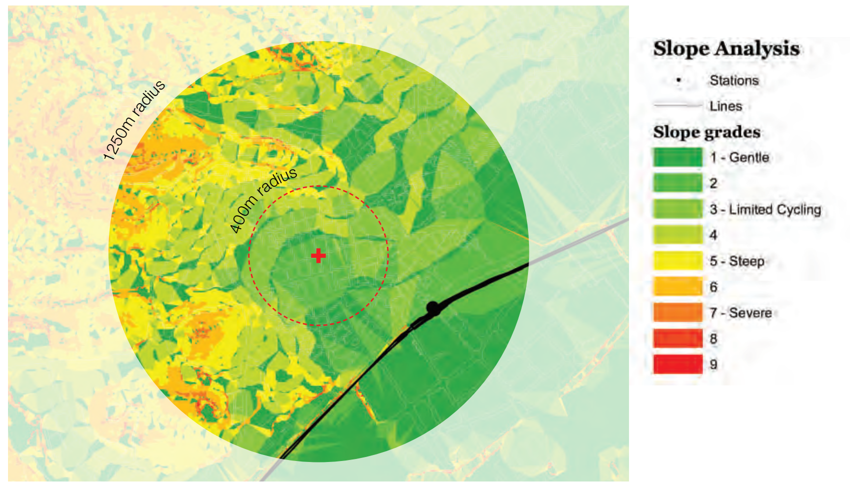


11 Gavà

Located on the south-western periphery of the city, just above the coastal plain, Gava is a former agricultural settlement that grew suddenly and rapidly at the turn of the 20th century. While the urban area follows a compact form it serves as a largely car based commuter neighbourhood for both travel to Barcelona and other neighbouring municipalities. This could be due to the station's location away from the physical centre and away from the main population concentration – as for many residents, a trip to the station would require an additional bus link for accessibility. Despite the relatively narrow streets, there are significant amounts of surface parking.

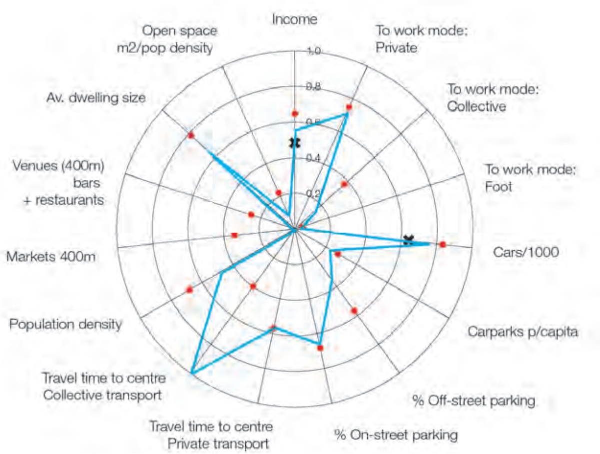
Area (m)	*31600*
Lots (m)	*24975*
Coverage (m)	*20855*
L	*3*
GSI	*0.66*
FSI	*1.98*
OSR	*0.17*
Tare	*21%*
N (/m)	*0.023*
w (/m)	*86*
b (/m)	*10*

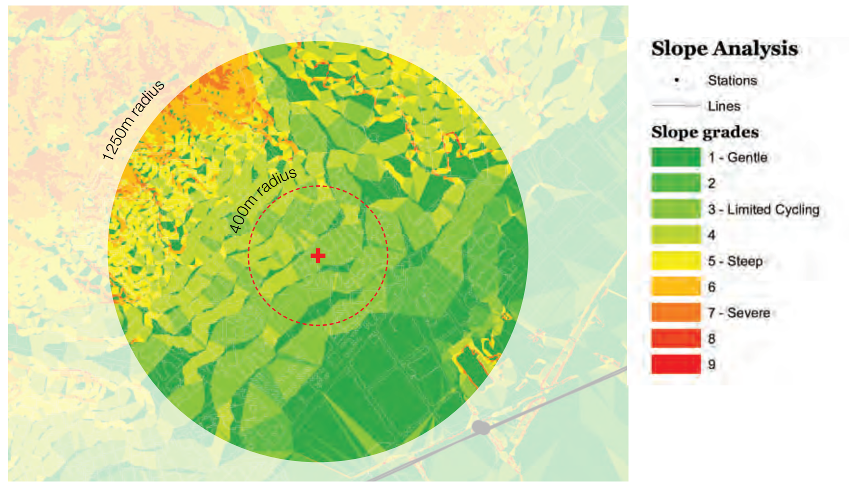




12 l'Alba-Rosa

L'Alba Rosa is a late 1950's suburban development, established as Franco era middle-upper class industrialists were fleeing the working city. Then located outside Barcelona at some distance away from other settlements, shops, amenities or collective transport. Projects such as this established the city's first commuter settlements. The Municipality of Viladecans continues to support a demographic of high commuters and dependence on personal transport due to the variety of amenity. In fact the urban form that was established there over 50 years ago remains largely unchanged with very few amenities nearby (shops, schools and/or open space).

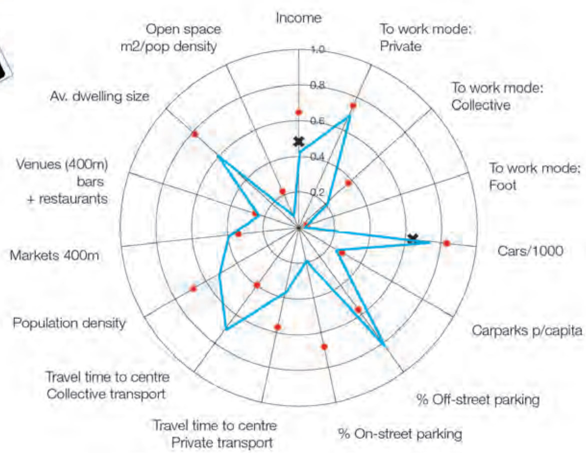




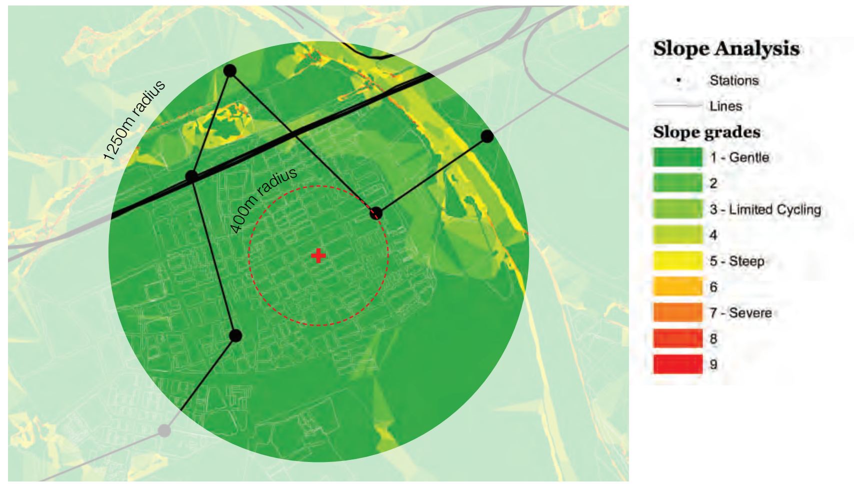
Area (m)	*40700*
Lots (m)	*32100*
Coverage (m)	*10000*
L	*1.5*
GSI	*0.25*
FSI	*0.37*
OSR	*2.05*
Tare	*21%*
N (/m)	*0.025*
w (/m)	*80*
b (/m)	*9*

13 El Prat de Llobregat

El Prat is a former rural settlement on the flat coastal plain at the mouth of the Llobregat River. Much of the urban area grew suddenly with Francoist industrialisation and particularly with the development of larger industrial sites on the shores of the Llobregat. While located on the periphery, the area is very well connected to the highway, rail and soon also metro. It is also notably flat, despite lack of bike lanes and suitable bike streets, it is strong candidate for a municipal cycling network. Conversely it is highly car orientated - with over 20% more cars per / capita than average for the metropolitan area.



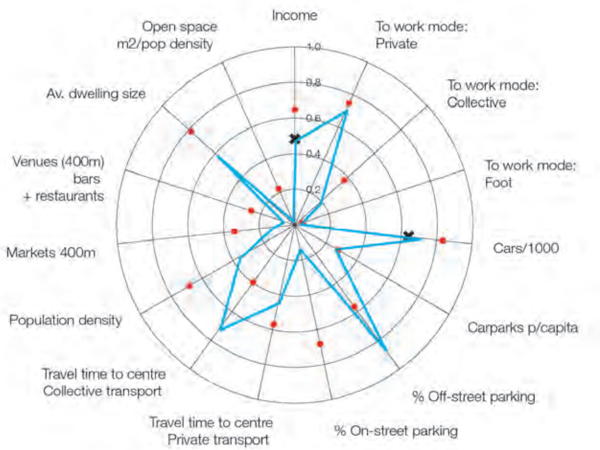
Area (m)	*40750*
Lots (m)	*31110*
Coverage (m)	*24630*
L	*3.8*
GSI	*0.60*
FSI	*2.30*
OSR	*0.17*
Tare	*24%*
N (/m)	*0.024*
w (/m)	*84*
b (/m)	*11*

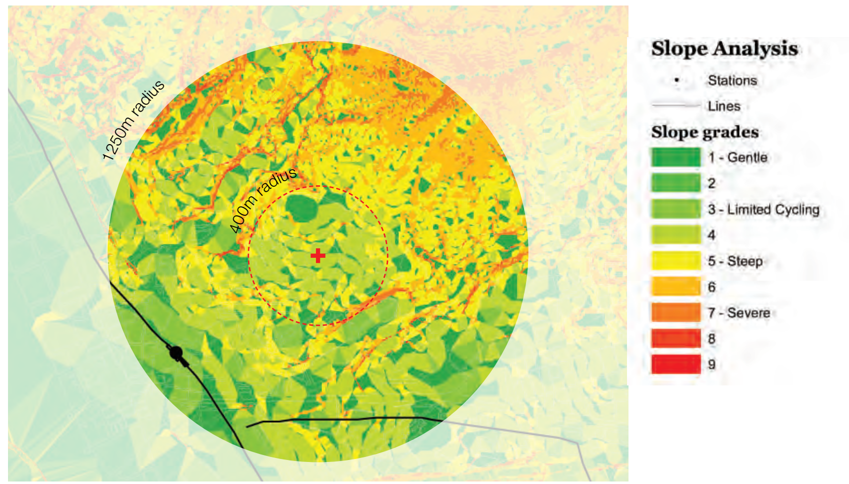


14 Sant Feliu

Sant Feliu is a fringe development, expanding on a former rural and then industrial area. Like other similar sites such as El Prat, Gava and Santa Coloma, this area grew quickly during the Urgency Period and has taken on the density but not the proximity to goods and services that older areas such as Raval and Eixample. Therefore the site has a relatively low amount of commercial space and fewer shops and venues than many others with similar densities. This may be largely due to the low job density, with a large number of its inhabitants commuting for work. For its physical density, it also has a relatively low population density.

Area (m)	*39800*
Lots (m)	*26700*
Coverage (m)	*24000*
L	*3.5*
GSI	*0.60*
FSI	*2.11*
OSR	*0.19*
Tare	*33%*
N (/m)	*0.031*
w (/m)	*64*
b (/m)	*12*

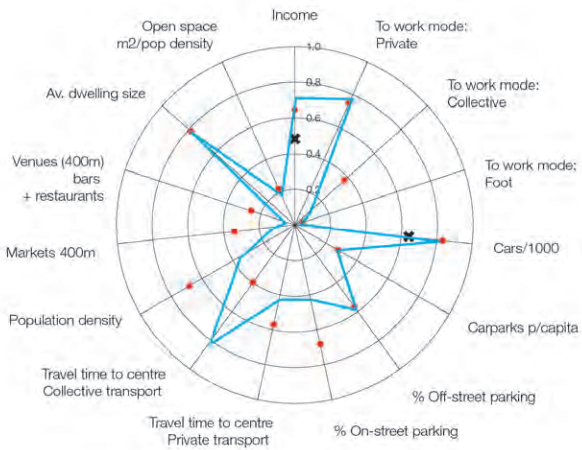


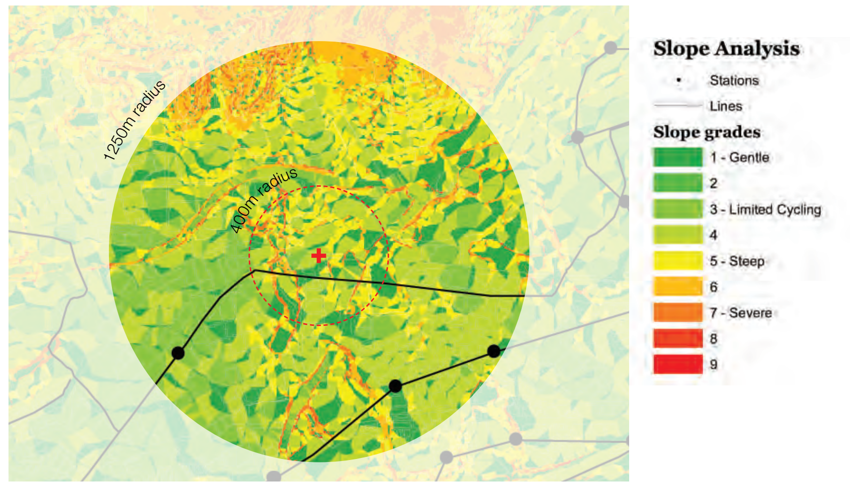


15 Sant Just Desvern

Just a little further away from the centre than Pedralbes and with just a small difference in mean dwelling sizes, Sant Just follows many of the same trends. Higher incomes, higher car ownership, low physical and population density, low access to shops and venues within walking distance, low access to collective transport – qualities that make inhabitants highly car dependent. Ironically, the municipality has a very high job ratio, yet most of the inhabitants do not work within it.

Area (m)	*42500*
Lots (m)	*35500*
Coverage (m)	*10800*
L	*1.8*
GSI	*0.25*
FSI	*0.46*
OSR	*1.63*
Tare	*16%*
N (/m)	*0.020*
w (/m)	*101*
b (/m)	*9*

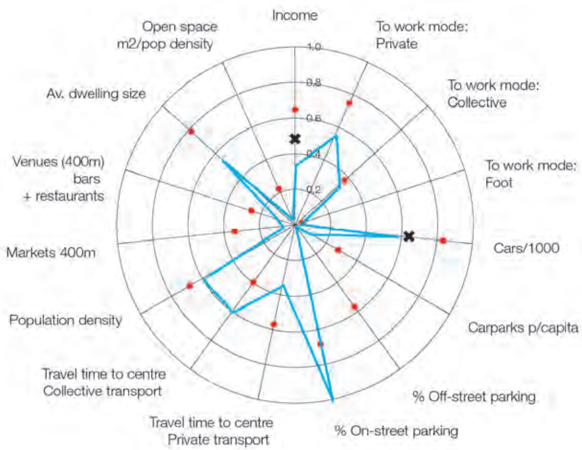


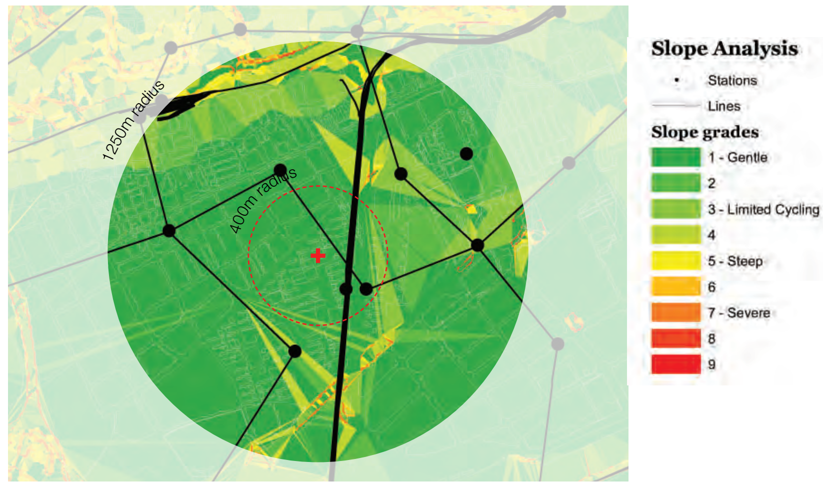


16 Bellvitge

This site is associated with one of the large urbanisations built quickly during the Urgency Period. This project, as de Sola Morales explains, has no clear rationale behind orientation, contains large open spaces at the base, which feel overwhelmed by the adjoining 18 storey modernist apartments with very low levels of complexity due to the large plot sizes. While the site supports a relatively high population density (over 30,000 resident / km2), there is very little in the way of shops and venues due to the lack of commercial space. This accounts for the site's highly mobile workforce and low numbers of local jobs.

Area (m)	*34200*
Lots (m)	*21500*
Coverage (m)	*8000*
L	*12*
GSI	*0.23*
FSI	*2.81*
OSR	*0.27*
Tare	*77%*
N (/m)	*0.035*
w (/m)	*57*
b (/m)	*29*

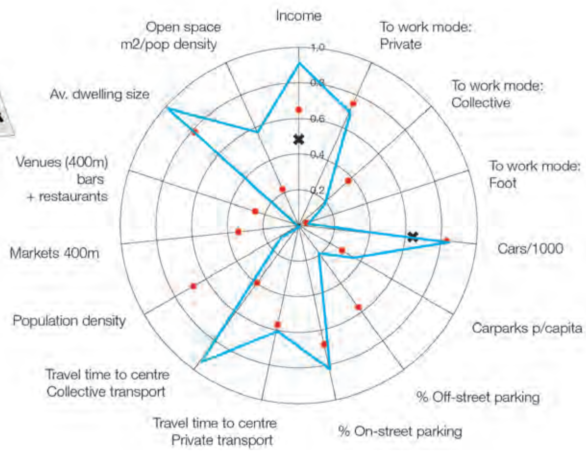


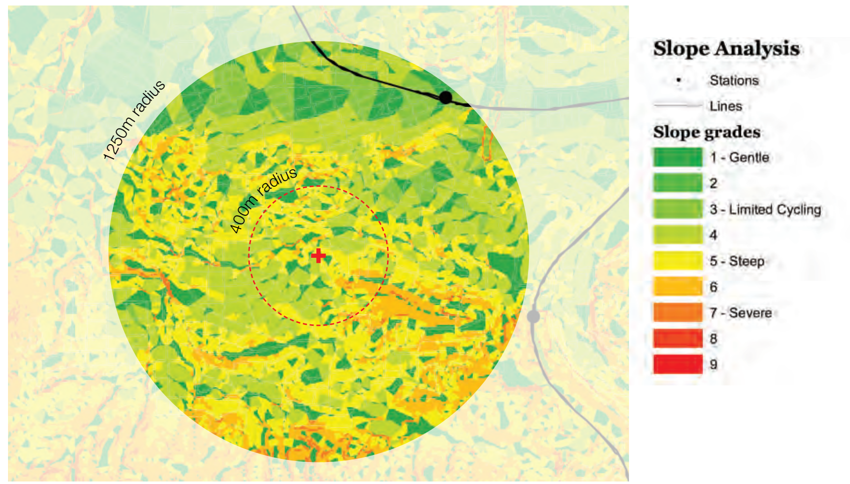


17 Mira-Sol

Suburbanisation is a relatively new and still novel concept for Barcelona, which remains a largely compact urban area. Mira-Sol is one of the bedroom suburbs who's workers commute either into the centre or out to commercial centres to the west. The site contains almost no local shops, local schools or venues. The site is heavily undulated and unsuitable for all but sport cycling. The train station is some distance away too. In other words, almost every aspect of life in this suburb involves private mobility. Regardless, incomes are amongst the highest for the metropolitan area which allows residents this level of flexibility and mobility.

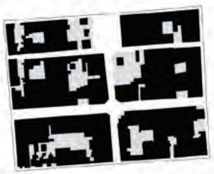
Area (m)	*64900*
Lots (m)	*55170*
Coverage (m)	*11300*
L	*2*
GSI	*0.17*
FSI	*0.35*
OSR	*2.37*
Tare	*15%*
N (/m)	*0.017*
w (/m)	*121*
b (/m)	*9*



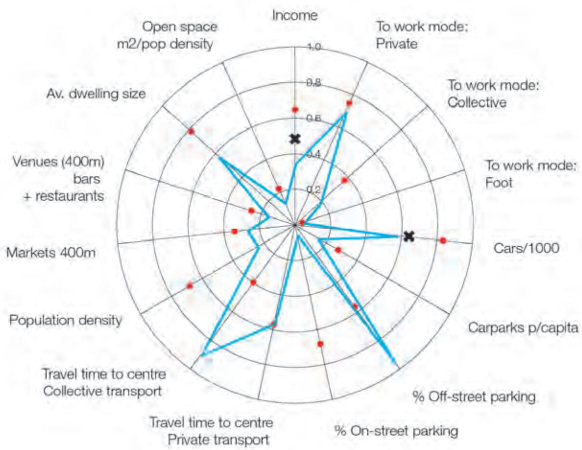


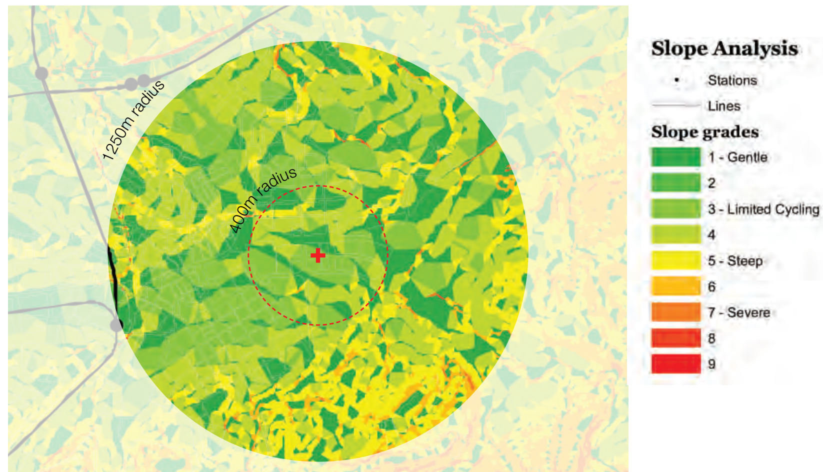
18 Sant Cugat

Located some distance from the city centre, Sant Cugat contains an unusually high density (both form and population density) that are similar to those found in inner city areas. The density is abrupt and concentrated in a relatively small area, therefore the benefits of having such a high concentration of residents is not fully appreciated. This area contains some of the lower incomes within the metropolitan area, while within one kilometre away, some of the highest incomes are found. This makes for either a highly mixed or highly segregated combination of two income groups. The area otherwise is located some distance from the train station, which is also unusual considering its density.



Area (m)	*373987*
Lots (m)	*58258*
Coverage (m)	*45525*
L	*4.2*
GSI	*0.62*
FSI	*2.58*
OSR	*0.15*
Tare	*100%*
N (/m)	*0.015*
w (/m)	*138*
b (/m)	*136*

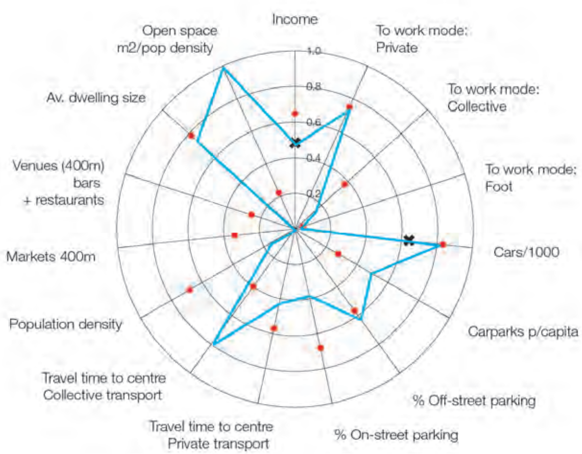


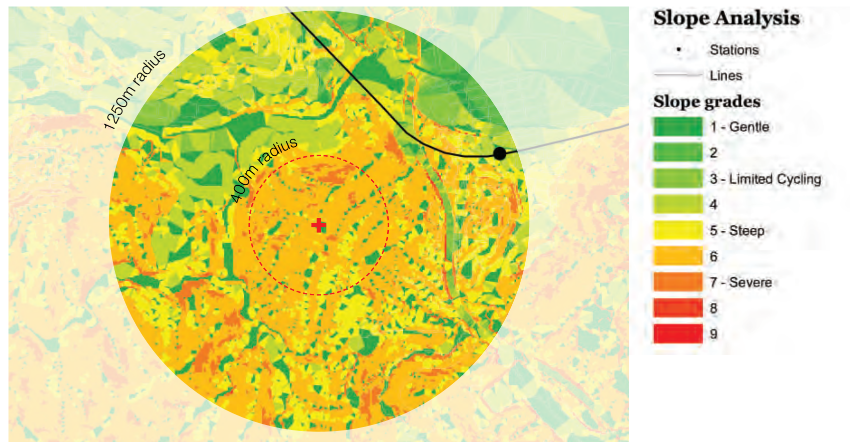


19 Cerdanyola

Typical of 1950's suburban low-density growth due to the car, Cerdanyola is located some distance from the physical centre and with few shops or venues, is highly dependent of private transport. The site's location makes it an ideal commuting point into the centre and to other regional centres such as Terrassa, Sabadell and the industrial areas lining the major highways out of Barcelona. In this sense it has retained a higher income yet highly mobile population, on which it was founded. Like l'Alba Rosa and Mira-Sol, this site is located on sloping topography making it unsuitable for generally cycling.

Area (m)	*40300*
Lots (m)	*31200*
Coverage (m)	*11200*
L	*2*
GSI	*0.28*
FSI	*0.56*
OSR	*1.30*
Tare	*23%*
N (/m)	*0.025*
w (/m)	*80*
b (/m)	*10*

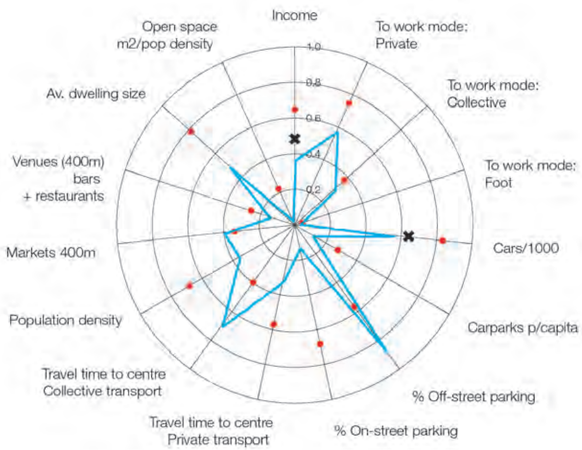


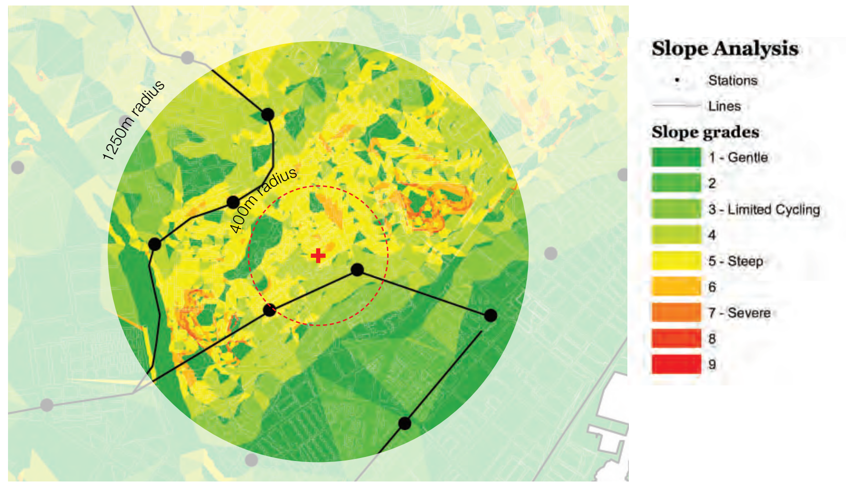


20 Santa Coloma

At the end of metro lines on the periphery of the metropolitan area, a number of higher density, low income settlements have established that depend on jobs and attractions within the centre of Barcelona – the metro link has created what may be considered 'compact suburbia'. In this sense, these areas support a low number of local jobs and a high number of commuters. In addition, Santa Coloma contains the highest physical density explored amongst the 22 sites, yet contains a mid-range population density (around 20,000 residents per/km2).

