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Six fundamental aspects for conceptualizing multidimensional urban form: A spatial mapping perspective

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ABSTRACT

Urbanization is currently one of the most profound transformations taking place across the globe influencing the flows of people, energy, and matter. The urban form influences and is influenced by these flows and is therefore critical in understanding and how urban areas affect and are affected by form. Nevertheless, there is a lack of uniformity in how urban form is analyzed. Urban form analyzed from a continuum of a simple urban versus non-urban classification to highly detailed representations of land use and land cover. Either end of the representation spectrum limits the ability to analyze within-urban dynamics, to make cross-city comparisons, and to produce generalizable results. In the framework of remote sensing and geospatial analysis, we identify and define six fundamental aspects of urban form, which are organized within three overarching components. *Materials*, or the physical elements of the urban landscape, consists of three aspects (1) human constructed elements, (2) the soil-plant continuum, and (3) water elements. The second component is *configuration*, which includes the (4) two- and three-dimensional space and (5) spatial pattern of urban areas. Lastly, because of the dynamics of human activities and biophysical processes, an important final component is the change of urban form over (6) *time*. We discuss how a this urban form framework integrates into a broader discussion of urbanization.

1. Introduction

The increase in the number of people living in urban areas, the proliferation of megacities, and the pervasive expansion of periurban areas are some of the most challenging transformations of the 21st century. As cities grow and transform, we have the opportunity to rethink urban form so that transitions underway contribute to solutions rather than problems for pressing global challenges. Key examples of such transitions include sustainable economic development, climate change, human health and well-being, and social justice. To improve urban planning and leverage urban transformations toward solutions, a focused and encompassing understanding of the rate and magnitude of urban change and urban form is required (Buijs, Tan, & Tunas, 2010; Childers et al., 2015; Seto et al., 2016). Urban form influences interconnectedness within urban areas and ultimately the pathways by which people, materials, energy, and ideas can flow (Hough, 1995; Spirn, 1984; Steiner, Thompson, & Carbonell, 2016). Urban form has strong effects on the human experience, among them including mental health (Miles, Coutts, & Mohamadi, 2012), social interaction (Dempsey, Brown, & Bramley, 2012), neighborhood cohesion (Bramley, Dempsey, Power, Brown, & Watkins, 2009), and physical activity and health (Frank & Engelke, 2001). These interconnected pathways identify the deep linkages, speed, and complexity between urban form and land use planning, urban infrastructure, economic development, ecological processes, and well-being. Urban form, therefore, is a key element for understanding urban systems as social-ecological-technological hybrids (Grimm, Cook, Hale, & Iwaniec, 2016) because urban form influences mobility, interactions, processes, and networks where people live and

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work. Urban form is not static and the ongoing transformations create new dynamics, which are increasingly rapid throughout the world. Urban form must be studied because of the growing global extent and importance of cities and because cities and urban regions are exhibiting new forms, especially in high growth areas and post-industrial cities (Ding, Graffland, & Lu, 2015; McHale et al., 2015; Soja & Kanai, 2014; Taubenböck et al., 2017).

In a remote sensing and spatial analysis framework, urban form is analyzed from a continuum of simple to highly detailed representations. In a simplistic manner, spatial mapping analysts often reduce urban complexity into a two dimensional (2D) urban/non-urban binary classification system. This approach makes analyzing rates of change over time and city-to-city comparisons possible and straightforward. A large body of literature utilizing this approach has provided insight on urbanization patterns throughout the world, particularly extent of urban, typically impervious, surfaces (see Sexton et al., 1984). What the approach lacks, however, is any capacity to analyze within-urban patterns or dynamics, crucial to understanding the complexity and nuance of urban conditions. With more categorical detail, such as traditional land use and land cover categories, there is more specificity of the spatial composition and configuration showing simple within-urban dynamics, such as the distances between residential and industrial places (VandeWeghe, 2007; White & Engelen, 1994). While authors such as Xiao et al. (2006) and Hassan and Southworth (2017) demonstrate it is possible to analyze trends over time and make generalized comparisons utilizing only a few discrete categories of urban land use and cover, this effort rarely provides insight into the nuanced and complex relationships between land uses and cover. The coarse urban dichotomy also artificially separates lands that are biologically active from those dominated by human construction (Cadenasso, Pickett, & Schwarz, 2007; McPhearson, Haase, Kabisch, & Gren, 2016; Zhou et al., 2017). Biological activity in urban systems provides relevant services to the human population, such as shading, aesthetics, food production, and stormwater mitigation, and fundamentally affects the dynamics of the urban system (Baró, Haase, Gomez-Baggethun, & Frantzeskaki, 2015; Gómez-Baggethun & Barton, 2013). On the other end of the spectrum, at a more detailed level, studies of urban form at specific locations reflect the particular characteristics of individual cities or regions. The complexity of cities is inherently reflected in typologies of urban form established in specific cities and regions, meaning that deriving generalizable results or comparisons are difficult to make (Forman, 2016; Jabareen, 2006). In these cases, the uniqueness of individual urban settings obscures the regularities in urban form that can be commonly found among many urban environments (Groffman et al., 2014). Thus, these fine-grained typologies calibrated to individual cities or regions limit our ability to understand generalized patterns of urban dynamics.

