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The study of slums as social and physical constructs: challenges and emerging research opportunities

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ABSTRACT

Over 1 billion people currently live in slums, with the number of slum dwellers only expected to grow in the coming decades. The vast majority of slums are located in and around urban centres in the less economically developed countries, which are also experiencing greater rates of urbanization compared with more developed countries. This rapid rate of urbanization is cause for significant concern given that many of these countries often lack the ability to provide the infrastructure (e.g., roads and affordable housing) and basic services (e.g., water and sanitation) to provide adequately for the increasing influx of people into cities. While research on slums has been ongoing, such work has mainly focused on one of three constructs: exploring the socio-economic and policy issues; exploring the physical characteristics; and, lastly, those modelling slums. This paper reviews these lines of research and argues that while each is valuable, there is a need for a more holistic approach for studying slums to truly understand them. By synthesizing the social and physical constructs, this paper provides a more holistic synthesis of the problem, which can potentially lead to a deeper understanding and, consequently, better approaches for tackling the challenge of slums at the local, national and regional scales.

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R1

INTRODUCTION

Over the last century there has been tremendous growth in the urban population. This growth, however, has not been uniform. Growth in urban areas in less developed regions of the world has been especially rapid, increasing at an average rate of 2% annually compared with 0.5% in more developed regions. This trend is expected to continue with most of the less developed countries faced with the challenge of absorbing the majority of the future population growth (United Nations, 2015a). Increased urbanization is a major concern for less developed countries since they often lack the infrastructure and basic services (e.g., water, sanitation and healthcare) necessary to absorb the increasing number of people (Cohen, 2006; Montgomery, 2008). Unable to adequately

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meet the demands of the growing population, slums have emerged and continue to proliferate in many less developed countries. Currently, about 1 billion people live in slums, with most slum dwellers located in less developed countries, which accounts for about 30% of their urban population (United Nations, 2015a). The number of slum dwellers is projected to increase to 2 billion by 2030 and to 3 billion by 2050 if current trends persist (UN-Habitat, 2010). The presence of slums has regional and global implications, impacting areas such as education, health and child mortality, and political and social exclusion, among many other things (UN-Habitat, 2003).

Although widely studied, most work on slums[1] has focused on one of three main lines of enquiry: socio-economic and policy (e.g., Omole, 2010; Patel, Koizumi, & Crooks, 2014; Sola, 2013); physical characteristics using approaches such as remote sensing (e.g., Filho & Sobreira, 2005; Kit, Lüdeke, & Reckien, 2012; Kohli, Sliuzas, Kerle, & Stein, 2012); and, more recently, modelling using approaches such as cellular automata (CA) and agent-based models (ABMs) (e.g., Augustijn-Beckers, Flacke, & Retsios, 2011; Jokar Arsanjani, Helbich, Kainz, & Darvishi Boloorani, 2013; Patel, Crooks, & Koizumi, 2012; Sietchiping, 2004). Each line of enquiry is often characterized by its own set of assumptions and interpretations, leading only to a partial view of slums. However, these different themes are all interrelated at various levels. For instance, modelling slums without considering the social constructs that reflect the choice to migrate to a slum or ignoring the physical layout of the slum can lead to misrepresentation and misinterpretation of the model results. In order to grapple with the complexities of slums one must consider both their social and their physical constructs. Arguably, this must take into account the drivers that cause people to live in slums, along with their physical location, so that appropriate policies can be developed and explored in order to improve the well-being of slum dwellers. This approach requires one to consider slums as multifaceted, with various social and physical constructs at play for each slum. Consequently, slums should be examined using a interdisciplinary approach, ensuring a more holistic and systematic assessment.

Building on prior research, and motivated by the need for a more holistic approach for studying slums, this paper presents a novel framework for understanding and studying slums. The approach, as shown in Figure 1, first begins in the second section with a *contextualization* of slums through which the variability of slums can be captured. This *contextualization* includes studying slums as a form of human settlement, understanding their impact and identifying the various factors relating to their continued growth and persistence. In the third section, the *contextualization* of various slums enables the development of an abstract *conceptualization* of slums. In such a *conceptualization*, the focus is on the challenge of deriving an operational definition for slums, identifying data needs, as well as understanding the monitoring and analysis challenges associated with studying slums. We argue that while these issues have been longstanding challenges, several emerging data sources and methodologies provide new opportunities to address them. In the fourth section, in particular, advancements in the use of remote-sensing technology to study slums, the emergence of crowdsourced information on slums and advancements in modelling enable one to understand better the intricate nature of slums. The fifth section summarizes and highlights areas for further research.

In the light of the framework put forward, the main contribution of this paper is twofold: first, it identifies the most pressing issues surrounding slums based on current understandings, which ranges from theory to practice; and second, it puts forward a future integrated research agenda for developing a deeper understanding of the fundamental underlying processes that define and shape slums. The framework depicted in Figure 1 should be regarded as evolutional rather than static in order to capture and understand the dynamic nature of slums and their complex interaction in the urban environment.

However, before moving onto the various aspects of the framework, a caveat is required. While a more detailed discussion for each component in Figure 1 is possible, this is beyond the scope

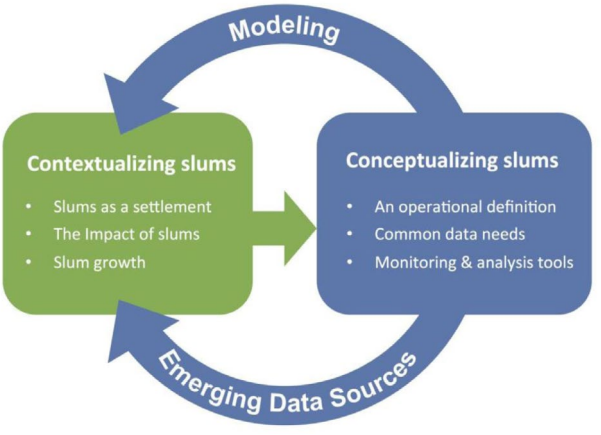

Figure 1. Framework for studying and understanding slums.

of this paper. For example, the modelling of slums is a large and extensive area of research, which to cover comprehensively would require its own paper. To overcome this issue, we include some representative studies and reviews that provide a gateway to a more detailed description of each topic (e.g., see Roy, Lees, Palavalli, Pfeffer, & Sloot, 2014, for an overview of modelling).