Area (m)	36380
Lots (m)	29580
Coverage (m)	25230
L	3.5
GSI	0.69
FSI	2.43
OSR	0.13
Tare	19%
N (/m)	0.022
w (/m)	92
b (/m)	9

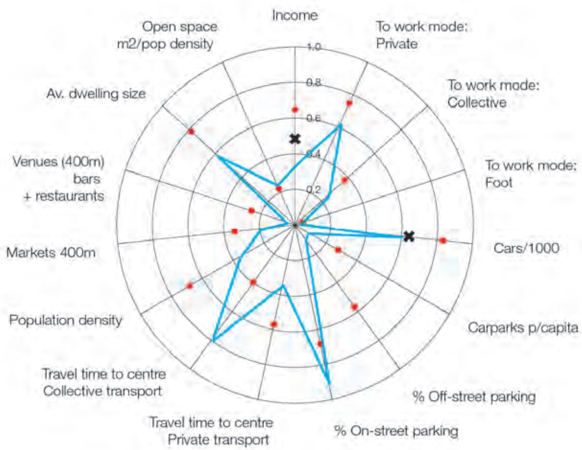


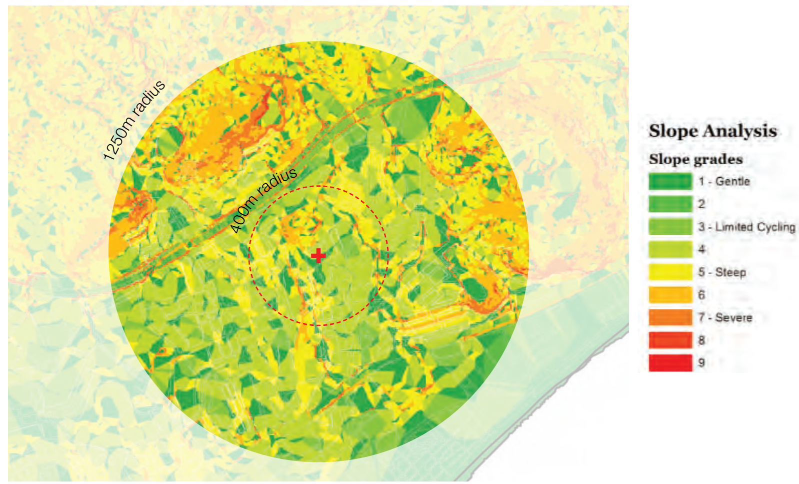


21 Badalona

Some sites on the periphery of the metropolitan area, developed within the last 50 years, have not fully matured. Badalona, while feeling compact on site with 4-5 storey buildings with little apparent public open space, it actually has relatively low physical and population density. As this site is primarily accessible via the adjoining highway (some distance from the rail stations), it makes for a semi-compact, car dependent commuter suburb. As it is located on steeper terrain, it also means alternative non-motorised modes are of little attraction as a choice of mobility. Densification may provide a suitable solution, if coupled with collective transport use.

Area (m)	*57490*
Lots (m)	*36200*
Coverage (m)	*20460*
L	*4*
GSI	*0.36*
FSI	*1.42*
OSR	*0.45*
Tare	*37%*
N (/m)	*0.022*
w (/m)	*92*
b (/m)	*19*

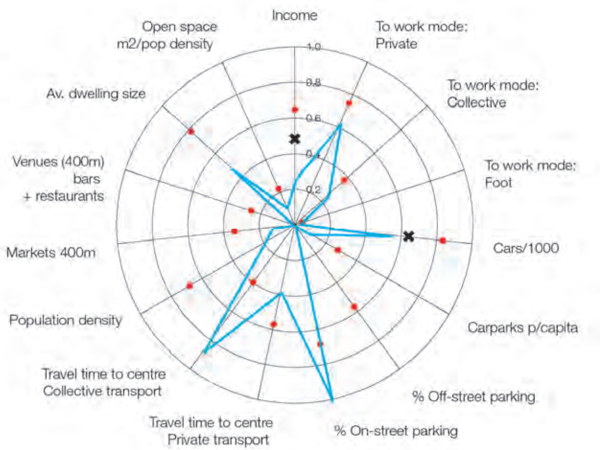


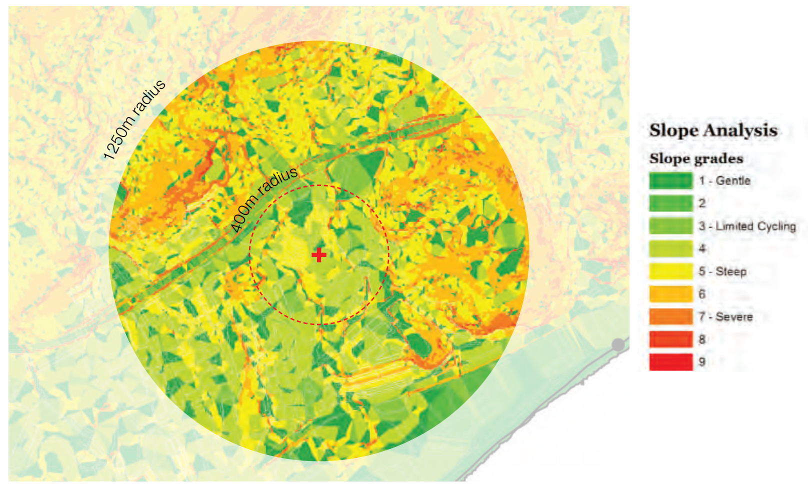


22 Pomar

Pomar is a Francoist period extension that grew out of the Urgency Period. The former industrial areas which may have once employed residents from Pomar has since been largely decommissioned and now residents travel to workplaces. The area consists of modernist 2-4 storey walk-up flats surrounded by large swathes of largely unused open space. This urban extension is a mono-functional residential area with only a handful of small shops and a single bar making it almost impossible not to leave the neighbourhood on a daily basis for even the most basic of purchases. The development also precedes the adjoining highway that it now depends on with residents earning some of the lowest incomes in the metropolitan area yet with relatively high car ownership.

Area (m)	*27840*
Lots (m)	*22900*
Coverage (m)	*7024*
L	*4*
GSI	*0.25*
FSI	*1.01*
OSR	*0.74*
Tare	*18%*
N (/m)	*0.038*
w (/m)	*53*
b (/m)	*5*





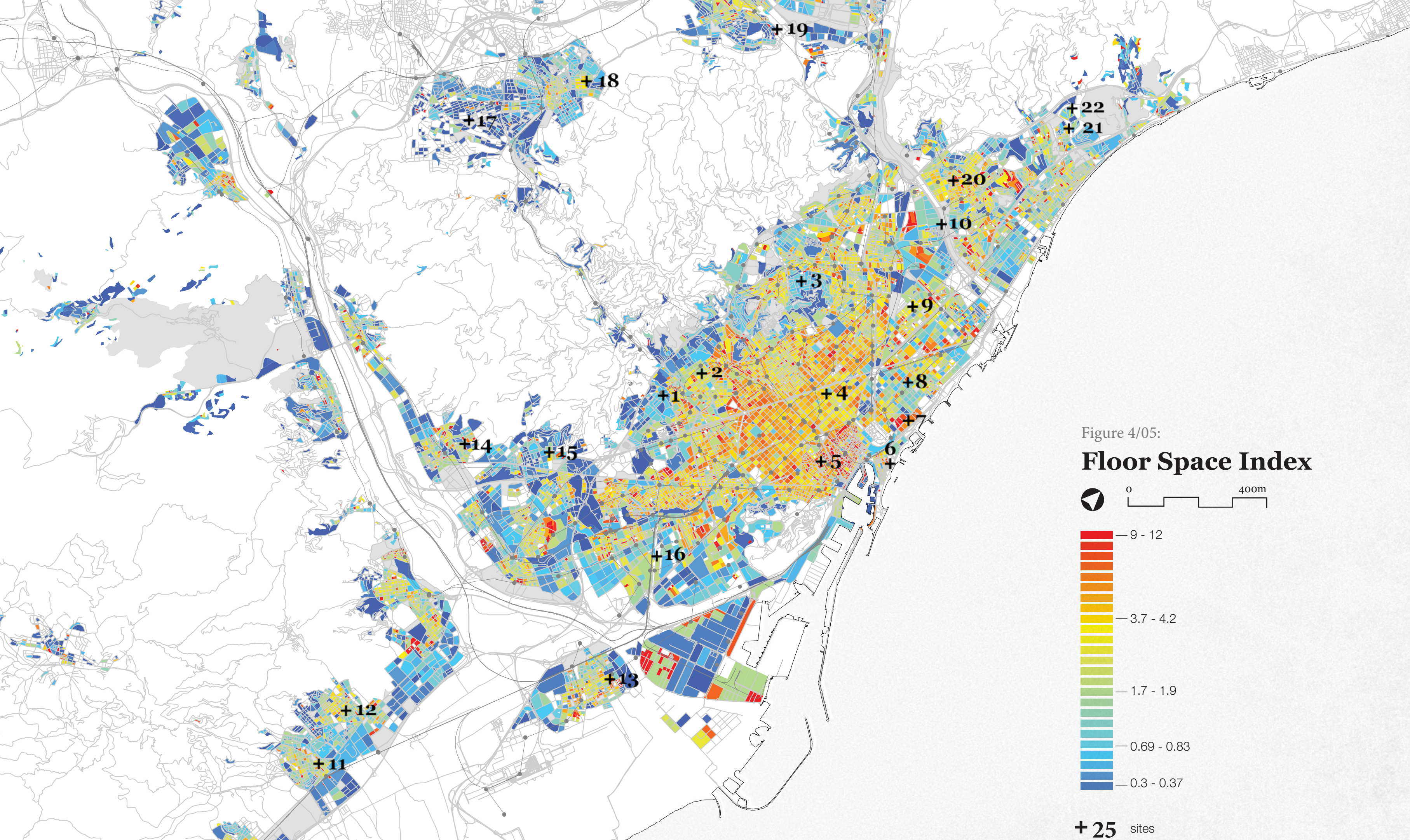


Figure 4/05:
Floor Space Index

Density

Density is a Theme often associated with energy consumption. In this case various types of density will be discussed including population density, occupation (GSI), gross floor area (FSI), job density, open space and density of services or facilities.

Newman + Kenworthy's extensively cited findings on transport energy consumption concluded that population density is a significant factor in terms of transport related energy consumption at a city level (Newman & Kenworthy 1989). But analysing a city as a whole assumes averages, neglecting how certain parts of the city may perform over others. Likewise, density according to Cervero + Kockelman was found to be related to lower amounts of private transport use – conditional to environmental qualities such as mixed land use (Cervero + Kockelman op. cit.).

Building density is associated with heating and lighting (Salat 2009), and will be explored at the end of this chapter. A study focusing on the nuances of building technology would look for subtle differences in thermal mass and passive orientation and possibly find links with FSI / GSI. However as these account for a relatively small amount of the total energy budget, they will not be covered in detail within this project.

It is clear that energy consumption is highly cultural and geographically sensitive, relating to accessibility and flexibility. Therefore a large part of density depends on how users take advantage of the facilities nearby or whether the facilities nearby are suitable for the users. In an extensive literature analysis on density, Boyko and Cooper (2011) concluded that there are two particular qualities of density. Firstly, 'hard' or quantitative forms of density relating to

Figure 4/06-07: *Two areas with similar physical density, Barceloneta + Saria, yet a world apart in may other ways - particularly energy consumption.*

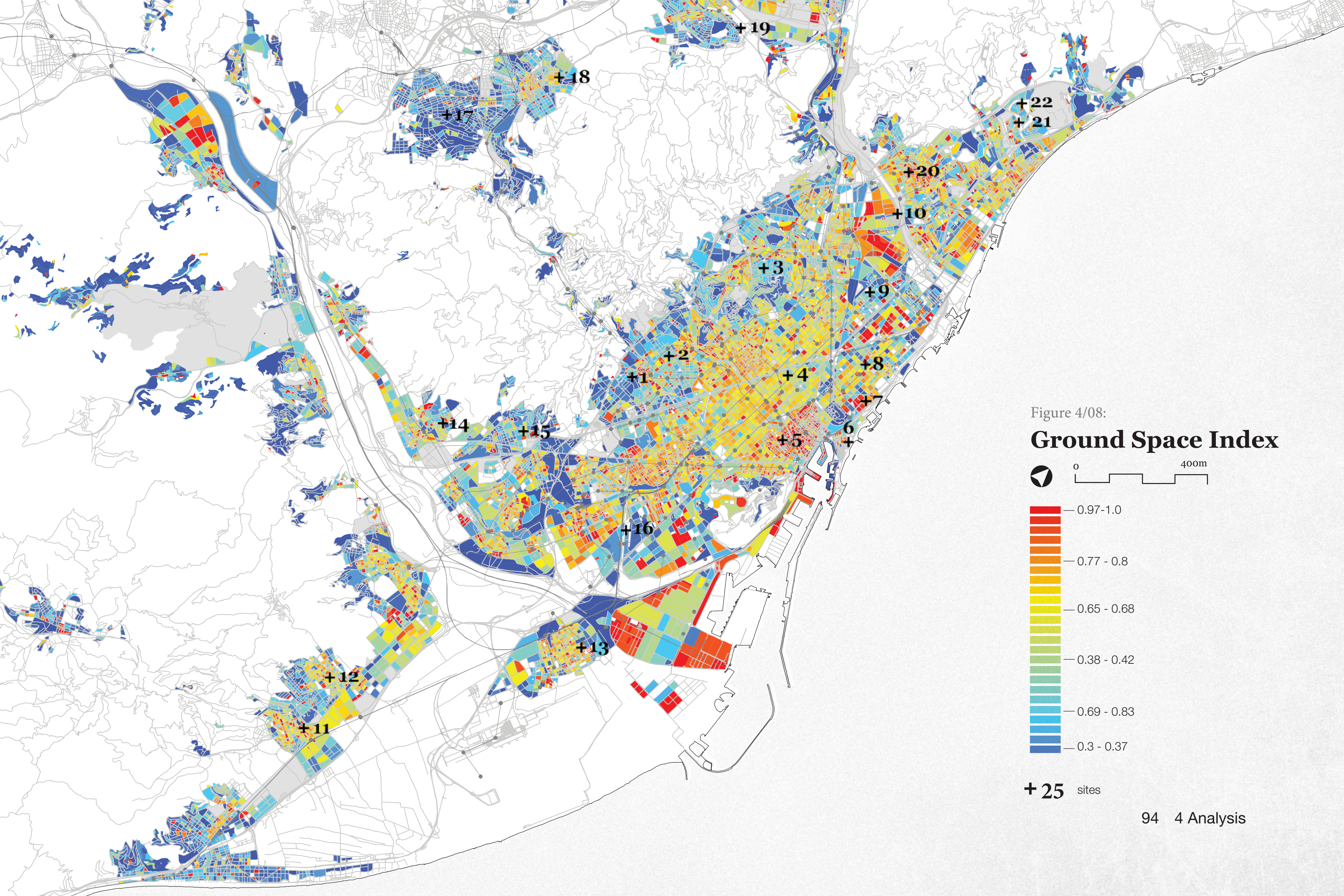


Figure 4/08:

Ground Space Index

measurable values: population density, FSI / GSI, energy consumption, car-parks. On the other hand, perceived density or 'soft' concepts of density involve the way people relate to their environments. This 'soft' side of density is not easily determined and can vary significantly according to culture, income and climate.

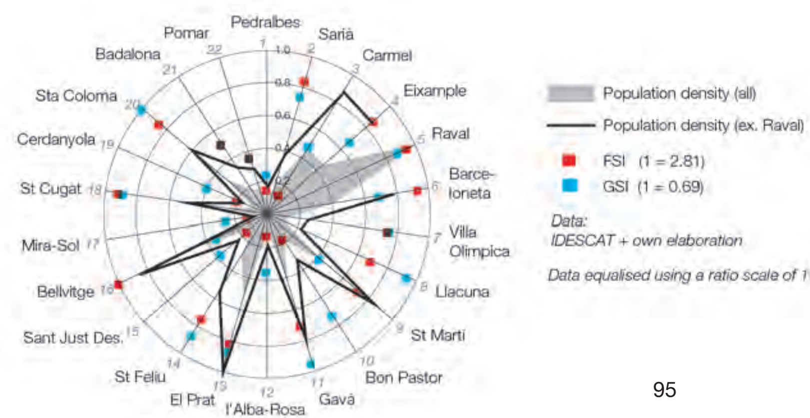
For instance, denser urban areas in some studies have been found to reduce overall energy demands. However due to other qualities of urban areas (such as lack of open space), there may be a 'compensatory' demand to travel in leisure time thus counteracting proximity to shops and work (Næss 2005; Holden & Norland 2005). The scope of this study will not cover research into leisure or social activities however it is necessary to be aware of the 'rebound effect' where seemingly lower energy lifestyles depend on travelling to certain amenities / destinations due to a lack of local facilities. Under lower energy conditions, these compensations may in fact be reduced, but at least they provide some indication that denser urban environments are associated with some but not other needs.

Physical density and population density

Population density is connected, as will be shown, to the provision of certain amenity and services; access to these can be linked to lower energy consumption. Can physical density be linked to population density?

Physical density and population density are not always consistent as shown with a number of inner-city sites in Figure 4/09 density. Statistically unique sites such as Raval are extreme cases – therefore the diagram has been adjusted without Raval. Closer links between FSI and density are shown in other more typical urban areas such as Santa Coloma, Santa Feliu, El Prat and Gavà and with lower densities in Pedralbes, l'Alba, Sant Just and Mira-Sol. Links between physical density, population density and energy will be shown later in this chapter.

Figure 4/09: *FSI, GSI and Population density*



Density and Income

As shown in Figure 4/10, density and income are not clearly linked – unless dwelling size is included. In Barcelona, low income areas can be associated with low density areas (Pomar, Bon Pastor) while other denser areas also support high income residents (Eixample, Villa Olimpica). Size of living space will be later shown to have a greater connection with income than density. This accounts for the differences noted above, showing that variations between physical density and population density are likely to be associated with income / housing size ratios.

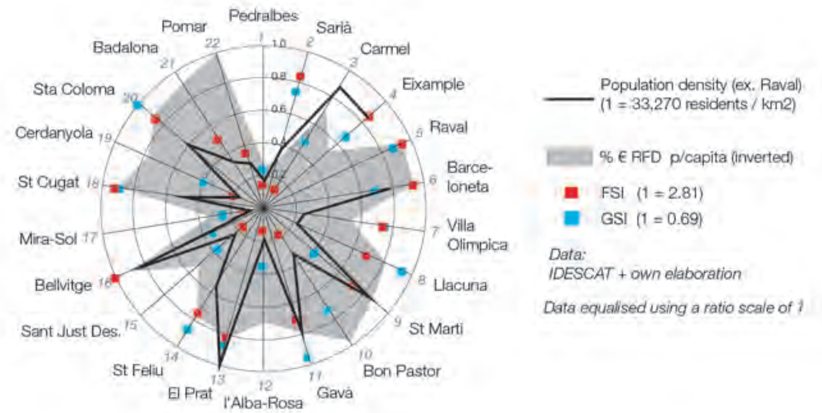


Figure 4/10: *FSI, GSI and income.*

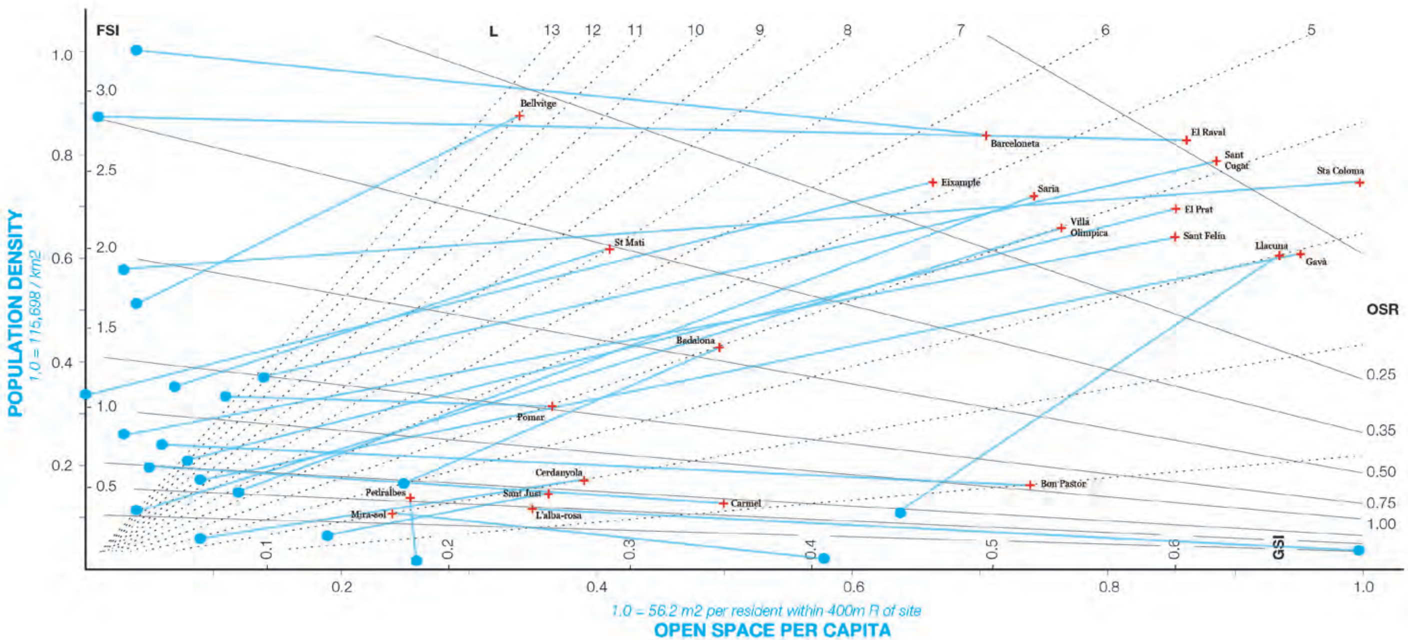
Population density and open space

Open space is a measure relating to the 'soft' side of density, as explained by Boyko and Cooper earlier (Boyko & Cooper 2011). As a result of little open space and discomfort associated with density, residents of highly populated inner city areas may be inclined to compensate their demands for open space by travelling some distance to it. This may be unnecessary if suitable public space was available locally.

It is difficult to qualitatively measure open space, as some streets or pathways with low traffic may be treated as open space while some parks may be treated otherwise. Quantitatively, designated open space can be measured in two ways: gross quantity of open space or per capita (relative – Figure 4/11). In some cases such as Barceloneta, there appears to be a high level of grass public space. As shown in the diagrams, a number of sites (which tend to be situated within the older centre of the city such as the Raval, Eixample and Barceloneta) have low levels of open space per capita. This results in two demographic groups – the richer more mobile population which will travel for recreation (associated with Eixample) and the lower income 'captive audience' residents (associated with Raval and Barceloneta).

A number of urban areas on the fringe of the metropolitan area also experience low levels of open space. Yet these sites have lower population densities and higher income (than Raval and Barceloneta) and include Santa Coloma, Santa Feliu, El Prat and Gavà. These sites share relatively similar GSI / FSI, urban form and age. Car ownership in these sites is also significantly higher than in the lower income areas in the inner-city (between 340-440 cars per 1000 inhabitants), allowing residents to depend on travel for leisure on weekends when car trips increase (EMQ 2006).

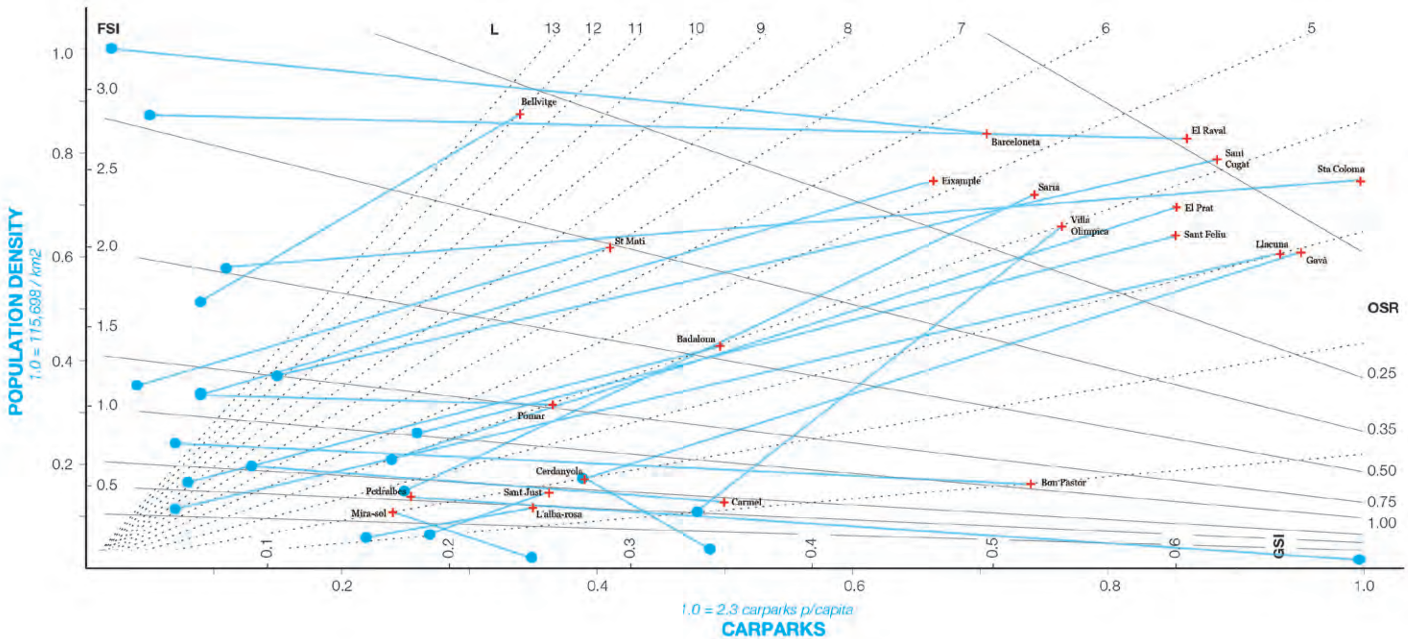
Figure 4/11: *Population density, open space and physical density*



Cars and Population Density

Links between population density and availability of car-parking spaces may provide some hints in terms of the indicators of car ownership. As shown in Figure 4/12, there is a link between population density and car-parks, however car-parks cannot be equated with car ownership. As will be confirmed later, car ownership is linked to income rather than location. Therefore sites such as the Eixample with seemingly little available car-parking space, in actual fact support a relatively high level of car ownership (460 cars / 1000 residents). Conversely car ownership conditions change in the Raval (167 cars / 1000) and Barceloneta (262 cars / 1000) where car-parking is at its scarcest, where incomes are very low and where accessibility to amenities is very high. These three sites regardless of income have access to a high number of shops, bars and cafes. Areas with low incomes yet greater car-parking or reduced access to services or venues (such

Figure 4/12: *Population density, carparks and physical density.*



as Pomar, St Cugat and Bon Pastor) support higher car ownership (350 cars / 1000 residents).

While the link between car ownership and income is high, a closer connection can be made with mean dwelling size. Density does appear to be connected with car ownership but it is unclear if car ownership has a link to population density or income as both are relative. Therefore, physical density (FSI / GSI) cannot be used as an indicator of car ownership.

Cars and carparking

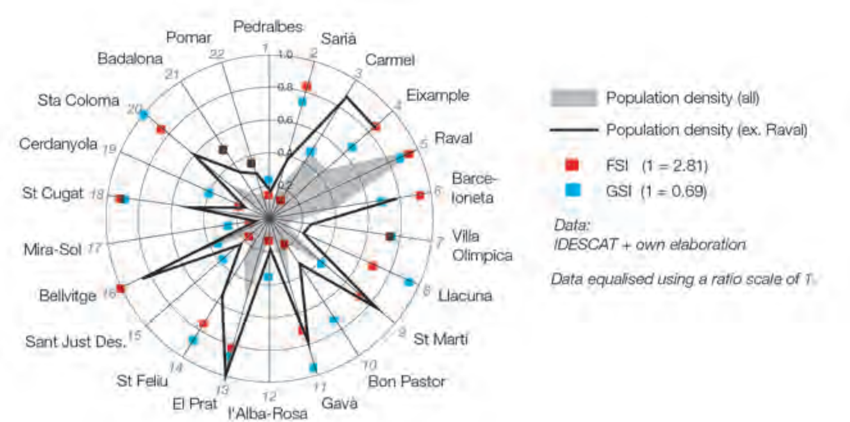
Evidently carparking (refer to Figure 4/13), for areas with both higher density and higher GSI / FSI (combined), is generally in off-street carparking lots. Lower densities and lower GSI afford greater levels of on-street parking. Therefore in many cases, those areas where surface area is most precious, or where OSR is highest, and car numbers are high, most of these cars are parked in off-street parking. Therefore, on street carparking in these areas benefits relatively few of total car-owners despite consuming valuable surface area – in some sites such as Gavà, El Prat, Santa Coloma and Eixample, surface carparking can account for between 25-45% of the road space.

Accessibility

Accessibility can play a significant role in energy consumption. Mobility currently accounts for approximately one quarter of the city's energy needs in Barcelona (40% of stated needs). Accessibility, and particularly the mode of transport, have been found to have a significant link to energy consumption (AGO 2002).

Private mobility is a significant consumer regardless of the provision of collective transport. In a study of English and Dutch urban areas, it was found 24% of cars were associated with 78% of the private mobility consumption (Banister et

Figure 4/13: *Cars, carparking location and density*



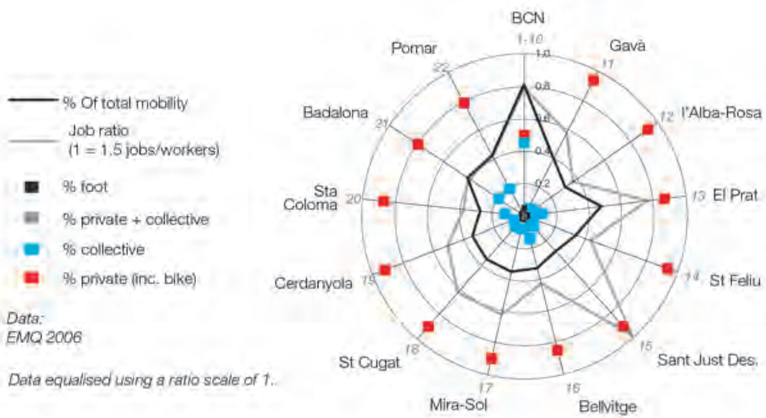


Figure 4/14: *Municipal transport mode, internal trips*

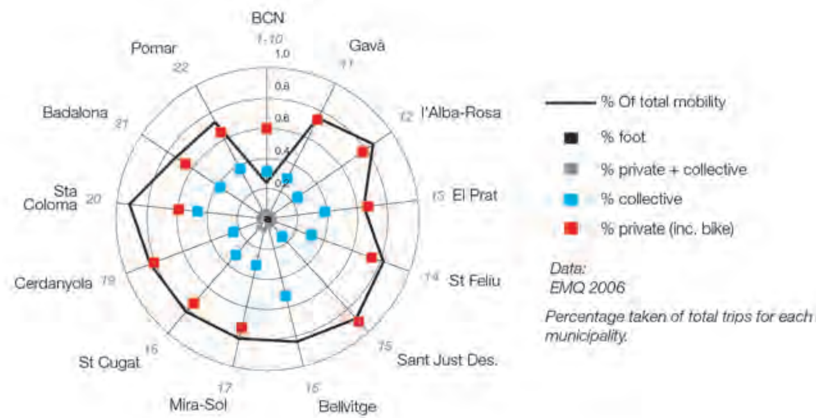


Figure 4/15: *Municipal transport mode, external trips*

al. 1997). Mogridge (1985) states that car ownership has a far greater association with energy consumption than density and access to public transport. Private mobility use has a strong association with energy dependence.