In this paper, we posit a solution to the problem of how to effectively utilize remote sensing and geospatial analysis to represent and quantify the complexity of urban form. The framework provides the needed detail to analyze within-urban dynamics and also provides the medium to produce generalizable results. The fundamental constituent parts of urban form provides scholars and practitioners with the tools to analyze urban functions, to identify drivers of urban dynamics, and to begin to rigorously hypothesize and test the links between urban form and outcomes. To that end, we identify and define six fundamental aspects of urban form. The six aspects of urban form are organized within three overarching components: materials, configuration, and time. *Materials*, or the physical elements of the urban landscape, consists of three aspects (1) human constructed elements, (2) the soil-plant continuum, and (3) water elements. The second component is *configuration*, which includes the (4) two- and three-dimensional space and (5) spatial pattern of urban areas. Lastly, because of the dynamics of human activities and biophysical processes, an important final component is the change of urban form over (6) *time*. Recognizing that the six aspects of urban form do not exist in isolation, we discuss how a framework on urban form integrates into a broader discussion of urbanization.

2. Background

The relevant literature needed to support the identification and definition of six aspects of urban form includes a synthesis of the data sources and analytical methods that are used to define and describe urban form. We recognize that missing from this discussion is a whole literature based on early work by Lynch, Rodwin, and Alexander on urban form that is more descriptive in nature (Alexander et al., 1977; Lynch & Rodwin, 1959). While we acknowledge important insights from this body of work, we focus our discussion instead on literature emphasizing quantitative and empirical measures of urban form, particularly those derived from remotely sensed data, image processing, geographic information systems, and spatial analysis. The relevant quantitative data at any given point in time can identify the surface materials, the 3D form, and their respective locations in geographic space. The associated analytical methods describe the organization, composition, and changes of the spaces within the built environment and areas surrounding human settlements. We review these contributions and identify their shortcomings.

The most common data source for supporting and advancing urban form are the land cover and use maps derived from remotely sensed multi-spectral imagery (Friedl et al., 2010; Han, Hayashi, Xin, & Imura, 2009). These data sources rely on the spectral characteristics of the land surface to identify urban land cover classes, which are in turn used to infer land use or used in combination with other datasets to understand the land cover and land use relationships (Brown & Duh, 2004; Comber, Fisher, Brunsdon, & Khmag, 2012; Mesev, 2010). The resultant studies have been instrumental in quantifying how cities compare to one another and change over time (Herold, Goldstein, & Clarke, 2003; Keys, Redman, & Wentz, 2007).

The major limitations with the commonly used passive remote sensing based representation of urban form are the resolution of the data; the classification methods used for urban areas; and the limitation of the data to two dimensions. First, spatial resolutions have improved so that detailed classification of land surfaces is possible; however, they are rarely coupled with a wide spectral range (e.g., there is limited access to the thermal range) or frequent temporal coverage (e.g., daily coverage). Even with high spatial resolution, the heterogeneity of the urban land surface inherently leads to pixels with a variety surfaces, challenging the classification process. Beyond spatial resolution, there are also tradeoffs with respect to spectral, radiometric and temporal resolution yet the needs of developing robust representations of urban form demand more suitable products to infer rapid or even real-time change.

