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Editorial: Future urban worlds: Theories, models, scenarios, and observations of urban spatial expansion

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Editorial on the Research Topic
Future urban worlds: Theories, models, scenarios, and observations of urban spatial expansion

Introduction

As is well known, the world is in the middle of an extraordinary burst of urbanization, a global urban transition that accelerated through the 20th century. The world passed 50% of total population living in cities early in the 21st century, and is projected to complete the rural to urban transition over the next few decades. Cities are seeing explosive growth in terms of population, GDP share, and environmental impacts. At the same time the climate crisis is now fully on us, with climate-change induced disasters reported almost every week, and a rapidly diminishing window of time in which decisive action may yet avert the worst impacts, or at least avoid a self-reinforcing and unstoppable acceleration of climate change.

Urbanization transforms lives and livelihoods, economic change, resource consumption, and environmental impacts, and urban scholarship is growing in importance in global assessments such as those of the IPCC, and within UN development pathways, such as the SDGs, and well as in NGO work (OECD, 2015; United Nations, 2015; OECD and European Commission, 2020; World Bank, 2023). In this context there is greatly increased research interest in modeling different possible scenarios and pathways of future development, and there are increasing efforts to capture observations, theorize, and model urban change. Yet research on the potential role of cities in shaping different global futures is still relatively under-developed. This is not at all surprising, given the complexity of the task, serious data limitations, and the wide range of possible outcomes.

This Research Topic seeks to examine some of the challenges and potentials of a research agenda focused on developing better theories, models and observations of urban expansion as a component of scenario building to help understand possible global developmental pathways in the context of rapid urban transition and climate crisis. Papers in the issue explore the question of what can we say given the limits of data, theories and models about future urbanization. It includes attempts that use various data and theories to model urban futures at multiple scales. There are clearly major challenges in developing detailed models and scenarios that incorporate climate, urbanization, and development processes. This Research Topic serves as an exploration of some of these challenges, with a focus on issues of scale, land conversion, social justice, and vulnerability. We suggest that this provides some useful insights into the challenges and potential value of integrating urban spatial expansion scenarios with climate scenarios and development models and points to several priorities for future work.

This introduction will briefly overview some of the challenges of defining cities, conceptualizing urbanization and projecting future urban worlds before presenting comments on the papers in the issue.

Defining cities: urban descriptive indicators

There is no consensus on the definition of cities and there are a number of methods used to identify and measure them (Marcotullio and Solecki, 2013; Deuskar, 2015). For example, the UN uses the definitions of urban established by each member country, which vary greatly (UN, 2018). As such, scholars use a number of different data sources to identify, describe and analyze urban centers and their growth. Examples include population size, population density, economic sectoral activity, and infrastructural footprint.

The UN has been able to claim the most authoritative information on urban growth (Brockerhoff, 1999). The UN population and urbanization revisions published regularly are among the world's leading sources of data for urban population research. These data show that urbanization over the past several decades has been underpinned by explosive population growth. Between 1990 and 2020, over 2 billion people were added to the world's cities. This 30-year addition is larger than the total global urban population in 1985. Moreover, while the world's total population grew, the urban population grew much faster. For example, in 1990, the urban population accounted for about 43% of the total population, but by 2020, the share grew to over 56% (UN, 2018). UN data also suggests that urban population growth has taken place across the world, but over the past several decades has been led by the less developed nations, which accounted for over 92% of urban growth since 1990. The Asian region experienced the most intense urbanization, accounting for over 63% of this increase (UN, 2018). African urban population expansion accounted for approximately 18% of the urban growth and Latin America and the Caribbean accounted for another 11%. The remaining urban population growth was experienced in the developed world: North America (5%), Europe (2.5%), and Australia and New Zealand (0.5%).

