Estimating Resource Consumption using Urban Typologies

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Abstract

This paper describes an approach developed to estimate the resource consumption of cities using urban typologies. Urban typologies are identified at the neighbourhood scale using parameters that describe the physical environment. These typologies are then used to estimate the resource consumption of neighbourhoods. The objective of this methodology is to identify relationships between parameters describing urban form and resource consumption. In this paper, the focus is on measuring the material required to construct the infrastructure and buildings required for each typology.

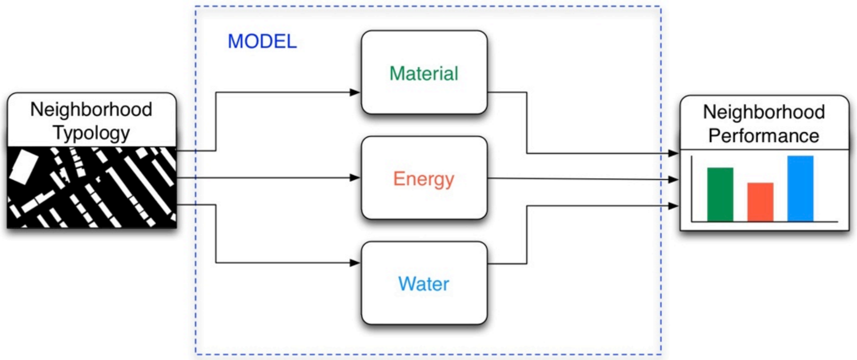

Figure 1: Neighbourhood typology analysis: this paper focuses on material usage.

Introduction

Typologies are identified from the existing building stock of London, and their material intensity is analysed. Material intensity is calculated based on construction materials used in residential buildings and urban infrastructure. Future work will examine the energy consumption of typologies (considering heating, cooling and transportation), as well as water consumption (*Figure 1*).

Background

This work draws upon the research area of urban metabolism to consider the resource demand of urban areas at the micro-scale. The analysis seeks to identify mechanisms of behaviour that consume resources and to develop a rigorous method to estimate resource demands. The focus on an explanatory mechanism is an important aspect of this work, as it can inform policy makers about strategic targets for resource efficiency.

Although global urbanization is rapidly occurring, most economic and resource-use data is collected at the national, or regional scale. Therefore, the development of standardized methods to calculate resource consumption at the neighbourhood scale has global relevance, as it can fill these systematic data gaps and help estimate the resource consumption of cities.

Urban Typologies

Developing an approach for urban typology identification and assessment is motivated by a holistic view of urban systems where trade-offs between material, energy and water consumption are explored. Through the development of a repeatable methodology for identifying urban typologies, the performance of urban forms can be compared throughout a city and across cities. Typologies can be analysed in detail, considering renewable energy potential [1], as well as urban heat island calculations, or urban air-flow patterns.

Characterizing urban form using typologies has previously been done using several different approaches. Some examples of typology analysis from US cities have considered land-use [2] and socio-economic factors [3], but physical criteria were not considered. Other work has examined the influence of neighbourhood-scale urban form on travel behaviour [4]. Detailed neighbourhood measurements were used to measure the policy effectiveness of an urban growth boundary, to identify if it had reduced urban sprawl [5]. Neighbourhood typologies have also been used to examine energy use. Yamaguchi [6] divided Osaka city into representative districts depending on their land-use, and created typologies using urban form measures. These typologies were then used to predict the energy used for heating and cooling.

METHODOLOGY AND DATA

This analysis is structured in two parts. The first part describes the process of identifying typologies through grouping of urban form measurements; the second part describes how these physical characteristics are converted into material units. This analysis is applied to the greater London area at the *Lower Layer Super Output Area*[1] (LLSOA) scale. In the greater London area there are approximately 5600 LLSOA units. Average values for the number of people, buildings and area, per LLSOA, are summarized in Table 1.

Measure	**Count (St. Dev.)**
Population	1500 (11)
Buildings	178 (113)
Area [km^2]	0.49 (1.4)

Table 1: Average characteristics of LLSOAs used in this analysis

Typology Identification

Physical parameters were identified that describe the urban form (Table 2) and these measures were used to identify clusters. The data sources used for clustering in this analysis were a 3D building model [9] and a 3D building model with land-use categorizations [10]. After calculating urban form measures for each LLSOA, a statistical clustering technique was used to identify groupings in the data.

