Routledge
Taylor & Francis Group

Urban, Planning and Transport Research
An Open Access Journal

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/rupt20

In support of sustainable densification in urban planning: a proposed framework for utilising CCTV for propagation of human energy from movement within urban spaces

Emil Jonescu, Titus Mercea, Khoa Do & Monty Sutrisna

URBAN, PLANNING AND TRANSPORT RESEARCH
2020, VOL. 8, NO. 1, 24–43
https://doi.org/10.1080/21650020.2019.1703800

ARTICLE

OPEN ACCESS

In support of sustainable densification in urban planning: a proposed framework for utilising CCTV for propagation of human energy from movement within urban spaces

Emil Jonescu[a], Titus Mercea[b], Khoa Do[a] and Monty Sutrisna[c]

[a]School of Design and the Built Environment, Curtin University, Perth, Western Australia; [b]Faculty of Health, Arts and Design, Swinburne University, Melbourne, Australia; [c]School of Built Environment, Massey University, Palmerston North, New Zealand

ABSTRACT

Co-generation of energy derived from human movement is not new. Intentionally accumulating energy, from mass urban-mobility, provides opportunities to re-purpose power. However, when mass-mobility is predictable, yet not harnessed, this highlights critical gaps in application of interdisciplinary knowledge. This research highlights a novel application of geostatistical modelling for the built environment with the purpose of understanding where energy harvesting infrastructure should be located. The work presented argues that advanced Geostatistical methods can be implemented as an appropriate method to predict probability distribution, density, clustering of populations and mass-population mobility patterns from large-scale online distributed and heterogeneous data sets published by the Australian Urban Research Infrastructure Network. Where clear urban spatio-behavioural relationships of density and movement can be predicted – understanding such patterns supports cross-disciplinary city planning and decision-making. A data-informed – predictive spatial decision-making framework is proposed – facilitating the endeavour of cogenerating kinetic human energy within a prescribed space. This novel proposition could further sustainability strategies for compact living for cities such as in Perth, Western Australia which is increasingly economically and geographically pressured to densify. This research argues that surveillance data elucidate a capacity to interpret and understand impacts of densification strategies, efficacy of CCTV networks in existing and emerging cities.

ARTICLE HISTORY
Received 28 December 2018
Accepted 5 December 2019

KEYWORDS
Big Data; CCTV; GIS; Kernel Density Estimation; Geostatistics; sustainability

1. Introduction

Populace growth raises financial and asset expectation upon cities. This requires reconsideration of everyday activities, increased flexibility and adjustment to compact living. Highly densified cities increasingly experience unique challenges such as social cohesiveness, inclusion and security. This is especially profound in the West with a number of key commentators attributing individualism and waning uptake in the formation of community groups to significant impacts upon solidarity, unity and social order (Jones & Newburn, 2002, p. 140).

CONTACT Emil Jonescu emiljonescu@gmail.com

Jones and Newburn (2002, p. 141) draw consideration to the critical decay of occupations that would otherwise have provided an inherent presence of authority and social control, for example, the authors contend that private security companies now administer what was formerly overseen by 'caretakers, receptionists, teachers, prefects and park-keepers'. Further to this, Smith and Clarke (2000, pp. 177–8) maintain that public officers involved in the rail and public transportation sectors once provided vital ancillary support to policing efforts in effecting safety and order. Jones and Newburn (2002, p. 140) mention that:

> there has been a marked decrease in employment in a range of occupations providing 'natural surveillance' and other low-level controls as a corollary to their primary functions. In part, this has been a consequence of the development and spread of new labour-saving technologies such as self-purchasing ticket machines and automatic barriers, CCTV, and automated access control … the 'rise' of private security has been on the back of [such] reductions in (or, at least, restrictions on the growth of) public policing

Accordingly, this study advocates for a geostatistical modelling aimed at predicting patterns, the likelihood and distribution of trends and location of occurrence. In so doing statistical data assists and substantiates design decisions and understanding space-informed relationships between density and pedestrian flow patterns. This in turn leads to improved positioning and provisioning of kinetic energy harvesting technologies to co-generate power.

Findings from this research could be used to develop sustainable design strategies in cases such as Perth, Western Australia and other cities that are economically and geographically undergoing densification. Increased sources of information and data – improving decision-making capacity regarding densification strategies. Moreover, improved understanding in this area of built environment research stands to contribute to ied research relating to perceived safety in urban public realms, which underpin positive social interactions in the current and future cities.

Revealing the connections between design and behaviour through quantitative statistics, this research examines a number of international exemplars of densified cities to highlight successful sustainable collective social activities. Geostatistical modelling of non-sensitive surveillance data, Geographic Information Systems (GIS), Building Information Modelling (BIM) and psychology of space are integrated to initiate more cohesive approach design future cities. The proposed framework allows for city-scale alteration and adaptation through the application of technology for human energy harvesting, driving developing cities in the pursuit of a sustainable existence. Contemporary technologies such as piezoelectricity or 'pressure-driven electricity' while in early stages of achieving efficiencies and economies of scale seek to address this notion. As a result, an 'as built' project with the inclusion of piezoelectric sensors is utilised herein. To determine mobility patterns, some of the methods proposed consist of literature reviews, analysis of site constraints and physical built environment qualities, observational analysis, analysis of raw surveillance data and analysis of available database statistics (discussed further in 'Methodology' section)

The paper is organised as follows: in the next section, a comprehensive literature review is presented to highlight the state-of-the-art in surveillance of cities. Next, the research method is presented along with the integrated framework proposed for city surveillance.

2. Literature review

2.1. Surveillance theory

For years, esteemed commentators in the field such as Raymond Unwin, Lewis Mumford, Jane Jacobs, for example, contend that electronic surveillance is typically ineffective in influencing behaviour next to natural surveillance deriving from activation and human occupation of space. Subsequently, studies by Welsh and Farrington (2002) and Goodwin (2002) highlight this enduring sentiment through their findings and research, and more recently Gehl (2011) and Cozens (2011), among other practitioners continue to posit that digital surveillance does little to engender behavioural modification. It is critical to consider these attestations since digital surveillance technologies were initially adopted for social control to the advanced networked capacity of the 'Internet of Things' (IoT) available today (discussed further in '2.6 Big Data' section of this paper) next to concepts of natural surveillance otherwise referred to passive surveillance. The rapid rate of densification of contemporary cities provides significant challenges and opportunities for using density, proximity and many 'eyes-on-the-street' to effect natural surveillance. Harnessing and co-generating human movement within densified cities also offer opportunities to exploit the relationship between urban spaces, compactness and population. This paper considers this principle in conjunction with digital data, geostatistical modelling and piezoelectric sensors (discussed later in this paper), to detect, understand and predict mass movement patterns. This creates opportunities for co-generating energy for use in our cities. Next to this, improved pattern data provide designers with visual cues to improved understanding of how specific aspects of designed spaces influence behaviour. This allows for remediation of problematic existing spaces and the creation of future spaces that promote socially acceptable behaviours.