Another problem is that urban classification methods focus disproportionately on classifying "urban" with less attention to biological, geophysical and hydrological characteristics that exist within urban areas. This limits insights on the inherent complexity between urban (i.e., impervious surfaces) and non-urban categories (i.e., within urban water bodies), challenging the ability to consider the multiple functions of urban areas for movement and flows (Baró et al., 2015; Boone et al., 2014). These narrowly defined classification systems limit the ability to understand urban complexity and dynamics.

The last challenge is that despite case studies that illustrate and view cities in 3D, urban topography, including the 3D structure of the built environment, is rarely incorporated into studying how cities function and change over time. Data collection methods for measuring and recording include LiDAR and other forms of active remote sensing or stereo images. Height information in combination with the spectral signature of the land surface has been used to infer land use because of a positive correlation between building height and land use (Walde, Hese, Berger, & Schmullius, 2014). Similarly, vegetation height allows mapping analysts to differentiate plant types in the classification of vegetation (Tooke, Coops, Goodwin, & Voogt, 2009). These new

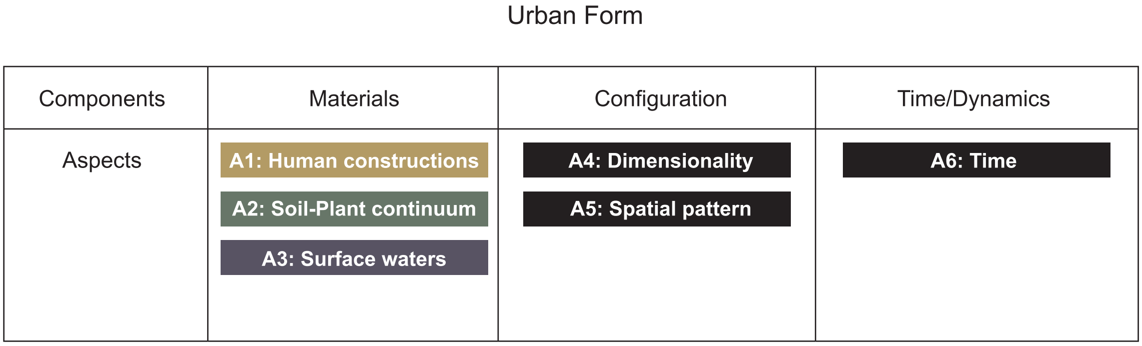

Fig. 1. Conceptual relationship of the six aspects of urban form.

classifications in turn allow for detailed analysis of the interrelationship between human constructed objects and soil-plant materials, such as the impact of tree shade coverage on building facades for heat mitigation and energy use efficiency (Zhao, Wentz, & Murray, 2017). The shape of the land surface, modified by site preparation, excavation and filling, the layout of curbs and streets, along with any remaining native topography, are also important features of the three-dimensional configuration of urban areas.

While technology exists to both collect and represent the surface topography and 3D structure, these have been less accessible than the spectral data and therefore less widely used. Nevertheless, 3D urban form is the basis for understanding urban dynamics and has been used to measure and model biophysical properties and urban climate (e.g., Nazarian, Fan, Sin, Norford, & Kleissl, 2017); economic development and competitiveness (e.g., Hawken and Hoon, 2017; Inostroza, 2014); and human health and well-being (e.g., Deng, Cheng, & Anumba, 1573). Studies of within-urban dynamics and generalization of urban form and function require analysis of the third dimension.

To understand the variation in urban form and the transitions over time, a prolific literature of quantitative landscape approaches has developed where landscape metrics of shape, size, and connectivity are used to describe and compare urban form (e.g., Alberti, 2005; Irwin & Bockstael, 2007; Lu, 2015). Studies utilizing these metrics indicate a high degree of fragmentation among urban land use types indicating patterns of sprawl and heterogeneity. Fragmentation, configuration, and connectivity metrics provide insight into the flows of energy, responses of the natural environment, and the demands on the built environment (e.g., transportation infrastructure, urban parks and preserves) (Leitao, Miller, Ahern, & McGarigal, 2006). Utilizing these same metrics, scientists have developed grid cell-based or cellular automata models to further understand urban dynamics showing patterns of development such as envelopment, whereby land around urban areas is overtaken; or multiple nuclei development, when new urban areas develop that are not adjacent to existing urban areas (e.g., Clarke, Hoppen, & Gaydos, 1997; Han et al., 2009; Soares-Filho, Cerqueira, & Pennachin, 2002; Verburg et al., 2002). Despite the argument that the patterns being quantified and described by these metrics are the emergent properties of underlying social and biophysical processes, few studies have successfully made the pattern-process link (Kupfer, 2012).

