

# A machine learning-based method for the large-scale evaluation of the qualities of the urban environment



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## ARTICLE INFO

### Article history:

Received 13 August 2016

Received in revised form 30 May 2017

Accepted 14 June 2017

### Keywords:

Machine learning

Physical quality

Street view image

Urban design

Architecture

## ABSTRACT

Given the present size of modern cities, it is beyond the perceptual capacity of most people to develop a good knowledge about the qualities of the urban space at every street corner. Correspondingly, for planners, it is also difficult to accurately answer questions such as 'where the quality of the physical environment is the most dilapidated in the city that regeneration should be given first consideration' and 'in fast urbanising cities, how is the city appearance changing'. To address this issue, in the present study, we present a computer vision method that contains three machine learning models for the large-scale and automatic evaluation on the qualities of the urban environment by leveraging state-of-the-art machine learning techniques and wide-coverage street view images. From various physical qualities that have been identified by previous research to be important for the urban visual experience, we choose two key qualities, the construction and maintenance quality of building facade and the continuity of street wall, to be measured in this research. To test the validity of the proposed method, we compare the machine scores with public rating scores collected on-site from 752 passers-by at 56 locations in the city. We show that the machine learning models can produce a medium-to-good estimation of people's real experience, and the modelling results can be applied in many ways by researchers, planners and local residents.

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## 1. Introduction

As a city grows, it becomes hardly possible for its dwellers, as well as planners, to gather a complete knowledge about how it looks at every street corner and in every narrow alley (Lynch, 1960). Theoretically, the human perception of the urban environment is inherently incomplete, discontinuous and distorted, as depicted by research on cognitive mapping (Downs & Stea, 1973) and the city's image (Lynch, 1960). It is especially the case, given the overwhelming size of modern cities. Questions such as 'which are the worst-looking places in the city where regeneration should be given first consideration' and 'in fast urbanising cities, how is the city appearance changing' are hard to answer.

For the past many years, several studies have attempted to measure a city's appearance in a consistent manner on a larger scale (Harvey, 2014). The dominant method is by sending human auditors to the field to observe and record the city's appearance (Brownson, Hoehner, Day, Forsyth, & Sallis, 2009). However, this method is quite limited in terms of sample size because its manual nature makes it inherently expensive and derives few economy of scale (Harvey, 2014). Recently, the

availability of online street view images, which have an unprecedentedly wide coverage on the built environment, provides a new methodological opportunity for this topic (Dubey, Naik, Parikh, Raskar, & Hidalgo, 2016; Hara, Le, & Froehlich, 2013; Hwang & Sampson, 2014; Kelly, Wilson, Baker, Miller, & Schootman, 2013; Sun, Fan, Bakillah, & Zipf, 2015; Zhou, Liu, Oliva, & Torralba, 2014). When combined with computer vision techniques, there is a possibility for the large-scale automatic evaluation of various high-level judgements of the urban environment (Doersch, Singh, Gupta, Sivic, & Efros, 2012; Lee, Maisonneuve, Crandall, Efros, & Sivic, 2015; Naik, Philipoom, Raskar, & Hidalgo, 2014; Ordonez & Berg, 2014; Quercia, O'Hare, & Cramer, 2014; Salesses, Schechtner, & Hidalgo, 2013).

Our goal in this paper is to explore this possibility in terms of the physical quality of the urban environment. We refer to architectural and urban design theories (explained in Section 2) and choose two physical qualities, the construction and maintenance quality of building facade and the continuity of street wall, to be measured in this study. Beijing, a fast-growing city with quite diverse urban environment, is chosen as the case study area.

However, the use of street view images and computer vision is challenged by several issues in producing an appropriate estimation of people's real experience. First, we used the method of expert rating to label images and train the models. Although we attempted to make

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the rating standard as objective as possible, there may be a gap between the experts' opinions and the public's preference (e.g. in terms of what makes a good quality and what is considered a bad condition). Moreover, the expert rating is based on static and two-dimensional images instead of the on-site, dynamic, three-dimensional experience (e.g. in real settings, how people judge the immediate urban environment may be affected by what he/she experienced few seconds ago, so the experience is dynamic).

Regarding the validity of using street images in place of field survey, there have been a few studies that compare the results of observational field audits and street view image-based audits and show that there is generally an agreement between them (Hara et al., 2013; Kelly et al., 2013). However, what these studies deal with are usually quite objective and straightforward variables such as the building height and the existence of obstacles on the sidewalk, while the physical qualities that we are looking at are integrated judgements. To test the validity of our proposed method, we conducted a field survey on 752 passers-by at 56 locations in Beijing and compared the public's rating scores with the machine rating scores.

The research questions that we aim to explore include

- How is the performance of machine learning models in judging the physical qualities of the urban environment based on street view images? Is it possible to apply this method as a replacement to conventional labour-intensive manual audits?
- How is the correlation between image-based machine rating and the public's in-situ rating?