Articulated for the understanding of the general population by Foucault (1975) much of the emerging literature relating to behavioural self-modification derives Bentham's scriptures on omnipotent power (Bentham, 1787). A nineteenth-century British philosopher, Benham's supposition suggested that surveillance could be leveraged through architecture. Design, it was argued, could prescribe control through power-relationships articulated through sight-lines between an observer and the observed. His ideology sought permanent behavioural shifts in prison contexts – spaces under the constant physical examination of authority, and to elicit the desired response, the subject must believe they are under constant physical surveillance. This required a passive power structure, erroneously lacking in contemporary arguments that involve technological interventions that continue to cite his theoretical principles. Bentham's ideals concerning laws, democracy, utilitarianism and government had a considerable impact on historical norms on crime and punishment – many of these have endured reflecting in contemporary social attitudes towards punishment. The chronological impact of this precedent is critical to the timeline of surveillance theory. It is, however, misaligned with current shifts in social attitudes on state-sanctioned actors applying acceptable punishment on civilians.

Bentham focuses on the psychology of the *observed* with little regard for the *observer*. Today, this omission is unavoidable. Regardless of guilt or innocence modern public spaces are under indiscriminate digital (with a paucity of physical) surveillance. The unmitigated quantity of data derived from such spaces serves little purpose beyond that of capturing evidence for reactive policing. Police and government organisations rely on CCTV cameras and other digital technologies develop a digital fingerprint or profile of individuals, and in the event of a reported crime, finite segments of the mass meta-data collected from these sources are reviewed for the purpose of discerning evidence.

Whilst understanding the principles of surveillance types is critical as it substantiates its initial implementation, it is not the main thrust of the research which focuses on utilising existing surveillance infrastructure to understand macro-level mass movement patterns of pedestrians transitioning through surveilled public spaces for the purpose of informing design decision-making for urban and city planning (Jonescu, Sutrisna, Khoa, & Mercea, 2018).

2.2. City-wide surveillance through CCTV

Contemporary surveillance involves constant monitoring of populations. Technological advancement sees monitoring emerge through possession and use of mobile phones, social media and video-sharing websites, CCTV, GPS, Biometric scanners, telecommunications interceptors and other networked technologies. Seemingly innocuous activities such as banking, using public transport, shopping and so on build upon our digital footprint and provide preference and trend-based data (Jonescu et al., 2018). This includes CCTV with 'smart' surveillance capacity, 'Google Home' and other integrated home automation appliances and other systems that 'can track individuals within a camera image or across multiple screens' or with facial recognition technology, or by voice and preference that can recognise and follow individuals across networked CCTV systems (van den Hengel, Dick, & Hill, 2009).

Telecommunications towers and repeaters allow for the unique digital fingerprint (electronic serial number) of mobile phones to be tracked and for telecommunications agencies to identify users. Equipped with GPS features, and networked telecommunications towers – mobile phones expose the location of the user with a high degree of accuracy. Moreover, mobile phones also have 'digital visual and sound recording capabilities, and connection to the internet. A consequence of the convergence of surveillance technologies is the greater ability of surveillance users to compile detailed pictures of members of the public' (New Zealand Law Commission, 2008, p. 136).

2.3. International examples of ineffective use of CCTV

Studies in Europe, U.S. and Australia suggest that hyper-surveillance elicits little (measurable) data that positively influences behaviour next to the physical presence of authority (Jonescu et al., 2018). The foremost example of this is London with an approximate population of 8.2 million. Here, the population has increased by 12% as has the density since 2001 (Office for National Statistics, 2012) and CCTV cameras number one for every 32 people (Lewis, 2011). In a heavily surveilled city such as

London which relies predominantly on CCTV with a lesser on the physical presence of authority, there is a striking resemblance to Perth's CCTV implementation strategies that both conclude that camera numbers have an insignificant bearing on behaviour-related crime statistics (Davenport, 2007). Moreover, crime statistics for offences against the person (from common assaults to assault occasioning grievous bodily harm) for both cities when examined over a significant period (over 30 years) from 1980–2010 suggest a steady increase over time (Home Office Statistical Bulletin, 2009) with the highest rates in the central London area which has the most CCTV infrastructure (London Metropolitan Police, 2019).

New York, another example of increased CCTV infrastructure in the extreme sparked by 9/11 as well as in reaction to other international incidents such as the London Underground bombings (Banovic, 2013). Through collaboration between New York Police Department (NYPD) and Microsoft, the city has implemented the Domain Awareness System (DAS) an extensive CCTV network offering tracking capabilities for police in search of suspects. The system is able to detect distinguishing features powered by intelligent recognition technology (Francescani, 2013). This infrastructure pales next to the 'Intellistreets' program (Margolin, 2012), and Mail Isolation Control and Tracking program (Nixon, 2013). Although New York boasts some impressive reductions in violent crime generally the weakest performing reduction was in assault crimes and personal property crimes which more typically account for crimes in public areas. Though serious crimes such as murder and rape received some of the greatest reductions (some in excess of 80%) these are less likely to represent crimes that have correlation with having occurred in public spaces under surveillance and is representative of the US generally with violent crimes down by half since the 1990s (Brennan Centre for Justice 2017; New York City Police Department, 2019).

Lastly, Perth, Western Australia's capital was one of the fastest growing cities in Australia by population (Australian Bureau of Statistics, 2011). Though reasonably small compared to other major global cities, yet its demographic and density shift appears to be unprecedented. Similar to London and New York, crime records for Perth have seen, when viewed over an extended period, a disproportionate increase in similar crimes (Sullivan, 1997). It is important to consider crime over an extended period to discount for fluctuations due to police 'crackdowns' and short-lived initiatives and that these increases have occurred irrespective of increases in CCTV infrastructure implemented in the City. Goodwin (2002) corroborates this by outlining the ineffectiveness of CCTV in a Tasmanian report that suggested that modifications to the built environment could yield better and more effective results than CCTV.

To date, the literature overwhelmingly finds that without a physical presence of authority, CCTV has an imperceptible impact on behaviour. It can be argued, therefore, that the purpose for their inception into the public realm is not proactive, simply capturing evidence of 'committed' crime, with little correlation between their capacity and quantity and a reduction in crime. Considering this, although ineffective in encouraging acceptable behaviour, CCTV does, however, allow for data collection, and when strategically analysed, the output and lessons-learnt may facilitate design professionals to effect design decisions leading to better urban outcomes that *do* positively impact behaviour. With this, surveillance-initiated power structures when coupled with built form are harnessed through this research which adapts surveillance-captured data (behaviour) next to the principles of urban design and form.

Through methods of interpreting and understanding surveillance data, this proposal seeks to make positive contributions towards pedestrian mass movement through the urban environment, provides for improved logic in CCTV locations, pathway destinations and projected nodes to enable efficient harnessing of human energy from such movement through cities.

2.4. Contemporary attitudes to surveillance contemporary attitudes to surveillance

Contemporary attitudes towards surveillance within most cities appear to have shifted. Acquiescence has resulted in the application of extensive networks of diverse surveillance technologies, in what could be considered as a perverse counterpoint of user experience and convenience in questionable proportion to a surrender of privacy.