The tools from quantitative geospatial information and analysis continue to improve providing a new window into urban form. This includes data sources and data collection methods such as citizen science programs (e.g., volunteer geographic information, crowdsourced data), extraction of data from social media and mobile devices, and new data collection platforms (e.g., drones). These new and emerging data sources need to be coupled with a conceptual framework to understand complex urban phenomena (Cadenasso et al., 2007; Qureshi, Haase, & Coles, 2014). This paper therefore posits a framework of six aspects of urban form to lay the foundation for integrating existing and new forms of data and analysis.

3. Six aspects of urban form

The six aspects of urban form are organized within a framework of three components: materials, configuration, and time. *Materials* refer to the physical matter, including living and non-living, which constitute the stock of human settlements. *Configuration* refers to how the material elements of urban areas are spatially arranged within a two-dimensional (2D) flat surface perspective and a three-dimensional (3D) perspective that includes height. *Time* explicitly emphasizes that the materials and their configurations are dynamic assemblages changing over different spans of time. The intent of identifying and defining six aspects of urban form within this component framework is to create an approach that can be consistently applied across all spatial resolutions and scales and allows for intra- and interurban comparisons. The remainder of this section describes each aspect within the proposed overarching urban form framework.

3.1. Materials

The first component of the urban form framework is materials. Materials represent the physical matter of above ground urban form and includes three distinct aspects (Fig. 1). The human constructed materials (Aspect 1) of urban form include any and all land surfaces containing buildings, roads, above ground utilities, and altered topography. The soil-plant continuum (Aspect 2) of urban form includes land surfaces with biological activity including microbial activity, living plants, dead organic matter, and soil processes. The surface water (Aspect 3) of urban form includes land surfaces that are predominantly water such as streams, ponds, lakes, canals, reservoirs, swimming pools, and large fountains but excluding subsurface water such as groundwater and sewer systems. We separate materials into three aspects because all three are required to comprehensively characterize these key dimensions of the built environment. Traditionally, constructs of urban form focus exclusively on the human constructed elements, limiting understanding of the within-urban dynamics of plant and water features.

The human constructed materials of urban form are those features that are most often considered the built infrastructure of a city. As such, we utilize the color brown as a metaphor for human constructed materials because of the association to structure and support (Fig. 1). From a remote sensing perspective, human constructed materials are often classified from “impervious surfaces” and therefore create the basis of the simple binary urban classification. The human constructed materials in this framework, however, aims to move beyond the binary classification of urban represented by concrete, asphalt, and steel, to include all land surface features with human alteration. For example, topographic alternations are crucial in the making and maintenance of roads but are often not classified as urban. The benefit of this broader perspective on human constructed materials is that surface alterations change or obliterate soil profiles, change the permeability of even unsealed surfaces, alter watershed boundaries and flowpaths of water, and relocate or establish sources and sinks of biogeochemical activity.

While human constructed materials are often exclusively used to define urban form, it is increasingly clear that the soil-plant continuum plays a vital role in shaping the ecological and social environments of urban form. Green is a metaphor for the living components of urban form because of the links to biological processes (Fig. 1). The Normalized Difference Vegetation Index (NDVI) and derivative radiometric indices offer tools to catalog this aspect of urban form but it is increasingly important to measure and represent the soil-plant continuum from high spatial resolution data and refined classification methods (Pickett, 2010; Zhou, Pickett, & Cadenasso, 2016). While the soil-plant continuum is affected by human activities, this aspect of urban form would not exist without biological processes. The soil-plant continuum emphasizes the structural and metabolic linkages between plants and the soils and the ecosystem functions that they can support, such as the potential for mitigation of the urban heat island effect (Harlan, Brazel, Prashad, Stefanov, & Larsen, 2006; Ng, Chen, Wang, & Yuan, 2012).