Since around 2000, there has been another useful dataset for analyzing urban growth. With the use of satellite imagery, arterial photos and other sources, urban footprints have been identified at the global scale. The Global-Rural-Urban-Mapping Project (GRUMP) was one of the first efforts to outline urban areas around the world (CIESIN and Center for International Earth Science Information Network, 2004). Other global datasets include, *inter alia*, the GlobCover (Arino et al., 2007), the History Database of the Global Environment project (Goldewijk et al., 2011; Goldewijk et al., 2017), the MODIS 1-km project (Schneider et al., 2010) and the Global Urban Footprint (Esch et al., 2014). The availability of satellite imagery and advancing techniques for classification have allowed for improvements in global urban land use estimations. A recent set of data has supplanted most other efforts. The Global Human Settlement Layer (GHSL) includes several global urban footprint areas (1975, 1990, 2000, 2015). The GHSL data demonstrate that urban land areas are growing rapidly all around the world. From 1975 to 2015, urban settlements expanded in size approximately 2.5 times, while population increased by a factor of 1.8, indicating ongoing significant reductions in overall urban population densities (Pesaresi et al., 2016). More recent urban footprint estimations suggest that nearly 70% of total urban expansion between 1992 and 2015 occurred in Asia and North America (Liu et al., 2020). Expanding the usefulness of this work is the inclusion of population figures with the urban land area (i.e., GRUMP, GHSL, Global Urban Footprint), which allows for a platform to contextualize the relationship between land use change and population growth.

Significant for both urban land use and urbanization studies is the emergence of large urban agglomerations. In the literature, these are called megacities and are usually defined as urban areas with populations of 10 million or more inhabitants (Fuchs et al., 1994; Sorensen and Okata, 2011; Labbé and Sorensen, 2020). Most recently, attention has focused on the emergence of even larger polycentric urban megaregions and mega-conurbations (Taylor and Pain, 2007; Harrison and Hoyler, 2015; Friedmann and Sorensen, 2019). These phenomena were identified by population and those examining urban land use footprints (Schweitzer and Steinbrink, 1998) and has been a focus of early studies of urban land use growth (Clarke et al., 1997; Seto and Fragkias, 2005; Taubenböck et al., 2008; Angel, 2012). These studies suggest that megacity emergence has been tied closely with modern globalization, which provided flows of capital and finance, goods, services, people, and ideas into highly networked cities (Lo and Yeung, 1998; Lo and Marcotullio, 2001). Megacity growth was also encouraged by advances in transportation technologies (Rimmer, 1998). Although there is variation in the growth patterns and dynamics within these cities, one commonality is that these large urban centers are voracious consumers of goods and services and are significant drivers of local, regional and global environmental impact (Wackernagel and Rees, 1995; Decker et al., 2002; Rees, 2020).

With the study of urban land use change and population growth urban scholars emphasize the importance of gradients of population density as an important urban indicator and dynamic stressor. Early work focused on population density as a mitigating factor for urban sustainability (Newman and Kenworthy, 1989; Ewing, 1997; Williams et al., 2000). Further work suggested that population density cannot be analyzed successfully in isolation of a large set of issues found in the built and natural environment (Churchman, 1999; Boyko and Cooper, 2011). Nevertheless, recent research suggests that most urban regions exhibited a trend of decreasing urban population densities, suggesting expansive urban growth patterns. Compared to larger cities, small-medium urban areas with populations of less than 2 million have greater declines in urban population densities and higher rates of urban land expansion (Güneralp et al., 2020).

Finally, economists have long argued that urban economies are special (Alonso, 1964; Spiegelman, 1966). Currently, the world's cities generate approximately 80% of the global Gross Domestic Product (GDP) (World Bank, 2023). Such importance is attributed to the economic advantages that cities offer which have a significant pull on populations, even in less developed nations with low economic growth (Scott and Storper, 2015; Henderson et al., 2021). There are few studies that have attempted to spatialize urban economic activity over regions. This lack of research is due to the lack of GDP data at the city, county and provincial levels, particularly for developing countries. Recently, gridded datasets for GDP have been developed for 1990 to 2015 (Nordhaus, 2011; Geiger et al., 2017; Kummu et al., 2018). These studies aim to provide economic data for use in other modeling exercises, including integrated assessment models and scenario work, as in the paper by Murakami et al. in this Research Topic (Murakami et al.).

Integrating these four factors (population, land use, density and economic activity) in historical models of urbanization remains an important Research Topic. Theories that describe and explain urbanization patterns are key to this effort. We next turn to a brief overview of selective urbanization concepts.

Understanding the past: urbanization theories

Urbanization theories include, *inter alia*, three general aspects. The movement of people and economic activity into and through cities, the dimensions and cycles of these processes, and the evolving configurations of urban forms and infrastructures as cities grow. Economists, demographers, geographers and others have developed models for each aspect.