The results show that our machine learning models can reach a mean squared error (MSE) of 0.61 on the task of rating the construction and maintenance quality of building facade (rating scale: 1–4) and an accuracy of 75% on the task of judging the continuity of street wall. When compared with the public's in-situ rating scores, the street view image-based machine rating scores show a Spearman's correlation coefficient of 0.66 ( $p < 0.0001$ ) with the public's rating scores on the former task and 0.71 ( $p < 0.0001$ ) on the latter task.

The rest of the paper is organised as follows: Section 2 provides the conceptual framework; Section 3 reviews the long-lasting efforts in measuring the qualities of urban environment and the recent progresses in applying machine learning on extracting high-level information from city images; Section 4 explains the definitions and impacts of the physical qualities modelled in this study; Section 5 introduces the data and methodology; Section 6 presents the performance of the machine learning models and the validation results and the urban physical quality maps of Beijing produced from the model results; Section 7 concludes and discusses the potential directions of research.

## 2. The conceptual framework

The research question tackled in this paper stems from the larger conceptual framework that links the objective physical environment with individual's subjective experience (Fig. 1). The framework is based on the notion that specific physical features of buildings are mediated by a number of more abstract qualities and then the perceptual processes to shape the experience in the urban space. Wohlwill (1976, p. 108) argued that affect has often been found unrelated to individual physical features unless features are combined in a more meaningful composite measure, which makes the physical qualities such as order and enclosure. However, unlike the specific physical features such as building height and width, these qualities are not easily measured directly with a physical measure (Nasar, 1983). Physical measures of different parts of the scene would have to be combined to arrive at visual prominence (Nasar, 1983). The conceptual framework points to several issues in relation to a meaningful understanding of the physical environment: what are the key qualities that affect people's perceptions,

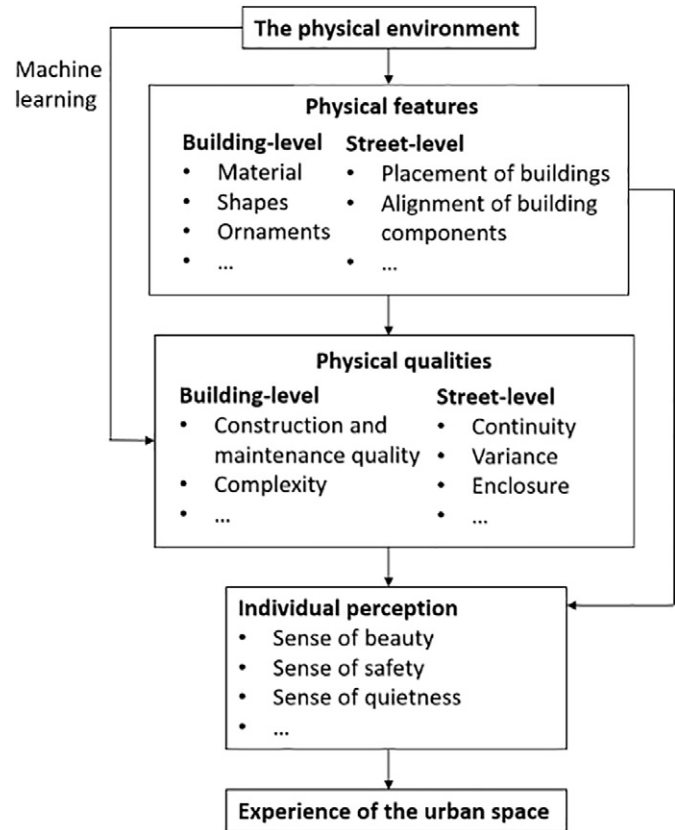


Fig. 1. The conceptual framework. Partly adapted from Ewing and Handy (2009).

how can these qualities be measured from raw materials of the physical environment and how do they impact perceptions.

The fields of architecture and urban design have made many efforts in identifying the key qualities that contribute to people's experience. For instance, Moughtin (2003, p. 59) wrote that 'order, unity, balance, symmetry, scale, proportion, rhythm, contrast and harmony are among the important tools used to define good architecture'. In urban design, rules of enclosure, coherence, variety and so on are widely acknowledged and discussed in many design handbooks as well as governments' design codes (see for instance, Ewing et al., 2013, p. 8; American Planning Association, 2006, p. 165; Parolek, Parolek, & Crawford, 2008, p. 41 for the narratives on enclosure).

Our work focuses on the second question mentioned above and aims to explore the potential of machine learning algorithms in measuring the physical qualities from street view images. Our approach is different from relevant works by Quercia et al. (2014) and Ordonez and Berg (2014), which directly measured people's perceptions from street images. While appreciating their works, we argue that our approach is of particular importance for at least two reasons. First, the physical qualities are more operational than perceptual variables for urban planning and design practice, which themselves point to specific measures to improve. Second, our approach could facilitate further research on the relationship between physical qualities and human perceptions by providing consistently measured inputs.

## 3. Related works

### 3.1. Measuring the qualities of urban environment

Over the last four decades, there have been constant efforts in measuring the physical qualities of the urban environment that would potentially be perceptually meaningful. According to Stamps (2000, p.

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