BACKGROUND AND THEORY

Slums and informal settlements

Slums have been in existence since the time of cities and their presence has long been documented in the literature (e.g., Booth, 1903). The word 'slum' has mainly been used to describe people living under substandard conditions and squalor. For example, Cities Alliance (2006) describes slums as 'neglected parts of cities where housing and living conditions are appallingly poor'. Often the terms 'slum' and 'informal settlements' are used interchangeably in the literature (UN Habitat, 2012). However, some would argue that there is a distinct difference between slum and informal settlement (e.g., Hurskainen, 2004; Rashid, 2009). (Readers interested in this debate are referred to Gilbert (2007) for a more thorough discussion). This paper adopts the view that slums and informal settlements are one in the same and, therefore, can be treated as one. Usually, as argued by UN-Habitat (2003), most characteristics of these environments, whether slum or informal settlement, are not found in isolation, leading to multiple levels of deprivation for slum dwellers. Whether slums and informal settlements are viewed separately or as a single entity, they represent disadvantaged communities continuing to have large impact on the physical and economic landscapes, as will be discussed below.

The vast majority of the slums are located in less developed countries, and most of the growth in slum populations is expected to occur in such countries. However, just as the term 'slum' can have multiple connotations, so does the term 'developing country'. For the purpose of this paper, we adopt the United Nation's definitions of 'less developed country' and 'developing country' for a country where the majority of the population makes significantly less income and has weaker social indicators than the population in highly industrialized countries (UN-OHRLLS, 2016). Furthermore, in such countries there is lack of basic public services. Although alternative terms have been used to describe less developed countries (e.g., 'emergent nations'), much of the literature on slums that is reviewed here has used the terms 'less developed' and 'developing country' to refer to areas most impacted by slums.

The impact of slums

The growth of slums is expected to have major consequences on both humans and the environment, which are inextricably linked. On the one hand, the conditions that exist in slums such as living under physical threat from natural and manmade disasters and improper housing have direct impacts on their residents (Napier, 2007). This is mainly due to the low capacity of slums dwellers to recover from disasters, such as floods and earthquakes, compared with more formal communities (Ajibade & McBean, 2014; Ebert, Kerle, & Stein, 2009). On the other hand, slum residents themselves can impact their environment due to lack of basic services, which results in contaminated soil and polluted air and waterways. This results in a perpetuated cycle of decline for both slum dwellers and the environment (Ali & Sulaiman, 2006), with the possibility of impacts extending to communities beyond the slums (e.g., flooding). The growth and expansion of slums can therefore threaten sustainable urban development at local, national and regional scales (Patel, 2012).

Growth and expansion of slums can also impact the national and regional economy, both negatively and positively. For example, the negative aspect of slums relates to the fact that they are often burdened with high transaction costs, including increases in transportation expenditures because of inadequate infrastructure, and disease burden on urban dwellers because of the large number of people living in slums (Fox, 2008). In addition, ambiguous property and tenancy rights can reduce the efficiency of urban land and housing markets, and may discourage investment or reduce participation in urban labour markets (Marx, Stoker, & Suri, 2013a). This may potentially impact a country or a region's overall economic outlook in the global economy, making it less competitive in the worldwide arena (Gambo, Idowu, & Anyakora, 2012).

Less often mentioned in the literature is the economic good provided by slum dwellers. Slum dwellers subsidize the middle classes and the business world by providing a comparatively cheap source of labour (Brugmann, 2010; Malecki & Ewers, 2007). Furthermore, it has been argued that their low economic standing and general lack of education forces them to accept low-paying jobs that may not be readily accepted by middle- and upper-class people (Pawar & Mane, 2013). Slum dwellers often find jobs in the informal sector, which is usually linked very closely to the needs of surrounding formal communities (Opeyemi, Olabode, Olalekan, & Omolola, 2012). In some cases, this informal economy has positively impacted the country's gross domestic product (GDP). Slums in Dharavi, India, for example, employ as many as 70% of its residents (Gruber et al., 2005) with current economic output estimates of US$700 million annually (Chege & Mwisukha, 2013). Other places such as Delhi, Bangalore and Kolkata, all in India, also depend heavily on the informal sector for supporting much of their day-to-day manufacturing activities (Benjamin, 2004). Some researchers (e.g., Brugmann, 2013; Saglio-Yatzimirsky, 2013) suggest that if such economic benefits were to be considered alone, places such as Dharavi would no longer be considered a slum.

Lastly, the poor conditions that exist in slums and daily struggles that slum dwellers face continues to be recognized as a global and ethical challenge. Many governments, regional and international non-government organizations (NGOs) have put in place legislation or systems recognizing the need to protect and improve the lives of slum dwellers (e.g., the Rajiv Awas Yojana programme in India; MHUPA, 2013). Likewise, Target 7D of the United Nations Millennium Development Goals (UN MDG) aims to improve significantly the lives of 100 million slum dwellers worldwide by 2020 (United Nations, 2015a). This target was further advanced with Goal 1 of the UN's Sustainable Development Goals, the MDG's successor. Goal 1 aims to reduce at least by half the population of all people living in poverty in all its dimensions according to national definitions by 2030 (United Nations, 2015b). Failure to take part in such global initiatives may have negative impacts on countries that depend on others for financial and political support. These impacts highlight the critical need for managing slum populations worldwide. To achieve this goal, it is necessary to understand the factors that have led to the emergence and

persistence of slums over time. We would argue that such issues must be dealt with for any future intervention to be successful.