The flows of people, finance, information into and through cities has been examined through urban connectivity and the emergence of urban hierarchies, which begin as least as early as 1915 with the examination of settlement connections in rural Wisconsin, United States (Galpin, 1915), but blossomed with the work at the regional level by Christaller (1966) and those that followed (see, for example, Losch, 1954; Berry, 1967; Berry and Horton, 1970; Preston, 1971; Bromley and Bromley, 1979). Starting in the late 1980s, scholars extended the concept of urban hierarchy to the international level with the work on global cities (King, 1980; Friedmann, 1986; King, 1990; Sassen, 1991; Sassen, 2001; Taylor, 2006). All these studies recognized that cities were systems and systems within systems (Berry, 1964). That is, they recognize that cities do not function in isolation, but exhibit strong interdependencies with their hinterlands, national counterpart cities and international connections. Within these inter-connections, however, there is also hierarchy. During the current era, the global city, those that contain most of the command-and-control functions of the global economy sit on the top of the hierarchy (Friedmann, 1986; Taylor, 2006). These cities are connected to other cities through financial flows, labor, knowledge and information and supply chains.

The types of connections, their directionality, and the details of the attributes of "global cities" continue to be a fruitful area for urban analysts. Indeed, the nature of urbanization and urban change is now more dependent on the global economy than ever before (Hall, 2020). A large and growing number of studies published on cities address aspects of globalization, world systems, the emergence of a world city system and "world city formation" [for a review see Sassen (2001); Brenner and Keil (2006)]. The connections between cities have recently been conceptualized using the teleconnections concept, borrowed from atmospheric science and the intensity of such connections remain an important area of study (Seto et al., 2012). Including these influences into urbanization modelling is critical for providing accurate predictions of urban growth patterns.

The second key principle focuses on the urbanization process focusing on the occurrence of cycles of development. Urbanization occurs within the demographic transition (Bongaarts, 2009), as these different processes interact and mutually affect each other. The urbanization process itself, however, is not unidirectional. Research has identified cycles and stages of the urbanization process and individual cities (Klaassen et al., 1981; Geyer and Kontuly, 1993; Champion, 2000). These models have brought clarity to understanding the growth of cities and suburbs and even the loss of urban populations. The theories, however, were developed from analyzes of the urbanization process in the more developed world, and may be of less use in less developed countries (Henderson and Turner, 2020).

The third key principle relates to urban form and its variation across regions and cultures. Originally theories of concentric zones (Burgess, 1925) sector models (Hoyt, 1939) multiple nuclei (Harris and Ullman, 1945) and post-industrial forms emphasized the development of land use patterns and their growth within cities of North America. These models were subsequently altered and adopted for cities in Europe (Mann, 1965; Kearsley, 1983), Asia (McGee, 1967; Gaubatz, 1998; Brunn et al., 2003; Ma and Wu, 2005), Latin America, (Ford, 1996), and Africa (Lemon, 1981). Given the differentiation of forces at play in shaping urban form across the world, the heterogeneity among cities has grown despite the homogenization of globalization forces. While there are generalized spatial patterns evident across cities of the world and even within national borders, there are also significant differences across a number of different urban form qualities (Jenks et al., 2008; Sorensen and Okata, 2011).

Current urban theory has likened urban areas to ecosystems (Grimm et al., 2008; Newman and Jennings, 2012; Acuto and Leffel, 2021), which has significant urban form implications. This notion, borrowed from ecological biology emphasizes systematic linkages and interrelations, but allows for diverse outcomes, depending upon the number, strength, and dynamics of inter-linked factors. Hence, under this notion, urban form and infrastructure, and land use patterns can be analyzed through different systems, i.e., transportation systems (Newman and Kenworthy, 1999). Changes in urban form and infrastructure can simultaneously affect multiple sectors, such as buildings, energy, and transport.

Integrating these definitions and theories of urbanization into models that project future urban development has been challenging. Over the past several years, new frameworks have emerged that have pushed this agenda forward. We next turn to selected urban futures projection efforts.

Projecting into the future: urban spatial modeling

Urban growth models have been developed and extensively adopted to study urban expansion and its impact on the environment (Li and Gong, 2016). Three classes of urban growth models include land use/transportation models, the cellular automata (CA) model (Aburas et al., 2016) and the agent-based models (Batty, 2009). What is common to these models is the use of economics, geography, sociology, and statistics to explore the mechanisms of urban evolution and feedback of the urban system. So far, the use of these types of models is largely limited to single cities or metropolitan areas or regions. They are also limited in terms of their projection periods.