The third aspect is water, often overlooked as a material component of cities. Cartographic traditions utilize blue for representing water, which led us to choose blue as a metaphor for water in this framework (Fig. 1). Mapping the spatial extent of surface water predominantly relies on medium to coarse resolution satellite data to capture surface waters of significant size and high-resolution data sources for smaller bodies of water, which are important for analyzing how urban form influences factors such as disease vectors (Becker, Leisnham, & LaDeau, 2014). We explicitly include surface water as a key component of the urban environment to fully represent the interactions between urban form and issues such as the food-energy-water nexus, climate change, water security, flood vulnerability, and the benefits and costs associated with coasts, lakes, and rivers.

3.2. Configuration

The second overarching component of urban form is configuration (Fig. 1), which consists of a two distinct but interrelated aspects: dimensionality of urban form (Aspect 4) and the spatial pattern of urban materials (Aspect 5). Dimensionality refers to the measurement and recording of height information of the material elements, resulting in a three-dimensional (3D) representation of urban form, including the underlying topography as well as the dimensionality of the structures in the built environment. Spatial pattern refers to how the patches of material elements of urban areas are arranged in space, both in 2D and 3D. Fig. 2 illustrates how configuration is represented now and how it could be represented in a new framework (see Fig. 3).

The analysis of urban form is largely conducted using the 2D footprint of urban materials, due in part to data collection and storage challenges. This results in an inaccurate assumption that cities exist, function, and grow as a homogenous flat plane. Nevertheless, the combination of the natural topography, and alterations to that topography, with the varying heights of human constructed materials and the soil-plant continuum result in a 3D urban form, which we specify as Aspect 5. Without 3D information, skyscrapers and single story structures are represented in the same way, yet differences in the height and volume of buildings has wide ranging implications for urban form (McGrath, 1994), such as population density (Tomás, Fonseca, Almeida, Leonardi, & Pereira, 2016), the urban climate (Palme, Inostroza, Villacreses, Lobato, & Carrasco, 2017; Perini & Magliocco, 2014), and energy use (Hui, 2001). Vertical farming and green roofs add further complexity to the 3D configuration of urban areas, and may suggest hybrid categories in coarser scale land classification.

The representation of urban materials in 3D and the quantification of spatially explicit arrangement of materials enable a richer approach to analyzing urban form. This shift will create opportunities to understand how cities function in a completely new way reflecting the reality of lived experience in cities and the ecological processes within them (Fig. 2). While challenging, this presents an opportunity for avenues of research to develop new theories, methods, and techniques to conceptualize and analyze urban form. Mathematical methods, such as geometric analysis which has been applied to detect the 3D change in building (Teo & Shih, 2013), can be refined for 3D urban analysis. Similarly, knowledge derived from fields such as ecology, architecture, and engineering provide new ways of thinking about the spatially complex and diverse structure of urban areas (Cadenasso et al., 2007; Inostroza, 2014; Pickett, Cadenasso, & McGrath, 2013). Our framing of the material component of urban form and its key aspects provide a link to these areas of investigation.

3.3. Time

The final component of this framework is time, which consists of Aspect 6 (Fig. 4). Time is a critical part of characterizing urban form because human activities and biophysical processes influence urban materials and their configuration over short and long time spans. Indeed, time itself is complex, and can be conceptually refined to deal with the onset, end, and duration of events as well as the existence of temporal lags and legacies (Cadenasso, Pickett, & Grove, 2006; Peuquet, 1994; Scheer, 2016). While the time dimension is often recognized in the widely documented expansion of urban areas, urban areas are also being abandoned or adapted through processes such as gentrification or repurposing of commercial zones (Dunham-Jones & Williamson, 2008). Time is an essential aspect of urban form because activities such as newly constructed buildings and roadways, diurnal and seasonal changes to vegetation and surface water, and demolition results in alterations to the 2D/3D structure and the arrangement of urban materials. For example, while the total amount of vegetation in a city may remain the same over time, the location and connectivity of the vegetation is altered, potentially impacting ecosystem functions (Kong & Nakagoshi, 2006).