Factors influencing the growth of slums

Many factors have been linked to the growth of slums. This section highlights several of these factors, specifically those relating to locational choice factors, rural-to-urban migration, poor urban governance and ill-designed policies. Those factors chosen for discussion have been identified as those most often discussed by others for the growth and persistence of slums based on an extensive review of the literature.

Locational choice factors

The emergence of slums has been linked to a number of socio-cultural, economic and physical factors. For example, Lall, Lundberg, and Shalizi (2008) examined the residential locational decisions made by slum dwellers in Pune, India, and found that locational decisions were made around theories relating to socio-cultural and economic factors such as commuting costs (e.g., Alonso, 1964), access to local public goods (e.g., Tiebout, 1956) and individual preferences for community or neighbourhood composition (e.g., Schelling, 1978). In addition to these classical models, they found that the locational choices made by slum dwellers was also guided by housing quality and neighbourhood amenities. Similar findings have been reported in other studies (e.g., Abramo, 2009; Takeuchi, Cropper, & Bento, 2006). Social ties related to common culture, language and similar income-generating activities have also been found associated with the locational choices of new immigrants (e.g., Barnhardt, Field, & Pande, 2014; Kombe, 2005). It has also been found that people born within or in close proximity to slums tend to remain in them or move to them (UN-Habitat, 2003), while some slum dwellers are of the belief that places outside of slums are out of their reach (e.g., Ahmed, Brookins, & Ali, 2011). This suggests that any efforts to address the issue of slums must also consider their surroundings and their social structures.

With respect to physical factors impacting the location of slum dwellers, the availability of land has been highly cited in the literature. It has been shown that slum dwellers typically inhabit marginal locations such as riverbanks, steep slopes or dumping grounds (e.g., Sietchiping, 2004). This is mainly due to the low purchasing power of slum dwellers in formal land markets when compared with high-income groups (Ajibade & McBean, 2014; Praharaj, 2013). Slums in South America, for example, Rio de Janiero in Brazil and Lima in Peru, are notoriously known for building on steep slopes (Fernandes et al., 2004). Such locations are usually unsafe, posing a risk to human life because of the occurrence of natural disasters such as landslides. Furthermore, slums are also found both within and on the outskirts of cities (UN-Habitat, 2003). These unique physical characteristics of slums and the complex interplay with the various socio-economic factors pertaining to their growth and persistence represent a challenging task that has yet to be holistically addressed.

Rural-to-urban migration

Within the literature, rural-to-urban migration not only has been the driver for the growth of cities, but also it has been identified as one of the primary drivers for the growth of slums. In less developed countries the current rapid and immense net movement of the rural population to urban spaces has intensified (Malecki & Ewers, 2007; Srivastava & Singh, 1996). This is due to several factors: those pertaining to the pulling of rural people to cities and push factors driving population away from rural areas. Often cited in the literature with respect to pull factors include the relative perception of better economic opportunities (e.g., Glaeser, 2011) and provision of basic services such as education and healthcare within cities (e.g., Khan, Kraemer, & Kraemer, 2014), or the freedom from restrictive social or cultural norms often found in rural

areas (e.g., Opeyemi et al., 2012; Ullah, 2004). Push factors include rural poverty (e.g., Khan et al., 2014), excess agricultural labour supply (e.g., Oberai, 1993), environmental hardships (e.g., Ishtiaque & Mahmud, 2011), threat from natural disasters or conflict and war (e.g., Black, Bennett, Thomas, & Beddington, 2011). While such events have pushed rural dwellers to urban areas, there has been a lack of economic growth in many of these countries and when combined has been touted for the growth and persistence of slums, especially in African countries (Fox, 2012). Whether a pull or a push factor, the net result of rural-to-urban migration is overwhelming to the urban centres in less developed countries, which are not equipped to support the additional population, especially when combined with the socio-economic factors discussed above. Faced with nowhere else to go, people turn to slums to meet their most basic housing needs (Vasudevan, 2015).

Poor urban governance

Other factors relating to the upward growth of slums in many less developed countries is the use of rigid and often outdated urban planning regulations, which are typically bypassed by slum dwellers to meet their housing needs. This is a reflection of poor urban governance (Chiodelli & Moroni, 2014). Many local and national governments are also unable to enforce planning regulations due to lack of resources (Tsenkova, Potsiou, & Badyina, 2009). In Cote d'Ivoire, for example, high infrastructure cost and rigid building standards have led to a slow pace of development, which resulted in unaffordable housing for many large segments of the population (Mayo & Angel, 1993). In Nigeria, official fees involved in the registration process to acquire land can be as much as 27% of the property value (World Bank, 2005), presenting a challenge for slum dwellers with limited finances. These circumstances ultimately lead to high rates of insecurity of tenure and provide conducive conditions that continue to drive the growth of slums due to poorly functioning land markets.

Another issue in many less developed countries is the failure of governments to incorporate slum dwellers as part of the overall planning process (Cities Alliance, 2014). This is often due to the inability of many governments to keep abreast with urbanization because of the lack of resources and corrupt governments (Fekade, 2000). Some governments also refuse to provide urban services to slum dwellers in fear that this will only escalate the issue of slums (Opeyemi et al., 2012), or lead to more established property rights, which many governments are unwilling to provide (Fox, 2014). As discussed by Werlin (1999), without more established property rights for slum dwellers, governments lack the ability to force slum residents into paying for public services and improving their homes. It is also the case that some governments simply lack the political will to address these issues (e.g., Rashid, 2009). Overall, one could argue that not enough attention has been given to the plight of slum dwellers on the part of government, further enabling the continued growth of slums.