Category	**Description**
Plot Ratio	Total floor space / LLSOA area
Green Space Fraction	Total green space / LLSOA area
Built Area Fraction	Total built footprint / LLSOA area
Average Building Height	Average height of buildings in LLSOA

Table 2: Measurements of urban form (both residential and commercial buildings are included)

[1] The LLSOA is a spatial unit defined by the UK census bureau [8]

The k-means algorithm was used to identify the clusters. This algorithm partitions data into k number of clusters (where k is chosen based on graphical observation), using n observations. In this case, three cluster groups were chosen (k=3, n=5625) and the statistical language R [11] was used for the calculations. The implementation of k-means in R was the default McQueen implementation, which functions by iteratively partitioning the data until it reaches convergence. The resulting clusters were then used to identify building typologies.

Material Conversion Factors

Several data sources were used to estimate the amount of material required to construct infrastructure and residential buildings. These data sources came from guidelines for road construction [12-16], aggregated surveys of existing buildings [17], and typical construction methods [18].

Infrastructure: Using UK road construction guidelines, values to convert geometric measurements of various road types into kilograms of materials were calculated by examining UK local council guidelines [12-16]. The data from these sources are summarized in Table 3.

	Asphalt	**Gravel**
Thickness *[m]*	0.15	0.34

Table 3: Local or minor road construction specifications

Linear vector layer road data with road-type categorization was used [19], in addition to polygons representing roads [10]. These polygons, which represented the street network [10], accurately measured the varying street widths using remote sensing data.

Residential Buildings: Residential buildings were identified from the UK building dataset [10] and analysed at the LLSOA level. In the study area, over 92% of houses in the English Condition Housing Survey (EHCS) [17] were constructed of masonry (masonry cavity 64.7%, solid masonry 27.2%). A typical masonry cavity house (the average glazed area was 37% of the wall area) was used to estimate the material requirements for an average house. Based on typical construction methods, conversion factors for wall, floor and roofs were calculated (Table 4). These conversion factors were then used to convert the geometric measurements of residential buildings into kilograms of materials.

Element	**Masonry** [kg/m^2]	**Glazing** [kg/m^2]	**Timber** [kg/m^2]
Wall	480	10	-
Roof	-	-	21
Floor	-	-	32

Table 4: Typical material requirements for the shell of an average masonry cavity wall.

RESULTS

The typologies shown in Figure 2, were identified using the urban form measures described in Table 2. These boxplots summarize the distributions of the input measurements by cluster. The boxplots exhibit a reasonable separation for each of the three groups (the mid-range of the quartiles do not overlap for three of the four variables). The results from the clustering process are used to categorize each LLSOA into one of the three typologies. The spatial distribution of the clusters is shown in a map of the greater London area in Figure 3. A representative example of each of these clusters is shown in Figure 4 where the differences in the urban form can be understood intuitively.

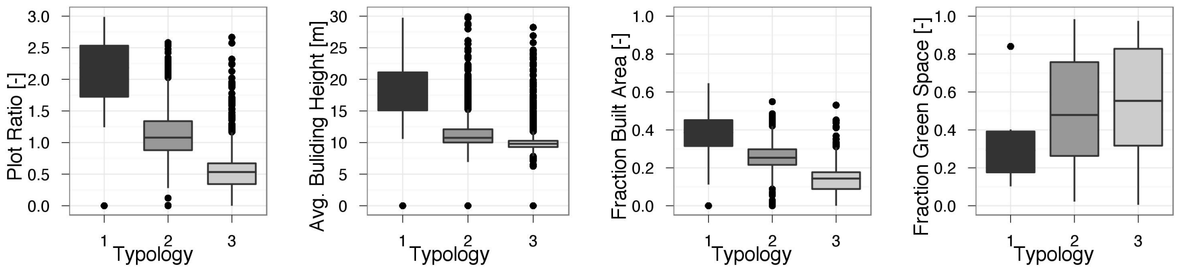

Figure 2: Typologies identified from clustering using urban form measures

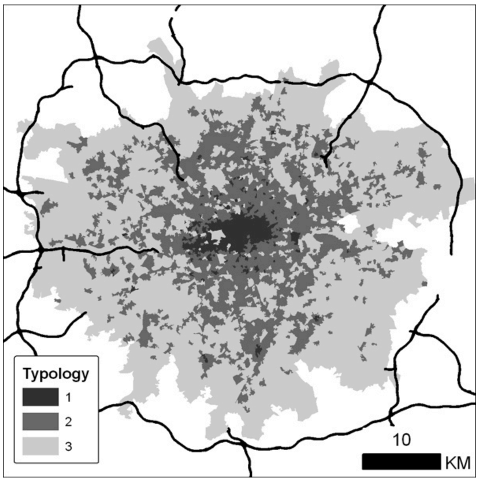

Figure 3: Map of London showing the grouping of the LLSOA divisions in three clusters. The black line represents the motorway around London.