Regional and global efforts in the development of scenarios have caught the attention of many researchers and are the focus of several of the articles in the Research Topic. They are based upon a scenario framework developed by the global climate community and extend projections to 2100 (Moss et al., 2008). The Representative Concentration Pathway (RCPs) provide different climate change related visions from lower carbon dioxide (CO_2) emissions in the future than today that keep the global temperature at around 1°C–2°C higher than 1850 levels to very high levels of CO_2 emissions that put the global mean temperatures at 3°C–5°C higher than 1850 levels in 2100 (van Vuuren et al., 2011). The Shared Socio-economic Pathway (SSP) scenarios provide a development time frame from 1990 to 2100. The SSPs describe alternative socio-economic and demographic futures. Each SSP scenario represents a plausible future and the set of scenarios as a whole addresses uncertainty by incorporating a wide range of possibilities (Jiang and O'Neill, 2017; KC and Lutz, 2017; Riahi et al., 2017). The SSPs are an ensemble of a variety of development pathways. Together with the RCPs they provide a framework for exploring different climate-development scenarios with implications for urban mitigation and adaptation.

These data have been useful for creating models of urban land use growth at the global and regional scale when all that is modeled in urban land use change and urban population (Huang et al., 2019; Chen et al., 2020). They tend to be less reliable for identifying detailed urban change at the very local or even the metropolitan scales (Rohat et al., 2019). There is therefore a need to develop new models for long term exploratory projection that could be used at these local scales.

Papers in the issue

The papers in this issue span a variety of methods and scales. We describe the papers starting with one that examined small and medium sized cities and end with the development of global urban economic projections. Each paper has important research and methodological findings.

The paper by Jaoude et al. "Understanding land take in small and medium-sized cities through scenarios of shrinkage and growth using autoregressive models," examines and models patterns of land development, shrinkage, and sprawl of small and medium sized cities in Southern Germany. Studies of urban sprawl have long shown that low-density sprawling areas consume far higher amounts of energy *per capita* than higher-density mixed-use areas, but in the longer run even more important is the higher infrastructure costs and the diversion of land from agricultural and natural heritage system uses (Whyte, 1968; Ewing, 1997). Land conversion to urban uses tend to create enduring patterns that are difficult and costly to reverse, not just because of sunk costs in associated infrastructure, land contamination, and destruction of ecological functions, but also higher land values that generate powerful incentives for further urban development and investment to maintain those higher values (Shatkin, 2017; Sorensen, 2018). As there are serious disincentives to turning a housing development back into a pasture, it has long been argued that managing land conversion to urban uses is a basic planning issue, especially for long-term questions (Girardet, 1999; Clifton et al., 2008). The authors show that in southern Germany the increase in urban land area continues even with population shrinkage, and that although higher-density developments do help reduce land take it is not enough to simply encourage higher densities of development and functional mix to be able to reduce the environmental burdens of sprawl type development, particularly in an era of widespread ownership and use of automobiles. They conclude that planning policies encouraging high density development and greater functional mix were not sufficient to reduce the amount of land conversion to urban uses. They also show that there is a much greater heterogeneity of towns than earlier approaches had suggested. Particularly useful here is the research method combining the TOPOI approach to classifying settlements (Carlow et al., 2022) with spatial autoregressive models to compare different scenarios of growth and shrinkage. Heterogeneity of spatial development patterns and of land take for urban uses present major challenges and opportunities for models and scenarios of future urbanization.

Balk et al. in their paper "Frameworks to envision equitable urban futures in a changing climate: A multi-level, multidisciplinary case study of New York City", develop an approach to modeling the Shared Socio-economic Pathways (SSPs) combined with scenarios driving climate change at urban scales known as Representative Concentration Pathways (RCPs). Vulnerability factors in urban areas see highly heterogeneous spatial patterns, and it is not a simple matter to take these meaningfully into account in models and scenarios of urban processes over extended periods. But as is well known, poverty, racialized populations, and environmental vulnerability routinely co-vary in patterns referred to as environmental racism (Bullard, 2005; Bullard, 2007). At the same time, socio-spatial polarization has increased sharply in most urban areas in recent decades, and urban geographies exhibit high spatial variability in risk factors. Most climate modeling tends to generalize cities, assuming that they are internally similar, but they are actually much more complex, and internal variability in vulnerability and adaptive/mitigation capacity are likely to be extremely important factors in structuring disaster risk within and between urban areas. This paper reviews existing approaches to modelling risk factors, and develops a conceptual framework to push thinking "towards a planning future that takes into account intersecting vulnerability indicators" at multiple scales within urban areas. The authors urge more attention to long-term modelling efforts in support of policies to mitigate environmental risks and vulnerabilities from the neighborhood to the city-regional scales.