Private modes on the city fringes typically take half the trip time of collective modes, which will be shown in the following pages. These patterns may change dramatically if energy costs increase – requiring quick adjustment to new demands.

Distance to the physical centre has been found to be indicatively connected to commuting times – regardless of the number of trips to the centre (Stead & Marshall 2001).

Trip frequency is considered not to change regardless of length of travel, however trips in denser areas are more likely to involve collective transport or walking (Banister 2005). Reduced private mobility will thus heavily impact quality of life values in car dependent areas.

Cevero + Kockelman found that job density had some influence on travel time but there was a greater association with mixed land use (Cervero & Kockelman 1997). This will be covered further in this chapter under 'Diversity'. Breheny has found that balanced areas have a job / dwelling ratio of 0.75 to 1.5 (Breheny 1995) – refer also to the research in the following pages regarding 'Proximity'.

Accessibility, mode and municipality

Barcelona is the only municipality within the AMB representing a greater level of internal trips to work than external. It is also however the largest municipality with the largest diversity of employment positions. Both El Prat and Badalona / Pomar also support a high proportion of internal trips to work; however most of these trips are by private modes.

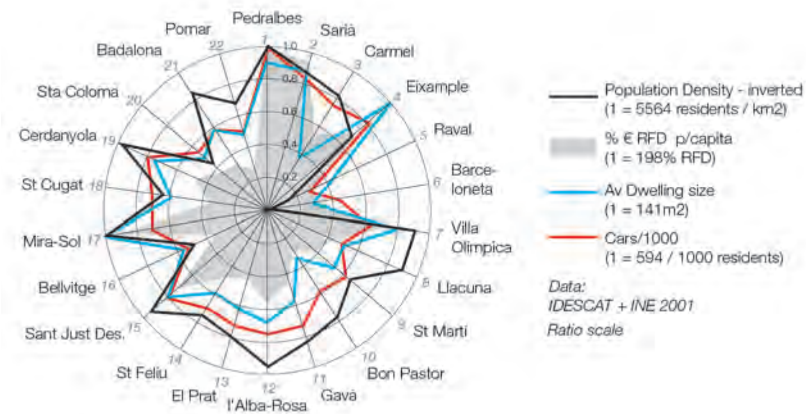
Income, residence size, car ownership

Income has been long associated with greater mobility habits (S. Hanson & P. Hanson 1982). Energy included in this context is connected with two indicators: larger dwellings and greater levels of mobility. Figure 4/15 supports a number of conclusions noted earlier such as links between income and car ownership and soft links between income and population density. Most significantly this diagram shows how some low-density areas with low incomes also have higher levels of car dependency (such as Pomar, Badalona and Bon Pastor) than those with similarly lower income areas in denser locations closer to the centre (Raval and Barceloneta). There are also numerous sites with high incomes, low density and high / higher car dependence (Sant Just, l'Alba-Rosa, Cerdanyola and Mira-Sol).

Distance to the centre and mode choice (to work)

Private transport use as shown in Figure 4/17 is highly connected with the distance from the centre. Collective mobility is used far less outside the municipality of Barcelona, with the modest exception of Sta Coloma and Bellvitge, both which are de facto neighbourhoods on the Municipality of Barcelona's 'accessible' fringes and connected to the metro system. Clearly the greater the distance from the centre, the greater the car dependence for work purposes.

Figure 4/16: *Income, population density, dweling size, car*



Modal share on almost all peripheral areas for work purposes is comparable to levels experienced in cities with much smaller population densities such as Sydney, Toronto and particularly Zurich (Mees 1999). While most workers travel outside of their local municipality for work (except in the Municipality of Barcelona), most of these do not involve journeys into the centre but rather from nodes across the periphery where collective transport is not effective. This also can be attributed to the highly efficient ring-roads allowing fast access across the city, and helping bi-pass the congested inner-city.

While Barcelona's modal share for work related trips highly favours private mobility, this does not fairly reflect income. It therefore suggests that many peripheral costs associated with private mobility (parking, tolls / charges etc..) are either low, covered by employers or that the speed of collective modes is considerably slower / less comfortable and / or more expensive.

However, if there is a sudden change to the price of mobility, collective modes may attract growth they cannot deal with. The AMB for instance has noted that an annual growth objective involves 1% ridership change (AMB 2011). Collective transport is based on slow levels of growth or change and can take years of planning. For instance, some of the metro lines currently operate at maximum capacity particularly during the morning peak period. Therefore, it can be assumed that all municipalities outside of the centre will have accessibility issues if energy conditions change.

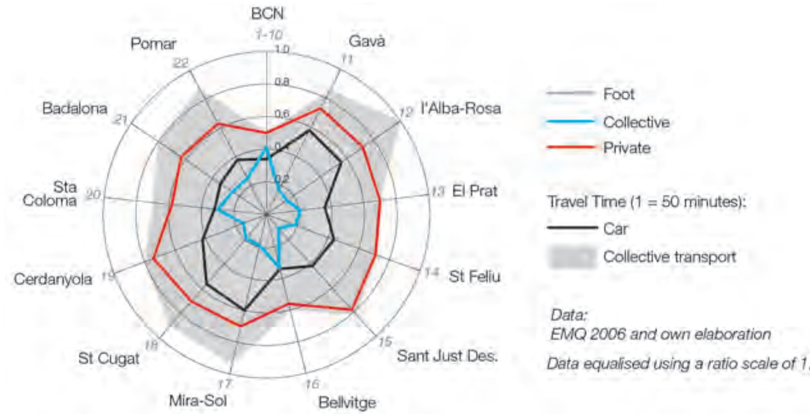


Figure 4/17: *Municipal transport mode, external trips*

Mode choice for daily movements (all)

The five yearly survey on mobility consists of data involving mode choice per movement. This does not account for distance or time, simply the mode taken per trip at a municipal level, which makes the data relatively general but can show general trends. A trip could involve buying bread or going to work. The results prove the importance of pedestrian movements. Despite high levels of private vehicle use for work purposes, overall trips, and particularly smaller trips, remain in favour of non-motorised transport (essentially walking). Motorised modes are also in greater favour than collective modes, generally with the exceptions of both Barcelona and Bellvitge. Sant Cugat / Mira Sol and Sant Just are two areas where pedestrian activity is significantly lower and will be of concern in lower energy conditions.

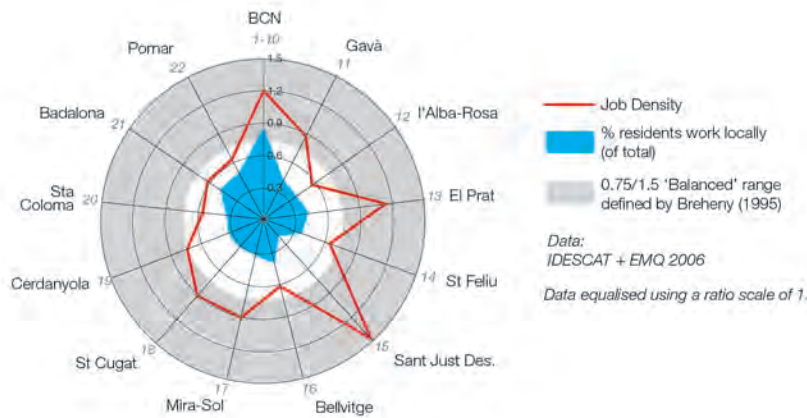
Proximity, job density and travel times

Job ratio as explored in Chapter 3 (Figure 3/18) can indicate 'self-sufficiency' in terms of jobs. Within the Barcelona Metropolitan Area, on average each municipality contains a balance of jobs and workers. As noted in Chapter 3, travel to work outside of Barcelona predominantly involves private mobility regardless of access to collective transport systems. The job ratio has some correlation with transport mode but has closer links to accessibility times, as shown in Figure 4/17 – proving that in the congested Municipality of Barcelona, collective transport is favoured. In other less congested areas where job ratio is high (El Prat, Sant Just) the private mobility share is also greater.

Generally, the Municipality of Barcelona is more robust in terms of jobs compared to the other municipalities which have lower job density. Municipalities with few jobs but high population density (St Feliu, Sta Coloma, Bellvitge) or low population density with lower income (Badalona, Pomar) and lower density but high income (l'Alba Rosa) are forced to travel to work. These areas may have low Diversity – which will be explored in the following pages.

As noted in Figure 4/18, while almost all the study sites fit into the 'balanced' range defined by Breheny (1995), all municipalities have approximately 80% of the working population travelling outside the municipality, generally by private modes of transport. In other words, jobs appear to be well distributed across the city however home-job relationships are not. Barcelona is an exception, where most of the workers have inner-municipal jobs yet overall travel times remain similar to the other sites studied (refer to Figure 4/18). Jobs outside the municipality of Barcelona have grown significantly within the last 20 years (as noted in Chapter 3) however this is a small portion of total jobs.

Figure 4/18: *Job density ratio and actual jobs held by local residents*



While this measure helps identify municipalities with high numbers of commuters, it does not help identify the links between working and living which are associated with energy consumption. But it is clear worker travel time averages are fairly similar across all municipalities with an average trip length of 26 minutes to work. In addition few work near where they live.

Travel patterns on the periphery

The city is certainly not a tree! Christopher Alexander's observation on urban networks are well depicted in Barcelona – with jobs distributed across the entire metropolitan area (Alexander 1966). Barcelona's large job market (60% of the jobs within 15% of the metropolitan area) attracts a high rate of in-commuting, with the remaining 40% of the jobs distributed across 85% of the territory. While a large number of workers living in the outer municipalities commute to Barcelona for work, an equivalent or greater number travel to many other non-central destinations with far inferior levels of connectivity by collective transport (IDESCAT 2001).

For instance Viladecans has only 20% of all movements to the centre with 50% of travel shared amongst six smaller surrounding municipalities. Cerdanyola has 25% heading to Barcelona with over 50% accessing municipalities inland (to centres such as Terrasa, Sabadell, Rubí). El Prat and St Cugat have almost 50% of work trips destined to Barcelona,

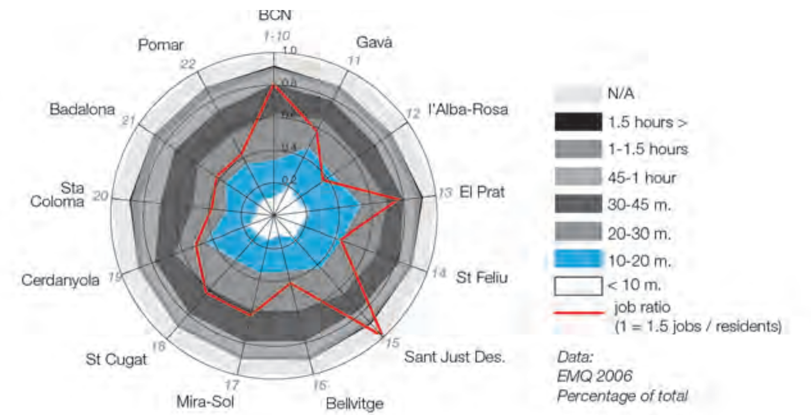


Figure 4/19: *Travel time according to municipality.*

while their remaining 50% is distributed less intensively across more than 20 smaller municipalities. Inevitably, commuters to the centre have a greater inclination towards collective modes representing almost 75% of trips. Commuters to other destinations are far more inclined to travel by private modes due to the time involved and connectivity with over 90% private transport use.

Non-motorised modes

As noted in Chapter 3, Barcelona is under-represented by cyclists with modal share comparable to much more dispersed cities (such as Portland, Seattle, San Francisco and New York) (US Census Bureau 2010). Barcelona contains suitable conditions for cycling across much of the densely populated coastal plain – before the topography rises steeply towards the Collserola Range. While pedestrians have a 5-10 minute walking threshold (up to 1km) before transport is considered (Moudon et al. 2006), cycling offers greater speed, more efficient energy use and a far larger accessibility radius - up to 3km for typical riders (AGO 2002).

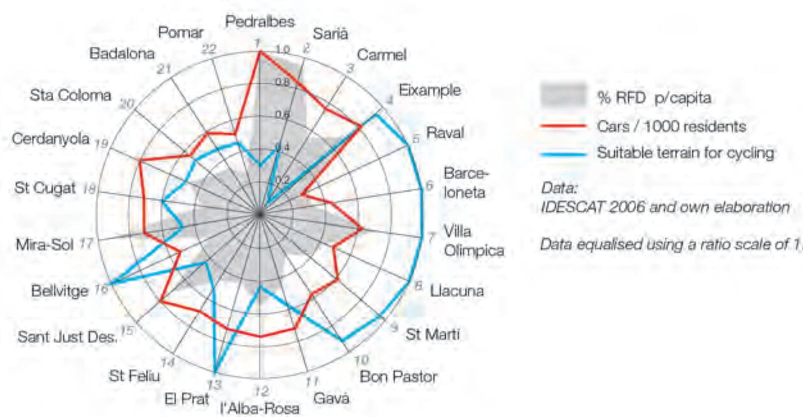
This cycling potential Figure 4/19 shows how many potential cycling areas also have lower car ownership and lowering income, thus affording greater levels of non-motorised accessibility. Cycling potential has been measured based on a slope analysis performed in GIS. Sites were analysed taking the suitability of topography within a 1.5 kilometre radius of the site. The average slope was rated then adjusted making the worst site 0 (Carmel) and the most suitable sites 1 (Eixample, Raval, Barceloneta, Villa Olimpica). Other sites considered suitable outside the centre include El Prat and Bellvitge. These values can be compared also to income and car ownership – which may provide an approximation of resistance towards cycling. Cycling is shown to be most suitable in the areas where collective transport use is highest (with the exception of El Prat).

Conversely sites that may not be able to easily benefit from cycling include a number of lower income areas such as Badalona, Pomar and St Cugat. Highly car dependent and higher income areas which are also unsuitable for riding include Mira Sol, l'Alba-Rosa and Carmel.

Proximity

Proximity in Barcelona is difficult to define as the city is notably compact and decentralised. In many parts of the Municipality of Barcelona, districts are equipped with medical centres, municipal offices, management bodies and libraries – firstly encouraging residents to use local facilities and secondly distributing mobility throughout the city.

Figure 4/20: *Cycling potentials.*



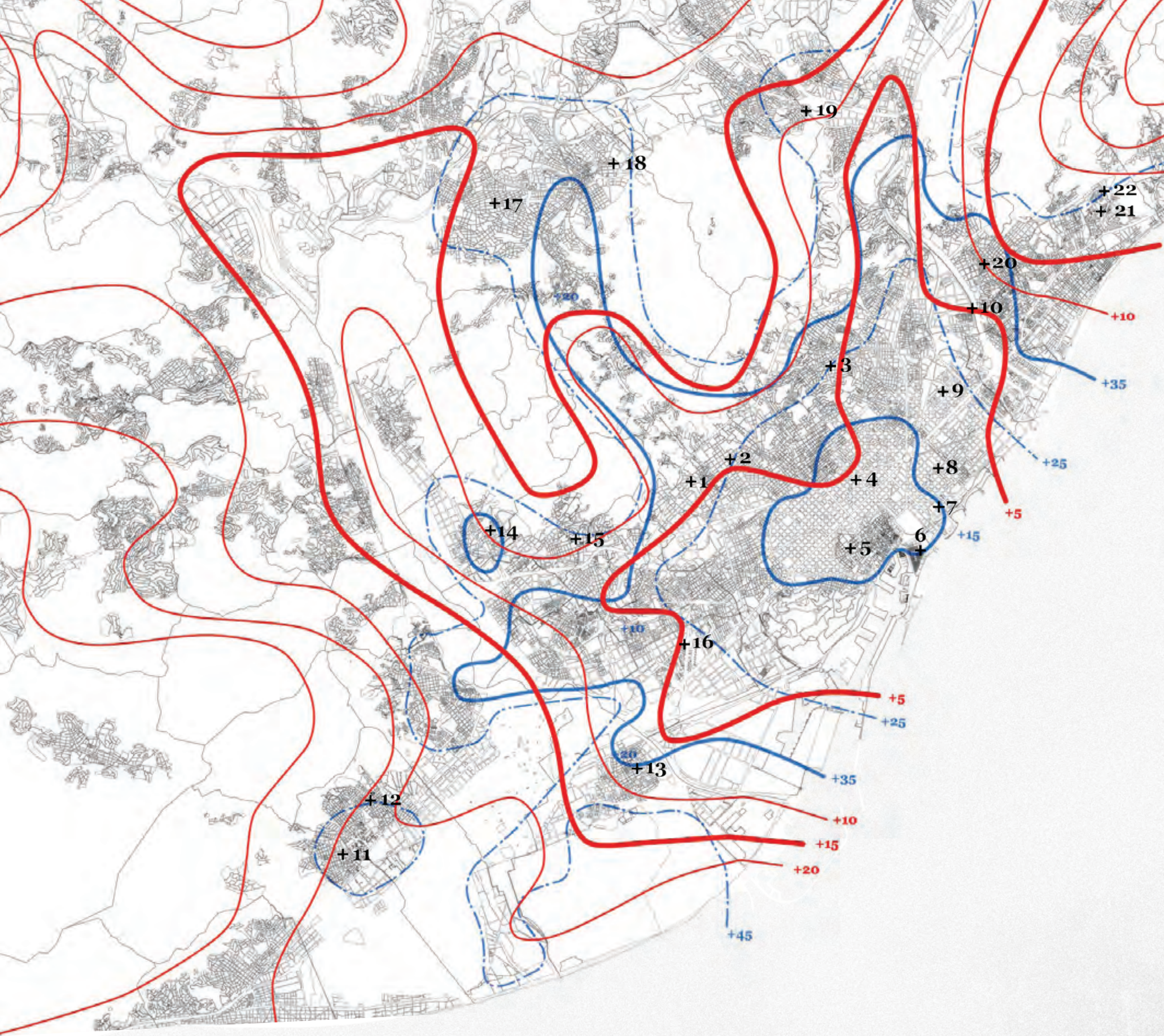


Figure 4/21

Time/travel

0 400m

Distance from the centre by private transport as defined by Herce (2005)

Distance from the centre (Plaça Catalunya) by collective transport (own elaboration based on timetabling).

+ 25 sites

As noted in the adjoining research, areas with a significant difference between private transport and public transport are more inclined to drive - or be dependent on driving.

As noted earlier, car ownership considerably increases notions of proximity. Therefore, all calculations in this chapter have been made according to pedestrian distances. Proximity also has much to do with population density and consequently levels of Diversity, which are explored later in this chapter.

Accessibility and Schools

A link may be found between income and access to schools (refer to Figure 4/22), at least with two neighbourhoods – Sarià and Pedralbes. However this is due to a historical relationship between schools and monasteries located in this area. Newer higher income areas (Mira-Sol and Sant Just) do not continue the close connection between income and schools. However a link can be made between lower income areas and slightly lower numbers of schools - Raval, Barceloneta and Bon Pastor have the lowest income and also have the lowest number of schools.

Density and Shops

Comparing income level, population density and shops, it is clear that population density (or a client base), rather than income, creates a demand for local shops. Income appears to be an inconsistent factor in mid-density sites with examples such as Carmel, Gavà, St Feliu and Badalona which have relatively similar urban form but a significant difference in the number of shops. From the research it appears shops (grocery shops) require a client base of around 2000 people. From observation, specialty shops emerge associated with higher population densities.

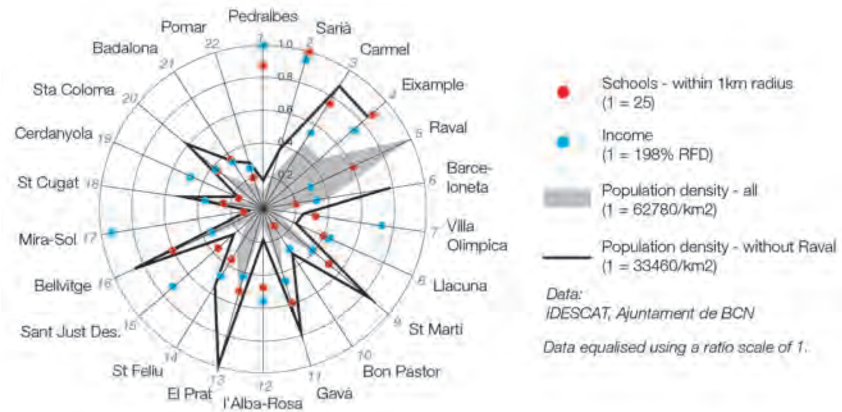


Figure 4/22: *Schools, income, population denisty*

Proximity and venues

As shown in Figure 4/24 higher GSI and FSI do not appear to correlate consistently with the number of entertainment venues (such as bars and restaurants). However the sites with highest populations in the centre (Eixample, Raval, Barceloneta and to some degree Llacuna) also support a disproportionate number of entertainment venues – which may have a cultural precedent rather than a morphological one.

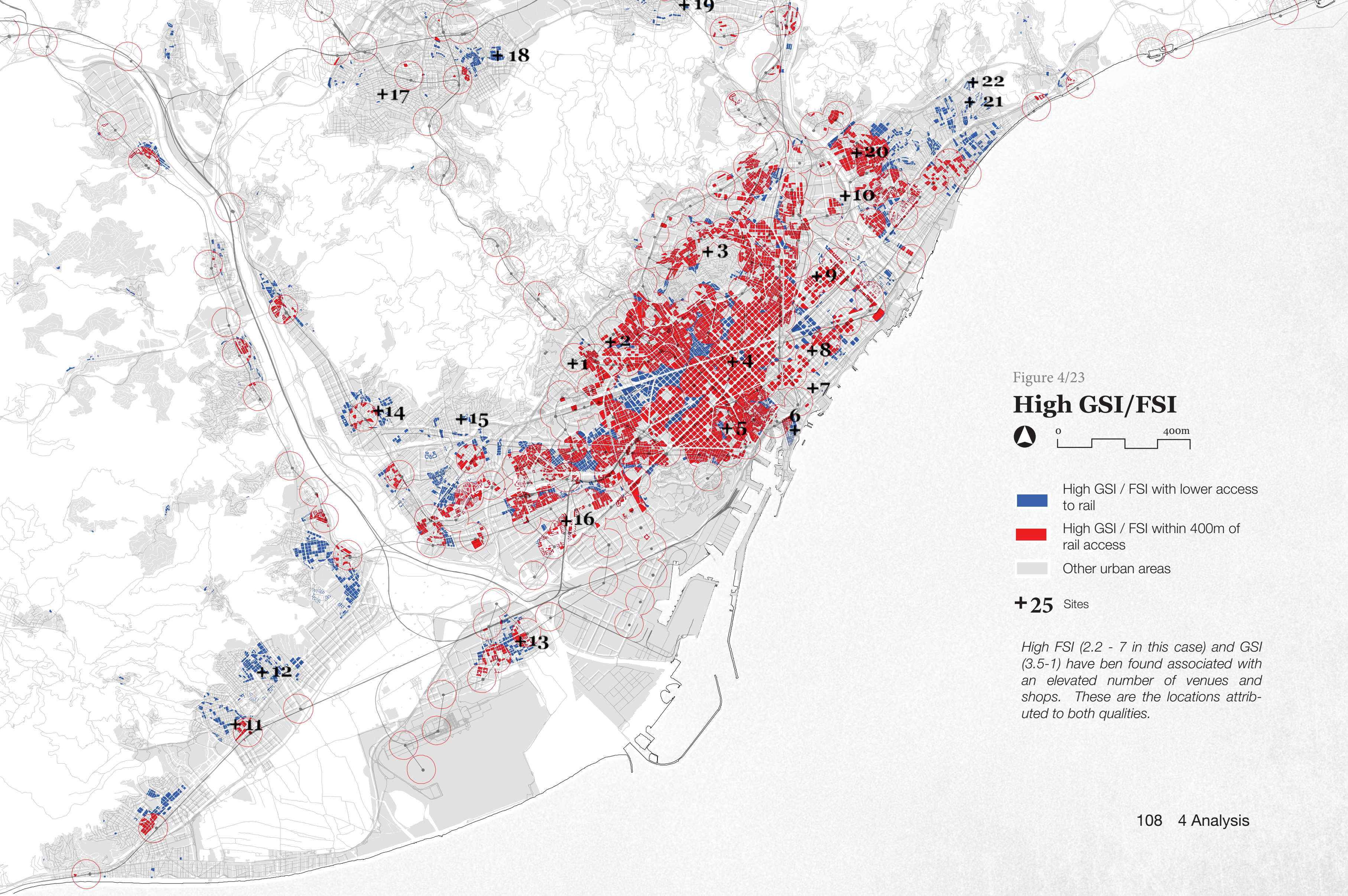


Figure 4/23

High GSI/FSI

High GSI / FSI with lower access to rail

High GSI / FSI within 400m of rail access

Other urban areas

+25 Sites

High FSI (2.2 - 7 in this case) and GSI (3.5-1) have ben found associated with an elevated number of venues and shops. These are the locations attributed to both qualities.

A second calculation, Figure 4/25 removing the three densest locations, exposes a strong correlation between GSI, FSI, venues and shops. In this case both FSI and GSI must be equally high. For example sites such as Bellvitge, Carmel, Cerdanyola and Bon Pastor contain either proportionally higher GSI or FSI and also support a lower level of venues and shops. These four sites were developed during the 1950s Urgency Period and thus also support lower levels of commercial space which may also be a significant factor proving a lack of diversity.

It is unclear whether high numbers of venues and shops contribute to reduced levels of energy consumption, due to mobility, however the data would suggest this was the case based on distribution and density. Other research has concluded that in areas with higher population density access to shops is associated with significantly lower levels of transport related energy consumption (Holden & Norland 2005). The links between density and venues or shops will be later explored further in terms of two other variables (income and commercial space) showing greater links than simply physical density.