Ill-designed policies

Closely related to poor urban governance are the inappropriate policies developed by local and national governments, and regional led organizations to curb the growth of slums. During the 1950s and 1960s, a time when urbanization was viewed as a positive, with large labour forces needed to fuel economic growth in cities (Fox, 2014), macro-policy intervention with respect to slums was largely ignored, leading to the widespread growth of slums. To tackle this issue, a sites and services approach was introduced in the 1970s. This policy provided infrastructure at new sites (e.g., roads and electricity) and slum dwellers were relocated to these sites (Fekade, 2000). Existing slums were demolished and slum dwellers were expected to pay for the newly developed serviced land as well as all home construction costs (Linden, 1986). With limited finances, and the added challenge of competing with the greater demand by higher income groups for the same available land, slums continued to grow (Arimah, 2001).

The failure of the sites and services approach led to a new wave of thinking during the 1980s, in which slums were upgraded with improved communal infrastructure and services. This avoided the unnecessary demolition of settlements (Gilbert, 2014) while lowering costs in many instances (e.g., Werlin, 1999). However, the slum-upgrading approach has been criticized at four major levels: failed financial commitment, negative socio-economic impacts, non-replicability of best practices and insecurity of tenure (Fekade, 2000). Subsequently, an enabling approach through security of tenure was introduced in the 1990s. Legal occupational status was given to slum dwellers in the hope that they would be more willing improve their own circumstances (de Soto, 2002). This approach relied heavily on the assumption that most slum dwellers owned the dwelling in which they lived. However, this was not the case, as most slum dwellers did not do so (e.g., Gulyani, Talukdar, & Jack, 2010; Marx, Stoker, & Suri, 2013b), and this remains the plight of many slum dwellers today. Further, some would argue (e.g., Desai & Loftus, 2013) that security of land tenure adds an additional burden on slum dwellers since landlords are more likely to increase rental prices and evict those slum dwellers unable to pay. Moreover, as de Souza (2001) argues, perceptions of security of tenure may vary widely from household to household. Specifically, their study showed that slum dwellers were more willing to invest in improving their housing conditions irrespective of land tenure status. Such findings further challenge the notion that security of land tenure alone would be enough to motivate slum dwellers to improve their own living conditions.

The most recent approach, at least from a macro-policy viewpoint, to reduce the growth of slums is the Cities Without Slums action plan, introduced during the 2000s. This approach forms part of the MDG to improve the lives of 100 million slum dwellers by 2020 (United Nations, 2015a). Central to this idea is the understanding that both poverty and slums are interrelated, with any attempt to fix one having also to consider the other (Arimah, 2001). However, several issues have been identified with the Cities Without Slums action plan. These include little attention being given to other important poverty-related variables (e.g., political instability and natural disasters) and the non-comparability of metrics because of issues with data in many countries and the unique characteristics of slums (Saith, 2006). Furthermore, as no metrics are available for monitoring newly emerging slums, it has been suggested that the goal of improving the lives of at least 100 million slum dwellers by 2020 is far too modest to generate a meaningful reduction in slums globally (Sietchiping, 2004). Finally, the key terms used for measuring the improvement of slums (e.g., 'access', 'improved' and 'sufficient') are far too abstract for capturing and monitoring change rigorously (Cohen, 2014).

As this section has discussed, the continued failure of implemented slum policies has, in reality, facilitated the propagation of slums. One could argue that this is due to the inability of governments to understand fully the needs of slum dwellers and incorporate their needs when developing appropriate policies (Fekade, 2000). In addition, the locational decisions of slum dwellers, rural-to-urban migration and poor urban governance in general are all interrelated factors that have contributed to the growth of slums. Taken holistically, these various factors are all important for designing more appropriate slum policies. Failure to do so will only lead to the continued growth and persistence of slums. However, to grapple fully with the problems discussed above, we would argue that one needs also to understand the various operational challenges encountered when trying to address the issue of slums, which we turn to next.

THE CHALLENGE OF MODELLING, MONITORING AND ANALYZING SLUMS

As discussed above, slums continue to persist, although many attempts have been made to curb their growth over the past several decades. Some of the main reasons identified for their continued persistence include locational choice factors, rural-to-urban migration, poor urban

governance and ill-designed policies. This section will argue that in order to investigate fully these various factors more holistically, two broad but interrelated challenges must first be addressed. The first issue relates to arriving at a consensus with respect to what is a slum. Once a definition has been derived, a set of measures can then be formulated in order to quantify the various aspects that characterize slums. Based on these measures, it is then possible to define the types and characteristics of the data required to analyze and monitor slums. This second issue is discussed.

Towards an operational definition of slum

The first step in developing a more structured approach to the studying of slums is to define what they are. However, there continues to be no agreed-upon definition for what is a slum (e.g., Gilbert, 2011; Richter, Miscione, De, & Pfeffer, 2011), nor at what scale with which to study them. For example, Smith (2013) states that as many as 12 different definitions for slums are used by the Affordable Housing Institute. Slums' definitions can vary based on location, official and unofficial descriptions, or differences on issues covered (e.g., temporary nature, land legality and health). Furthermore, some places (e.g., Nairobi in Kenya and Mexico City in Mexico) have no formal definition in place for identifying slums, adding yet another level of subjectivity in defining slums (UN-Habitat, 2003).