Increasingly in most developed cities, vast digitised and automated transportation systems have the capability of tracking movement across its network. Added to this, any stop along a journey to use automated banking, logging in WiFi networks, and physically having a cellular phone on one's person, for example, is surveillance (discussed later in 'Big Data'). These sources are adapted as counter-measures to be called upon as potential later evidence. As such this technology and methodology increasingly relies upon systems and data in the absence of authority – whose presence *does* impact behaviours. In essence, the principle of effecting behaviour through investment in CCTV and other digital surveillance is inconsistent with established research; however, the implementation of CCTV and other digital methods of surveillance continues to be favoured by the government and private interests given the relatively low-associated implementation and ongoing operational costs. Arguably, these forms of surveillance serve as reactive instruments for recording events, live tracking and collecting evidence for potential future use. Notwithstanding this, incalculable hours of uninterrupted surveillance data are also captured – only rarely punctuated with evidentiary footage – serving no meaningful purpose and is either archived or held for a time and destroyed. This research proposes, however, that disused surveillance, when set against the parameters in which it exists – when in the highly populated urban environment or strategically positioned locations, could be used to provide valuable clues through data which can be analysed. This would allow for better understanding of how spaces perform and how such spaces inform movement patterns, and with this, develop design strategies and municipal initiatives to further encourage community cohesiveness, positive behaviours, increased community participation and increased pedestrian density in urban spaces. All of these lead to implied or 'natural' surveillance – eyes-on-the-street that perpetuates a sense of belonging and safety. This research proposes that surveillance instruments and technologies can positively contribute to society, if their purpose was rearticulated – informing urban design decisions that *do* contribute to safer environments. Concurrently the research outcomes seek to add to the body of knowledge regarding surveillance analysis contributing to *informed* strategies – not theories for design, and cogeneration – utilised to positively advance sustainable sources of energy for cities.

2.5. City structure

The built (and remnant natural) environment of cities largely contributes to sustainable successes and enduring failures for its inhabitants. Mediaeval cities, for example, owing to its compact complexion, diverse typologies and pedestrian-orientated planning, effectively amalgamate functional and spatial interactions, offering improved opportunities for passive surveillance for its residents (Gehl, 2011, p. 101). Arguably older cities designed around pedestrian mobility – not the motor vehicle – highlight ratios of effective synthesis of inclusivity, activity and proximal access to goods and services. Such cities are not without their challenges, yet in comparison cities design with a focus on vehicular movement (automobile) are typically ordered into individual precincts. Cities planned as such risk societal alienation and the proliferation of mono-functionalist precincts divided by city streets.

The grid city layout facilitated rail networks and the motor vehicle, representing the physical manifestation of a societal shift in development and human triumph that conquered the restrictions of natural form. Other cities were formed to highlight the significance of government, power, divinity and military, each with key characteristics that include such elements as concentric orders importance from the centre, radial design and procession boulevard (Jonescu et al., 2018). Gehl (2011, p. 89) outlines that:

> It is not the lack of pedestrian traffic and residence that has prevented the establishment of more intimate and better used public spaces, but rather the decision to have many dispersed roads and paths instead of a more concentrated street network such as that found in old cities. In the entire history of human settlement, streets and squares have been the basic elements around which all cities were organised. History has proved the virtues of these elements to such a degree that, for most people, streets and squares constitute the very essence of the phenomenon 'city'

Historically, city-forming has resulted in a need for defence including walled cities, fortification and confusion, for example, the maze-like canals of Venice. For modern cities focused upon surveillance planning, architecture serves as the physical embodiment of control. Its proximities and interstitial spaces augment the capabilities of digital surveillance technologies including CCTV, biometric scanning, recognition technologies and the like.

2.6. Big Data

According to Batty (2013), Big Data, in urban context, is data that is tagged in space and time, and streamed live from a variety of sensors and sources. This huge amount of complex data is automatically collected by the Internet of Things (IoT) stored and processed through 'cloud' computers. Batty (2013) suggests that this data can be used for long-term strategic planning as well as short-term decision-making about 'smart cities' functions and management. With the IoT anyone connected to Wi-Fi networks, through GPS or telecommunications triangulation can have their movements tracked and their patterns of behaviour and preferences examined. Analytics-lead predictability metrics will provide valuable interpretive information – the basis upon which future planning decisions can be made.

The major challenges here are real-time processing, and the exponential increase in the amount of data collected through heterogeneous devices. Gunturi and Shekhar (2016) highlight an ever-increasing computational challenge and how the spatio-temporal 'Big Data' may be tackled using scalable analytics.

Silva et al. (2018) propose Big Data Analytics (BDA) that can be used in Urban Big Data planning (UBD) design. They proposed a three-tier system that performs autonomous real-time decision-making and can enhance the quality of smart cities services. Moreover, the new area of 'Urban Informatics' (Foth, Choi, & Satchell, 2011, 1–8) utilises Big Data for repurposing existing urban models and running data-driven simulations with significant potential for application in dynamic urban resources management, development of urban patterns, planning and policy analysis (Thakuriah, Tilahun, & Zellner, 2017). Another key urban application for Big Data is in the planning of transportation networks using mobility pattern analysis. The model enables forecasting of transportation patterns, trip generation and distribution (Kitamura, Chen, Pendyala, & Narayanan, 2000).

A practical example of UBD in use is the Australian Urban Research Infrastructure Network (AURIN). It provides online access to large scale distributed and heterogeneous data sets from across Australia that can be used to extract and run spatial statistical analysis (Pettit, Tice, & Randolph, 2016).

3. Research methods

The research implements, qualitative and quantitative methods required to procure an understanding of behavioural patterns within specific built environments (architecture and urban contexts) and cultural parameters in cities. This research presents an avenue for obtaining the required empirical data in relation to a subject where insufficient knowledge and inadequate research exists (Polit and Hungler 1985, p. 272).

3.1. Literature investigation and research review

Research on 'Piezoelectricity' provided an overview of the opportunities and limits of the technology for cogeneration of energy and contemporary applications. The most appropriate configuration was sought in its ability to harvest human kinetic energy (discussed in 'Harvesting of Human Kinetic Energy' section).

Research of published works pertained to contemporary design rationale of the observed densified cities that considers the use of space to fulfil specific functional requirements. Texts by Foucault and Bentham provide the theoretical underpinning of control through design of the built environment and architecture as a mechanism of control outlined in '2.1 Surveillance Theory'. This account argues that long-held principles persist in their influence over design and shaping of contemporary urban environments and cities. Government reports, policies, publications and design recommendations are archived and searchable through departmental databases, the state records libraries, internet sources and national and international data repositories. In addition to this, many electronically published development and local planning guidelines and public library reference sections have sources that clearly adapt, to varying degrees, 'safety' in spatial planning of cities and infrastructure that appear to stem from established surveillance principals set by a number of key commentators. A small sample of these include, for example, Bentham (1787), Foucault (1975), Jacobs (1961), United Nations Social Defence Research Institute (1975), Altman (1975) and more recently Cozens (2011) and others. Census and other statistical archives (Australian Bureau of Statistics) are a valuable source and will afford historical data for patterns and trends over time. The Heritage Council also proved to be a valuable source for historical data, directly contributing to developing a broad knowledge base relating to the objectives of the research. The principles of built environment design were then considered prior to undertaking site visits and analysis.

3.2. Site analysis

Site analysis and physical observation were undertaken in a number of densely populated cities. The study included public spaces in different regions around the world to attain an illustrative understanding of the constraints and context associated with highly populated cities. None of the observations involved studies during periods of inclement weather, and for safety reasons, none were conducted between 12.00 am and 9.00 am. The chosen locations offer conditions that provide high volume pedestrian movement both localised, through tourism, and through transit orientated design due to their proximity to transport infrastructure. They were considered to represent well-known high-density national and international cities that were geographically set across different continents, including; Kuala Lumpur, Malaysia (Jalan Bukit Bintang) and Singapore (Orchard Road) both in Asia; Barcelona, Spain (La Rambla near Carrer de l'Hospital) and Italy (Via Toledo, Naples) both in Europe; Brisbane (Queen Street Mall) in Australia; and New York, US (Grand Central) in North America. Moreover, it is important to note that while the sites share similarities there are also many differences in culture, actual levels of density when compared with each other. Having differences was considered to be important to the study as searching for sites that differed to a lesser degree would yield results relevant to a certain geographical location or, condition, or context.