Figure 4/24: *Physical density, markets and venues*

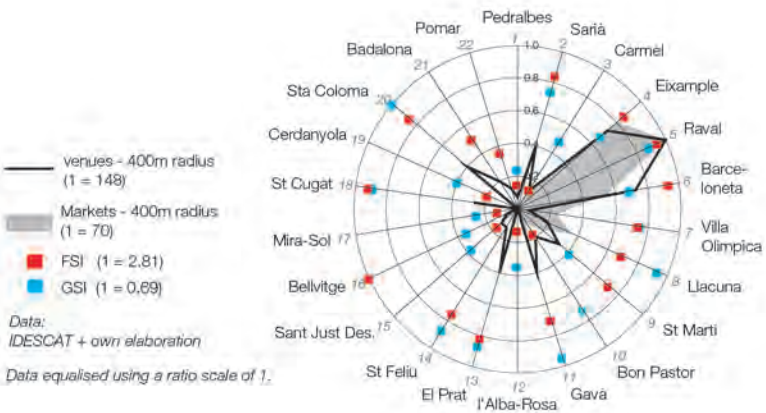
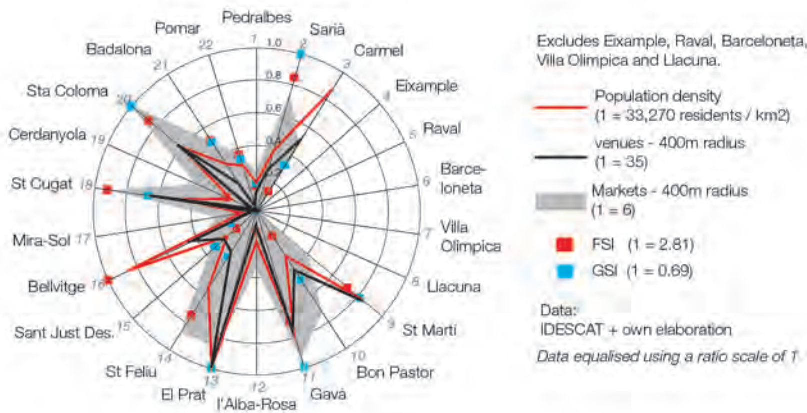


Figure 4/25: *Physical density, population density markets and venues adjusted without Raval*



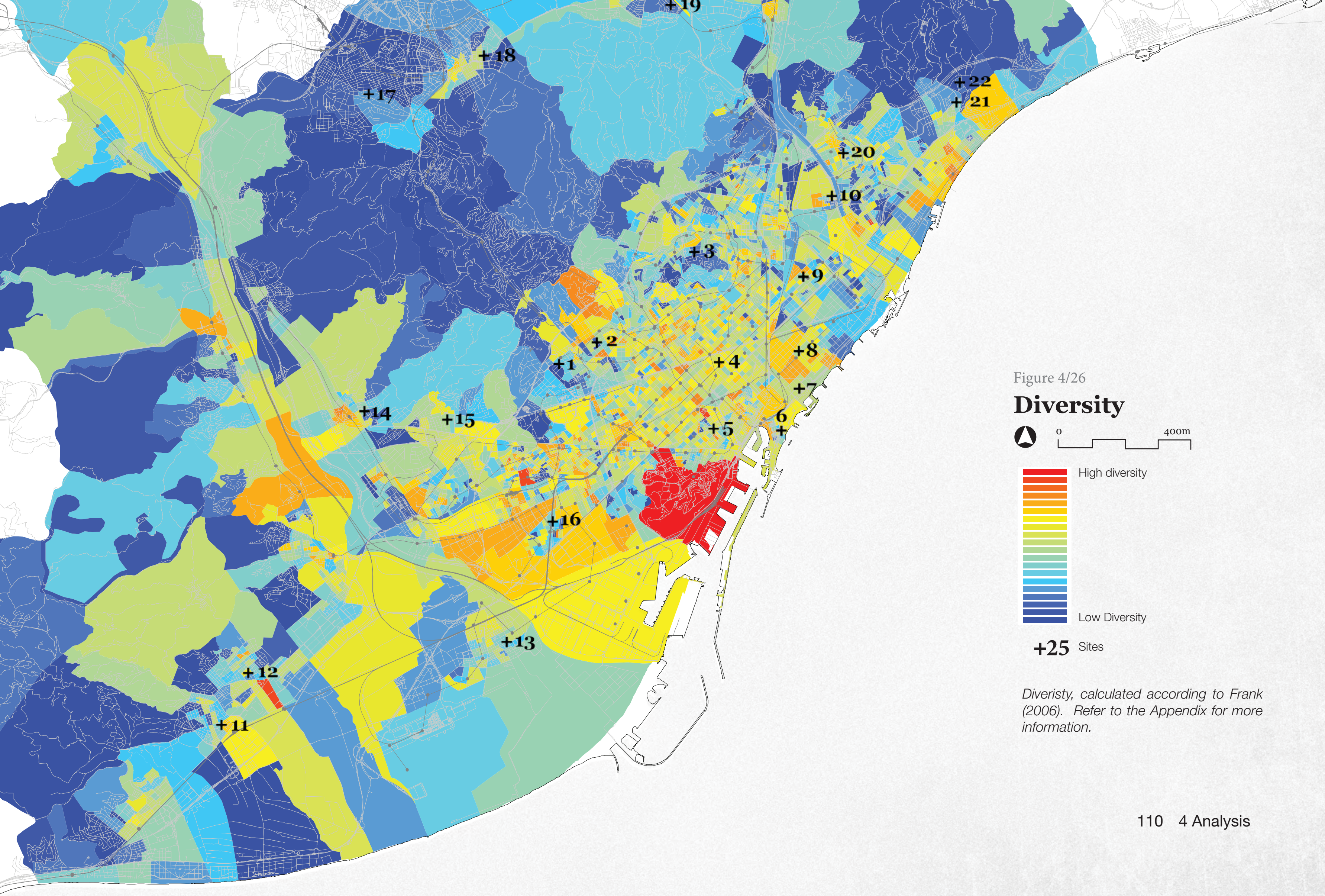
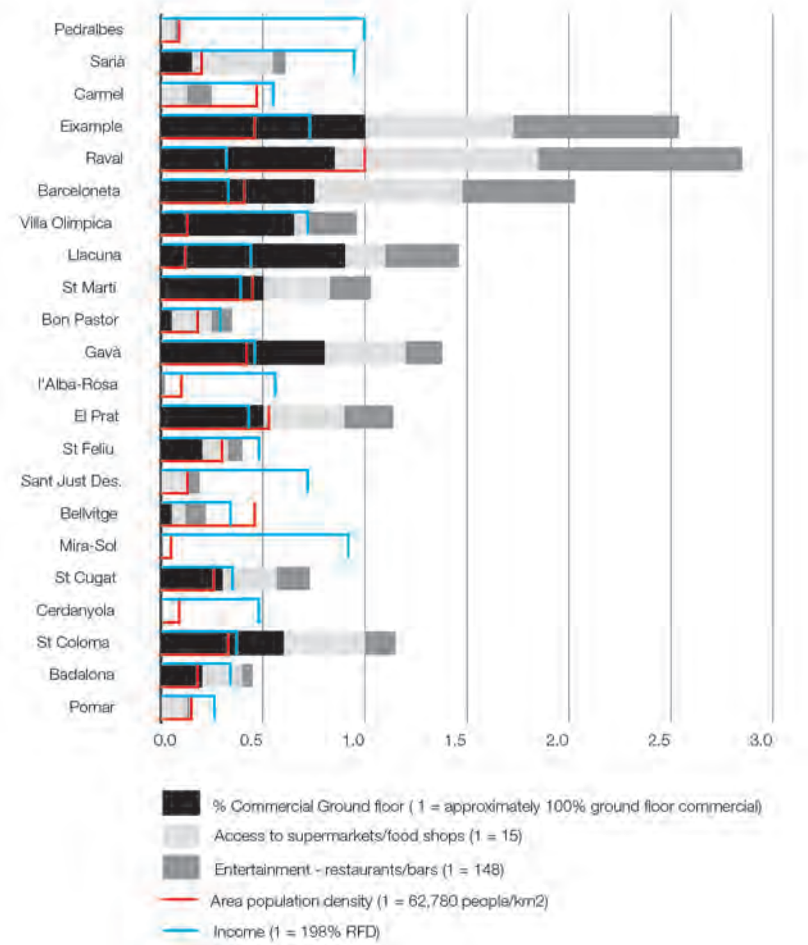


Figure 4/26

Diversity

Diveristy, calculated according to Frank (2006). Refer to the Appendix for more information.

Figure 4/27: *Density, income, commercial space and diversity*



Diversity

One of the greatest triggers for travel is the lack of suitable nearby amenities. Therefore, unsurprisingly, areas with higher levels of diversity have been found to also relate to lower car ownership and travel demands.

Proximity, Density and Diversity share many common attributes: diversity of land use is likely to be associated with a range of services or amenities. An important factor is the support of secondary functions associated with diversity, such as types of shops and services that benefit both residents and workers alike (Jacobs 1961). A quantification of complexity has been developed by Frank (refer to Figure 4/26) which shows how density is not necessarily related to diversity (Frank 2006). Sites like El Prat, Santa Coloma and Santa Feliu are dense areas with lower levels of diveristy which could partially explain their higher commuting patterns for this urban form.

Population density, income, venues + shops

Diversity can be gauged through comparing three factors; density, income and availability of commercial space. Links can be made between these three factors as shown in Figure 4/27, identifying proximity to shops and entertainment venues. High income, associated with lower density residential areas, is also associated with little to no commercial space (Pedralbes, l'Alba Rosa and Mira-Sol). This is no different to areas with lower densities and lower


Logifrio
la Vila
consum


CASINO

Previous page, Figure 4/28 (top - Villa Olímpica) and Figure 4/29 (bottom - Rambla de Poble Nou): *Diversity could be located in single points along a block or could be distributed across the block. This difference does not show up in the analysis but could provide a big difference in how a place is used.*

incomes which also contain little commercial activity or space for it (Bon Pastor, Pomar and Badalona).

Areas with high density and lower income do support a variety of commercial areas both within the city (Raval and Barceloneta) and on the outer neighbourhoods (El Prat, Gavà and Sta Coloma). Some high income areas with higher population densities (Sarià, Eixample and Villa Oplimpica) also contain a higher number of shops and entertainment venues.

Further research, if data were available, would correlate job ratios at a census district level in terms of availability of shops to find complimentarity between levels of jobs, population density and proximity to necessary goods and services.

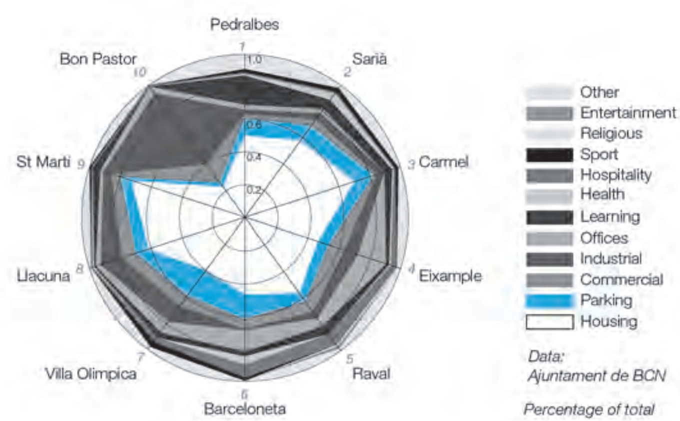
It can be concluded that areas with diverse commercial activity are found in areas with available commercial space, and they are associated with moderate to high density and low-median income or high density with lower income groups. Based on these observations, sites such as Bellvitge with moderate income and moderate density are underperforming due to a lack of commercial space.

These findings cannot be easily linked to mobility patterns based on available data. Nor, based on available data, can it be shown that urban areas with high levels of commercial activity also are associated with lower mobility patterns. Such conclusions require a qualitative analysis of user behaviour. However residents of sites which do not support diversity will clearly want to travel to find the goods or services they need – which would have clear implications for energy consumption.

Land-Use distribution

Land- use mixes can provide an indication of the allowance for diversity where a greater level of diversity also hosts a greater level of local needs to be met. While this does

Figure 4/30: *Land use mix, by sector for the municipality of Barcelona only.*



not indicate how an area is actually used, it does indicate potential. In this case, data is available at the neighbourhood level only for the municipality of Barcelona. As shown in Figure 4/30, sites such as Raval, Eixample, Villa Olimpica and Barceloneta show greatest range of functions and likewise greatest levels of diversity.

Figure 4/26 and Figure 4/27, show that diversity is highly connected to higher densities, a mix of income groups and availability of commercial space. In addition, as shown in Figure 4/31, density correlates with commercial diversity. Higher density areas support more highly specialised shops. Variations in intensity of the three also support diversity however they all must be present to foster diversity.

Building Types

General energy consumption can be estimated based on building types. This study aims to identify a simple strategy for analysing urban form in terms of inherent energy requirements. There are a variety of methods to take a generalised, desktop review of building-related energy consumption without a thorough investigation into thermal mass, materials and users' consumption patterns.

A first method considers a detailed evaluation of both heating and lighting requirements based on solar access and particularly thermal energy requirements of the specific building type (Ratti et al. 2005). This method maps floor height, fenestration, building depth and other

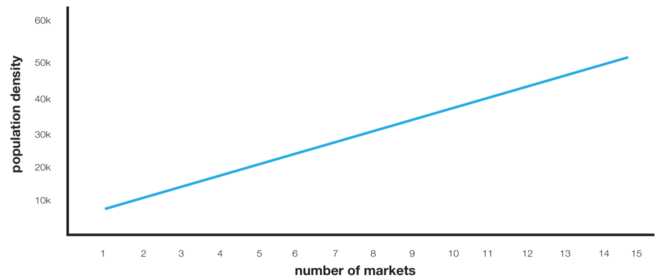


Figure 4/31: *Line of best fit based on the study sites showing correlation between population density and number of markets - on average 2000 residents per market. With this increase in density, there is also an increase in specialisation as found through the site study.*

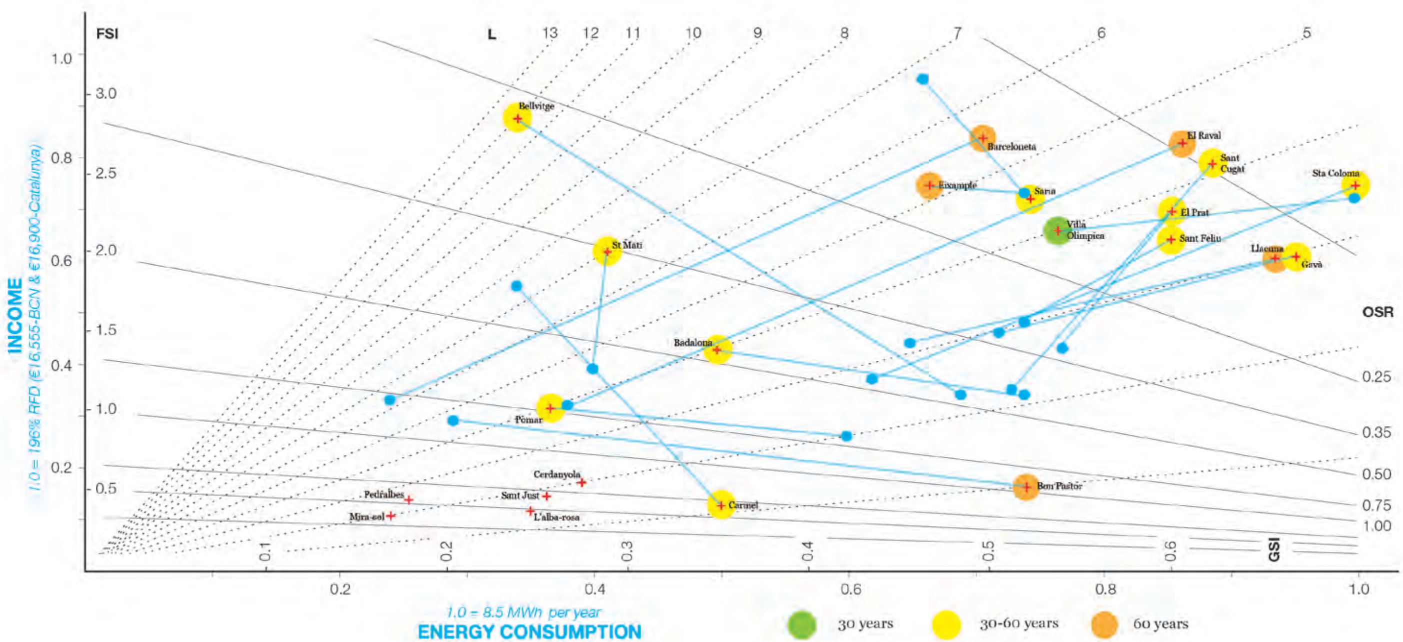
characteristics which could be measured with GIS and other suitable data.

However in many urban areas building periods are associated with easily quantifiable values (including floor heights, size of windows, materials) making heating requirements, solar access and technical details relatively easy to calculate. Based on knowing a building's age and floor space, a second method uses assumed mean consumption (Álvarez 2010; Ajuntament de Barcelona 2011). This type of study is suitable for mapping large areas with typical urban form at a district to metropolitan level for residential / mixed use development. Particular details such as orientation may affect the quantity of light entering a room, however as lighting is associated with only a small part of overall domestic energy consumption (7%), it is not considered a priority for this study.

Energy consumption and income

It could be assumed that energy demands and income are highly connected. Yet no direct links have been established between income and energy consumption. As shown in Figure 4/32 according to the evaluation method used, income is actually not a factor. Conversely higher income buildings are more likely to be renovated and thus updated with better insulation and / or glazing.

Figure 4/32: *Dwelling energy consumption relative to income.*



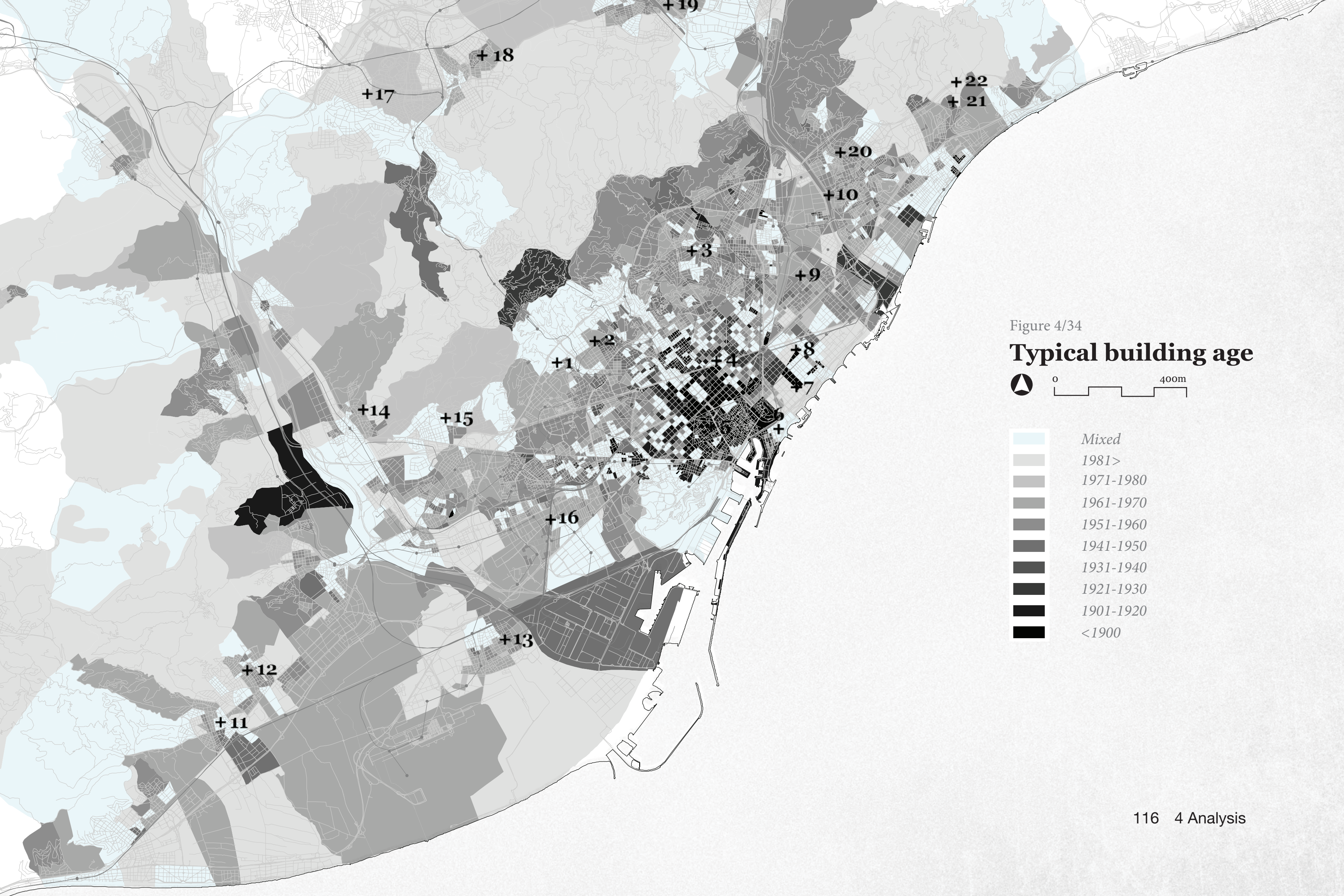


Figure 4/34

Typical building age

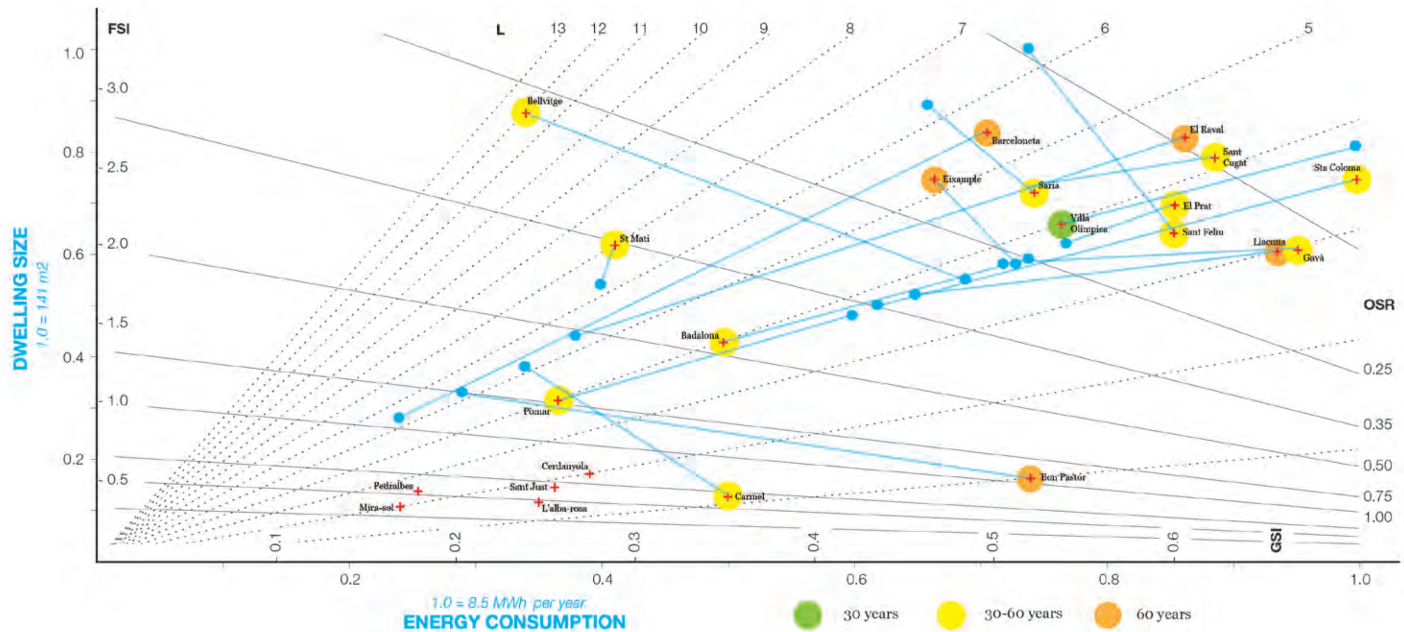
Energy consumption and age

Energy consumption is connected to dwelling size and age - which shows between income and energy consumption. Clearly the older buildings (in Raval and Barceloneta) consume less energy by virtue of size rather than inefficiencies. Urgency Period buildings represent the largest number of buildings developed during a single period. Many of these buildings are actually larger than their predecessors but were not effectively insulated and may have larger glazed surfaces.

Alvarez points out that the most effective reductions in energy demand due to insulation would be from the newer post-war dwellings – he indicates that the lifestyle costs to insulate the older buildings would outweigh the benefits (Álvarez 2010).

While modern buildings (such as Villa Olimpica) are far better insulated than older buildings, they also attract a much higher level of energy consumption due to electronics (lifts, lighting, central heating / cooling etc).

Figure 4/35: *Dwelling size relative to income.*



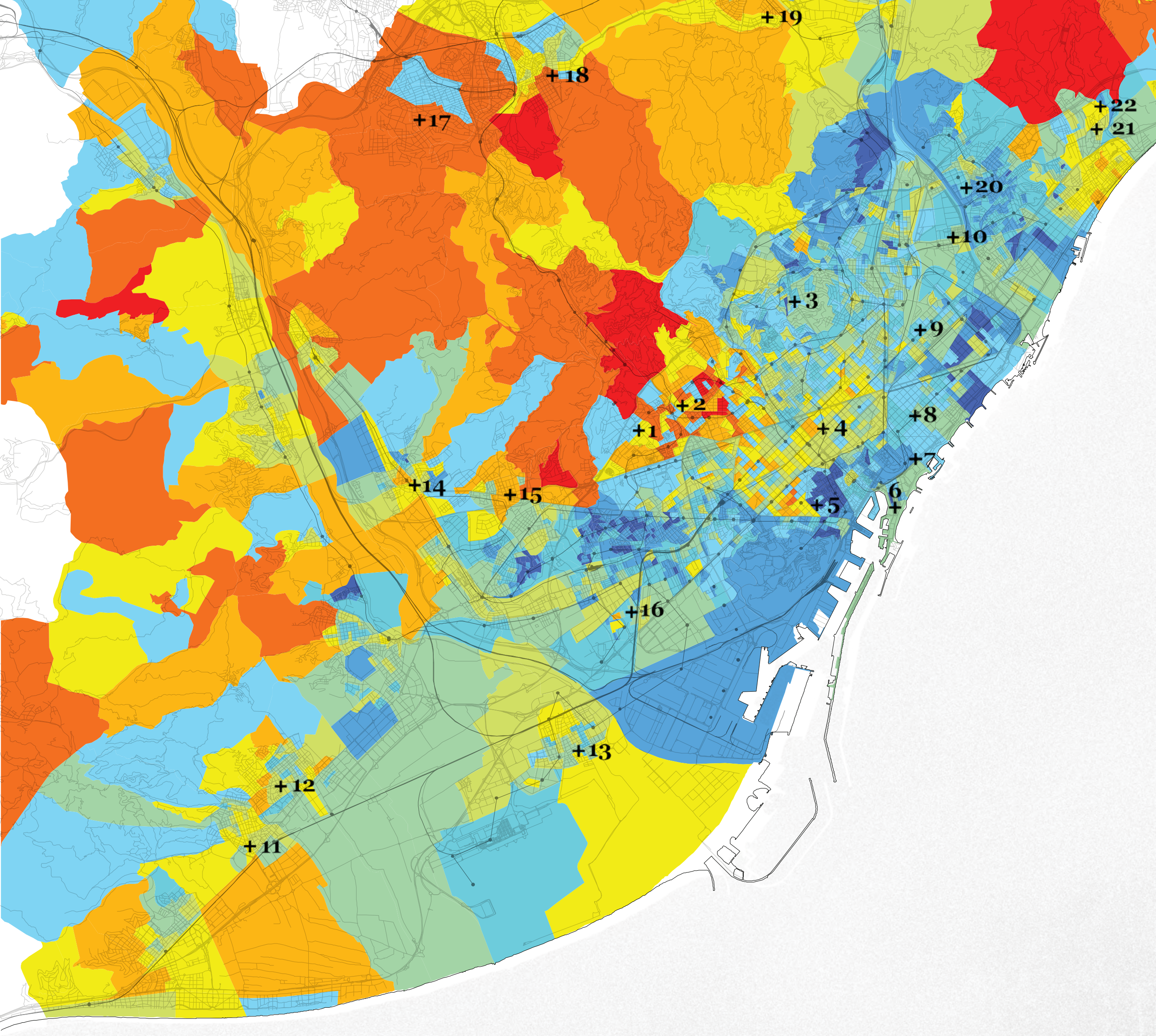


Figure 4/36

Floor areas

0 400m

140m2 >

100-114m2

82-90m2

70-75m2

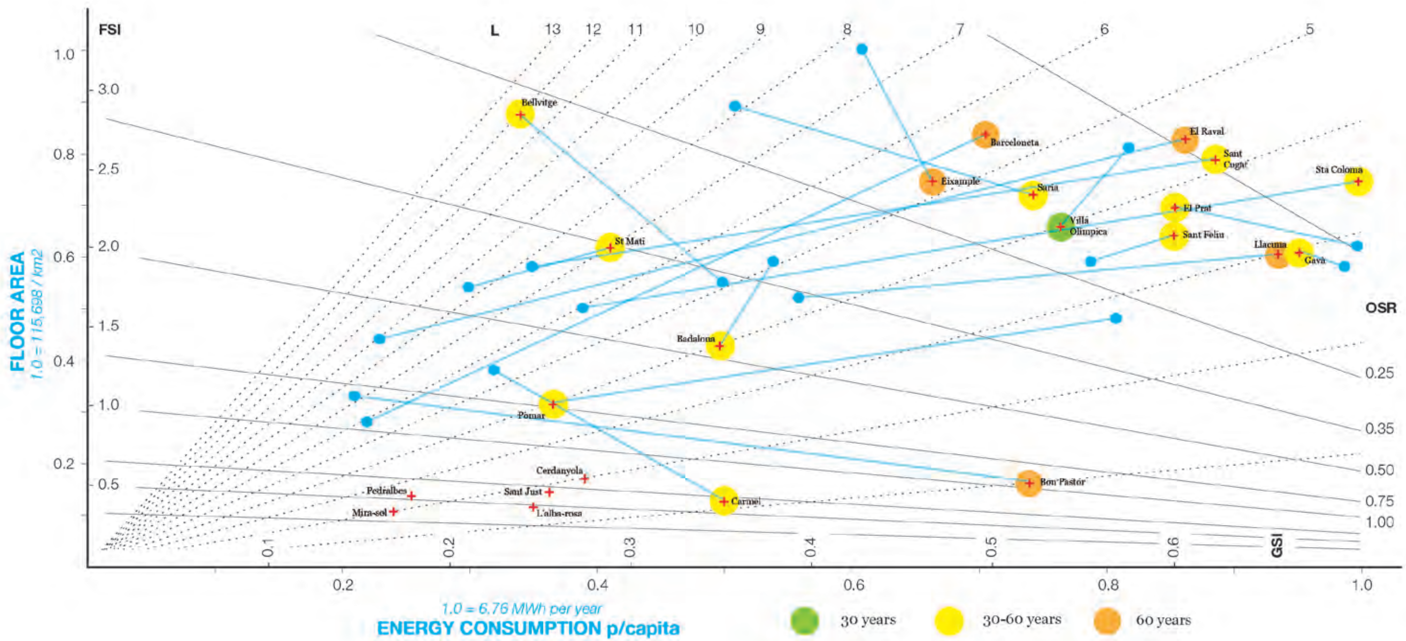
<62m2

Map showing residential living area, associated with residential energy consumption. This data is less precise than the data available from the Municipality of Barcelona, which has been taken at the block level.

Average Energy consumption per capita

Per capita consumption also changes the statistics on energy consumption. This is an important point to make as it shows a distribution of energy across the potential inhabited area and a number of users. This shows that in fact a number of higher income dwellings are relatively comparable to lower-mid income groups due to per-capita assessment.

Figure 4/35: Floor area *relative to income.*



Chapter Conclusions

This chapter has investigated how each of the 22 survey sites performs in terms of energy consumption indicators.

Accessibility. The metropolitan area is relatively well connected by collective transport but on average it opperates at half the speed as private mobility - this appears to be a defining factor for its lower levels of use. Car dependence for work purposes exists in all municipalities but most significantly for all municipalities outside the centre and involving trips along the periphery of the city. While income is a significant indicator of car ownership, car dependence is associated with lower population densities regardless of income (l'Alba Rosa, Mira-Sol, Cerdanyola, Pedralbes, Bon Pastor, Carmel, Badalona, Pomar). These areas are highly exposed to energy changes. Changes in energy will therefore advantage both low and high-income groups in the centre whom have greatest access to jobs, services, entertainment, shops and collective transport. Lower income groups located on the metropolitan fringes will be heavily affected by a change in mobility conditions.