Understanding the impact of how urban areas change over time requires the detection, monitoring, and analysis across the five aspects of urban form. The most common approach is to include time is to perform a cell-by-cell comparison of classified remotely sensed imagery from different time periods and to quantify the aggregate differences (Sexton et al., 1984). Most urban change studies permit only one urban class, so detecting changes to the soil-plant continuum, surface waters, or repurposed land use is limited. Similarly limiting is the emphasis on 2D representation of urban form, which minimizes any analysis and understanding of the 3D urban density, urban texture, and urban profiles. The problem intensifies because most change detection analyses are conducted at only two discrete time periods, restricting the ability to monitor and analyze urban form over extended time periods. The time aspect, in conjunction with the three material aspects and the two configuration aspects, provides a broader and more complete representation of urban form, but the value of these six aspects are best realized when they are embedded in the analysis of the more inclusive, complex, and dynamic social and biophysical urban system.

4. Discussion

The overarching components of urban form, comprised of materials, configuration, and time, provide a framework for comparing and generalizing within-urban dynamics as well as change over time of larger urban areas worldwide (Fig. 1). The approach solves the problems plaguing simplistic representations by allowing analysts to depict the unique physical, cultural, social, and economic characteristics of specific urban areas, while retaining the ability to generalize over time and across different areas. Simultaneously, the approach retains the ability for analyzing spatial specificity and complexity that exist with detailed representations of urban form by explicitly integrating biologically active characteristics and areas with those dominated by human construction, capturing the arrangement of 2- and 3D features, and addressing flows over short timeframes and changes over long

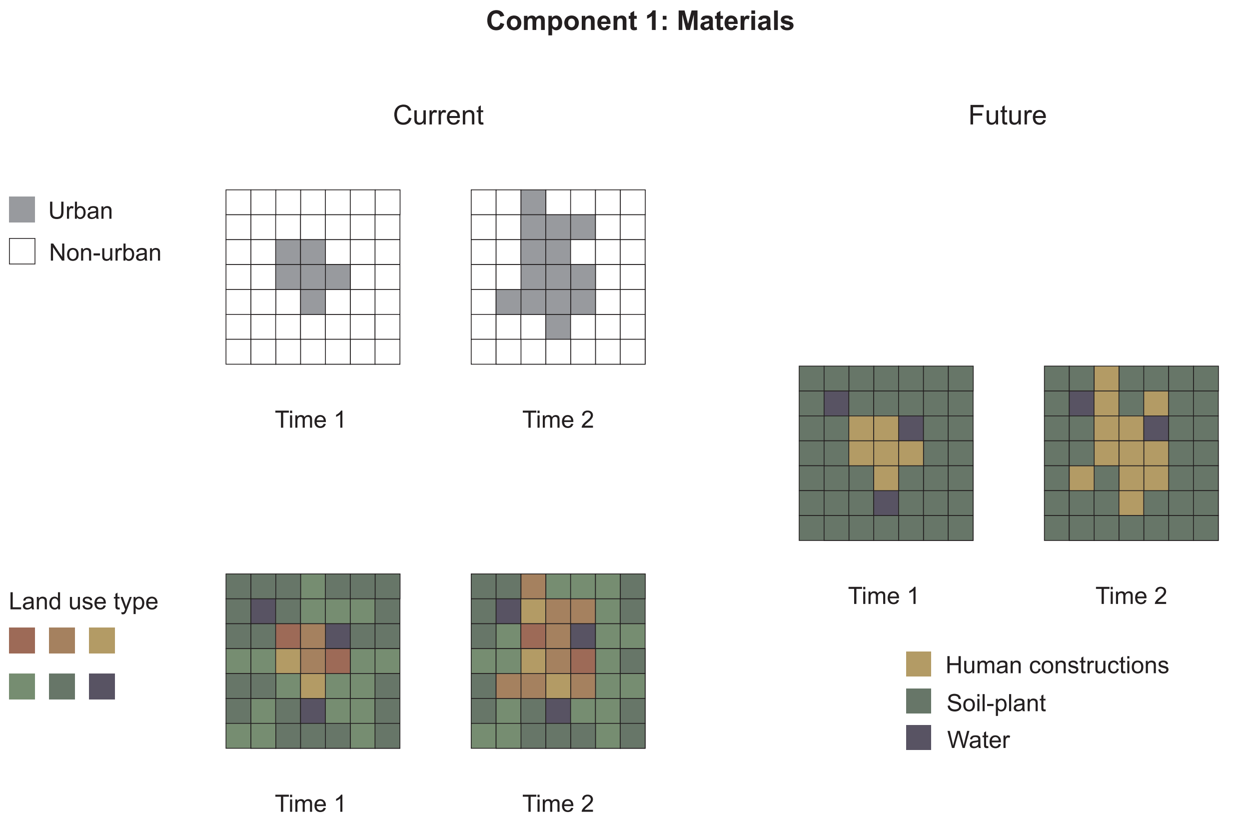

Fig. 2. The materials component of urban form presently represented in studies and how it could be represented in the future using the six aspects.