It is considered critical that a well-informed perspective is drawn through the observations made at chosen locations as the same space may not perform or be activated in the same way at different times of the day or week, during business or after-hours. Therefore, observations aimed to span across a breadth of times of day and evening, and both weekdays and weekends. Times and days were structured as follows: 1. Monday–Friday daytime (9.00am–5.00pm), 2. Monday–Friday, afternoon–night-time (5.00pm-12.00am), 3. Saturday & Sunday daytime hours (9.00am-5.00pm), and Saturday & Sunday afternoon-night-time (5.00pm-12.00am), to collect empirical data on human movement and circulation with respect to directional flow patterns. Site analysis focused on gathering specific information, including location, context, physical constraints, architectural form, layout and surveillance capabilities. Actual density, trends, patterns, frequency and movements were determined through extrapolative means and observation data gathered. Environmental conditions pertaining to materiality, lighting, and season formed part of the qualitative information that was used to interpret empirical data thus, allowing for a learned inference as to the impact on the empirical material. Methods of documenting findings include time-lapse audiovisual, photography, tabulated data gathering through field observations, flow diagramming and measurements, sketches (Jonescu et al., 2018).

3.3. Spatio-temporal analysis

3.3.1. Spatial analysis GIS and geostatistics

This study proposes to apply several interpolation methods, Geostatistical, KDE (Kernel Density Estimations). Selection will be based on the results of EDA (Exploratory Data Analysis) and ESDA. ESDA (Exploratory Spatial Data Analysis), essentially EDA for spatial data, will offer the spatial perspective (De Smith, Michael Goodchild, Michael and Longley, Paul 2007). The EDSA will use basic statistics, choropleth and trend plots, hotspot and cluster analysis and KDE. All methods proposed are available with ArcGis (ArcGIS Resource Centre 2019) and other GIS commercial packages.

Geostatistics uses a set of statistical methods that applies the theory of regionalised variables to spatial data. It includes both random and structured components of spatial variability (Sinclair, 2002). While it was originally applied to mineral resource estimation, today it is used more widely in areas of environmental studies, forestry, fisheries and hydrogeology and elsewhere. The theory of Geostatistics is applied with the purpose of optimising estimates, providing also a measure of error variance. It uses the degree of spatial dependence and similarity of two samples, in addition to the concept of random function. The random function describes the probabilistic spatial distribution of a variable (Sinclair, 2002). As opposed to classical statistics, geostatistical theory uses spatial information attached to data emphasising the underlying model. The model describes the continuity of natural phenomena mathematically, using adaptations of the regression theory (Isaaks, 1989).

Kriging is a set of methods, for example: OK, SK, IK, MIK applied in geostatistical analysis to minimise estimation error. Essentially it is a method of interpolation providing an unbiased estimator dividing data into deterministic variations or trends, and spatial—autocorrelated and uncorrelated noise (Burrough, McDonnell, & Lloys, 1998).

Kriging methods seek to obtain the best possible estimate at unknown points of data sets. GIS in conjunction with Geostatistics provides geo-registration of data, logical operations, multiple map layers, effective query tools and complex data display. Despite their differences, GIS link statistics with Geostatistics providing a powerful set of complementary tools. GIS software packages have embedded spatial analysis tool (KDE) that calculates the density of specific features (people and objects) in a neighbourhood as well as other aspects around those features, both for point and line features. KDE uses the Kernel method for the estimation of probability density functions (Upton & Cook, 2008). KDE is employed in determining housing density, crime reports, roads or utility lines influencing a town habitat, etc.

An example using a combination of GIS, KDE and Geostatistical techniques for spatio-temporal modelling in urban districts in cities from Italy was presented by Borruso et al. (see Figure 1). A selection of human activities was geo-coded and elaborated using Kernel Density Estimations (KDE) with focus on the border effect with Slovenia. That enabled the visualisation of density surfaces which highlighted times when recreational activities were most concentrated.

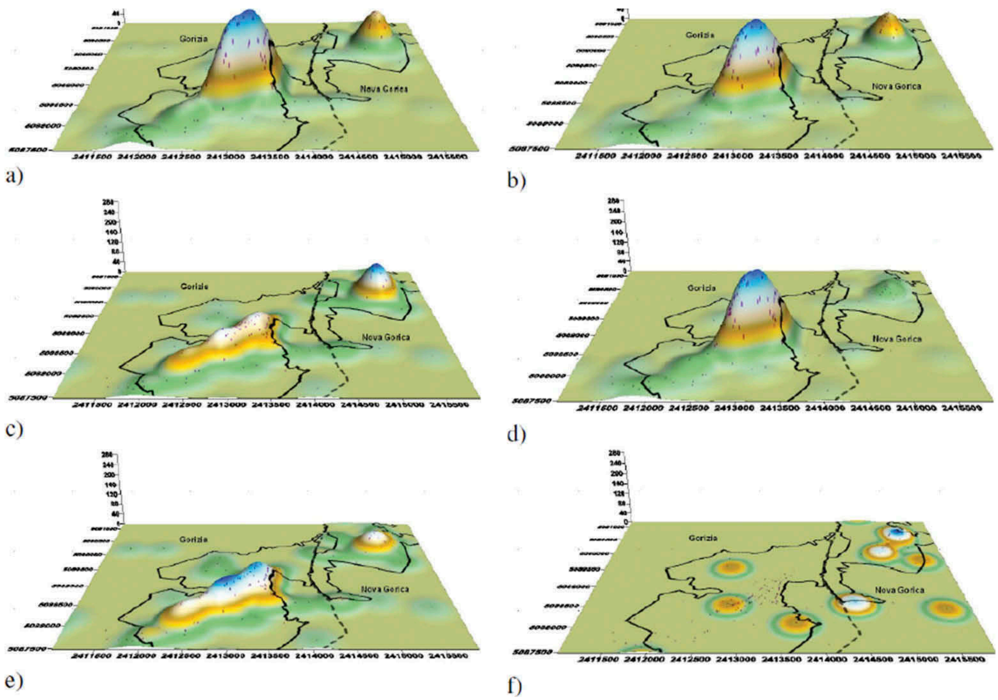

Figure 1. KDE on recreational and leisure urban activities (purple dots), with State border (dashed grey line) and urban areas (black lines): (a) all activities, (b) 09.00 am, (c) 01.00 pm, (d) 06.00 pm, (e) 08.00 pm, (f) 0.00 am (Source: Borruso, Valentino, & Porceddu, 2007).

Peredo, Garcia, Richardo, and Ortiz (2016) presented a method for studying population flow patterns in urban contexts. They used Inverse Distance Weighting (IDW [inverse to distance]) and Ordinary Kriging (OK) applied in conjunction with LVA (Locally Varying Anisotropy) to data collected by telecommunication companies in Santiago de Chile. The study was limited to an area of 10 km^2, and next to this, the methodology remains to be tested on Big Data.

The proposal will test other methods of Geostatistical interpolation combined with KDE. Indicator Kriging, with LVA, for example, which this paper suggests is more appropriate for the type of data collected from CCTV, mostly discrete, categorical variables and qualitative information. Indicator kriging is a non-linear, non-parametric form of kriging in which continuous variables are converted to binary indicators. The advantage of this method opposed to the classical ones is that it can handle distributions of various kinds and accommodate 'soft' qualitative information to improve prediction (Webster & Margaret, 2007).