Slow modes. Cycling has great potential across the city, particularly in the higher density areas that are often located on the flatter terrain.

Jobs + Mobility. Jobs are relatively independent of job locations as all areas surveyed share similar statistics of travel times regardless of distance. Clearly, workers located on the fringes travel greater distances over those in the centre, which is allowed through private transport. Transport mode clearly offers greater scope and flexibility for residents living in the less congested periphery of the Metropolitan Area. All but the Municipality of Barcelona are highly dependent on private mobility for access to work. Many of the outer municipalities have greater numbers of commuters tangential to the city centre, between areas with relatively poor collective transport.

Population density. Reduced mobility will be a significant issue for working and living patterns. For shops, venues and schools to be nearby, densities need to be relatively high. Populations with under 5,000 residents / km^2 do not support markets or shopping. Populations up to 10,000 / km^2 support some shops and venues but with little variety. The most significant variety occurs for populations exceeding 15,000 / km^2. This is associated with

Income. Income was not found associated with increases in commercial diversity but simply in supporting lower population densities. For instance this includes higher physically dense areas such as Saria (12,000 residents / km2), Villa Olimpica and Eixample (28,000 residents / km2). Urban form is significant in this regard. Saría has relatively little commercial space while supporting low numbers of shops and venues - yet Villa Olimpica with similar population and physical density and following a more traditional block type (buildings built to the edge of the block) has far greater amounts of commercial space and supports greater levels of commercial diversity.

Diversity. Diversity is supported by provision of suitable space. Many sites with higher population density do not support commercial diversity simply because there is no space to do it (for instance Sariá, Bellvitge and Pomar). Higher levels of both GSI and FSI support higher numbers of shops and venues (bars and restaurants). Sites with lower GSI / FSI will require inhabitants to travel greatest distances and therefore be most exposed to energy changes. Sites with imbalanced GSI / FSI (such as Bellvitge and Bon Pastor) do not contain commercial diversity and show signs of opportunity for adjustment with urban regeneration.

Open space. Typically central locations (Eixample, Raval) suffer from a severe lack of open space – this is typical of conditions in the centre and does not follow a trend related to urban form. Sites that do follow a more consistent trend related to urban form are those associated with former settlements (Sta Coloma, El Prat, St Feliu, St Cugat, Gavà). These areas have median population densities for Barcelona (20,000-35,000 residents / km2) and lower incomes.

In summary, the urban forms that would best survive reduced energy conditions are those associated with Barcelona's 1st and 2nd cities noted in Chapter 3 – compact in form and with a complex mix of activities. These involve both higher FSI (1.5-3.0) and GSI (0.4-0.65), mid-high population densities (15-30,000 inhabitants / km2 and greater), locations adjacent to a rail station (particularly metro / urban rail), with mixed use development (particularly a commercial ground floor), located on flatter topography (allowing for cycling) within a short walk to schools (up to 400m) and open space. This type of urban form is almost representative of sites similar to El Prat, Gava and to some extent Raval, Barceloneta and Eixample (although these last three have excessive or insufficient amounts of a number of these qualities). As noted, income heavily affects population density as income is associated with larger floor space but in turn reduces the demands on open space.

5

Futures into Action

IV) Change Models: How might the place be altered – by what actions, where and when?

V) Impact Models: What predictable differences might the changes cause?

VI) Design Models: How should the place be changed?

Overview

- A Futures Study based on a transition into a lower energy economy was presented in Chapter 2, establishing setting a scope for research themes. Chapter 3 showed how energy is consumed in Barcelona and described processes that have created demand. Chapter 4 has shown how certain areas perform in relation to energy consumption in terms of access to jobs, use of transport, availability of services and performance of building types – determining which sites are most and least dependent on energy.
- This Chapter will consider how urban areas will need to adapt or prepare to deal with the likelihood of a reduction in the availability of energy.
- Firstly, some of the larger implications of a lower energy economy will be explained. This includes elaborating on the Futures Study noted earlier, based on Odum & Odum's 'A Prosperous Way Down' (2006). The Odums' study is provocative yet relatively vague - lacking the

technical detail required for such an analysis. This will be elaborated on in the following pages.

- The Futures Study will be explained in terms of the four main energy consumption sectors: transport, secondary industry, tertiary industry and residential / domestic. Conditions will be reviewed for a future based on surviving with 40% of current energy supply.
- The Futures Study will then look at the types of urban form best suited for adaptation and those that despite energy reduction strategies will likely become more disconnected or require new forms of private transport.
- Finally, based on findings from the analysis conducted earlier, intervention strategies will be proposed.

Introduction

Chapter 4 indicated that some urban areas are better equipped for less energy than others based on access to amenities, shops and other attractions. However, how prepared would these areas be if an energy crisis were to arise? How would conditions change? Consumption creates conditions of dependency. Based on certain assumptions, relatively small changes to some urban areas can increase quality of life and result in significant reduction in overall energy dependencies.

Current mobility and land use based goals can be highly subjective and conflicting. Outcomes, therefore, will depend largely on using energy consumption data as a primary objective to frame urban planning goals.

A short or sudden descent?

The Odums describe how a range of areas will be affected within the 'Prosperous Way Down', described in Chapter 2. However as noted earlier, their futures study has no specific timeframe. This makes it difficult to distinguish the nature of a slow or sudden decline. An assumption can be made that a 'slow' decline will take the larger part of a lifetime – perhaps 50 to 100 years (a period similar to that experienced in the global adoption of the internal combustion engine). A 'sudden' descent therefore may take significantly less time – as little as 20 years – a period short enough to fit within most people's lifetime. It can also be assumed that based on existing fossil fuel supplies, this 'sudden' change will not result from an abrupt supply loss as experienced in the 1973 oil crisis. Residents and urban areas will have an opportunity to adapt if the change is taken seriously.

An assumption can be made that if current trends in population growth and energy demand continue for the next 20 years, then many other issues will be triggered. Projections indicate that by 2032 world population will continue to grow towards nine billion (United Nations 2004). This growth will be accompanied by increased energy demand particularly from industrialising regions.

The need for energy intensive agriculture will also be followed by increasing energy costs due to the increasing demand for food. In addition fossil fuel reserves will decline (Edwards 2001) thus making traditional extraction less profitable (Heinburg 2009); alternative energy production with lower Energy Return On Energy Invested (EROEI) would then be expected to make energy more expensive. During this time much of the technical equipment associated with fossil fuels will require replacement or will be decommissioned – ranging from cars to coal fired power plants. Finally climate change will become an inevitable and unavoidable issue. If these projections are accurate, it can be assumed that the Odums' descent scenario has indeed begun. This chapter will focus on the consequences of such trends over the next 20 years.

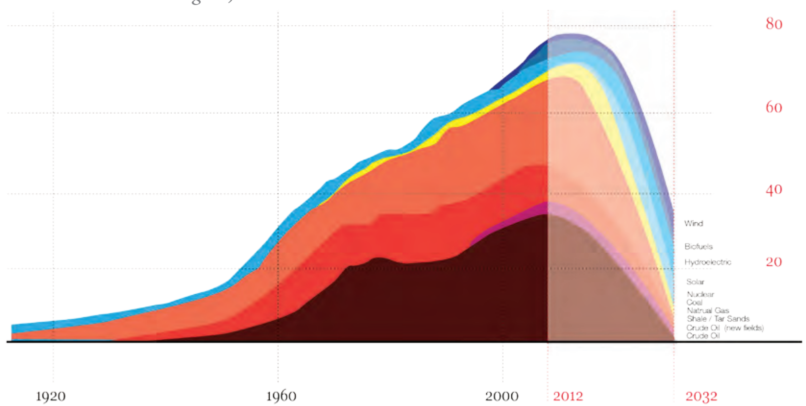
A position on technology

First of all, energy (in the form of electricity) will be as necessary in the foreseeable future as it is now. Energy production cannot be ignored in a low energy future but it is worth understanding its potential limitations. This will also help to found assumptions for minimum energy available under sudden changes in energy supply.

While current 'state-of-the-art' technology may be considered capable of supplying current energy demands, there are many 'externalities' large-scale energy plans disregard. For large national (or continental) energy plans to create a smooth transition to renewable energy production, social acceptance assumptions and / or many other variables regarding supply and demand must be made.

The toolkit of renewable energy production technology is diverse. It ranges from highly exposed but high yielding systems such as wind, hydroelectricity dams and solar farms (PV and concentrated solar) to lower yielding and better scenically integrated systems such biogas digesters, woodchip incinerators, wave technology, bio-fuels (sugarcane, corn and palm oil typically) and most geothermal. All of these technologies have significant issues associated with their implementation such as

Figure 5/01: *An energy technology transition scenario in world energy economy with less fosil fuels? (Based on Edwards, American Association of Petrolium Geologists)*



scenic impact, energy yield, environmental impact, supply latency and high establishment costs. These new renewable technologies may be far more complicated to introduce at a national scale than traditional technologies (Mackay 2009; H+N+S Land 2008).

Even though a significant range of technical solutions currently exists, there are many reasons why these solutions cannot be implemented to their full potential. Both David Mackay and Richard Heinburg suggest that the tedious and complicated externalities hidden behind energy 'production' make energy 'reduction' appear to be a more practical option (Mackay op. cit; Heinburg 2009). Therefore, the following 20-year projection will be made based on existing available technology and current rates of long term growth.

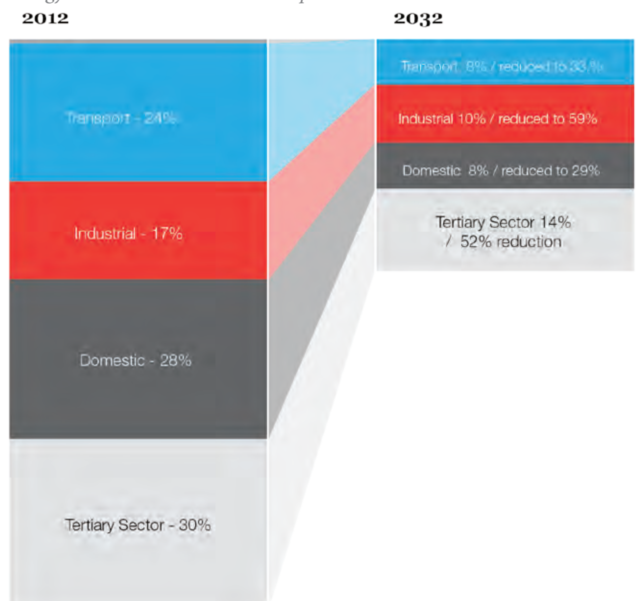
Available energy

With no or low access to once cheap fossil fuels, energy prices will increase dramatically. This will force consumers to become very conscious of their energy consumption.

Spain has achieved an incredible growth in renewable energy technology within the last decade, with almost 10% of its energy needs now met through renewable sources (European Commission 2011). Further growth is aimed at reaching over 20% of total energy needs by 2020, in line with current EU requirements. Under current projections it is set to achieve this (Congreso de España 2010). This rate could optimistically rise by a further 10-20% by 2032 if investment is increased, if decentralised energy production is increased (individuals invest in solar technology or wind for instance), if local residents support the infrastructure and if predicted efficiencies continue, particularly with respect to solar technology.

It should also be noted that over time, energy pressures would be reduced if implementation of renewable energy

Figure 5/02: *Municipal level energy distribution now, and with 60% less energy. How could urban areas be protected under such conditions?*



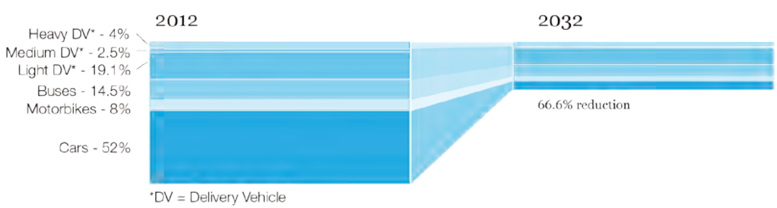
continues. However such long-term speculations, depend on many uncertainties (as noted in Figure 2/02).

In addition, traditional fossil fuel sources are not likely to suddenly disappear by 2032. It could be assumed that at least 10% of fossil fuel supply will remain available. Yet this supply will be dedicated to large industrial infrastructure such as collective transport, some manufacturing and power plants.

Therefore in the event of a crisis scenario as of 20 years from now, a mix of 30% renewable energy and 10% fossil fuels will be available. How would 40% of today's energy be made available across the current network? Which sectors are most flexible? Where can energy cuts be made? Generally this will mean returning to energy consumption levels of the 1960s-70s.

As this research focuses on two of these four sectors, the consequences for transport and dwellings will now be considered.

Figure 5/03: *The possible energy mix transition for transport.*



Transport

Catalunya - 40% now, 15% in 2032

Barcelona - 24% now, 8% in 2032

The 2032 transport sector mobility budgets are expected to fall to 33% of current energy consumption. With commercial delivery vehicles currently accounting for a little over 20% of current total energy, and buses a further 14%, it can be assumed that these vehicles will have priority access in the transport energy budget to keep the economy running and to distribute goods.

Technically, electric vehicles would be appropriate for mobility systems. But, energy sources for mobility are the same as those for other sectors so electric personal transportation must be limited where possible.

With personal mobility currently largely required for social or non-obligated mobility, significant savings can be made based in usage patterns. In addition, many of the currently obligated work commutes will also be exchanged for collective mobility. This will create centralities around stations and weaken connectivity with those areas not accessible to the rail network. Naturally some higher income residents living on the city's periphery will not feel inclined to follow this pattern as their purchasing power will allow them access to electric cars. These areas (such as l'Alba Rosa, Mira-Sol and Cerdanyola explored in Chapter 4) are far more dependent on energy and will either

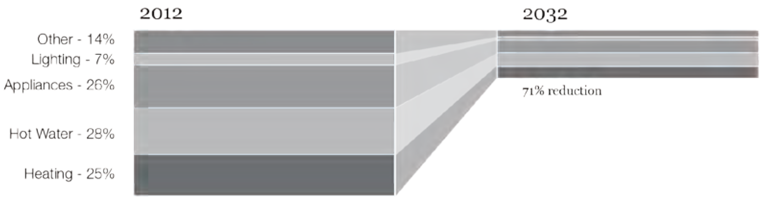


Figure 5/04: *The possible energy mix transition at a domestic level.*

depopulate or the lower income groups will filter into more accessible locations closer to mobility networks.

With a significant number of commuters shifting from private transport to collective modes, transport operators will need to reconfigure networks so that they are based largely around rail. Collective mobility will be stressed and therefore could suffer collapse if a transition strategy is not implemented. Workers with geographically-flexible services jobs may choose to work closer to home. Weekend leisure trips will also fall victim to energy prices. Residents living away from the centre will choose to stay more regularly within their local neighbourhoods.

Transport for food, logistics and some manufacturing will require priority energy use.

Domestic / Residential

Catalunya - 14% now, 5% in 2032

Barcelona - 28% now, 8% in 2032

Residential areas will have dramatically less access to energy in the future. Living environments will have to be more efficient and robust.

Population densities in some areas will increase. According to the Odums' scenario, populations decrease as a result of decline in food, jobs and income. This is a fundamental contradiction to the very nature of cities, which are inclined to grow. Shrinking implies a significant loss of their creative 'generative' power (Jacobs 1969). Regardless, many cities are losing population, in some cases with impacts on or due to the effects of agglomerating services and industry as Jacobs explains (evident in Detroit and Manchester for example). In other cases there are small reductions that are less noticeable. What is clear is that some (particularly larger) cities retain ongoing growth due to their diversity. Growth in this sense may refer to physical growth or at least growth in 'development' – such as industry, technology, knowledge etc. In addition, by virtue of proximities, larger compact cities are far more energy efficient than smaller or sprawling urban areas (Bettencourt & West 2010).

Economies rely on large cities. Consequently it is expected that Barcelona will continue to support economic and population growth. However other cities and urban areas surrounding Barcelona, outside of its accessible 'daily urban catchment', may feel pressure to reduce their tertiary workforces and focus their economies around particular industrial work which is cheaper than in Barcelona. Such cities include Girona, Lleida, Reus and possibly Tarragona and Sabadell. Therefore, the objective should be to find ways Barcelona can grow while reducing its energy demands.

Currently unbalanced urban areas with relatively low population densities are likely to require reconfiguration and urban renewal. Increasing population densities could also provide a diverse range of job opportunities and access to local amenities with integrated urban planning. Current energy prices are likely to be increased significantly. The average family of 2.3 people, currently consuming 3.2 MWh/yr electricity and 3.6 MWh/yr gas, will haveenergy costs growing from around €1000 to €3000 per year- thus accounting for more than 15% of a typical family's income (Ajuntament de Barcelona 2011; Eurostat 2011).

Commuter districts that dependent on recently developed road corridors and private forms of mobility may be abandoned with population redistributed to urban areas or semi-agrarian fringes.

Impacts and Strategies

In the assessment made in the previous pages, significant energy savings could be possible without dramatically affecting lifestyles – if resources and facilities are located nearby.

With suitable precautions urban areas that are prepared will not be as highly exposed to the consequences of energy changes. Urban areas that have good access to the larger rail network will not be affected as significantly by increased transport costs. Areas with access to goods and services nearby will also be significantly advantaged. Buildings with low energy demands will allow residents to live within current quality of life standards without attracting higher energy costs.

How could urban areas prepare for such conditions? What actions can be taken now? Which areas will be worst affected and which will thrive based on new levels of centrality and densification?

Three types of strategy are discussed over the remainder of this chapter. Firstly, it is necessary to consider 'network' strategies which link throughout the city particularly in terms of mobility and accessibility; typical interventions will be considered that can be repeated throughout the larger metropolitan area. Secondly, it is critical to review the performance of urban form and how it performs within its immediate surroundings; the metropolitan area will be therefore categorised into six groups and considerations will be made in terms of various 'typologies'. Finally, a number of specific interventions are discussed which relate to the six typologies.

1- Working with movement

Currently mobility is of considerable concern for the city's performance in the likelihood of reduced energy supply.

Mobility is a complex political issue. It is not only a practical and economic issue but an emotional one too. Car lobbies protect accessibility and the flexibility of the automobile. Collective transport enthusiasts and social welfare groups rally behind improved and increased collective transport. Communities challenge traffic, noise and pollution. With often diametrically opposite objectives, rarely is consensus achieved. These typical mobility related issues will affect energy transitions unless clear energy related objectives are established.

Projected usage levels can tie infrastructure and policy into path-dependency for mobility – in terms of both roads and collective transport. In other words, construction of a new metro line depends on a certain increase in usage to cover infrastructure and maintenance costs. Fortunately, many of the highways no longer depend on tolls which means infrastructure does not require ongoing patronage (with the exception of the 'Autopista de Montserrat' between Barcelona and SantCugat de los Valles). On the other hand as discussed earlier, locally many municipalities have made agreements with car-park operators – thus requiring ongoing minimum patronage. Provision of car-parking was earlier found to be linked to car ownership and car ownership is clearly linked to car use. Fundamentally, providing space for cars will allow demand for cars to grow – and the opposite will apply if car-parking is reduced.

Relative to the offer of collective transport, there is a very high level of private transport dependence. Should energy availability drop suddenly and significantly, many current private transport users will be expected to swap to collective modes. With a large influx of new users, the system is likely to collapse as mobility systems take many years to modify. Alternative forms of mobility may be a solution.

A final issue regards cycling – a largely unaccounted for mode of transport that is slowly beening adopted within transport planning. Cycle paths have not been comprehensively accommodated within the larger road network; existing cycle paths are illogically placed and inconsistent. They are clearly a secondary mode to the private mobility system. A deadlock mentioned earlier exists between public transport operators and cyclists, where increased numbers of the latter are attributed to decreased numbers of the former. This thinking savages both modes of transport as it ultimately does not resolve private mobility dependence.

Figure 5/05:

Mobility zones

Major highways, autoroutes and roads can define the 'pricing' zones.

Zones, while large should divide larger pockets of employment to discourage to work driving habits.

Balancing mobility networks

In the event of changed energy conditions, inflated energy prices will leave many of those currently dependent on private mobility stranded. These changes will favour collective transport as energy costs can be better distributed. Changing mobility habits is a slow process, therefore incentives and restrictions must be employed simultaneously to shift mobility to collective systems or to cycling or walking. So as the road system is constricted, the collective transport system must be expanded and / or improved.

To prepare for lower energy conditions, users and transport operators must be eased into changes. Road charging will be the most effective way of penalising rather than restricting usage. As mobility offers a city significant economic benefits, accessibility should not be completely restricted to particular types of transport (logistics, goods, certain jobs). Major roads, highways and freeways could be tolled to discourage long distance and cross-city travel.

As major roads will charge access, the short-term weakness of this strategy is increasing attraction to cross or outer city movement and connectivity with areas north-west of the Collserola range such as Terrassa, Sabadell, Rubi or Martorell.

Road pricing is likely to result in significant reduction in congestion, as experienced in London (Santos & Fraser 2006). This will lead to less vehicles occupying road space, which in turn will increase private mobility speed and efficiency. This may invert current trends and promote private mobility for inner-city residents and those who can afford it. To minimise a 'rebound effect', roads should be simultaneously modified to accommodate dedicated bus lanes and dedicated cycle lanes.

Collective transport could further depend on its city-wide rail network to improve access. Bus services, operating on precious liquid fuels, could offer higher frequency feeder

Figure 5/06: *Passeig San Joan, mentioned earlier, underwent a largescale transformtion in 2011, from six lanes into two bus lanes and two general traffic lanes with a cycle path in the centre. The road narrowing was balanced through expanding public space and providing the dedicated bus lane. This is a perfect example of providing a greater balance of local amenity.*

links to the rail stations' cross-city lines to areas not serviced well by rail. In this case, dedicated bus lanes will need to be defined.

Collective transport will significantly favour denser areas. Currently, most of the city areas with densities greater than 5,000 residents / km2 are associated with a rail link. As all mobility systems have a limited carrying capacity, and peak hours reduce travel comfort, employers may choose to distribute their working day across a number of smaller 'shifts' thus allowing employees to avoid highly congested peak periods.

The disadvantage for the rail network is that it is currently highly radial and does not favour tangential trips. For instance, there are strong mobility links from Sant Cugat to Viladecans – possibly a 40 minute car trip, which could take up to twice that time by train.

Apart from increasing some services, effective draw-cards to increase ridership will be reduced congestion, reduced parking, lowered seasonal ticket prices and tax deductible public transport. This is the basis of Zurich's highly successful mobility strategy. The Swiss city's collective transport ridership accounts for some of the highest usage rates in Europe (annually around 550 trips per capita) as the system is cost effective, efficient, fast (priority over private modes) and yet in a city region with only a third of Barcelona's population density (Mees 1999; Newman & Kenworthy 1999).

The Cycling network – a matter of resolution

Cycling has great potential in Barcelona as an attractive, healthy, medium distance, low energy mode of transport. Naturally, not all areas have suitable topography - it favours the lower / flatter districts containing a greater mix of income groups which acquire the bicycle as a form of mobility. This particularly suits the sites in the city centre such as Raval, Barceloneta, Eixample, Villa Olimpica, Llacuna, St Martí. Other areas such as El Prat and Bellvitge are also suitable candidates. Other sites can find strategies to integrate the cycle yet it is suited to younger and fitter residents who can manage the more challenging topography.

There are many precedents for cycling that can be used. Most importantly, a mobility 'language' is necessary to create cohesion across the larger road network. The Dutch have embedded cycling into all aspects of mobility and therefore cycling is simply ubiquitous in the Netherlands. At the moment, the almost 200 km of cycling lanes in Barcelona are awkwardly located and often inconsistently designed; some are on shared roadways, others share with pedestrians, some are in the middle of the road, others travel against oncoming traffic. Even materials, size of cycle lanes, and design resolution makes cycling awkward and therefore uncomfortable. Often also, cyclists are mixed with at-grade pedestrian traffic which has some difficulty leaving spaces for cyclists.

Most recently cities in North America have invested heavily and successfully in cycling, having attracted far greater numbers than those experienced in Barcelona associated with levels of investment in cycling infrastructure (as mentioned in Chapter 3). New York has developed a number of retrofitting solutions which protect cyclists from moving cars with parked ones and has seen an increase to 10% of total trips. Montreal and San Francisco, both on relatively undulating topography, have successfully developed cycling networks. San Francisco uses the flatter streets, perpendicular to the hills, to traverse the desired assent or descent location. A similar solution would be very suitable for Barcelona, thus allowing cycling to reach all but the very steepest areas (such as Carmel).

Road network strategies must include locating space for cycling democratically within road use planning. From the examples noted, cycling must be treated as a fast mode rather than mixed with pedestrians. Currently in Barcelona, cycling is illegal on footpaths less than 5m wide. By negotiating pedestrians, café seating, shop stands and other obstacles on footpaths, median cycling speed can be as low as 10 km/h rather than optimum 15-20 km/h available with dedicated cycle lanes. Cycling lanes or cycling conditions must therefore be integrated intuitively into all streets and mixed with motorised traffic. This may be either grade separated or delineated from pedestrians. Importantly, cycling should be used as a tool to calm private vehicle traffic, particularly on slower local streets.

Figure 5/07 (top) + 08 (bottom): *In Barcelona, cycling is seen as competition for space and speed by motorists. In many cases, it is inconvinient to cross busy roads to reach cycle lanes traveling in the correct direction so cyclists often travel against the traffic flow (top - Gran Via). The cycling streets are also inconsistent, sometimes on the road space with cars, other times on footpaths with pedestrians.*

Cycling is a key component of the Super-Block. Cycling and pedestrian networks can also provide incentives to remove or reduce surface parking areas – thus reducing demand for cars while increasing amenity for local residents. This strategy may not be initially popular. However it is clear from examples in Raval, Gracia and a number of the most exclusive streets in Barcelona (Carrer Enrique Granados and recently Paseig de Sant Joan), that road closures dramatically improve amenity in highly dense urban areas. Most importantly, density numbers must be high enough to support local shops – fostering highly pedestrian lifestyles. This will be further explained in the following strategy.

In the Netherlands, biking is an integral way of life. The fact is that streets are generally associated with a pattern which allows cycling to be intuitive, pleasurable and safe rather than awkward, confusing and complicated (as the case in Barcelona). This small difference may be one of the reasons why Barcelona can only attract 2% of all movements by bicycle while in Amsterdam the number exceeds 30%. The Dutch cycling system is an ideal case study as it can be divided into three types of streets which are largely repeated throughout the entire country;

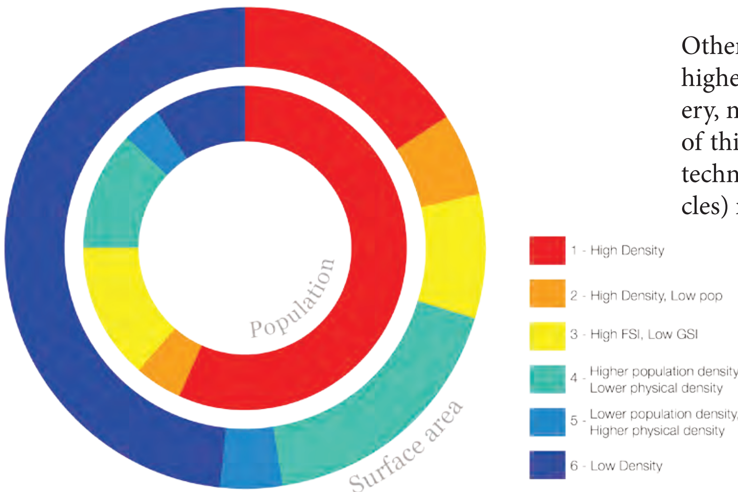
1. **Main or large roads** *with separated bike lanes (Figure 5/09 - top). Biking lanes are completely divided from the motorised traffic.*
2. **Arterial roads** *(Figure 5/10 – middle). Cycling is integrated between the motorised traffic lanes and in many cases the parked cars.*
3. **Local or neighbourhood roads** *(Figure 5/11 - bottom). While traffic in many cases is single direction, bikes can travel in both. Bike lanes are also not defined and the width of the road space is just wide enough for a passing car and bike - these are small details which have a significant psychological impact on the way traffic uses these smaller streets.*

2- Density and energy consumption

As noted throughout the analysis and as will be concluded in this synthesis, it is clear that a large portion of the city has potential to tolerate changes by virtue of density, accessibility and proximity. But in many cases it is not advantaged due to mobility conditions - encouraging a larger distribution of jobs and attractions.

Areas with high physical and population density represent almost one third of the city's population yet consists of less than one tenth of the surface area. These areas are generally well connected and associated with the rail network and can be easily improved through simple interventions.

Figure 5/12: *Comparison of the size and population representing the six areas noted in the synthesis.*



Areas with high physical density but lower population density could be improved through targeting densification around mobility nodes and particularly with a focus on slow mobility networks.

Areas with low GSI and high FSI, associated with the Urgency Period (1950's-60's), could be selectively improved by increasing diversity and particularly commercial space. This may require further selective densification. Associated also with this period are areas with lower physical density and lower incomes but higher population densities. These areas, while often associated with higher car ownership and lower diversity – force residents to travel.

Other areas will require lower population densities and higher incomes, particularly where located on the periphery, may require other strategies not included in the scope of this research. This may involve new energy producing technology and mobility systems (likely with electric vehicles) not covered in this research.