In an attempt to enable a better accounting and monitoring of slums, the UN in 2003 formulated one of the first operational definitions for slums. Specifically, a slum was defined as a group of households lacking one or more of the following: (1) durable housing of a permanent nature that protects against extreme climate conditions; (2) inadequate living space; (3) easy access to safe water in sufficient amounts at an affordable price; (4) adequate access to sanitation in the form of a private or public toilet shared by a reasonable number of people; and (5) security of tenure that prevents against forced evictions (UN-Habitat, 2003). This definition for a slum was later revised by UN-Habitat (2006) to the individual household level (i.e., a group of individuals living under the same roof). These definitions are based on two major tenants: physical and legal characteristics of slums. Physical characteristics look at the circumstances that surround slum life, depicting the deficiencies and poor conditions that occur within slums. Legal tenure status, other the other hand, often depends on *de facto* or *de jure* rights, or a lack of them. This measure looks at the denial and violation of housing rights, as well the progressive fulfilment of these rights. The UN-Habitat (2006) definition, however, does not capture the full degree of deprivation faced by slum households, nor does it capture information on how the extent and type of deprivations change over time. As McFarlane (2012) points out, the type of informality experienced by slum dwellers is far from being static, and instead, it is in a dynamic state that changes over time. Consequently, it is important to monitor continuously whether implemented policies and other interventions are changing the conditions within slums.

An enhanced definition for slums proposed by UN-Habitat (2008) groups slums into broad categories of moderately deprived (one-shelter deprivation), severely deprived (two-shelter deprivations) and extremely deprived (three- or more-shelter deprivations). The main issues with this enhanced definition, as with those previously mentioned, relate to the absence of a social dimension, and the difficulty in capturing information as it relates to security of tenure within slums. These factors are therefore not present in any global comparison of slums (United Nations, 2012). In conjunction with this, some would argue that risk posed to human life has been highly underplayed in previous definitions for slums (e.g., Khalifa, 2011). Without incorporating risk factors, it is difficult to provide adequate resources to mitigate risk for individual slums, as each slum is unique with its own set of associated risk factors (Jankowska, Weeks, & Engstrom, 2012).

The variety of definitions and the lack of consensus on the appropriate scale at which slums should be studied poses serious challenges for monitoring and reducing their populations

worldwide. This has led to a variety of area-specific slum-mapping approaches in different areas. From a policy perspective, the enumeration of slum dwellers may mean that national governments need to allocate more resources for welfare programmes (Patel, 2012). Likewise, it is difficult to compare slum populations using different definitions from a research point of view. Multiple definitions further result in different estimates of slum populations (e.g., Patel et al., 2014) and variations in the types and quality of data being collected on slums. Moreover, without a common slum definition in place, issues in monitoring the growth of slums and determining the overall success of slum policies will prove challenging. Consequently, without a common slum definition, efforts to estimate the magnitude and extent of slums as a global issue will be hindered. At the same time, a common definition alone without adequate data for identifying and monitoring slums will be of limited benefit from a practical viewpoint. Some of these data challenges are identified next.

Data

Despite a lack of consensus on how to define what represents a slum, researchers have been collecting data on these environments for some time. However, we would argue, this has been piecemeal at best given that most data are collected for specific slums and at different spatial and temporal scales. Traditional methods for detecting slums have often inferred their presence using census data. These approaches collect information though surveys as a basis of deprivation or poverty mapping. Although more commonly available for most countries when compared with other forms of data (e.g., high-resolution remotely sensed imagery), census data present several issues when used to detect slums. One major issue is that there are long temporal gaps between collection events and the release of statistics (Martínez, 2009), usually 5–10 years (Hall, Malcolm, & Piwowar, 2001). Given the dynamic spatial and temporal behaviour of slums (e.g., a growth rate of more than 1000 people per hour in Dhaka, Bangladesh; Kotkin, 2014), the spatial information mapped by surveying may already be obsolete when consolidated.

Another identified issue with census data is that they are made available to users at coarse spatial scales, leading to a loss of spatial heterogeneity of landscape features, which may mask the presence of slums (depending on the specific definition of slums used). It is further difficult to link survey data collected on small populations (e.g., ethnographic information and dwelling attributes) with aggregated statistics collected from census. Such data integration is increasingly becoming important because of growing research and interest on marginalized populations (Galeon, 2008; Gibson-Graham, 2008). Moreover, census campaigns are expensive and labour intensive, which some governments are unable to afford, especially with increasing public sector cutbacks in many less developed countries (Leete, 2003). Other issues reported in the literature for census-related studies include safety issues for field workers and respondents being absent from their dwellings during data collection (Marx et al., 2013b). This may lead to skewed results in statistics generated from such census data. Given these issues, reliance on census data, at least on their own, is unable to provide the spatial and temporally disaggregated information needed to inform more comprehensive slum assessments.

Another major issue with slum data is their absence in some cases. For example, Makoko, one of Nigeria's oldest slums, was not included in any census until 2007 (Babalola, 2009). Whereas for large and well-known slums such as Kibera in Nairobi, Kenya, a wealth of information exists. This is mainly due to Kibera's large footprint on the landscape and its international presence from a humanitarian and socio-political point of view. Others institutions such as national and regional governments may do little to remove the presence of slums given the large voting population that exists within them (Marx et al., 2013b). For example, in some slums in Mumbai, India, while residents may not have the legal rights to reside within them (Chatterjee, 2004), local government institutions often use the distribution of toilets to sway slum residents' votes

(McFarlane, 2008). These issues altogether add another layer of complexity with respect to collecting and obtaining reliable data on slums, which eventually can lead to neglect and/or having limited assistance entirely.

Even when data on slums are available, this information may be fragmented across different organizations and with different levels of quality. There may also be significant restrictions when trying to access such information (e.g., Killemsetty, 2013; Sen, Hobson, & Joshi, 2003). Many less developed countries also do not implement any quality control during data collection, leading to low confidence in the use of these datasets (Henderson, Storeygard, & Weil, 2012). Moreover, most less developed countries lack the information infrastructure necessary for cataloguing slum information. Failure to continue without such systems in place will hinder the potential for advancing the research on slums at the global context, and, by extension, impact our capacity to address the challenges associated with them.

OPPORTUNITIES

While the above section has identified challenges with respect to defining, identifying and monitoring of slums, current advances in technology present several new-found opportunities with respect to addressing the challenges of slums. Specifically, the availability to acquire and analyze remotely sensed imagery, the emergence of crowdsourced information and advances in computational modelling are providing new opportunities to monitor, analyze and model slums.