These typologies are distributed radially (Figure 3) and reflect the population density of London. As a measure of population density is not used as an input, the typologies are considered to be an appropriate characterisation of the urban form.

Figure 4: Examples of a representative LLSOA unit from each typology

Although the material conversion factors used have several simplifications regarding residential construction (see section on Material Conversion Factors); the envelope area of residential buildings has a more significant impact on material consumption, than the road area of local infrastructure (Figure 5). Although typologies 2 and 3 have comparable amounts of green space (Figure 2) and similar material requirements per household, the variation in urban form can be explained through a difference in plot ratio (Figure 4) and infrastructure per household.

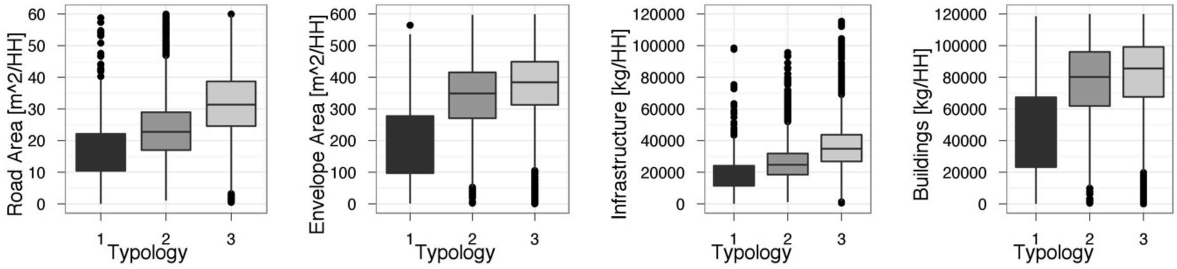

Figure 5: Area of infrastructure and residential envelope; material required for infrastructure and residential buildings. All measures are per household and typology.

DISCUSSION

Through the calculation of material required for the built environment of the three different typologies, a spatially resolved resource intensity measure has been obtained. This measure can be used to develop an efficiency metric, where the resources required for a certain typology, are attributed to the residents of that neighbourhood[2]. However, the fabric of the urban form is not homogeneous as there is usually a mixture of land-use types, where residential and commercial areas are mixed. Adequately attributing the physical infrastructure to residents requires measurements of the relevant part of the built environment that is used by residents. In this study, only the residential aspect of urban form was considered and a distinction between road infrastructure and buildings was made. In the case of roads, only local and minor roads were considered to be directly attributable to each LLSOA; motorways and major arteries have been excluded from the calculation of material required for the road infrastructure per LLSOA.

Using these assumptions the road are and envelope area are shown in Figure 5. Using the material conversion factors previously described, estimates of the material required for infrastructure and buildings are also shown in Figure 5. In a future phase of this work, a more comprehensive measure will consider the amount of business activity so that non-residential material intensity can also be calculated.

CONCLUSION

The goal of this work was to develop a repeatable methodology for estimating typology performance based on resource consumption; an approach that can be applied to different cities around the world. Formalizing how to identify typologies and how urban typologies perform with regard to material intensity is the first step in this approach. This analysis has shown that urban typologies can be identified using simple neighbourhood scale measures of the urban form. Comparing the material intensity of each typology has shown significant differences in the material quantities in the case of the greater London area.

The potential practical impacts of this work are two-fold: (1) the knowledge acquired can be used in urban design by helping improve design guidelines for new sustainable neighbourhoods; (2) this analysis can contribute to policy development, by identifying areas relevant for regulation so that improved urban resource efficiency can be achieved.

[2] Such an efficiency measure assumes that both neighborhoods are providing the same unit of service which could be measured using a 'quality of life' metric. However, this is a subjective measure.

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