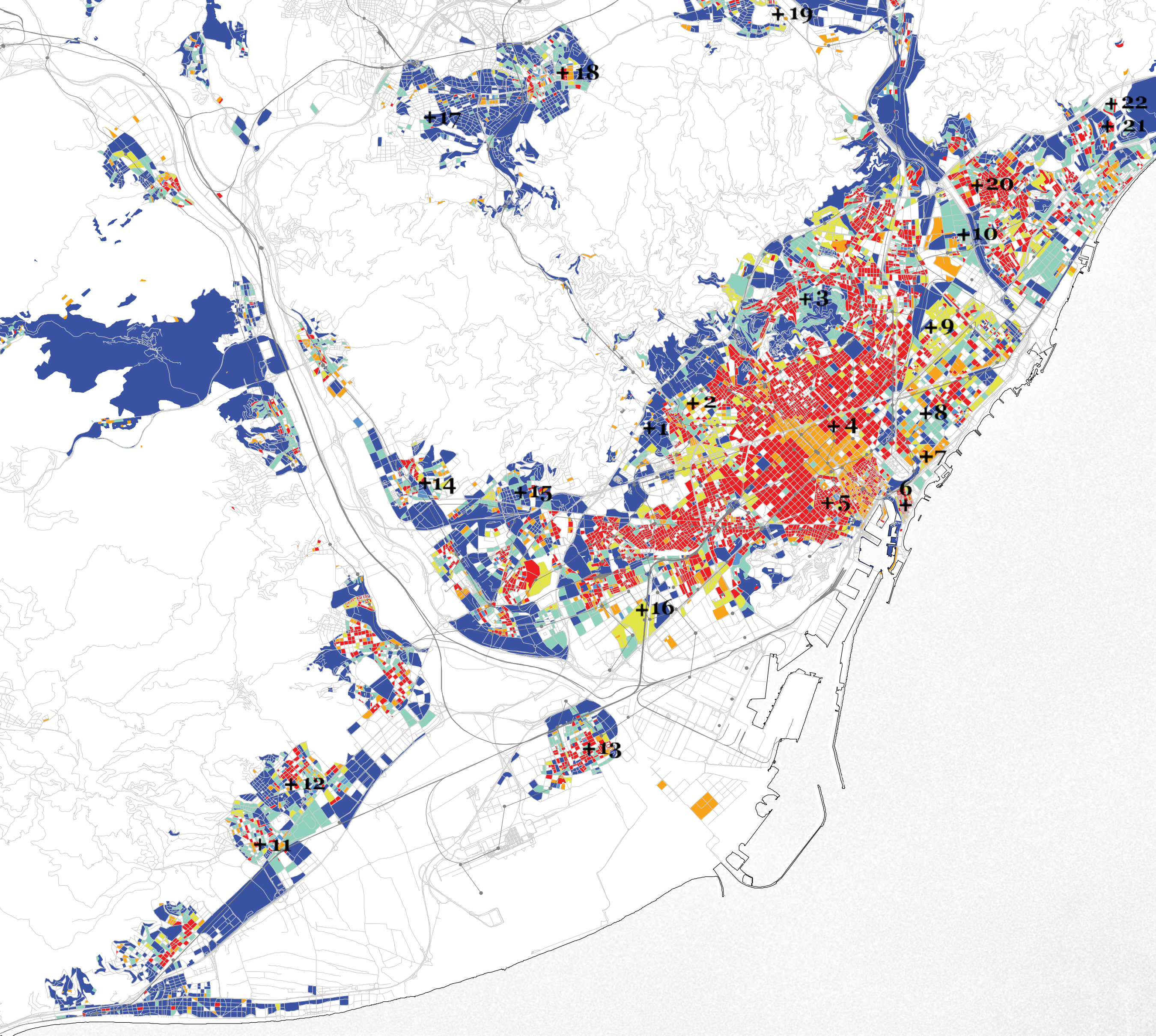


Figure 5/13

Density groups

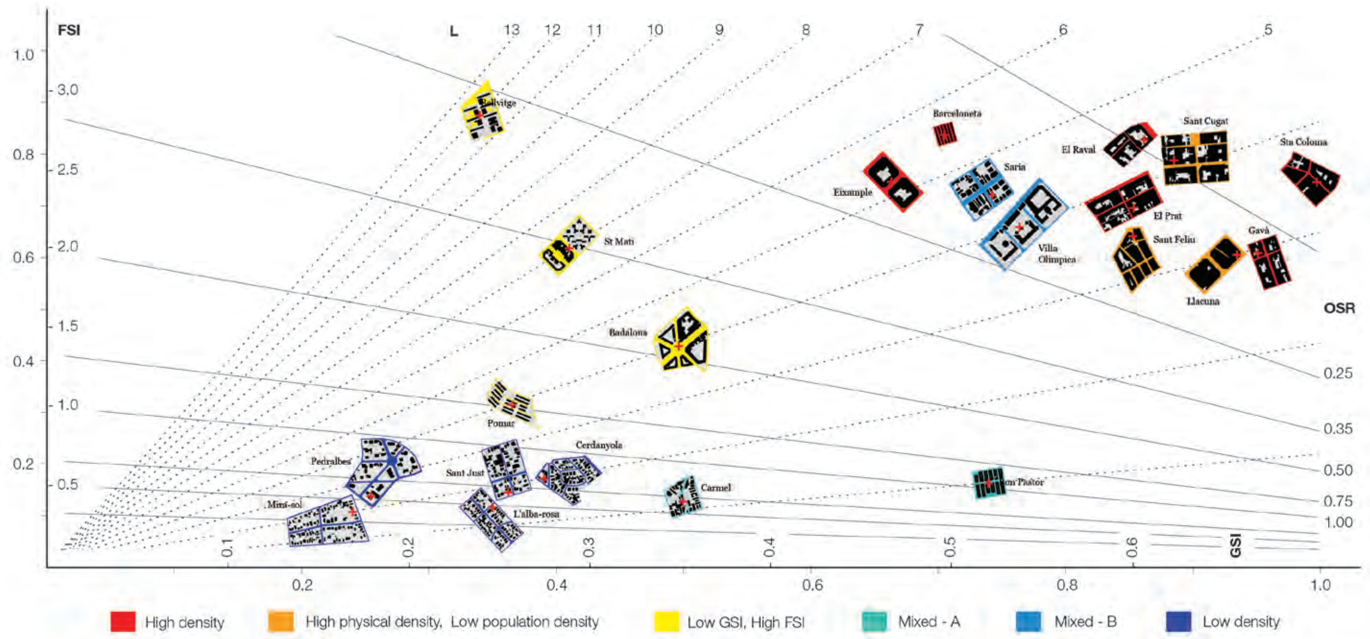
0 400m

- High density
- High physical density, Low pop.
- Low GSI, High FSI
- Mixed - A
- Mixed - B
- Low density

+25 Sites

Findings taken from the analysis have been synthesised into six groups (refer to Figure 5/13 and Figure 5/14) according to density and performance of the density. Based on these qualifications, areas associated with these conditions have been mapped and identified in terms of typologies and population densities. These findings can be used for larger metropolitan planning and will be able to target particular areas which area expected to have greatest return on investment. Not all areas will fit into these conditions but approximations can be made which help to target more particular analysis. In additions, assumptions may not apply to all sites as some areas are associated with tourism, for instance, which may provide a large but non-permanent population and is not registered in census data.

Figure 5/14: *Synthesis of sites according to the Spacematrix diagram.*



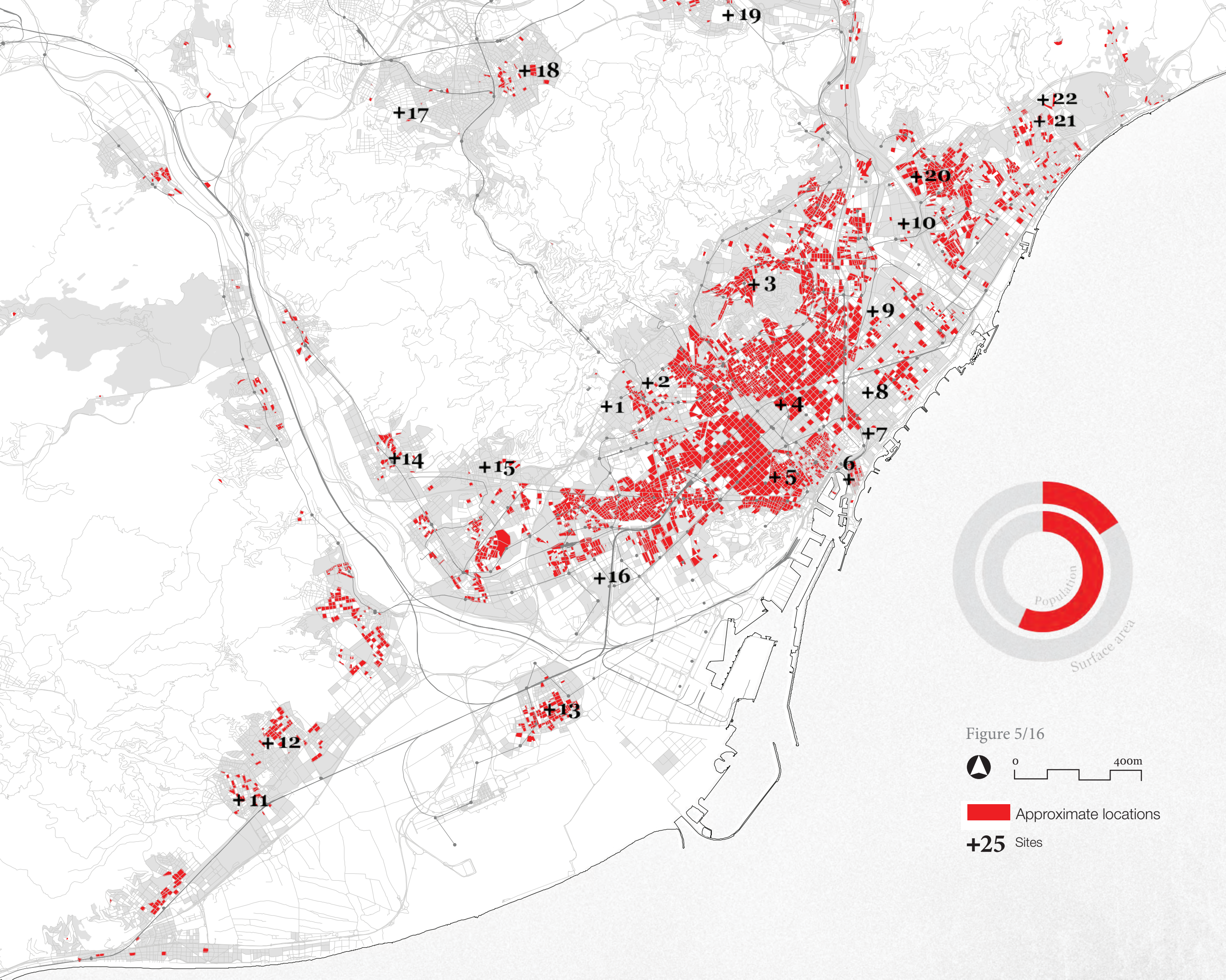

+1
+2
+3
+4
+5
6
+
+7
+8
+9
+10
+11
+12
+13
+14
+15
+16
+17
+18
+19
+20
+21
+22
Population
Surface area
0
400m
Approximate locations
+25 Sites

Figure 5/16


4 Eixample
5 Raval
6 Barceloneta
11 Gavà
13 El Prat
13 Sant Feliu

High density

Population density:	> 25000 residents / km2
FSI:	> 2
GSI:	0.46 - 1
Total population:	1571000
Total area:	27km2

This is the most robust type. It has high levels of diversity; access shops, venues, services and collective mobility systems. Links were found connecting population density and urban form with access to shops and venues.

Issues: As this type involves high population levels it is also associated with a lack of amenities encouraging a need to travel. These environments are typically noisy and congested - largely due to vehicle traffic. They also generally lack public space and roads are often overrun by car parking, which benefits a relatively small portion of the resident population. As this type is often associated with older buildings, most of this type is not well insulated and unprepared to deal with extreme weather conditions.

Opportunities: These areas require relatively low cost modifications to improve their urban qualities and to bring services and attractions closer to residents. Barcelona has experimented significantly with this across the city yet has not developed larger strategies. For instance, approximately 30 interior courtyards have been converted into parks. A number of small library / community centres have been developed which have been inserted into inner-city blocks (refer to Diagram 5/25 + 5/26). A number of streets have also been closed to vehicle traffic.

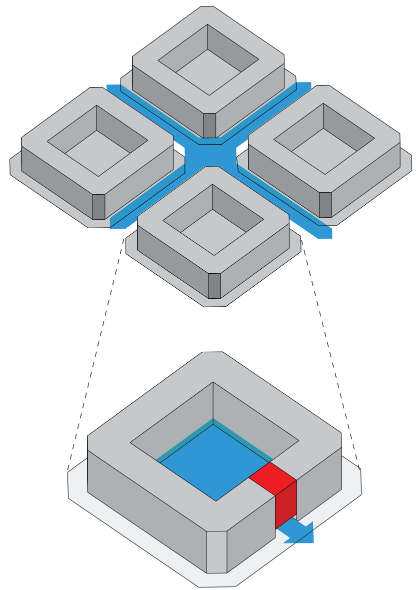
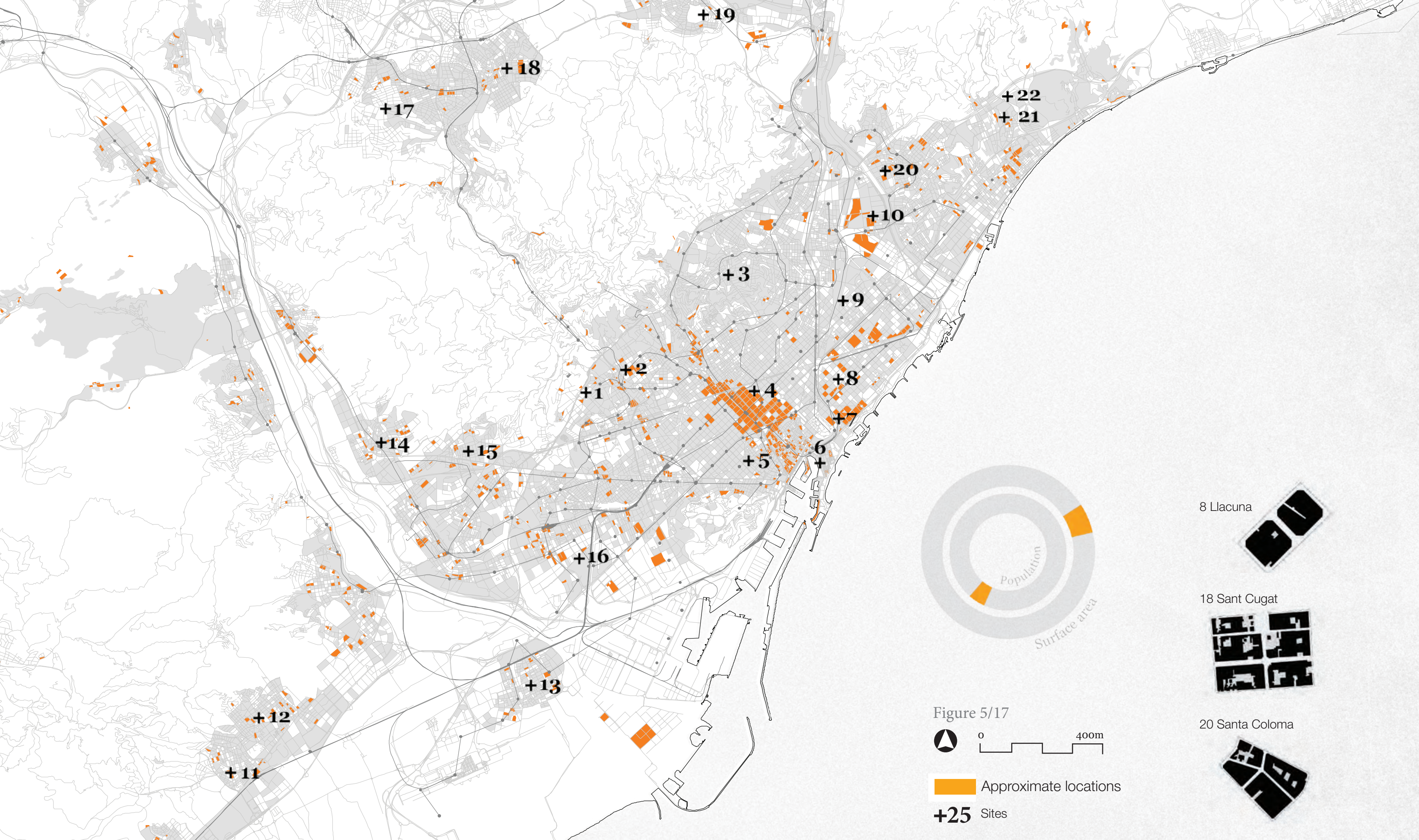


Figure 5/16 b - Streets in dense urban types have great potential. Many currently are largely occupied by parking areas which serve only a small part of the population. Significant energy savings may be afforded if these spaces served a greater variety of functions.

Figure 5/16 c- Small interventions (community centres, health centres, libraries etcetera) could be inserted into the block and open up internal courtyards for public use.



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Population
Surface area
0
400m
Approximate locations
+25 Sites
8 Llacuna
18 Sant Cugat
20 Santa Coloma

Figure 5/17

High physical density low population density

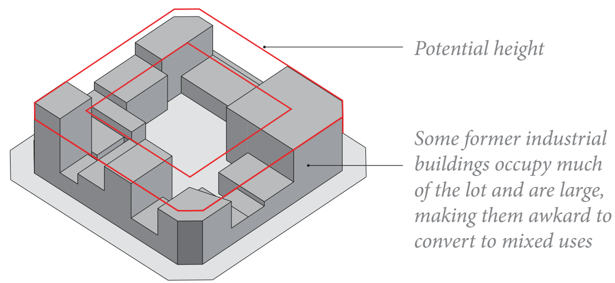
Population density:	2000 - 25000 residents / km2
FSI:	2- 6
GSI:	0.46 - 0.9
Total population:	132430
Total area:	9km2

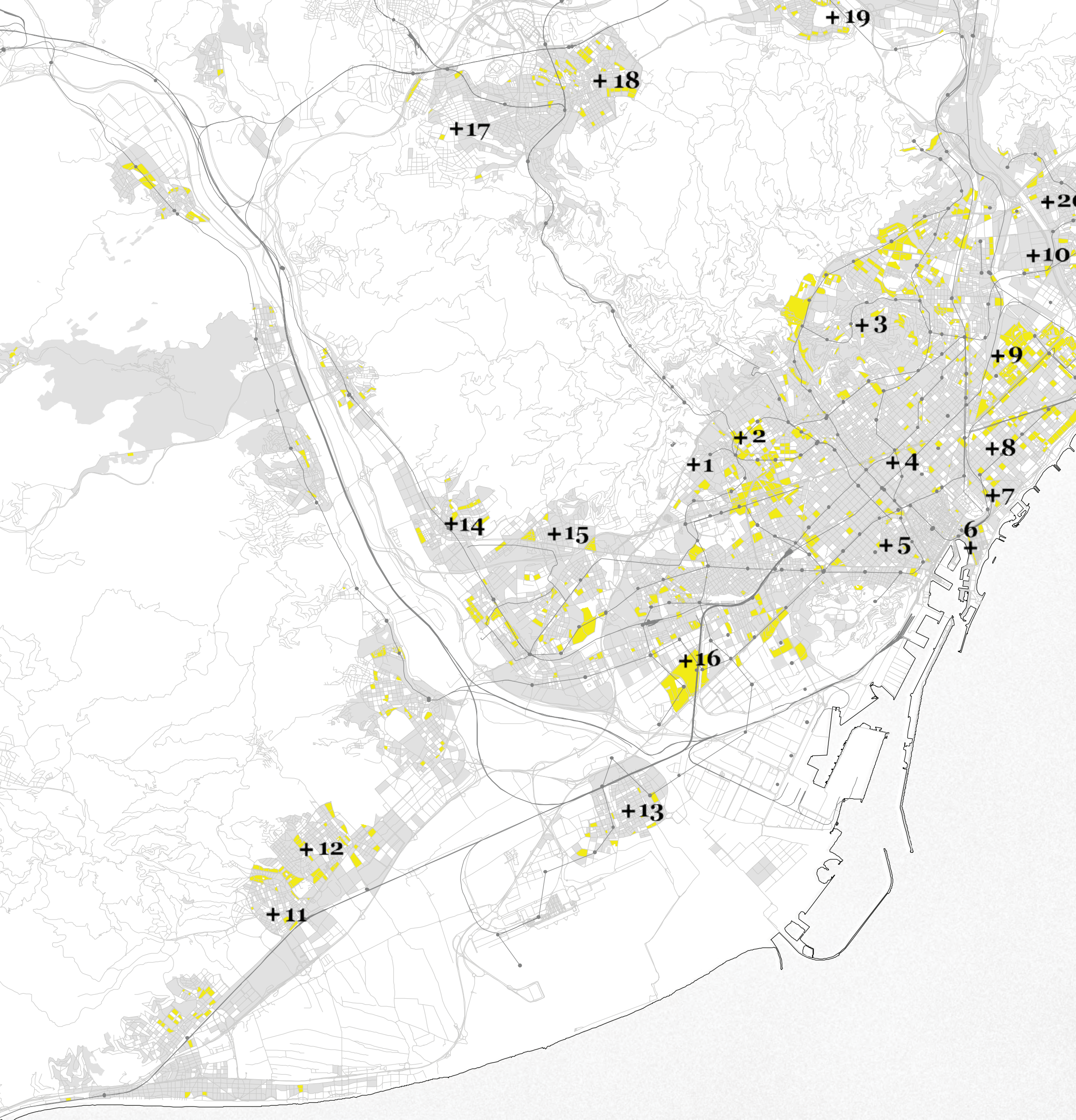
This type largely follows the physical or population density associated with the previous type, yet not concurrently. It often contains a great functional mix at the neighbourhood scale yet often these mixes involve industrial and / or other land intensive functions that do not support variety at the block level.

Issues: This type generally does not support access to a variety of goods and services found in denser conditions. While areas have access to mobility networks and jobs, a high number of workers travel for work and typically by car. Car ownership is mixed and not relevant to population density or income level. Like the previous type, this one also consists of a large number of older buildings which do not conform to current insulation standard.s

Opportunities: While the street network oriented to private mobility, it can be easily modified. Densification in key areas would improve the variety of shops and services in key areas. An accessibility strategy, which includes a pedestrian and a cycling network with small infill projects, could dramatically increase cohesion and improve the quality of the public spaces.

Figure 5/17 b- Through gradual redevelopment, density and diversity may be increased. As many of these sites are or were former industrial sites - therefore the building form may need to change significantly to not only accept a greater level of diversity. For instance lot size may need to be reduced to create greater diversity at the block level. In addition, building areas may also need to change, such that built areas occupy a portion of the block only. In addition, as many of the former industrial areas do not contain much open space, this new land-use may be best located as an incorporation into the block as interior space.





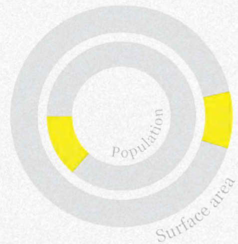


Figure 5/18

0 400m

Approximate locations

+25 Sites

Low GSI, High FSI

Population density:	> 2000 residents / km2
FSI:	> 1
GSI:	< 0.36
Total population:	370900
Total area:	14km2

The 'Urgency Period' (1950's + 1960's) was a period of rapid and unplanned growth. These areas are generally associated with large open spaces – some used while others remain surplus space. In addition, many of the buildings associated with this period have a large amount of natural light, which is not as common in older developments.

Issues: Many of the areas associated with this period have relatively high population densities yet do not include commercial or working environments for the immediate residents which results, as found in the research, in an inherent mobility demand. In addition, ownership arrangements are also confusing which makes remodelling buildings difficult; buildings are located on large lots which make it difficult to achieve the richness of the finer grain older neighbourhoods. A further issue typical for almost all of these buildings is the poor insulation.

Opportunities: Two groups exist, both requiring different strategies. Firstly there are typically multi-storey medium / high density blocks which often include clusters of commercial space (such as Bellvitge). Then, typically on the outer fringes, development is less intensive with lower population densities (such as Pomar). Both can be adapted but require some investment to reconfigure the layout with smaller infill development including commercial space.

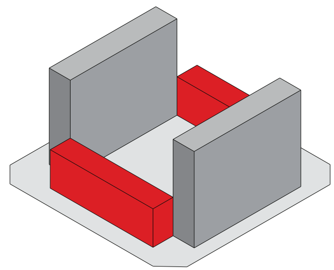


Figure 5/18 b - The modernist tower style developments typically have high residential density but have relatively little diversity. They typically also have a significant amount of open space, which is largely under-used. Small infill projects could augment space for commercial and community needs.

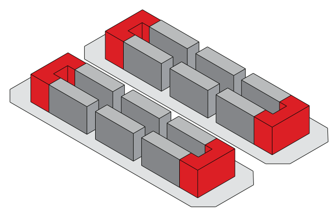
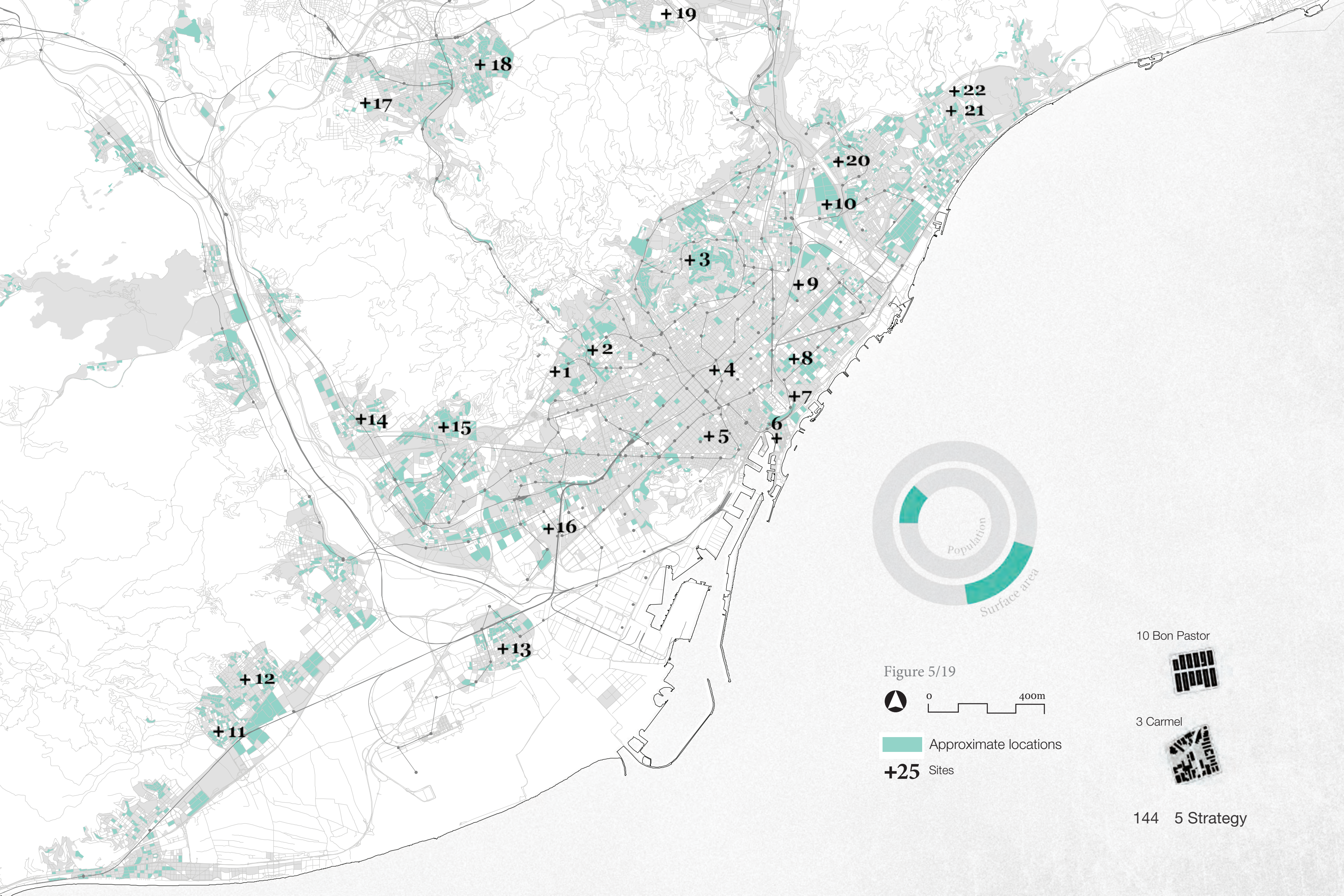


Figure 5/18 c - Lower density development could follow a similar strategy, but also accept increase residential space too.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Population
Surface area
0
400m
Approximate locations
+25 Sites
10 Bon Pastor
3 Carmel

Figure 5/19

Higher population density
Lower physical density

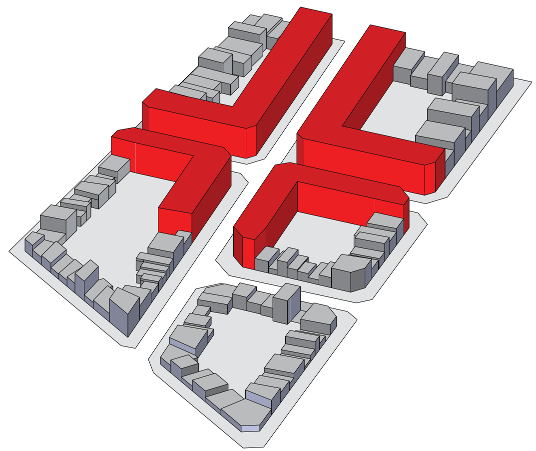
Population density:	> 2000 residents / km2
FSI:	0.3 – 1.5
GSI:	0.25 – 0.75
Total population:	332800
Total area:	30km2

These sites are associated with often piecemeal or unplanned development and in some cases associated also with a mix of residential and industrial development. The sites are often also associated with low physical density and high population density. Generally inconsistent or unique typologies as they were either built quickly or were not intended to be integrated into the larger urban fabric. They are also located on fringes or on awkward sites.