Remote sensing

While remote sensing is not a new technology, the current and continued advancement of remote sensing makes it a sustainable source of information on slums and, therefore, an important opportunity to improve our ability to map and monitor slums. The most notable application of remote sensing as it relates to slums has been the capturing of their different surface characteristics, represented in the form of geospatial images. These images are then used to detect, identify and monitor slums in both space and time, allowing for greater understanding of their physical manifestations. In addition, remote sensing provides an unobtrusive method for collecting physical data on slums, and in some cases provides the only source of available information for some slums.

As discussed above, data on slums often suffer from a variety of issues. These include, among others, poor spatial and temporal coverage, prohibitive cost, and limited availability when using traditional modes of data collection (e.g., surveys). Compared with traditional methods, remote sensing offers several advantages. Remote sensing systems can capture physical information on slums at higher temporal resolutions that can range from continuous coverage to daily, weekly or monthly coverage. This provides us with the ability to better monitor and track the growth of slums towards a better understanding of their dynamics. Moreover, such timely information is important for slum upgrading (Augustijn-Beckers et al., 2011), as well as in the implementation of required services (e.g., water and healthcare facilities) in slums given the differences in settlement growth stages (Fekade, 2000). Also, studies have shown how remote sensing can be used as a proxy for deriving population estimates for slums (e.g., Veljanovski, Kanjir, Pehani, Otir, & Kovai, 2012). Thus, compared with the collection of census data once every several years, if done at all (as discussed), remote sensing provides an opportunity to capture population estimates in addition to the physical characteristics of slums.

Remote sensing systems also enables the collection of disaggregate information at a range of different spatial resolutions and for large geographic areas, allowing for a cost-effective collection of information on slums (Taubenböck et al., 2009) compared with traditional survey-based methods. The range of spatial resolutions offered by remote sensing platforms can be used to map slums to varying levels of analysis. For example, data can be collected at a fine spatial resolution

(e.g., sub-metre), capturing information on individual dwellings, or at a more coarse resolution (e.g., 30 m), providing information for settlements-level analysis. Even finer spatial resolution can usually be obtained using airborne and unmanned aerial vehicle platforms (Meier, 2015), with the additional flexibility of capturing information at user-defined times. Higher spatial resolution data on slums can also lead to a greater settlement characterization. The reason for this is their better ability to capture the physical and structural heterogeneity, which occurs in such environments, a property generally not captured in census data (Weeks, Hill, Stow, Getis, & Fugate, 2007), as discussed previously.

Another important characteristic of newer remote sensing systems is the provision of higher spectral resolution data. Such information collected on slums has been used in numerous studies to discriminate them from their surroundings because of the differences in spectral characteristics, such as roof colour and the surface properties of roads (e.g., Hofmann, 2001; Veljanovski et al., 2012).

However, several challenges have been identified with the use of remote sensing, at least on its own, for detecting and mapping slums. One limitation of optical space-borne remote sensing relates to significant and persistent cloud cover over many areas with large slum populations (Kuffer, Pfeffer, & Sliuzas, 2016). To overcome this issue, cloud-covered parts of images must be removed and combined with other images captured within a small temporal window to avoid problems of seasonal effects. This can be a difficult task at times since some locations close to the equator have very few cloud-free images available annually (e.g., Asner, 2001). Such a requirement impacts the cost of obtaining remote sensing data, which can quickly escalate given the requirement for frequent and large-scale monitoring of slums. While other remote sensing technologies such as radar have the potential to overcome cloud-coverage issues, very few studies have utilized radar for the study of slums (e.g., Lisini, Gamba, & Dell'Acqua, 2012; Stasolla & Gamba, 2008). This could be attributed to the limited availability of radar data, as well as the contributed complexity of processing such data.

Another limitation of remote sensing is that it only captures the physical properties of slums. While this may be adequate for identifying the physical characteristics of slums, such as irregular and crowded patterns of dwellings and the location of slums at hazardous places, this information alone may be insufficient for identifying slums. As discussed, slums are multifaceted, for which several types of information not related to physical properties (e.g., lack of tenure security) are required for their identification. For such data integration to occur, social data collected on slums with similar spatial and temporal coverage as the remote sensing imagery data must be available. However, this is a long-standing problem with census data due to their infrequent collection in many developing countries, as previously discussed. Other sources of social data that have the potential to provide information on slums are therefore required to overcome some of the challenges. One of these sources is crowdsourced spatial data.

Crowdsourcing and spatial data infrastructures

As discussed above, often the collection of slum data was mainly carried out in a top-down manner. However, with advancement in technology (e.g., geographic information systems (GISs), global positioning systems (GPSs), mobile computing and web services), alternative methods for the collection of slum information have emerged. One such approach is that of crowdsourced information gathered from experts and non-experts alike (Goodchild, 2007). Much of this new stream of information has been enabled by open-source initiatives such as OpenStreetMap, and, with respect to slums, the Map Kibera initiative. Prior to this project, little to no spatial information existed on the Kibera slum in Nairobi. In this project, members of the Kibera community actively took part in the collection of information on their slum, including data on the location of water, sanitation and health facilities, and these data were made available on OpenStreetMap.

Although OpenStreetMap has been widely used for the collection of slum information, other mapping platforms also exist, e.g., Wikimapia and Google's Mapmaker to name just a few. These initiatives have reversed the top-down approach typical of most traditional data-collection methods to a bottom-up approach.