3.3.2. Copula-based geostatistical modelling

Our study proposes to predominantly deals with count (discrete) data collected and processed from CCTV sources. Spatial count data is regularly collected in ecology, epidemiology, demography, geography and urban planning (De Oliveira, 2013). While they are widely used in financial and actuarial statistics, they are just beginning to become used in Geostatistics.

There are limited studies using Geostatistics with count data. One of the reasons might be that just a few models have been proposed in the literature, due to the scarcity of families of multivariate discrete distributions, and other than Diggle and Ribeiro (2007) limited sources present models for geostatistical count data (De Oliveira, 2013).

Copula-based Geostatistics (see Figure 2) is an advanced method that is suitable for spatial count data. In the statistical literature Madsen (2009) and Kazianka and Pilz (2010) proposed the use of Gaussian copulas to model geostatistical count data and investigated methods for performing parameter estimation and prediction. The term 'copula' was first used by Sklar (1959) to describe distribution functions on the n-dimensional unit cube, that link multivariate distributions to their one-dimensional marginals (Kaqzianka and Pilz 2010). The authors suggest copulas can be used to flexibly describe spatial dependence and to perform spatial interpolation – available in the R statistical software. We consider this method as suitable for our data.

3.3.3. *Temporal analysis*

Temporal data collected through CCTV will be modeled through 'time series'. Time series is a sequence of discrete-time data, or a collection of observation sequentially made through time – with this, time and date captured on video footage (Timestamps) will allow the use of univariate methods for modelling and generating forecasts as well as identifying trends (Chatfield, 2001). Further analysis will involve the testing of the variable dependence and multivariate time-series. A multivariate model might be used depending on the correlation strength of the variables. This type of model is based on past and present of values of the main variable as well as on the past and present of the predictor variable (Chatfield, 2001).

One of the most important forecasting tools in univariate time series is ARIMA (autoregressive integrated moving average) model, originally introduced by Box and

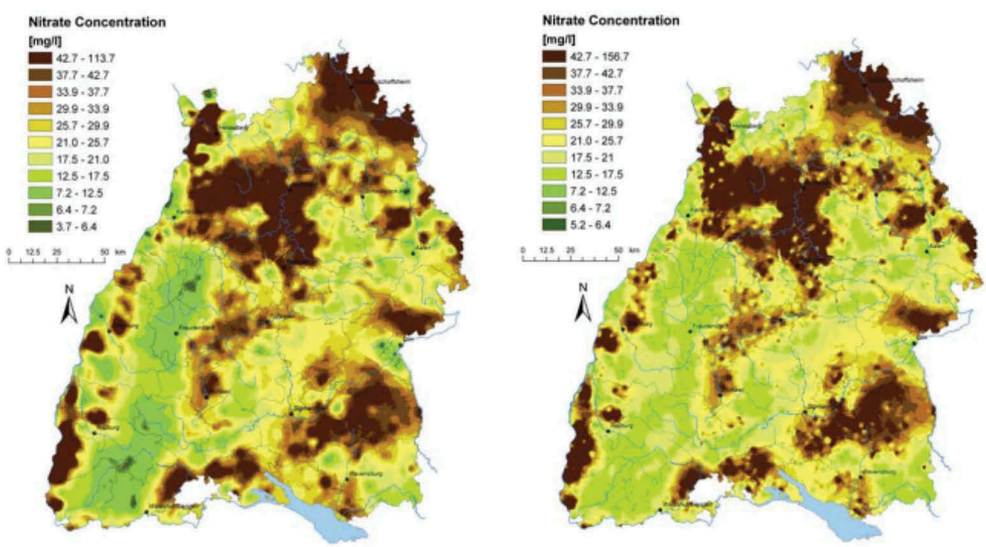

Figure 2. (left) Interpolation maps for chloride using v-transformed normal copula mean and (eight) median. (Source: Bardossy & Jing, 2008).

Jenkins in (1970). Most often time series are analysed by linear models like ARIMA. A linear process is when the value of the time series can be expressed by a (possibly infinite but converging) linear sum of the present and past values (Chatfield, 2001). However, many observable phenomena cannot be modelled by linear models; instead, the special non-linear models are adapted (Everitt and Anders 2010). Our data will be tested, and a suitable model will be selected.

3.4. Data analysis – raw data analysis (trends and patterns)

This research incorporates published database statistics (see 'Research Methods') with site analysis observations. Data from the Australian Urban Research Infrastructure Network (AURIN) will be used to run spatial statistical analysis substantiated through quantitative statistics (Geostatistics). This quantitative statistical approach evolved moreover for use in geography-based disciplines. Geostatistics, however, has been successfully implemented in support of a diversity of geospatial disciplines in particular, when master-planning of spatial networks in alignment with geographic information systems (Jonescu et al., 2018). It has been defined as a 'branch of statistical sciences that studies the spatial and temporal phenomena … on spatial relationships in order to model possible values of variable(s) at unobserved, un-sampled locations,' (Caers, 2005).

Geostatistics analyses data to predict probability distributions and determine trends and patterns of occurrence. Accordingly, this research seeks surveillance-derived non-sensitive statistics to illustrate behavioural patterns at known locations. Through this, we propose to produce an interpolation map that offers 'best predictor' of similar data at unknown locations also referred to as a User-Centred Surveillance Analysis Predictive Modelling (SA—PM) Framework (see Figure 3, Do 2018). Temporal maps will corroborate patterns. An increasingly advanced technique of conditional simulation considers the application of various scenarios offering additional feedback to the processes subject to geostatistical analysis (Jonescu et al., 2018).

4. Findings and discussion

4.1. Harvesting of human kinetic energy

As pressure-driven piezoelectric technology as a means by which to harness energy has matured, it has gained momentum. Understanding its application and moreover how to maximise the efficacy of the technology is considered in this research. This paper considers the interaction between applied materials in urban spaces and architectural finishes (floors and footpaths, for example) and various modes of movement of the users within the space involving walking, sitting, touching, pressing, or driving upon strategically positioned materials.

The most popular types of harvesters of mechanical vibrations are linear and non-linear, with linear examples using vibrations to collect energy from mass-spring devices (Ferrari et al., 2010). Piezoelectricity, on the other hand, is used in non-linear devices that eliminate the need for mechanical parts and are thus more efficient (Wang, Cao, Bowen, Zhao, & Lin, 2017). According to Ando, Baglio, Bulsara, Marletta, and Pistorio (2015)

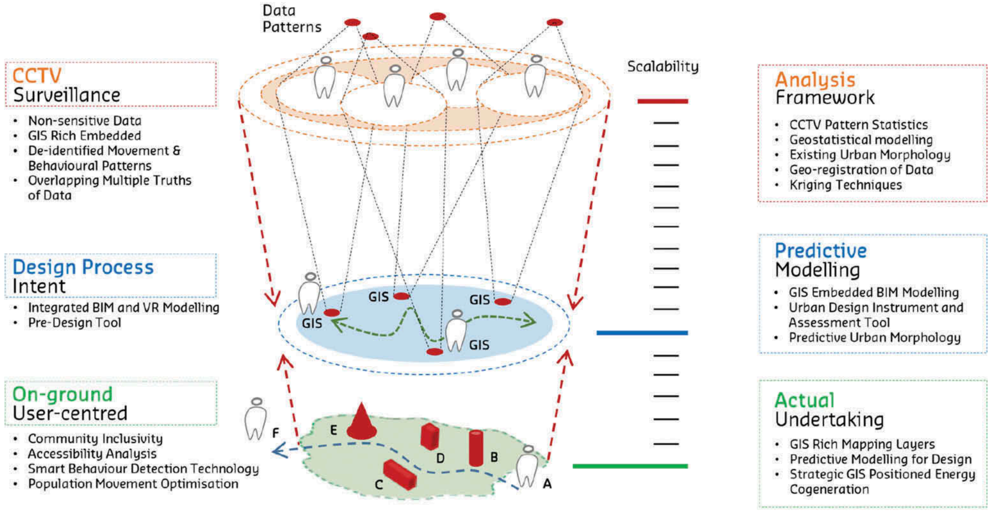

Figure 3. User-Centred SA—PM Framework diagram (Source: Do 2018).

non-linear configuration using piezoelectricity harvest a greater amount of energy through mechanical vibrations than the linear devices.