Issues: Many of these areas contain low levels of diversity, particularly shops and venues which means residents inherently. They are associated with higher levels of car ownership and private transport dependence.

Opportunities: May require significant and long term interventions. These sites may need much greater levels of connectivity (such as Carmel). On the other hand they may simply require increased population densities to support local shops and amenity (such as Bon Pastor).

Figure 5/19 b - Suitable interventions depend largely on the site's circumstances as in some cases access or topography are significant inhibiting factors. These sites contain a high percentage of residential use and have slightly lower access to schools and other facilities, as noted in Chapter 4. Lower densities also make it hard to support commercial activity – these lower densities may be as a result of older unplanned piecemeal development.



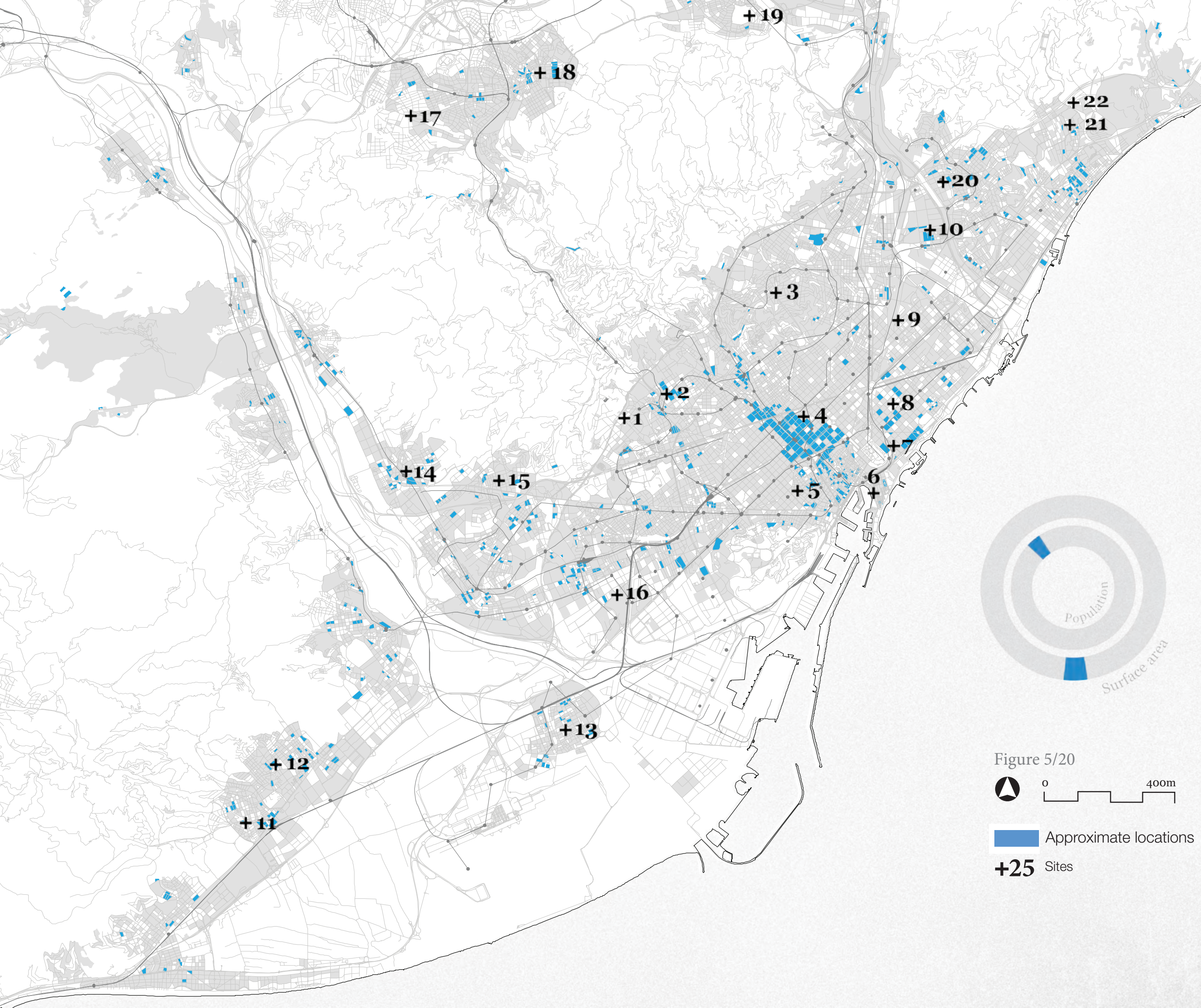
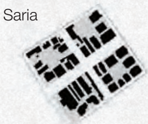


Figure 5/20

7 Saria



7 Villa Olimpica

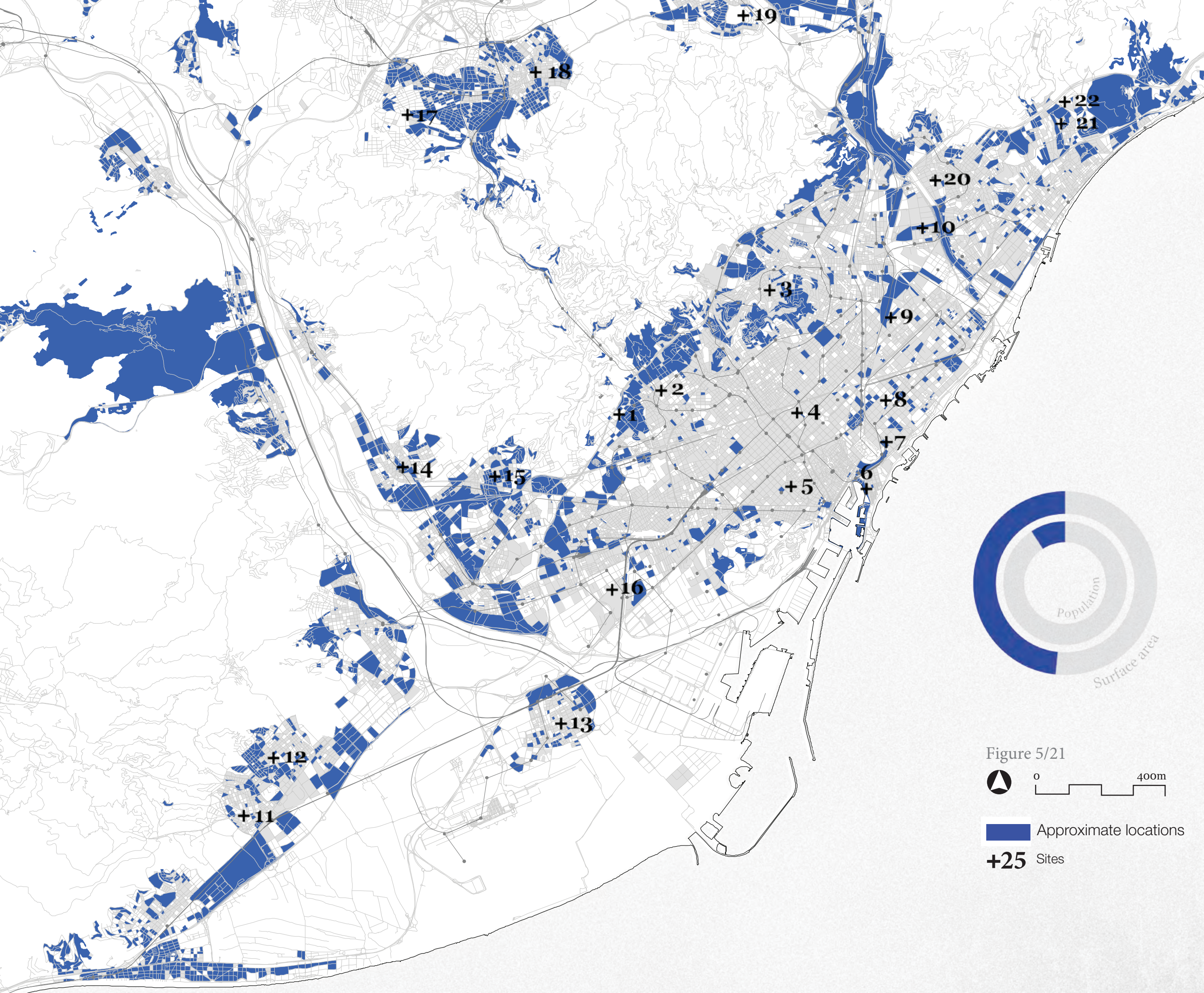
Lower population density,
Higher physical density

Population density:	2000 - 25000 residents / km2
FSI:	1.8 - 5
GSI:	0.5 – 0.9
Total population:	104400
Total area:	7km2

This type consist of higher physical density but lower population densities. The research found this type associated with high income levels and consequently larger dwelling sizes with lower resident numbers. Other characteristics involve higher car ownership, highly educated and highly mobile residents but far lower numbers of shops and other amenities. In other words, these sites perform very differently from areas with both equivalent population sizes but lower physical density or equivalent physical density but higher population densities – largely associated with income. These sites generally are associated with more recent development and so are often better insulated, but are also associated with high-tech buildings that inherently consume a lot more energy than older ones as noted in Chapter 4.

Issues: There are only a small number examples of this type within the city and account for only a small portion of the population. They work well when distributed with denser urban form and mixed demographics so shops and amenities are easily accessible. However if clustered they may become unbalanced, lifeless and not support diversity found in dense urban environments. In addition, these types may support a large number of jobs but a relatively low population (as seen in the physical centre of Barcelona) or may involve predominantly residences and contain fewer jobs (Sarià + Villa Olimpica). In residential areas, with these characteristics, there is often little commercial space that provides opportunity for diversity to occur. In addition, some of these areas also have limited access to quality open space – as much of the 'open space' is located on private property.

Opportunities: The value of these types of developments should be associated with higher value land, such as parks, views and or other high value attractions. Unfortunately market economies play a heavy hand in job and residential locations but they may be also restricted by local planning regulation dictating land uses. In this regard local planning may improve these areas, albeit slowly, by demanding mixed residential and commercial space in planning regulation.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Population
Surface area
0
400m
Approximate locations
+25 Sites

Figure 5/21


1 Pedralbes
13 l'Alba Rosa
17 Mira Sol
15 Sant Just
19 Cerdanyola

Low physical + poluation density

Population density:	1000-12000 residents / km2
FSI:	0.05 - 1
GSI:	0.02 – 0.5
Total population:	252900
Total area:	81km2

This type is characterised by low physical and population densities, highly car dependence, low collect transport use, low diversity and most significantly are associated with higher incomes. These areas are relatively new – emerging during the mid to late 20th century and based heavily on private mobility. While the population occupying these areas accounts for a small portion of the whole, it covers a significant portion of the whole region. They are therefore the most difficult type to resolve and based on the scope of this research are not considered to be robust in the event of an energy decline. Conversely, many of these areas have also been recently renovated and many have better insulation than those in older areas – but this is a relatively insignificant detail considering the dependence on private mobility systems.

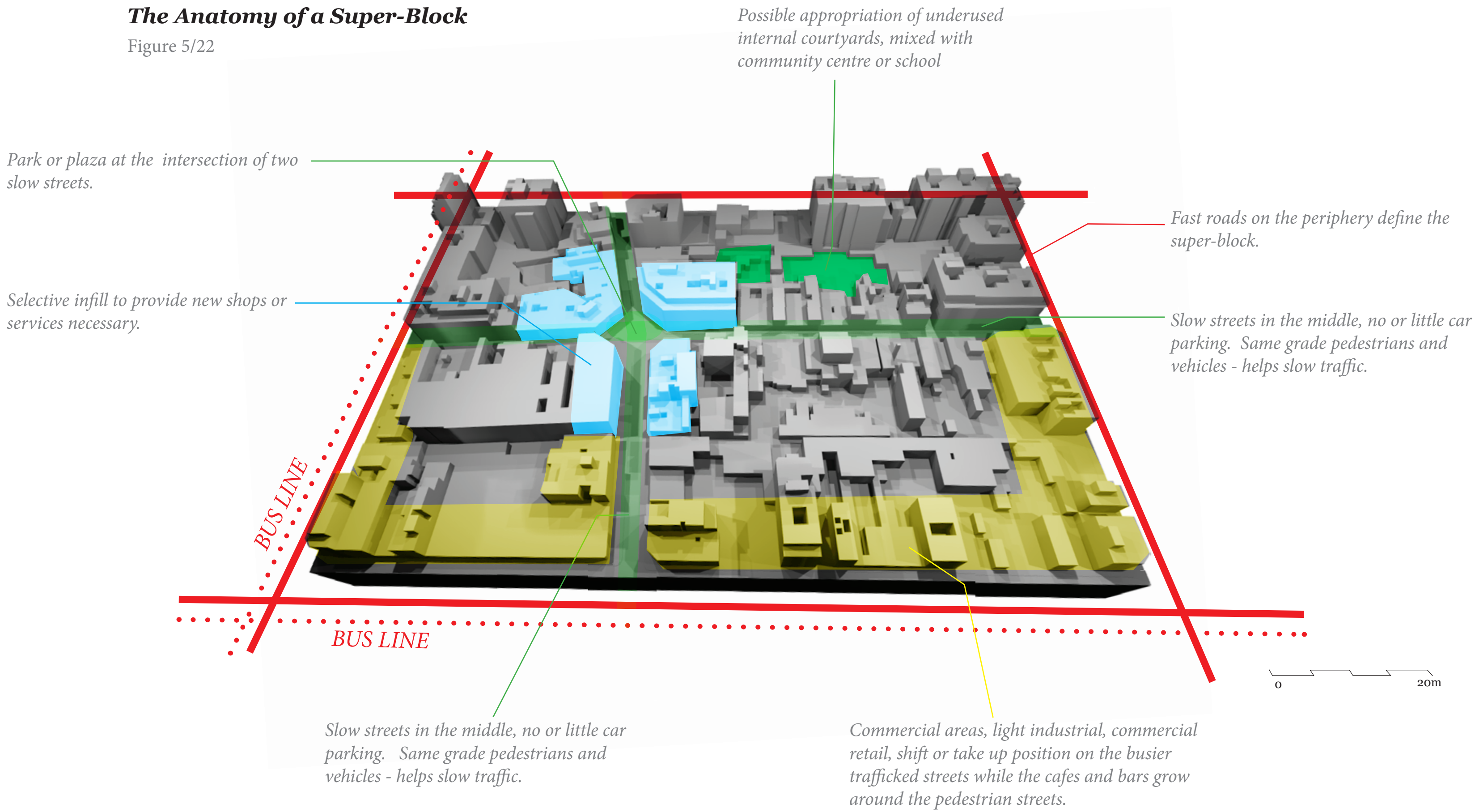
Issues: Many of these areas are typically located on the urban fringes in large clusters – in other words they are not mixed with higher density types. In these areas the land is typically undulating making cycling and even walking fairly inconvenient. The low densities (median around 4000 residents per/km2) means that almost all amenities such as shops, schools, health centres and even distances between friends and family are likely to be large.

Opportunities: Without densification, diversity and will be impossible in these areas. In addition, as many of these areas are located in relatively inaccessible areas, connections with collective transport systems are complicated and often not economically viable without the serviceable population. Alternatives will depend largely on development of new technology such as electric vehicles and domestic energy production.

Figure 5/21 a - A possible self-sufficient energy future for low-density areas inhabited by highly mobile and high income residents; electric cars and solar power production. (from http://sunpoweredevs.com accessed 05/03/2012)

The Anatomy of a Super-Block

Figure 5/22



3 - Neighbourhood Strategies

Expanding on the conclusions made regarding densities, the following pages will consider some more particular interventions that can be used to prepare for and reduce energy consumption embedded in urban form.

The 'Super-Block'

Mobility and the neighbourhood scale – the 'super-block' . The 'super-block' ('super-ille' in Catalan or 'super-manzana' in Spanish) is an integrated mobility and land use strategy suited to compact urban areas (refer to Figure 5/22 on the previous page). At a neighbourhood level, streets may be re-organised to accommodate a variety of functions and uses, not within the street itself but across various streets. In this way streets are specialised; certain streets are treated as 'fast' or accessible, while others are 'slow' and neighbourhood oriented. This allows pedestrians, residents, business and commercial space, light industrial and workshops to co-inhabit the same accessible and workable areas while supporting their inherent mobility needs.

The term 'super-block' has been in existence since the dawn of Cerdà's Eixample. It has since been re-imagined by many others, notably the modernist proposal by GATPAC (associated with CIAM) in the 1930s, projects developed during the Olympics in Villa Olimpica, in terms of traffic management in Gracia and most recently in terms of sustainability by architects and designers (Rueda 2002).

Concentrating density: more closer

Both higher physical and population density were found earlier to be associated with the greatest levels of energy efficiency. A significant aspect of mobility related energy consumption is attributed to relatively large numbers of small car trips with simple destinations such as shops, leisure, health / fitness and visiting friends. Through suitable density, many of these motorised trips can be easily exchanged for walking thus supporting local businesses and local diversity. Figure 5/24 and 5/28 (following pages) illustrate how this could be resolved. Interventions may seem relatively superficial however the impacts on energy consumption area significant.

Density, diversity and proximity were found earlier to be highly connected. Some urban areas were found to be underperforming due to lower densities – providing an incentive to use increased physical and / or population density to support local diversity. Sensitive densification is required to achieve the carrying capacities of these existing urban fabrics. Badalona and Pomar are characteristic of the 1950s - 60s era 'Urgency Period' developments with low physical and / or population densities.

Sant Cugat and Santa Coloma on the other hand have high physical densities but relatively lower population densities than other similar sites. This suggests all four of these sites could be the focus of urban infill to selectively increase population.

Figure 5/23 (above), Figure 5/24 (following page)


Selective densification, infill with local attractions such as gyms, community centres, child-care etc.
Where necessary, private car parking underground
Active commercial groundfloors
Bike paths on both sides of the road, calming vehicle speeds
Comfortable pedestrian space
Family friendly spaces

Other much lower-density sites located on the fringes will be far less advantaged by less energy. These include Cerdanyola, Mira-Sol, SantJust, l'Alba Rosa and to some extent Pedralbes. These sites are generally too spread out for densification and do not have the urban structure that would allow simple infill. All these sites are associated with higher income groups which, if given financial choice are likely to fight against collective mobility with electric vehicles based on off-the-grid energy sources.

Proximity cannot operate without suitable densities. Population densities in certain areas will need to be increased before essential shops (grocery shops, bakeries, fruit shops), businesses (hair dressers, accountants, lawyers) and services (health and civic) can be made commercially viable. Herce points out there are some administrative challenges that are triggered when new residential development exceeds 10,000 residents / km2 which further favour smaller infill development (Herce 1992).

With reduced mobility within dense urban areas, open space will become a considerable issue. In many cases this will require innovative interventions. Increasing the amount of public space, particularly since the 1980s in Barcelona, has involved reclaiming streets and in some cases opening interior courtyards to the public. The Rambla del Raval, Avinguda Mistral and most recently Passeig de San Joan are characteristic of this.

Some public services and civic centres will also need to become more accessible and thus smaller. Hospitals may need to reduce in size and be restructured into health centres where they treat basic ailments. Libraries may need to appear more like cultural centres than repositories of books – associated with open space and other community facilities.

With the loss of mobility, large commercial centres will likely experience a contracting consumer catchment. Attention will therefore return to many smaller local neighbourhood-scale shopping areas.

Jobs and employment conditions are also likely to change dramatically. Organisations will need to find new ways of assessing performance, which will allow for some services industry workers to distribute their working time between workplaces near their homes and offices located elsewhere in the city. This also could allow work-spaces to be shared and for larger organisations to afford more centrally located office space.

Neighbourhood densification

Concentrated densification should occur in areas that contain suitable levels of accessibility to the rail network and in areas of lower population densities which require improvements to increase diversity, commercial areas or general amenities. Infill development is preferential as it allows mixed uses to be integrated into the larger neighbourhood area based on existing needs and market opportunities, described below.

Diversity in the block

While the 'super-block' appears to be a healthy and effective strategy, it is also likely to inspire inequality. Blocks associated with the 'fast' roads inevitably will be exposed to higher noise levels and less tranquil environments. These streets may alternatively be much more attractive for other functions requiring higher levels of exposure and accessibility.

As it is clear that space is required to support diversity, building owners must see the commercial benefit of their street level space and convert inactive facades into shops or commercial space. Building owners may need to be compensated for potential disadvantages if located on an street unsuitable for their business. However gains could also be made if buildings are suitably adapted to attract commercial interests. A greater level of diversity should therefore occur at the neighbourhood block level and building level to distribute functions and jobs.

While this may seem tangential to energy consumption, it forms the fundamental basis for renovating and retrofitting unbalanced neighbourhoods. Without this level of mix,

Figure 5/25 + 5/26: *Biblioteca de Sant Marti, a recently developed community space which provides small, locally focused facilities. The library is small and simple. Other facilities include a community centre and public open space.*

Figure 5/27 (above), Figure 5/28 (following page)


Increased vertical density
Active commercial groundfloor.
Delivery and resident vehicle access only
Active commercial groundfloor.
Higher speed biking lanes, grade separated from the pedestrian areas

proximity to a range of shops, goods, services and open space would be difficult to achieve.

Decentralised jobs

As a large number of jobs are service based, many workers do not need a physical work place therefore reducing transport related energy consumption. Service jobs currently account for over 80% of the job market and also a significant amount of energy consumption that may be easily improved in work conditions were to change. Significant changes may consequently occur at a local level.

A number of these require location based jobs, while others could be partially location based or occasionally location based. In other words to reduce transport costs and congestion, workers may choose to start work intermittently throughout the day to distribute peak travel periods, alternatively work half days or half-weeks at the office location – thus modifying usage of the transport systems to improve travel distribution, reduce operation costs, travel time and most importantly energy (Vuchic 2005).

Telecommuting is a concept that has been promoted for many years both locally (Ajuntament de Barcelona 2011) and internationally (USDOT 1992) with mixed results. Residents with higher incomes and less travel requirements may find the lower density suburbs an attractive option. In this way telecommuting may in fact provide conditions for

Figure 5/29: *Will something as modest as increasing tele-comuting and the home office have an impact on urban areas? (Brotschi Labs 2012)*

sprawl and / or encouraging living away from the centre; this kind of strategy needs to be carefully structured. While this model is highly conceptual it may become a practical reality if mobility patterns are limited yet communications technology contines to improve.

Initially this kind of strategy could be instigated through taxing or a tax incentive to employers and employees who actively promote working near their homes. Such an incentive would be economically viable for employers, transport operators and energy providers. However if transport costs or congestion rise, then telecommuting may evolve into a natural trend.

The spatial implications of such a strategy will inevitably mean greater investment in the residential communities where work is being done. This in turn will support a greater number of shops and even services. It may also mean an improved demand for smaller office space, located within homes or within local commercial areas. All of this can help reduce mobility related energy dependence but the consequences require further research.

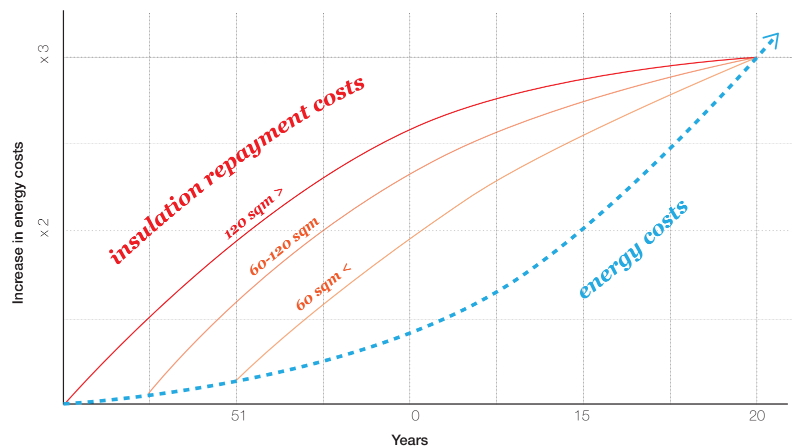
Resilience for the building level

Domestic energy consumption has been projected to be reduced to 29% of former levels in the event of a global energy calamity. Much of the savings are likely to occur through more conscious use of technology, heating and hot water. However with most of the city's building stock constructed prior to the thermal standards legislation of 1979, many parts of the city have poor insulation. Heating forms a significant amount of the city's overall energy budget (close to 7%) and can be easily addressed. If not, it will remain a drain on the energy producing infrastructure and heating will compete with other energy demands such as industry and employment.

While a large part of domestic energy consumption is associated with life style comforts (televisions, entertainment and communications technology, excess lighting, kitchen appliances, air-conditioners and excess heating etc), there are certain limits to energy forced savings before quality of life may be affected (i.e. suitable thermal conditions).

As this strategy involves buildings, owned and used by individuals or workplaces, investment must be largely driven by individuals. Individuals also have much to gain if energy costs rise, particularly with over 50% of the domestic energy budget dedicated to heating and hot water in a relatively temperate Mediterranean climate.

Figure 5/30: *Many buildings have remained largely unchanged since first built. Therefore energy reduction strategies at the building level will involve retrofiting a large portion of the building stock. Pricing is considered the most effective method to cover construction costs and encourage voluntary energy reduction.*



With a large part of Barcelona's building stock requiring improvements, a gradual development process is necessary, particularly to keep costs competitive and effective. Simple building changes may be the most effective strategy. Windows could be double-glazed. Cavity walls and ceilings could be insulated and openings properly sealed.

A policy strategy involves increasing energy costs in accordance with occupied floor space for buildings that do not pass certain thermal performance criteria. As few residents will have the finances or inclination to invest in suitable insulation, a strategy to finance insulation could involve repayment through increased energy costs – the additional costs for each bill would be related to the amount of refurbishment required to raise the building to suitable standards. With energy costs projected to triple, the 'repayments' could reduce as energy prices rise.

As has been identified, residence size is associated heavily with income – which likewise is associated with energy consumption. Income is also associated with age of building as generally the larger residences were also the most recently developed (within the last 50 years).

The strategy involves a raising energy costs steeply to firstly encourage energy savings and secondly to better accommodate future energy costs. When the insulation has been repaid by the consumer, prices will have transitioned such that the consumer is unaware of the actual energy prices. The strategy would start with the largest consumers – those with the largest incomes. Smaller residential units could be the last to fall into the scheme and then attract a suitable subsidy to help.

This policy would also be calculated on the number of inhabitants in a dwelling, as inhabitants share demand. A spatial outcome of this policy may be that larger dwellings that do not support higher income residents are subdivided – this can be seen as an oblique strategy for densification.

Figure 5/31: *In some cases, areas that were occupied by once large dwellings may be divided into allow for smaller lots (A + B) due to increased energy costs. This may obliquely attract further population density and even necessary diversity with certain districts.*

Chapter Conclusions

The most efficient method to significantly reduce energy consumption involves using compact development, minimising travel demands, and sharing resources and access to high speed collective mobility systems. Conditions must be developed that make living in denser areas more attractive without significantly reducng current quality of life standards.

Establishing energy consumption objectives may be the most effective strategy to achieve urban planning objectives amongst incompatible interest groups,

Three strategies were explored: mobility, densification and neighbourhood energy consumption. These may directly or indirectly reduce energy dependence through increasing proximities, reducing travel and increasing independence.

Strategies to change mobility conditions in the short term will involve penalising drivers with charges and changing road conditions to reduce flow rates, while improving collective transport connections and non-motorised transport networks. Technical strategies for promoting greater levels of cycling are considered to be very important.

The concept of the 'super-block' involves an integrated neighbourhood level mobility and land use strategy. In this way a diversity of transport modes and commercial and residential conditions can be achieved at the 'super-block' scale while residents can be provided with greater access to public space or tranquil areas.

As diversity is related to density, both increased diversity and density can be achieved simultaneously with infill development.

Some low-density areas will be unsuitable for increased densification. Such areas represent relatively small portions of the population, spread over large areas. Therefore residential areas on the periphery will either support high-income residents who can afford the expense associated with high-energy lifestyle costs, or these areas will decline. Such areas include Mira-Sol, Cerdanyola, l'Alba Rosa. Other low density and low-income sites of the periphery such as Pomar and Badalona will require greater levels of densification and diversity or else they too will be heavily impacted by rising energy costs.

There are many sites which with small modifications could become much more effective. These include Gavà, El Prat, St Feliu, SantCugat and Santa Coloma – and similar types can be found across the city. Other higher density city centre sites currently support high levels of diversity and proximity to services and shops – however a number require particular interventions to improve quality of life standards - for instance open space.

6

Conclusions & Reflections

How would our cities tolerate sudden reductions in energy availability? What areas will be most suited to less energy and what changes will be necessary?

Energy, or more specifically electricity, is the basis of modern cities; without it modern cities would collapse. There are few other challenges apart from war, disease and lack of food that expose cities to such a sudden demise. This could be minimised if urban planning were focused around energy consumption and the conditions required to support lower energy lifestyles.

The notion of a lower energy lifestyle is often associated with ideas of rationing, of hardship and of less – hardly an attractive option based on current quality of life standards.

The approach used in this research is quite the opposite. It takes the position that by obliquely focusing on existing quality of life standards, or more specifically improving aspects of them, robustness can be built into urban form to accommodate changing energy conditions. This approach is likely to attract stakeholder confidence through an energy 'decoupling' process.

As transport accounts for 24% of total energy consumption in the city and over 40% elsewhere in the state, the research has focused largely on mobility patterns and qualities of urban form that may trigger mobility. Based on the research, findings indicate that urban form is a trigger for mobility demands. In some cases people travel because of work opportunities or because there is no other effective mobility option. In other cases, people travel to access goods, entertainment, fitness or sport, places or people that are not nearby. The demand for these is greater than the demand for work travel and if they are not found nearby, mobility will be involved (with a preference to private modes).