In conjunction with the emergence of crowdsourced data, centrally collected spatial data are increasingly being made openly available. In some developed countries open data initiatives are well on their way by governments (e.g., OpenData.gov in the United States and Data.gov.uk in the UK), NGOs (e.g., Data.worldbank.org by the World Bank), and industry (e.g., google.com/mapmaker by Google), making such data freely available to the general public. Currently, there are few such examples in less developed countries (discussed below). Therefore, any global initiative to map slums should consider not only the role of crowdsourced information but also how other open sources of information (along with remote sensing) can be utilized for the identification and mapping of slums. This could potentially allow for a suite of slum indicators to emerge in a similar vain to other urban indicators more generally applied and used in developed countries (Kitchin, Lauriault, & McArdle, 2015).

As alternative and complementing sources of information are being relied upon and harnessed to supplement existing data on slums, it is becoming increasingly necessary to have systems in place for adequately storing and managing these data. One such approach is the use a spatial data infrastructure (SDI) which can be used systematically to store, catalogue and distribute geographical information (United Nations, 2000). In the case of slums, this approach can be applied to provide data to a multitude of users, at different spatial and temporal resolutions. Such datasets can then be used in a variety of other applications such as planning infrastructure (Fekade, 2000), growth modelling (Dubovyk, Sliuzas, & Flacke, 2011) and disaster management (Ebert et al., 2009). With the advancement of web technologies, distributed computing and open data standards, SDI systems are increasingly moving towards a service-oriented architecture approach and cloud services (Crooks, Hudson-Smith, Croitoru, & Stefanidis, 2014). In this approach, greater focus is placed on the generation of knowledge from data (Davis & Alves, 2005). Many governments worldwide (especially in developed countries) have begun placing substantial investments in SDIs or similar initiatives (e.g., WebGIS). One such initiative in a less developed country is Virtual Kenya (2015), a web-based geospatial portal providing information on Kenya, including mapped locations of slums. Such systems have benefited substantially from the increased availability of open-source hardware and software programs, compared with the previous paradigm of either investing in commercial software or developing one's own applications, thus lowering the cost of participation (Reades, 2014).

Modelling

While there have many advances with respect the collection of data and mapping of slums, little attention has been paid to modelling their growth trajectories. Modelling of urban growth has received a large amount of attention in the developed world (e.g., Batty, 2009), but little has been done with respect to modelling the growth of slums in the less developed world (Patel, 2012). Previous models such as those developed by the Chicago School (e.g., Burgess, 1925) are based on rigid and outdated assumptions that do not fit today's rapidly changing slums. These models further do not take into account factors such as advancement in transportation, rural-to-urban migration and the transformation in the global economy, all of which impact the growth of slums. While newer models based on post-modern theory such as social area analysis (Shevky & Bell, 1955) have made remarkable strides in poverty detection and characterization, they still continue to assume a static system. More adaptive approaches are therefore needed to understand better how slums grow and evolve over time.

According to Jacobs (1961), cities are complex, self-organizing systems made up of many different parts that dynamically interact with each other, both competing and engaging in mutual relationships. Taking such notions from complexity science, attempts have been made to model slums as dynamic systems. Approaches such as cellular automata (CA) and agent-based models (ABMs) have been used to develop dynamic models to simulate and explore the growth and evolution of slums (Roy et al., 2014). Such modelling approaches offer a different lens with which to view and understand slums from the bottom-up. These models further have the added benefit of being able to work with both quantitative and qualitative data in a single environment (O'Sullivan, 2008). Various studies have used CA to develop models of slums. Sietchiping (2004), for example, integrated GIS and CA to study the dynamic growth of slums in Yaounde, Cameroon. Similarly, Arsanjani et al. (2013) used CA, combining it with logistic regression and Markov chain modelling techniques to create a new hybrid model for a better understanding of slums in Tehran, Iran.

Compared with CA models, ABMs focus not only on the environment but also on individual entities (i.e., agents) within the environment, and it has been argued that ABMs more closely resemble the real world (Crooks & Heppenstall, 2012). With respect to slums, there has been several ABM attempts ranging from the theoretical formation of slums in Latin American cities (Barros, 2012) to the growth and shape of slums based on residential preferences and the availability of land in Tanzania (e.g., Augustijn-Beckers et al., 2011; Young & Flacke, 2010). Patel et al. (2012) explored the spatial and temporal dynamics of slum formation in India, incorporating slum dwellings, developers and politicians, which unlike previous ABMs captured the cross-scale dynamics of several actors known to influence the formation and persistence of slum settlements. Other tools exist for understanding complex systems, such as interacting state machines, genetic and particle swarm approaches; however, little work has been done using these approaches to study slums. Such approaches are expected to have a large impact in slum research, as such a shift will focus on slums being seen not as static systems but rather as dynamic and complex entities in their own right.

However, while dynamic models continue to provide valuable insights into slums and the people who live in them, several key challenges must be addressed when interpreting the results from such models. One consideration is that the output of any model is only as good as its data sources and the theory upon which it is grounded. However, without a common definition of what a slum is, building such models will continue to prove challenging. Moreover, as is common in many modelling approaches, including CA and ABMs, the models created tend to be specifically tailored to the data types and characteristics of the specific place being modelled (Crooks, Castle, & Batty, 2008). Given the uniqueness of different slums, knowledge gained from models built for slums in one location may not be easily transferred to slums in another location. This is especially problematic when the scale of specific variables (e.g., population density) being incorporated into the model for one location is different for another location. Such issues are common in many less developing countries because of lack of standards and systems in place for collecting data and making these data available to users, as previously discussed. The high variability in the characteristics of slums, as well as in the way that data are collected, may also present challenges with respect to the calibration, verification and validation of such models. In particular, such variability in the data-collection process and data coverage may lead to inconsistent results, which cannot necessarily be attributed to the model itself. Moreover, because models such as CA and ABMs try to model complex behaviour, rich datasets spanning the micro-preferences of individuals and their behaviours, and more macro-data to evaluate emergent patterns are required for such models (Heppenstall, Malleson, & Crooks, 2016). This poses a significant challenge with respect to slums as such data are often unavailable. This could explain in part why only a few studies have used dynamic models to study slums.