To this end, several types of non-linear devices have been theoretically modelled and tested in the prototype phase. Three such devices, for example, include a bi-stable piezoelectric harvester, converting environmental vibrations to power, designed and tested by Wang et al. (2017). This device proved to be an efficient harvester and converter through simulation and in the prototype stage. Additionally, Ando et al. (2015) used a non-linear Snap-Through-Buckling (STB) configuration and two piezoelectric transducers to extract energy from a wide range of mechanical vibrations. Lastly, Xie and Minjing (2014) proposed a unique harvester that uses kinetic energy produced by the human foot impact. An amplification mechanism is attached to a piezoelectric bimorph that is deformed during the impact and then releases power.

This paper argues that these devices can be used to collect other information as well, e.g. geolocation, frequency and other data suitable for statistical interpretation. Moreover, the research proposes to utilise CCTV data in conjunction with other information collected, e.g. geolocation, frequency and other statistics to understand and predict how design shapes collective or 'mass' behaviours. Moreover, the nexus between intended and unintended outcomes and the subsequent predictive capacity of people transitioning through cities affords palpable use of latent human kinetic energy (Jonescu et al., 2018).

4.2. Implications of city structure on human kinetic dynamics

Considerable research establishes the relationship between density and mass public transport (human mobility). This research furthers the discourse and application to the consideration of design of thresholds, pathways and nodes for cogeneration of energy to the discourse. Notably, in support of this, Jenks and Burgess (2004, p. 1) state that:

> sustainability gains that can be realised are related to improvements of the fuel efficiency of public transport equipment, improved regulations and enforcement and the construction of environmentally friendly mass transit systems

Sustainable public transport systems engender reductions in vehicular reliance for commutation, and concomitant need for expenditure on road infrastructure. Roads segregate cities, and create physical boundaries, limit flow-architecture, create mono-functional precincts and divides activities and people. In response, a measured blend and shift in land use and networking of pathways, streets and nodes are required to meet the needs of commuters and pedestrians (Hyungun. & Ju-Taek, 2011). In Australia, planners and government continue to refer to 'healthy growth'. This is suggested to occur 'when a city grows at 2.3% each year' yet fails to mention that results in a 'doubling every 30 years' and when compared with Asia with a growth rate currently set at 1.1% per year, Australian population growth (in 2008) even eclipses a number of third world countries (O'Connor & Lines, 2008, p. 6: 77).

There is an extraordinary paradox in Australia between our perception of the human population, levels of education and environmental issues. Biologically, Australia is one of the richest nations in the world – environmentally it is one of the most degraded. Australians are relatively well educated, but not with regard to issues associated with population size, density and long-term ecological sustainability (Foran and Poldy 2002 cited in Goldie & Betts, 2014, p. 9). The aforementioned population growth results in increased impacts. Cited in Jonescu et al. (2018) based on figures calculated in 2002 (1) around 200 tons of natural resources must be moved each year to maintain each Australian at current standards of living – 2.5 times higher than for a person in the USA and 5 times greater than for an individual in Japan. The environmental impacts of additional resource use and movement associated with each extra person have been outlined above. (2) Every extra person in Australia is responsible for approximately 24 tonnes of $CO2$ emissions per capita, per year – twice the OECD average and 4 times the world average (Hughes 2014 cited in Goldie & Betts, 2014, p. 9). Arguably, city structures that are poorly conceived or executed or are incompatible with harnessing human kinetic dynamics present missed opportunities for the betterment of the community in which it exists as well as sustainability initiatives generally. This highlights critical areas of concern in Australia particularly given the alarming abovementioned statistics. Thus, we argue (as outlined in 'Further Research') that improved predictive modelling of pedestrian behaviours whilst transitioning through cities affords for more informed design decision-making for new urban precincts and mass transit nodes, through to potential modifications to the existing design to better utilise latent human kinetic energy.

4.3. Limitations

This research does not present data at this stage. This paper highlights the opportunity and makes logical justification for the novel application of geostatistical modelling and sources of data and analysis methodology for the built environment for the purpose of understanding where energy harvesting infrastructure should be located.

4.4. Further research

This research could also help guide municipal planning, the development of policy, and steer the formulation of strategic plans. The study contributes towards an increasing design knowledge-base for professionals in the area of urban design. The novel methods inform how we understand and plan cities for efficiency, movement and higher density with strategies to achieve safer and more sustainable spaces. Future master planning set against municipal strategic plans would allow for more efficient energy harvesting mechanisms through calculated alignment of nodes and pathways and spatial relationships with other spaces and functions, for example, where urban centres interface with transit orientated design.

5. Conclusion

This research examines the relationship between surveillance data and the environment in which it occurs and considers how this untapped data resource could be used to inform design, co-generate energy, improve safety and create a more sustainable built environment. This research argues that the collective behaviours to the built environment in highly densified cities can be mapped and predicted with patterns produced that contribute to decision-making in design that shape spatial–behavioural relationships.

It has been said that knowledge is power. If designers had access to data and visual patterns of behaviour in designed spaces – to understand how people move and inhabit space, designers would undoubtedly be better equipped to successfully determine the placement and design of elements. In particular, 'hot-spots' or concentrations of activity and pedestrian flow provide further opportunities for the placement of energy harvesting technologies.

It has been shown that research findings in the U.K. and U.S., as well as Australia, suggest that CCTV footage is not proactive, but reactive and thus does little more than record data, at times used as evidence. This research outlined opportunity for the novel application of geostatistical modelling to spatial CCTV data in the urban environment for the purpose of understanding people's movement patterns, and with this, where energy harvesting infrastructure should be located to capitalise on human movement to co-generate energy. This paper outlines dependable sources of large-scale online distributed and heterogeneous data sets from across Australia published by the Australian Urban Research Infrastructure Network that will support phase 2 of this research. This data will allow researchers to better understand how spatial parameters affect human behaviour through patterns and trends leading to predictability and probability. In addition to CCTV surveillance data, telecommunications triangulation, GPS tracking and powerful networks of the IOTs identify routine activities providing further correlational data for understanding design for inclusivity and mobility through the urban environment. This becomes even more critical as our cities densify due to the monumental shift in populations from regional to urban areas, and a general increase in global population by the billion. Given this, it is otherwise a missed opportunity – not to consider the relationship between the built environment and the data-gathering technologies within it that allow us to improve our understanding of behaviours and probability through evidence-based analytics.