Robustness was also explored at the building level – of which dwellings account for 28% of the city's energy, 14% at the regional level. Domestic energy consumption largely involves heating (one quarter thermal and one quarter hot water). Inherently building energy demands were found to be highly connected to income levels – by virtue of dwelling size rather than a factor of use.

The research shows population density in association with higher levels of gross floor area (FSI) and footprint (GSI) were found linked to higher levels of shops, venues and services. In this way densification can be used as a tool to transition imbalanced or poorly performing areas by integrating facilities or the amenity required to promote lower travel levels and improve existing qualities of life. In addition, many of the frivolous, high energy consuming habits accepted under today's energy conditions will need to be re-accommodated into design strategies.

Based on a Futures Study, conditions were imagined in terms of a likely reduction in energy supply, 20 years from now. After evaluating current energy supplies, a 40% scenario was developed. This involved considering how mobility conditions would evolve, how work conditions could be reconfigured and how urban areas would be likely to absorb changes. In accordance with Steinitz's methodology framework, 'design models' were produced consisting of a number of metropolitan neighbourhood scale strategies.

Generally, the metropolitan area has been distinguished into six zones according inheret energy consumption performance. This type of mapping helps to plan for mobility and urbanisation strategies at a city scale and to help target further research at a neighbourhood scale.

On the metropolitan scale, road pricing is a strategy to reduce private transportation. This will not likely be well received by current commuters so it requires a counter-strategy through increasing access and / or frequency of collective transport. Reconfiguring the metropolitan road network will be a strategy, including creating a greater balance between private, collective and non-motorised modes.

At a neighbourhood level it was found that the most effective remediation targets are the medium / higher density urban areas. A strategy to improve these areas involves defining 'super-blocks', producing small neighbourhood unit areas which allow residents access to pedestrian networks and open space, encourage walking and cycling and improve diversity with increased commercial and retail on the ground-floor areas. This strategy requires modifying traffic networks and selective infill to either increase population densities or target necessary commercial spaces. Some areas with medium population densities

Figure 6/01-04: Small changes, offer a big difference in terms of energy consumption combining density and proximity. Carrer Enrique Granados (top left and top right), a mostly pedestrian street - which is also one of the most expensive in the Eixample. Recent changes to Passeig de San Joan (bottom left) which reduces 6 lanes into four, providing much needed public space. A open courtyard in the Eixample offers a recreation space (bottom right).

yet less organic urban form, particularly sites developed during the Urgency Period, could likewise be densified but with far greater investment. Lower density areas (both in population and urban form) were consistently associated with higher income levels, higher car ownership / dependence and were expected to be less responsive to densification. Consequently lower density, high income areas located on the periphery of the metropolitan area will need to adopt other strategies to cope with lower energy conditions.

Finally considerations were made for reducing energy demands in buildings by implementing a city-wide insulation strategy. This involves targeting the source of the highest consumption first, through a 'tax' or 'insulation pricing scheme' aimed at larger dwellings. As this strategy targets per capita dwelling size rather than the highest consumers, the outcome may be the division of larger residential units to reduce energy costs - consequently increasing density too.

Through this research, it was found that urban areas could demand far less energy if comprehensive metropolitan level strategies are implemented. Changing lifestyles, in this case, means also improving them – which is an approach based on Odum & Odum's 'Prosperous Way Down' scenario. Based on this approach, density is seen as a tool to increase proximity to shops and services, open space and slow mobility networks.

This research has largely used associative rather than causal links to energy consumption so conclusions reached require support by more focused research. This may include understanding how users connect with their neighbourhoods, why they travel and how, what limiting factors there are on travel and to consider the perceived impacts of reduced energy conditions on actual mobility patterns. A combination of more precise quantitative and qualitative data is fundamental for understanding these ephemeral and relatively obscure urban processes.

7

Appendicies / Terms / Appreciations

Appendix A - Data

Data Sources

- INE 2001: 2001 National Census data (www.ine.es)
- IDESCAT: General annual population statistics for Catalunya (www.idescat.cat)
- Ajuntament de Barcelona: a combination of local data, census data, cadastral data and survey data. (http://w20.bcn.cat/opendata/Default.aspx?lang=CAT)
- Generalitat de Catalunya: generally state survey data for residential, commercial, mobility and other data. They commission a detailed travel survey every five years for populations over 50,000 residents, last produced in 2006 (EMQ 2006). (http://www20.gencat.cat/portal/site/dadesobertes)
- ICAEN: Catalan institute of energy (http://www20.gencat.cat/portal/site/icaen)
- AMB (ÀreaMetropolitana de Barcelona): general statistic collated from both national and regional sources (http://cartografia.amb.cat/cartografia/)
- Sedecatastro – Ministerio de Hacienda y AdministracionesPúblicos: general cadastral maps (https://www.sedecatastro.gob.es/)
- InstitutoGeografico de España – Ministerio de Formento: regional maps (http://www.fomento.gob.es)
- InstitutoCartogràfic de Catalunya: general cartography data and maps (http://www.icc.es/)

Method used for data collection.

Schools - For the Municipality of Barcelona, used the PlanolBCN online map. Departamentd'Ensenyament online map (http://aplitic.xtec.cat/MapaEscolar/)

Supermarkets - Google Maps with search terms; supermercado, supermercat, supermarket, fruita y verdura, frutaiverdura, Caprabo, SupermercatDia, Mercadona, Condis

Bars / Restaurants / Cafes - Google maps search: bar, restaurant, café

Civic Centres - Google maps search: Centre Civic, Centro Civico. PlanolBCN.

Cinemas / Theatres - Guia de Carresrs de L'ÀreaMetropolitana de Barcelona

GIS - FIS + GSI - Using SEDECATASTRO with 'ParcelasUrbanas' only. Select building heights in the 'CONSTRU' category 'I' to 'XXII' (1-30 floors). Some areas incorrectly categorised were removed.

Calculation for Diversity

Using calculation defined by Frank and others (2006). Where Land use mix = A/(ln(N)) where A = (b1/a)*ln(b1/a) + (b2/a)*ln(b2/a) + (b3/a)*ln(b3/a) + (b4/a)*ln(b4/a) + (b5/a)*ln(b5/a) + (b6/a)*ln(b6/a)

a = total square metres of land for all six land uses present in buffer

b1 = square m. of building floor area in education uses

b2 = square m. of building floor area in entertainment uses

b3 = square m. of building floor area in single-family residential uses

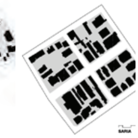
b4 = square ft. of building floor area in multifamily residential uses

b5 = square m. of building floor area in re

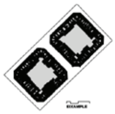
tail uses

b6 = square ft. of building floor area in office uses N = number of six land uses with FAR > 0

Appendix B Measures Table

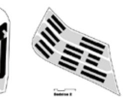


No.	Measure	Data source	Metric		
			Site Name	Pedralbes	Sarià
			Municipality	BCN	BCN
			Site Number	**1**	**2**
			Area (m)	66200	48600
			Lots (m)	48700	36759
			Coverage (m)	11000	25269
			L	2.5	4.6
			GSI	0.17	0.52
			FSI	0.42	2.39
			OSR	2.01	0.20
			Tare	26%	24%
			N (/m)	0.022	0.018
			w (/m)	92	110
			b (/m)	13	14
	Census no.			801905006	
	Census area			341070	237260
	% of census area			19%	20%
Density					
1.1	*Population density*	*INE (2001 census) + BCN*	Pop	120	828
1.2		*INE (census) + BCN*	Pop/km (block)	1813	17037
		INE (census) + BCN	Pop/km (area - 400m R)	5564	12756
1.3		*INE (census) + BCN*	No. dwellings	100	371
1.4			Av. dwelling size	127	125
1.5			Res/dwelling	1.20	2.23
1.6			Dwelling area m2/p	107	56
2.1	*Urban characteristics*	*BCN energy types*	Dom. blg type (below)	-	H5
2.2		*BCN energy types*	Av. Energy gWh/res/yr		7.63
2.3		*Above x FS / INE*	Energy p/capita		3.42
2.4		*GIS*	No. of lots		
2.5		*GIS*	Av. Lot size		
Income					
3	*Income (RFD =€16.555-BCN €16.900-CAT)*	Ajt BCN + IDESCAT	% RFD p/capita	196%	186%
4.1	*Age of buildings*	*INE (census) + BCN*	**% 30 yrs <**	2.2%	12.7%
4.2		*INE (census) + BCN*	**% 30-60 yrs**	83.4%	75.7%
4.3		*INE (census) + BCN*	**% 60 yrs >**	14.4%	11.6%
5	*% Commercial Ground floor*	*Mapping*	% total perimeter	0.0%	15.0%
Location/Proximity					
6.1	*Access to shops (supermarkets)*	*GIS / Mapping*	w/n 400m	1	6
6.2		*GIS / Mapping*	w/n 1000m	7	20
			pop/shop	2782	1063
7.1	*Schools (primary)*	*GIS / Mapping*	w/n 400m	3	4
7.2			w/n 1000m	22	25
8.1	*Entertainment*	*GIS / Mapping*	bars+restaurants (400m)	4	9
			pop (km2) / venue	906	3786
8.2			cmty ctrs (400m)	0	1
8.3			cmty ctrs (1000m)	1	2
8.4			cinema/theatre (1000m)	0	0
9.1	*Education*	*INE (census)*	primary (or less)	10.7%	10.5%
9.2		*INE (census)*	secondary	39.7%	39.5%
9.3		*Ajt BCN + IDESCAT*	tertiary	42.0%	41.9%
10.1	*Modal share (general)*	*Ajt BCN (district scale) 2010*	% private	32.5%	32.5%
10.2		*Ajt BCN (district scale) 2010*	% collective	23.0%	23.0%
10.3		*Ajt BCN (district scale) 2010*	% foot/cycle	44.5%	44.5%
10.4	*Modal share (to work) - internal*	*IDESCAT (municipal) 2001*	% private (inc. bike)	49.9%	49.9%
10.5		*IDESCAT (municipal) 2001*	% collective	44.7%	44.7%
10.6		*IDESCAT (municipal) 2001*	% private + collective	4.6%	4.6%
10.7		*IDESCAT (municipal) 2001*	% foot	0.8%	0.8%
10.8		*IDESCAT (municipal) 2001*	% TOTAL int. mobility	**81.3%**	**81.3%**
10.9	*Modal share (to work) - external*	*IDESCAT (municipal) 2001*	% private (inc. bike)	47.7%	47.7%
10.11		*IDESCAT (municipal) 2001*	% collective	25.5%	25.5%
10.12		*IDESCAT (municipal) 2001*	% private + collective	3.6%	3.6%
10.13		*IDESCAT (municipal) 2001*	% foot	0.3%	0.3%
10.14		*IDESCAT (municipal) 2001*	% TOTAL ext. mobility	**18.7%**	**18.7%**
10.15		*IDESCAT (municipal) 2001*	TOTAL movements	**590784**	**590784**
11.1	*Connectivity (to centre - Pl Catalunya)*	*Web/Mapping*	Private (minutes)	14	18
11.2		*Web/Mapping*	Collective (minutes)	26	21
12.1	*Service level Collective transport systems*	*Timetable*	services p/hr	6	10
12.2			(Rail, Metro, Tram, Bus)	M.B	M.B
13	*Pedestrian environments*	*Mapping*	% street pedestrian	30%	30%
14.1	*Open public space*	*Mapping*	number	3	4
14.2		*Mapping*	area (m²)	13080	58600
14.3			m2/pop density	14.4	6.9
15.1	*Vehicle ownership*	*INE (census)*	Cars/1000	594	496
15.2		*INE (census)*	Motorbikes/1000	339	338
16.1	*Car parking*	*GIS*	On street	180	80
16.2		*GIS*	Off Street	75	360
16.3		*GIS*	p/population	2.13	0.53

Carmel	Eixample	Raval	Barceloneta	Villa Olimpica	Llacuna	St Martí	Bon Pastor	Gavà
BCN	BCN	BCN	BCN	BCN	BCN	BCN	BCN	Gavà
3	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
23600	36000	25400	8600	76800	36500	36800	19400	31600
19600	25400	19600	4300	43700	24400	23000	10600	24975
8000	17000	15700	4200	40500	23900	10700	10000	20855
1.2	5.2	4.3	5.4	4	3	7	1	3
0.34	0.47	0.62	0.49	0.53	0.65	0.29	0.52	0.66
0.41	2.46	2.66	2.64	2.11	1.96	2.04	0.52	1.98
1.63	0.21	0.14	0.19	0.22	0.18	0.35	0.94	0.17
17%	29%	24%	50%	47%	33%	38%	45%	21%
0.024	0.015	0.022	0.076	0.013	0.015	0.018	0.074	0.023
82	135	90	26	160	136	110	27	86
7	22	11	8	44	25	23	7	10
801907058	801902080	801901010	801901038	801910055	801910058	0801910115 + 0801910114	801909011	808902003
63000	122000		16620	414460	76213		65570	47670
37%	30%	100%	52%	19%	48%		30%	66%
534	1402	2561	995	958	478	1495	538	629
22627	38944	100827	115698	12474	13096	40625	27732	19905
29368	28572	62780	25970	8220	7512	28542	11094	26394
296	684	920	529	461	241	646	231	512
53	141	62	40	114	73	76	47	81
1.80	2.05	2.78	1.88	2.08	1.98	2.31	2.33	1.23
29	69	22	21	55	49	35	20	66
H6	H3	H1	H1	H7	H4	H5	H2	H4
3.91	8.50	4.31	2.78	11.48	7.45	4.64	3.32	8.31
2.17	4.15	1.55	1.48	5.52	3.75	2.00	1.42	6.76
108%	143%	62%	64%	141%	87%	77%	57%	90%
19.5%	8.1%	10.1%	12.0%	100.0%	30.2%	44.7%	0.0%	17.0%
67.7%	30.7%	9.0%	27.3%	0.0%	28.9%	54.8%	0.0%	66.3%
12.8%	61.2%	80.9%	60.7%	0.0%	40.9%	0.5%	100.0%	16.7%
0.0%	100.0%	85.0%	75.0%	65.0%	90.0%	50.0%	5.0%	80.0%
2	11	15	11	1	3	5	3	6
18	65	70	20	6	14	13	6	10
7342	1298.727273	2092.666667	1180.454545	4110	1252	2854.2	1849	2199.5
2	4	4	3	1	1	4	2	5
19	22	15	5	8	10	13	3	15
18	120	148	82	36	54	30	15	27
2514	649	1363	2822	693	485	2708	3698	1474
1	1	2	2	1	0	1	1	0
2	4	7	3	1	2	1	1	0
3	12	20	1	2	6	1	0	1
19.6%	13.0%	36.2%	29.7%	9.4%	23.9%	28.5%	34.8%	40.0%
45.5%	39.0%	35.5%	37.6%	33.4%	42.7%	43.8%	40.8%	49.0%
22.5%	40.4%	17.7%	17.2%	48.7%	21.3%	12.3%	9.5%	10.0%
19.3%	20.7%	10.6%	10.6%	19.9%	19.9%	19.9%	22.0%	-
35.4%	33.3%	31.9%	31.9%	28.2%	28.2%	28.2%	27.9%	-
45.3%	46.0%	57.5%	57.5%	51.9%	51.9%	51.9%	50.1%	-
49.9%	49.9%	49.9%	49.9%	49.9%	49.9%	49.9%	49.9%	94.0%
44.7%	44.7%	44.7%	44.7%	44.7%	44.7%	44.7%	44.7%	5.1%
4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	0.6%
0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	0.3%
81.3%	**81.3%**	**81.3%**	**81.3%**	**81.3%**	**81.3%**	**81.3%**	**81.3%**	**40.3%**
47.7%	47.7%	47.7%	47.7%	47.7%	47.7%	47.7%	47.7%	59.1%
25.5%	25.5%	25.5%	25.5%	25.5%	25.5%	25.5%	25.5%	24.2%
3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.4%
0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
18.7%	**18.7%**	**18.7%**	**18.7%**	**18.7%**	**18.7%**	**18.7%**	**18.7%**	**59.7%**
590784	**590784**	**590784**	**590784**	**590784**	**590784**	**590784**	**590784**	**15775**
19	5	5	10	10	10	12	17	29
31	5	5	17	16	17	18	25	43
10	20	20	10	15	15	15	15	6
M.B	R.M.B	M.B	M.B	M.B	M.B	M.B	M.B	R. B
30%	50%	100%	30%	50%	50%	50%	20%	30%
3	3	5	9	18	5	20	13	15
30750	2450	29725	123455	225910	15785	81660	43425	50252
2.7	0.1	0.6	2.1	36.2	2.4	4.0	3.1	5.0
454	486	167	262	372	292	370	343	435
241	249	109	161	158	124	135	100	74
28	42	252	52	50	62	128	80	60
116	212	0	0	919	5	0	0	467
0.27	0.18	0.10	0.05	1.01	0.14	0.09	0.15	0.84

No.	Measure	Data source	Metric		
			Site Name	l'Alba-Rosa	El Prat
			Municipality	Viladecans	El Prat
			Site Number	**12**	**13**
			Area (m)	40700	40750
			Lots (m)	32100	31110
			Coverage (m)	10000	24630
			L	1.5	3.8
			GSI	0.25	0.60
			FSI	0.37	2.30
			OSR	2.05	0.17
			Tare	21%	24%
			N (/m)	0.025	0.024
			w (/m)	80	84
			b (/m)	9	11
	Census no.			830102005	816902002
	Census area			152441	77080
	% of census area			27%	53%
Density					
1.1	*Population density*	*INE (2001 census) + BCN*	Pop	274	981
1.2		*INE (census) + BCN*	Pop/km (block)	6732	24074
		INE (census) + BCN	Pop/km (area - 400m R)	6358	33460
1.3		*INE (census) + BCN*	No. dwellings	104	762
1.4			Av. dwelling size	95	87
1.5			Res/dwelling	2.63	1.29
1.6			Dwelling area m2/p	36	68
2.1	*Urban characteristics*	*BCN energy types*	Dom. blg type (below)	-	H4
2.2		*BCN energy types*	Av. Energy gWh/res/yr		8.87
2.3		*Above x FS / INE*	Energy p/capita		6.89
2.4		*GIS*	No. of lots		
2.5		*GIS*	Av. Lot size		
Income					
3	*Income (RFD =€16.555-BCN €16.900-CAT)*	Ajt BCN + IDESCAT	% RFD p/capita	110%	85%
4.1	*Age of buildings*	*INE (census) + BCN*	**% 30 yrs <**	29.7%	14.8%
4.2		*INE (census) + BCN*	**% 30-60 yrs**	66.5%	71.5%
4.3		*INE (census) + BCN*	**% 60 yrs >**	3.8%	13.7%
5	*% Commercial Ground floor*	*Mapping*	% total perimeter	0.0%	50.0%
Location/Proximity					
6.1	*Access to shops (supermarkets)*	*GIS / Mapping*	w/n 400m	0	6
6.2		*GIS / Mapping*	w/n 1000m	7	14
			pop/shop	0	2788.333333
7.1	*Schools (primary)*	*GIS / Mapping*	w/n 400m	1	3
7.2			w/n 1000m	12	13
8.1	*Entertainment*	*GIS / Mapping*	bars+restaurants (400m)	3	35
			pop (km2) / venue	4488	1376
8.2			cmty ctrs (400m)	0	0
8.3			cmty ctrs (1000m)	0	2
8.4			cinema/theatre (1000m)	2	3
9.1	*Education*	*INE (census)*	primary (or less)	32.8%	46.9%
9.2		*INE (census)*	secondary	51.0%	45.8%
9.3		*Ajt BCN + IDESCAT*	tertiary	16.2%	7.3%
10.1	*Modal share (general)*	*Ajt BCN (district scale) 2010*	% private	-	-
10.2		*Ajt BCN (district scale) 2010*	% collective	-	-
10.3		*Ajt BCN (district scale) 2010*	% foot/cycle	-	-
10.4	*Modal share (to work) - internal*	*IDESCAT (municipal) 2001*	% private (inc. bike)	93.3%	87.1%
10.5		*IDESCAT (municipal) 2001*	% collective	5.6%	11.0%
10.6		*IDESCAT (municipal) 2001*	% private + collective	0.8%	1.5%
10.7		*IDESCAT (municipal) 2001*	% foot	0.3%	0.4%
10.8		*IDESCAT (municipal) 2001*	% TOTAL int. mobility	**31.5%**	**48.4%**
10.9	*Modal share (to work) - external*	*IDESCAT (municipal) 2001*	% private (inc. bike)	62.5%	53.6%
10.11		*IDESCAT (municipal) 2001*	% collective	20.0%	30.7%
10.12		*IDESCAT (municipal) 2001*	% private + collective	4.0%	3.5%
10.13		*IDESCAT (municipal) 2001*	% foot	0.3%	0.3%
10.14		*IDESCAT (municipal) 2001*	% TOTAL ext. mobility	**68.5%**	**51.6%**
10.15		*IDESCAT (municipal) 2001*	TOTAL movements	**23507**	**12346**
11.1	*Connectivity (to centre - Pl Catalunya)*	*Web/Mapping*	Private (minutes)	28	18
11.2		*Web/Mapping*	Collective (minutes)	50	35
12.1	*Service level Collective transport systems*	*Timetable*	services p/hr	2	6
12.2			(Rail, Metro, Tram, Bus)	B	R, M, B
13	*Pedestrian environments*	*Mapping*	% street pedestrian	30%	20%
14.1	*Open public space*	*Mapping*	number	4	14
14.2		*Mapping*	area (m²)	16220	51319
14.3			m2/pop density	4.8	4.3
15.1	*Vehicle ownership*	*INE (census)*	Cars/1000	444	435
15.2		*INE (census)*	Motorbikes/1000	66	63
16.1	*Car parking*	*GIS*	On street	85	90
16.2		*GIS*	Off Street	45	400
16.3		*GIS*	p/population	0.47	0.50

St Feliu	Sant Just Des.	Bellvitge	Mira-Sol	St Cugat	Cerdanyola	St Coloma	Badalona	Pomar (Badalor
St Feliu	Sant Just Des.	L'Hospitalet	St Cugat	St Cugat	Cerdanyola	St Coloma	Badalona	Badalona
14	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
39800	42500	34200	64900	73987	40300	36380	57490	27840
26700	35500	21500	55170	58258	31200	29580	36200	22900
24000	10800	8000	11300	45525	11200	25230	20460	7024
3.5	1.8	12	2	4.2	2	3.5	4	4
0.60	0.25	0.23	0.17	0.62	0.28	0.69	0.36	0.25
2.11	0.46	2.81	0.35	2.58	0.56	2.43	1.42	1.01
0.19	1.63	0.27	2.37	0.15	1.30	0.13	0.45	0.74
33%	16%	77%	15%	100%	23%	19%	37%	18%
0.031	0.020	0.035	0.017	0.015	0.025	0.022	0.022	0.038
64	101	57	121	138	80	92	92	53
12	9	29	9	136	10	9	19	5
821103005	822101001	810106009 + 0810106024	820503002	820501007	826601006	824503008 + 0824503012	801504003	801506004
56380	274190	36800	1024477	58900	448120	35960	62580	35775
71%	16%	93%	6%	126%	9%	101%	92%	78%
1195	313	2025	150	3161	166	2427	1095	1072
30025	7365	59211	2304	42717	4119	66713	19048	38491
18802	8142	28958	2984	16516	5602	20484	11540	9546
755	126	866	46	903	64	901	475	849
83	112	78	140	82	105	70	83	68
1.58	2.48	2.34	3.25	3.50	2.59	2.69	2.31	1.26
53	45	33	43	23	40	26	36	54
H4	-	H4	-	H4	-	H4	H4	H4
8.49		7.96		8.36		7.14	8.47	6.94
5.36		3.40		2.39		2.65	3.67	5.50
95%	141%	67%	180%	68%	94%	73%	66%	50%
19.8%	15.3%	0.0%	31.3%	23.9%	58.4%	14.0%	5.2%	0.0%
69.1%	55.6%	96.3%	46.4%	67.5%	39.5%	83.1%	92.2%	100.0%
11.1%	29.1%	3.7%	22.3%	8.6%	2.1%	2.9%	2.6%	0.0%
20.0%	0.0%	5.0%	0.0%	30.0%	0.0%	60.0%	20.0%	0.0%
2	2	1	0	4	0	6	3	2
13	10	15	2	13	5	9	8	6
4700.5	2035.5	14479	0	2064.5	0	1707	1923	2386.5
0	1	2	0	1	1	3	5	1
9	9	15	3	6	4	9	9	5
10	9	15	1	23	1	22	7	1
6005	1637	7895	4608	3715	8238	6065	5442	76982
0	2	0	0	0	0	0	0	0
0	5	2	0	1	0	0	0	0
5	0	3	0	3	2	2	1	1
39.3%	28.0%	27.8%	23.0%	23.0%	26.3%	48.8%	34.3%	34.3%
49.3%	44.0%	62.3%	42.0%	42.0%	43.4%	45.4%	57.2%	57.2%
11.4%	27.0%	9.9%	35.0%	35.0%	30.3%	5.8%	8.5%	8.5%
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
94.0%	91.3%	84.7%	89.5%	89.5%	91.6%	87.1%	79.4%	79.4%
5.0%	7.5%	13.7%	8.3%	8.3%	6.7%	11.7%	18.6%	18.6%
0.6%	0.8%	1.0%	1.7%	1.7%	1.2%	0.9%	1.6%	1.6%
0.4%	0.3%	0.6%	0.5%	0.5%	0.5%	0.3%	0.4%	0.4%
33.7%	**29.1%**	**33.2%**	**35.4%**	**35.4%**	**33.8%**	**26.9%**	**41.7%**	**41.7%**
59.0%	73.0%	41.8%	59.1%	59.1%	64.4%	46.8%	51.7%	51.7%
25.4%	12.0%	42.4%	24.6%	24.6%	18.8%	36.9%	30.1%	30.1%
3.9%	4.0%	4.2%	6.3%	6.3%	4.2%	3.6%	3.6%	3.6%
0.5%	0.7%	0.4%	0.2%	0.2%	0.3%	0.3%	0.3%	0.3%
66.3%	**70.9%**	**66.8%**	**64.6%**	**64.6%**	**66.2%**	**73.1%**	**58.3%**	**58.3%**
17615	**5789**	**94179**	**26086**	**26086**	**29850**	**43509**	**77904**	**77904**
22	21	17	30	28	21	16	17	19
36	41	30	47	45	40	35	40	44
4	4	20	3	6	4	20	6	6
R. B	T. B	R. M. B	B	B	R. B	M. B	B	B
20%	20%	50%	20%	30%	20%	20%	50%	50%
5	9	44	7	25	5	5	8	6
27100	38550	68075	37750	168450	115700	57830	132350	114810
1.8	10.5	2.3	32.8	7.9	56.2	1.7	13.9	6.0
418	484	340	496	340	479	333	355	320
76	172	63	200	98	108	53	100	100
90	75	390	90	55	65	75	170	210
584	103	0	20	939	107	510	18	0
0.55	0.57	0.19	0.74	0.31	1.04	0.24	0.17	0.20

Terms

AMB – the managing authority charged with managing the Barcelona Metropolitan Area (Area Metropolitana de Barcelona). It involves three sectors: the urbanism (Macrocumunitat de AMB), mobility (EntidadMetropolitana de Transport) and environment (Mediambient de AMB).

Barcelona, City, metropolitan area– the 36 municipalities within the Metropolitan area.

BCN – Municipality of Barcelona

Collective transport – Public transport, transit, collective transit and high occupancy vehicles are all terms referring to high(er) capacity mobility. Sometimes these services are public, other times they are arranged privately, however all involve multiple travellers sharing energy demands of that trip. In this way taxis or public car-share are not considered collective transport as they result in higher energy consumption.

Decoupling – a term used by Banister and others to describe separating the mobility demand from mobility use (Banister 2000).

Modal Share–The distribution of mobility types according to use. Generally distributed in terms of private, public and non-motorised mobility. Modal share may be measured according to kilometres travelled or total trips.

Shops – throughout the study, shops refer to basic groceries, supermarkets, markets and other basic shops. This discounts fashion, appliances and speciality shops.

Robustness – in this sense robust refers to ability to handle reduced energy availability.

Urgencity Period – approximately a ten year period between the mid 1950s and the 1960s during which Barcelona experienced its greatest sudden growth with over 127,000 dwellings built.

Venues – refers to bars and restaurants.

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Biography

Adrian Vickery Hill

Born - 9/2/1982 (Montreal, Canada), Australian citizen.
adrian@colina.com.au

2011 - *kWh/m2, project assistant at TU Delft (a collaborative, multidisciplinary program combining various design disciplines within TU Delft and Wageningen University with H+N+S Land)*

2009 - 2012 *Masters of European Urbanism. Polytechnic University of Catalunya (1st semester), TUDelft Netherlands (2nd + 3rd semester)*

2010 *Certificate in animation, Escola Massana (Barcelona, Spain)*

2008 - 09 *Newcastle City Council, Public Art Advisory Committee*

2008 *AILA 2008 National Landscape Architecture Future Leaders Award*

2007 - 08 *Terras Landscape Architects, Associate*

2007 - *AILA registered landscape architect (001495)*

2007 - 08 *Trees In Newcastle, Chair*

2006 - 07 *Small Place, Artistic Director (Public art program)*

2006 - 08 *Australian Architecture Association - Newcastle Chapter*

2004 - 08 *Terras Landscape Architects (Newcastle, Australia)*

2003 - 04 *Urban Landscape Projects (Sydney) - Landscape Architect*

2004 *Bachelor of Landscape Architecture, UNSW (Sydney, Australia). Undergraduate thesis - Water Sensitive Urban Design Victoria Park, Sydney*

2002 - 03 *Anton James Design (Sydney), Landscape Designer*