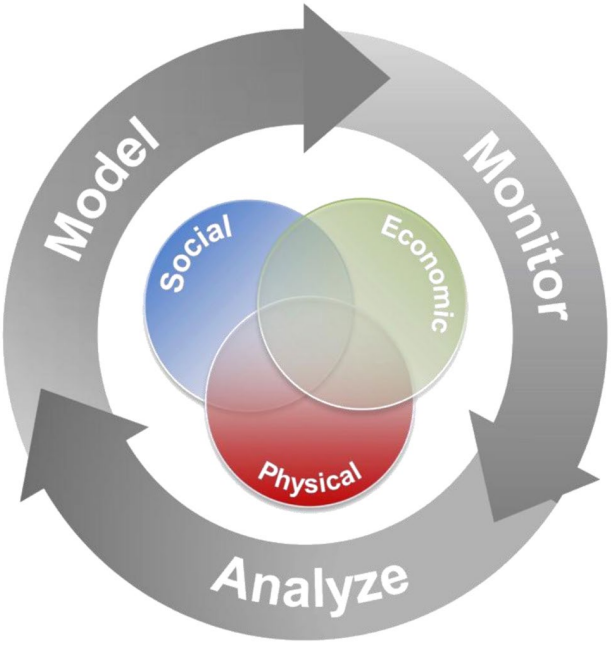

Figure 2. Conceptual model for integrating social and physical constructs to monitor, analyze and model slums.

SUMMARY

For the first time in human history more people live in cities than in rural areas. Cities have long been revered as the economic centres of the world, attracting a multitude of people for different reasons such as better jobs and economic opportunities. While for others cities provide an opportunity to escape social norms typical of many rural areas. Usually, urban growth and economic development must go hand in hand: as cities grow, so does the economy in order to adequately meet and provide the infrastructure and services necessary to support the increasing number of people. However, as history has shown, this is not always the case in many less developed countries. Unable to support the increased urban population, slums have emerged and continue to grow and persist in many less developed countries and, particularly, in rapidly urbanizing regions in the Global South.

In this paper we have presented a framework for understanding and studying slums, bringing together some of the most pressing issues surrounding slums identified in the literature. These issues are yet to be holistically addressed from both a research and an implementation viewpoint. Therefore, it is hoped that the information contained here not only will provide valuable insight for future research but also will help inform governments, NGOs and the public at large towards improving our understanding of slums. Towards this objective, we discussed the impacts of slums in terms of both the negative (e.g., burden on taxpayers for improving conditions in slums) and positive effects on society (e.g., contributions made to country GDP). However, most of the literature reviewed view slums as an issue that will continue to grow and persist for the foreseeable future. As all the fastest growing slums are found in less developed countries that suffer from a general shortage of resources, a key challenge is striking a balance between improving the conditions in slums and using the resources slums require to assist their economy.

While there has been a substantial amount of work on slums, such work has largely focused on only one of the constructs (e.g., social or physical). This review has shown that slums are a

multidimensional issue, with a wide range of factors attributed to their occurrence. Social factors such as rural-to-urban migration, poor urban governance and policies that fail to address the needs of slum dwellers, along with various locational choice factors, have led to the present state of slums today. Some slums also have very unique social and physical characteristics that set them apart from other slums. These characteristics, along with inconsistent definitions of what a slum is and a general lack of reliable data, make the quantification and comparison of slums a challenging undertaking both within and among countries, and across world regions.

Several attempts have been made to explain the emergence of slums. However, these assume a static system with rigid assumptions and do not take into account the diverse nature of slums and their multi-tiered and interrelated connections within society and the environment. Although newer methods have used dynamic approaches such as CA and ABMs to understand better the complex nature of slums, few such studies have been carried out, signalling a greater need for more research in these areas.

While the presence of slums has different implications not only for individual cities, countries or regions around the world, ultimately slums are a global issue. To grapple totally with their complexities, one needs to take a multifaceted and multidisciplinary perspective on slums. This is not a new concept and has been applied to other real-world societal problems such as climate change. However, in the context of slums, this first requires a common definition for slums followed by standardized procedures for the collection of slum-related data. We would argue that such data need to be collected at adequate spatial and temporal resolutions to accommodate a greater number of users' diverse needs, along with approaches towards managing and distributing data in general. Also, emerging sources of data that can provide spatial, temporal and social insights about slums (e.g., crowdsourced information and open data) should be further explored. These new information sources should be used to complement traditional sources of data collected on slums (e.g., census surveys and remote sensing). Moreover, there is a need to explore how traditional sources could be used to validate these newer streams of information. Furthermore, open-data initiatives should be investigated as a means of reducing the cost of acquiring data and support data-quality management.

Given the various opportunities for the collection of slum-related data, both qualitative and quantitative, it is imperative that such approaches consider both the social and the physical constructs typical of slums, such that slums can be more holistically analyzed and assessed. This should include data relating to the social, physical and economic factors, which continue to drive the growth and persistence of slums. In turn, this will allow one to analyze and model slum growth over time, as shown in Figure 2. Modelling approaches should include, but are not limited to, the use of technologies such as GISs, remote sensing and the use of more dynamic modelling approaches such as CA and ABMs. This integrated approach could potentially help monitor, analyze and model these complex environments. We would further argue that the output of such models should be viewed and assessed by a representative cross-section of stakeholders (e.g., slum dwellers, the government, the surrounding communities and NGOs) and with model outputs analyzed and the knowledge gained used for further improving the modelling process, and informing the data-collection process. With such an approach in place, it is only then that we can address the specific social, economic, environmental and policy issues necessary for addressing the challenge of slums in different cities, countries and regions of the world.

NOTE

1. The terms 'slums' and 'informal settlements' are often used interchangeably in the literature. However, UN-Habitat (2003) views an informal settlement as one type of slum, specifically where there is insecurity of tenure (this will be further discussed below).

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