This paper suggests that once harvested, kinetic energy could be applied to municipal purposes for direct use within our cities. Here, designers and specifiers are empowered to apply evidence-based outcomes to interrogate long-held assumptions. Applied progressive methodologies lead to improved conception the supports, disproves, or realigns previously accepted theories beyond their intended purpose for the betterment of humanity through creating more socially sustainable public spaces.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Emil Jonescu http://orcid.org/0000-0002-3508-406X

References

Acevedo, William and Penny Masuoka. 1997. *Time-series animation techniques for visualizing urban growth*. Computers & Geoscrences Vol. 23, 4, pp. 423–435, Elsevier Science Ltd

Altman, I. (1975). *The environmental and social behaviour: Privacy, personal, space, territory, crowding*. California: Brooks Cole Publishing Company.

Ando, Bruno, Salvatore Baglio, Adi Bulsara, Vincenzo Marletta, and Antonio Pistorio. 2015. "Experimental and Theoretical Investigation of a Non-Linear Vibrational Energy Harvester". *Procedia Engineering* 120: 1024–1027. 10.1016/j.proeng.2015.08.701

ArcGIS Resource Centre. (2019). ArcGIS Online. Retrieved from http://help.arcgis.com/en/arcgis desktop/10.0/help/index.html

Australian Bureau of Statistics. (2011). 3235.0 - population by age and sex, regions of Australia. Retrieved from http://www.abs.gov.au/ausstats/abs@.nsf/Products/3235.0~2011~Main +Features~Western+Australia?OpenDocument#PARALINK0

Banovic, J. (2013, July 13). Intelligent lights make up wireless network used for entertainment and safety. *ABC 7 Action News*. Retrieved from http://www.wxyz.com/dpp/news/region/oakland_county/intelligent-lights-make-up-wireless-network-used-for-entertainment-and-safety#ixzz2Yw1yZeUl

Bardossy, Andra and Jing, Li (2008). Geostatistical interpolation using copulas. Water Resources Research, 44.

Batty, Michael. 2013. "Big data, smart cities and city planning." *Dialogues in Human Geography* 3 (3): 274–279

Bentham, J. (1787). Panopticon or the inspection house. In J. Bowring (Ed.), *The works of Jeremy Bentham* (pp. 1838–1843). Edinburgh: Simpkin, Marshall & Co.

Borruso, Giuseppe, Valentino Iacoviello., and Andrea Porceddu. (2007). GIS and geostatistics for modelling urban times in neighbouring border cities. Retrieved from Geocomputations.org. http://www.geocomputation.org/2007/3C-Apps_Urban_Modelling_2/3C4.pdf

Bourguignon, Marcelo and Vasconcellos, Klaus L.P. (2015) Improved estimation for Poisson INAR (1) models. Journal of Statistical Computation and Simulation, 85, 412, 2425–2441. Brennan Centre for Justice. 2017. Crime in 2017: Updated Analysis. Retrieved from https://www.brennancenter.org/analysis/crime-2017-updated-analysis

Box, G., & Jenkins, G. (1970). *Time-series analysis, forecasting and control*. San Francisco: Holden-Day. revised edn., 1976.

Brennan Center for Justice. (2017). Crime in 2017: Updated Analysis. Retrieved December 15, 2019, from https://www.brennancenter.org/our-work/research-reports/crime-2017-updated-analysis

Burrough, P., McDonnell, R., & Lloys, C. (1998). *Principles of geographical information systems*. New York, NY: Oxford University Press.

Burrough, Peter. 2001. "GIS and Geostatistics: Essential Partners for Spatial Analysis." *Environmental and Ecological Statistics* 8 (4): 361–377. Kluwer Academic Publishers. 10.1023/A:1012734519752

Caers, J. (2005). *Petroleum geostatistics*. Texas: Society of Petroleum Engineers.

Chatfield, C. (2001). *Time-series forecasting*. Boca Raton: Chapman & Hall/CRC.

Cozens, Paul. 2011. "Urban Planning and Environmental Criminology: Towards a New Perspective for Safer Cities." *Planning Practice and Research* 26 (4): 481–508. doi: 10.1080/02697459.2011.582357.

Davenport, Justin. (2007, September 19). Tens of Thousands of CCTV Cameras, yet 80% of Crime Unsolved. *London Evening Standard*. Retrieved from http://www. standard.co.uk/news/tens-of-thousands-of-cctv-cameras-yet-80-of-crime-unsolved-6684359.html

De Oliveira, Victor. 2013. "Hierarchical Poisson models for spatial count data". Journal of Multivariate Analysis 122, 393–408

De Smith, M. J. G., Michael, F., & Longley, P. (2007). *Geospatial analysis: A comprehensive guide to principles, techniques and software tools*. Leicester: Matador.

Diggle, P. J., & Ribeiro, P. J. (2007). *Model-based geostatistics*. New York: Springer-Verlag.

Everitt, B., & Skrondal, A. (2010). *The Cambridge dictionary of statistics* (4th ed). Leiden: Cambridge University Press.

Ferrari, Marco, Vittorio Ferrari, Michele Guizzetti, Bruno Ando, Salvatore Baglio, and Carlo Trigona. 2010. "Improved Energy Harvesting From Wideband Vibrations By Non-Linear Piezoelectric Converters". *Sensors and Actuators A* 162 (2): 425–431. 10.1016/j.sna.2010.05.022

Foth, M., Choi, J. H.-J., & Satchell, C. (2011). Urban Informatics. Peper presented at *Conference on Computer Supported Cooperative Work (CSCW)*, Hangzhou, China, March 19-23, 2011.

Foucault, M. (1975). *Discipline and Punish: The birth of a prison*. London: Penguin Books Ltd. Alan Sheridan trans.

Francescani, C. (2013, June 21). NYPD expands surveillance net to fight crime as well as terrorism. *Reuters*. Retrieved from http://www.reuters.com/article/2013/06/21/us-usa-ny-surveillance-idUSBRE95K0T520130621

Gehl, J. (2011). *Life between buildings: Using public space*. Washington DC: Island Press. Jo Koch trans.

Goldie, J., & Betts, K. (2014). *Sustainable futures: Linking population, resources and the environment*. Collingwood VIC: CSIRO Publishing.

Goodwin, V. (2002). Crime Prevention and Community Safety Council [Tasmania], Evaluation of the Devonport CCTV Scheme. 34–44. Retrieved from http://www.popcenter.org/library/scp/pdf/76-Goodwin.pdf

Gunturi, V., & Shekhar, S. (2016). Big Spatio-temporal network data analytics for smart cities: Research needs. In P. (Vonu) Thakuriah, N. Tilahun, & M. Zellner (Eds.), *Introduction to seeing cities through big data: Research, Methods and applications in urban informatics* Cham, Switzerand: Springer. doi:10.1007/978-3-319-40902-3

Home Office Statistical Bulletin. (2009), *Crime in England and Wales: Findings from the British Crime Survey and Police Recorded Crime, 2008/09*. Volume 1 (22), Alison Walker, John Flatley, Chris Kershaw and Debbie Moon (eds) Home Office Statistics unit. Retrieved from http://www.homeoffice.gov.uk/rds/index.html

Isaaks, E., & Srivastava, M. (1989). *Applied geostatistics*. New York: Oxford University Press.

Jacobs, J. (1961). *The death and life of great American cities*. New York, NY: Random House.