In the paper "Global urban exposure projections to extreme heatwaves" (Marcotullio et al.) the authors model and develop projections of the range in the size of potentially exposed populations and the locations of the most vulnerable providing useful analysis in support of adaption efforts. The paper projects the ranges of population exposed to heatwaves at varying levels to 2100 for three future time periods (2010–2039, 2040–2069, 2070–2099) using the Shared Socio-economic Pathways (SSPs) and the Representative Concentration Pathways (RCPs). Unsurprisingly, the most vulnerable are urban areas in South Asia and Africa, areas that are currently among the fastest growing, poorest, with highest social polarization, and with greatest shortfalls in basic infrastructure. The paper shows that in the 2070–2099 period, over 3.5 billion people will be exposed to extreme heatwaves (>42°) even under the sustainability scenario (RCP2.6-SSP1), and those numbers only climb with greater projected climate change. As with all long-term projections, this is not a prediction, but scenario projections designed help to indicate the likely ranges of impacts. The projected geographies of greatest vulnerability provide potentially valuable and actionable insights when used in combination with more detailed spatial models of urbanization, and of internal variability of vulnerability within cities.

A completely different approach is seen in the paper "Gridded GDP Projections Compatible With the Five SSPs (Shared Socioeconomic Pathways)" (Murakami et al.) that disaggregates long-term national GDP projections to a 1/12° grid scale to create spatially detailed projections of GDP. As they argue, such projections will be essential for many other types of modelling efforts. It is well known that GDP projections past about 12 months are extremely unreliable, because unpredictable stuff happens, but GDP is such an important input to many other models that the development of methods such as this to disaggregate GDP spatially will be essential. The approach taken here is to downscale global historical GDP data from 1850 to 2010, and then to use that basis of spatially disaggregated GDP data to develop future scenarios of disaggregated GDP for each of the five SSPs. This requires estimates of population and spatial growth of cities to 2100 for each SSP scenario based on demographic projections and the gridded historical GCP data, a challenging exercise in itself. As with the other models and scenarios developed in this Research Topic, this is not seen as a prediction, but as scenario development that is useful in revealing a range of likely possible futures, in highlighting the challenges and significance of spatially disaggregated GDP projections for scenario building, and as a basis on which to build more robust models and approaches in future.

Conclusion

The papers in this Research Topic tackle important challenges of model building and scenario development from several perspectives, and at a range of scales from the neighborhood to global scale. At the global scale, the results suggest the usefulness of the SSP-RCP scenario framework. The two studies at this scale provide interesting and useful insights into current and future development and also significant knowledge gaps. At the scale of the city and metropolitan area, however, other means of projecting future urbanization are needed and have yet to be adequately developed. For example, further studies developing scenarios for the evolving impacts of migration, of rising sea levels, of evolving urban forms and settlement patterns, of urban socio-technical systems change, of economic change, and of evolving travel-to-work patterns all will help contribute to better understanding of possible global urban futures.

All these studies are critical. As the world moves towards higher levels of urban population and increasing risk of multi-scale environmental change that potentially could disrupt fundamental human support systems, we need research that provides insights into lower impact, efficient and resilient development. Once a city is built, its physical form and land use patterns can be extremely durable, perpetuating unsustainable (or sustainable) patterns of development and high (or efficient) infrastructure costs. The expansion of urban land consumption has already outpaced population growth by as much as 50% and on current trends may add 1.2 million km^2 of new urban built-up area to the world by 2030. Such development threatens to put pressure on land and natural resources, and puts lives and livelihoods at risk.

The research in this Research Topic point to several different alternatives to addressing these issues, but many more exist. If the past and current trends are a good predictor of the future, there will be increasing complexity with urban development and models should reflect those characteristics. Much more work is needed in this area.

Author contributions

PM and AS conceptualized, wrote and edited the paper.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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