Jenks, M., & Burgess, R. (2004). *Compact cities: Sustainable urban forms for developing countries*. London: Spon Press.

Jones, Trevor, and Tim Newburn. 2002. "The Transformation of Policing? Understanding Current Trends in Policing Systems." *British Journal of Criminology* 42 (1): 129–146. ISSN 0007-0955, 10.1093/bjc/42.1.129

Jonescu, E., Sutrisna, M., Khoa, D., & Mercea, T. (2018). Interaction between urban densities, surveillance and infrastructure: Re-Purposing CCTV to support social and physical densification, and trends that propagate sustainable urban spaces. 42nd AUBEA: Australasian Universities Building Education Association Conference. Singapore: Curtin University, 26-28 September 2018. [ISBN 978-0-9871831-3-2 (Print) & ISBN 978-0-9871831-6-3 (e-Book)].
Kazianka, H., and Pilz, J. (2010). Spatial Interpolation Using Copula-Based Geostatistical Models. In: Atkinson P., Lloyd C. (eds) geoENV VII – Geostatistics for Environmental Applications. Quantitative Geology and Geostatistics, vol 16. Springer, Dordrecht.
Kazianka, Hannes and Pilz, Jurgen (2010). "Copula-based geostatistical modeling of continuous and discrete data including covariates". Stochastic Environmental Research and Risk Assesment, 24, 661–673.
Kitamura, Ryuichi, Cynthia Chen, Ram Pendyala, and Ravi Narayanan. 2000. "Micro-Simulation of Daily Activity-Travel Patterns for Travel Demand Forecasting." *Transportation* 27 (1):25–51. Kluwer Academic Publishers. 10.1023/A:1005259324588
Lewis, P. (2011, March 2). You're being watched: There's One CCTV Camera for every 32 People in UK. *The Guardian*. Retrieved from http://www.guardian.co.uk/uk/2011/mar/02/cctv-cameras-watching-surveillance
London Metropolitan Police. (2019) Crime mapping: Data Tables 2000 – 2010. Retrieved from http://maps.met.police.uk
Madsen, Lisa. (2009). "Maximum likelihood estimation of regression parameters with spatially dependent discrete Data". Journal of Agricultural, Biological, and Environmental Statistics, 14, 375–391.
Margolin, Josh. (2012, February 13). PA Super Gizmos Military-Like Security at WTC. *New York Post*. Retrieved from https://nypost.com/2012/02/13/pa-super-gizmos/
McKenzie, E. (1985) *Some simple models for discrete variate time series*. Water Resources Bulletin 21(4),645–650.
New York City Police Department. (2019). Citywide crime statistics: City wide crime statistics weekly. Retrieved from https://www1.nyc.gov/site/nypd/stats/crime-statistics/citywide-crime-stats.page
New Zealand Law Commission. (2008). Privacy: Concepts and issues: Review of the law of privacy. *Stage 1 Study Paper 19 136*. ISBN 978-1-877316-43-2. Retrieved from https://www.lawcom.govt.nz/sites/default/files/projectAvailableFormats/NZLC%20SP19.pdf
Nixon, R. (2013, July 3). U.S. Postal service logging all mail for law enforcement. *New York Times*. Retrieved from http://www.nytimes.com/2013/07/04/us/monitoring-of-snail-mail.html? pagewanted=all&_ r=0
O'Connor, M., & Lines, W. (2008). *Overloading Australia: How governments and media dither and deny on population*. Canterbury NSW: Envirobook.
Office for National Statistics. (2012). Census gives Insights into Characteristics of London's Population. Retrieved from http://www.ons.gov.uk/ons/dcp29904_291554.pdf
Peredo, O., Garcia, J., Richardo, S., & Ortiz, J. (2016). Urban dynamic estimation using mobile phone logs and locally varying anisotropy. In J. Gómez-Hernández, J. Javier Rodrigo-Ilarri, M. Rodrigo-Clavero, C. Eduardo, & V.-G. Jose (Eds.), *Geostatistics Valencia 2016. Quantitative geology and geostatistics* (Vol. 19). Cham: Springer. doi:10.1007/978-3-319-46819-8_66
Pettit, C., Tice, A., & Randolph, B. (2016). Using an online spatial analytics workbench for understanding housing affordability in Sydney. In P. (Vonu) Thakuriah, N. Tilahun, & M. Zellner (Eds.), *Introduction to seeing cities through big data: Research, methods and applications in urban informatics* Cham, Switzerand: Springer. doi:10.1007/978-3-319-40902-3_14
Polit, D. F., & Hungler, B. P. (1985). *Essentials of nursing research : methods and applications*. Philadelphia: Lippincott.
Silva, B., Khan, M., Jung, C., Seo, J., Muhammad, D., Han, J., . . . Han, K. (2018). Urban planning and smart city decision management empowered by real-time data processing using big data analytics. *Sensors*, *19*(9), Basel. doi:10.3390/s18092994
Sinclair, A. (2002). *Applied mineral inventory estimation*. New York, NY: Cambridge University Press.

Sklar, A. (1959). *Fonctions de répartition à n dimensions et leurs marges* (pp. 229–231). Paris: Publications de l'Institut Statistique de l'Université de Paris
Smith, Martha, and Ronald Clarke. 2000. "Crime and Public Transport." *Crime and Justice* 27: 169–233. Chicago:University of Chicago Press. Retrieved from http://www.jstor.org/stable/1147664
Sullivan, L. (1997). *Rising crime in Australia*. Australian Capital Territory: The Centre for Independent Studies Limited.
Sung, Hyungun., and Ju-Taek Oh. 2011. "Transit-Oriented Development in a High-Density City: Identifying Its Association with Transit Ridership in Seoul, Korea." *Abstract. Cities* 28 (1): 70–82. doi:10.1016/j.cities.2010.09.004
Thakuriah, P., Tilahun, N., & Zellner, M. (2017). *Introduction to seeing cities through big data: Research, methods and applications in urban informatics*. Cham, Switzerland: Springer. doi:10.1007/978-3-319-40902-3_14
United Nations Social Defence Research Institute. (1975). *Prison architecture: An international survey of representative closed institutions and analysis of current trends in prison design*. London: The Architectural Press Ltd.
Upton, G., & Cook, I. (2008). *A dictionary of statistics* (2nd ed.). Oxford, UK: Oxford University Press.
van den Hengel, A., Dick, A., & Hill, R. (2009). *Activity topology estimation for large networks of cameras, school of computer science*. University of Adelaide. Retrieved from https://cs.adelaide.edu.au/~hengel/?/research/project-surveillance/
Wang, W., Cao, J., Bowen, C., Zhao, S., & Lin, J. (2017). Optimum resistance analysis and experimental verification of non-linear piezoelectric energy harvesting from human motions. *Energy*, *118*(1), 221–230.
Webster, R., & Margaret, O. A. (2007). *Geostatistics for environmental scientists* (2nd ed.). West Sussex, England: John Wiley & Sons, Ltd.
Welsh, B., & Farrington, D. (2002). Crime prevention effects of closed circuit television: A systematic review. *Home Office Research Study*, *252*, 42–45. Retrieved from https://popcenter.asu.edu/sites/default/files/Responses/video_surveillance/PDFs/Welsh&Farrington_2002.pdf
Xie, L., & Minjing, C. (2014). Increased piezoelectric energy harvesting from human footstep motion by using an amplification mechanism. *Applied Physics Letters*, *105*(14), 105.