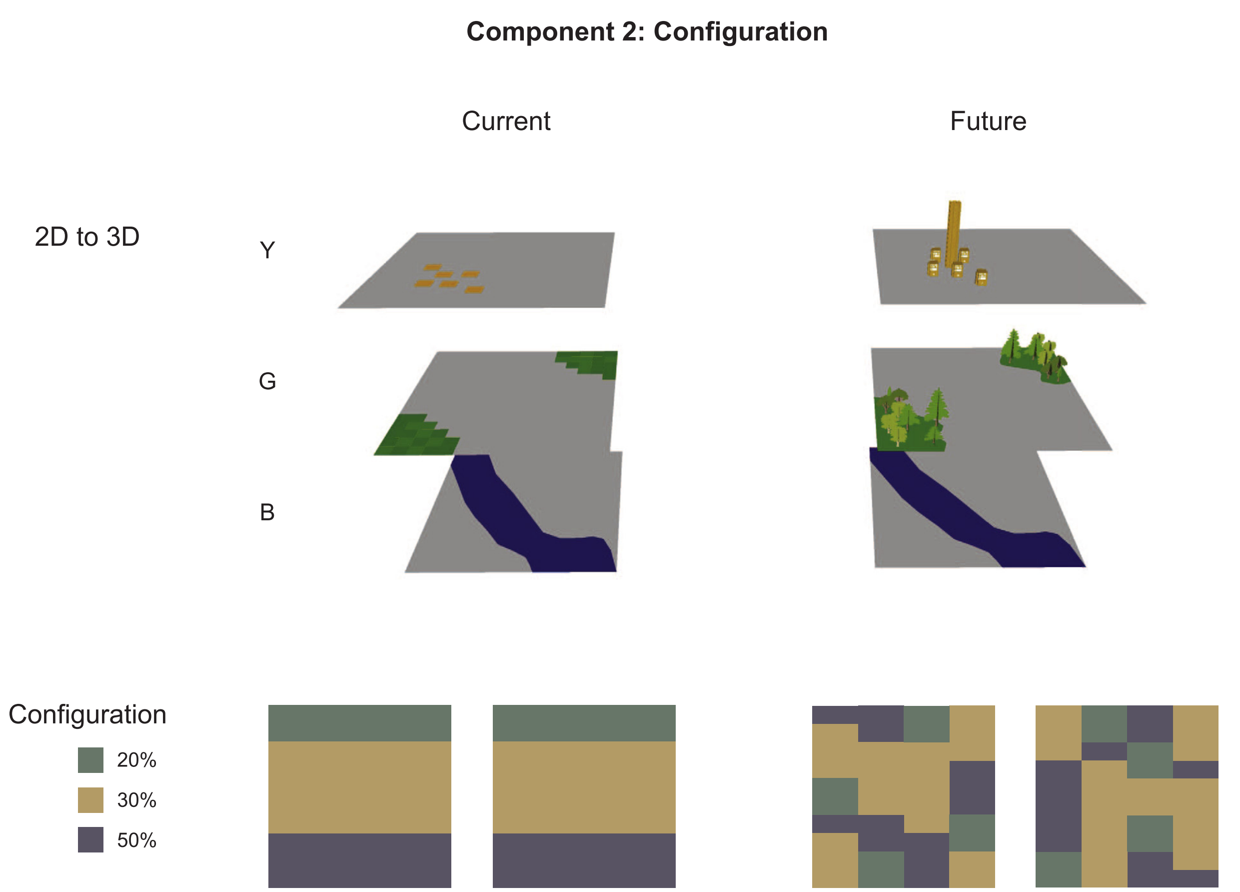

Fig. 3. The configuration component of urban form showing both the current representation and how configuration could be represented in the future.

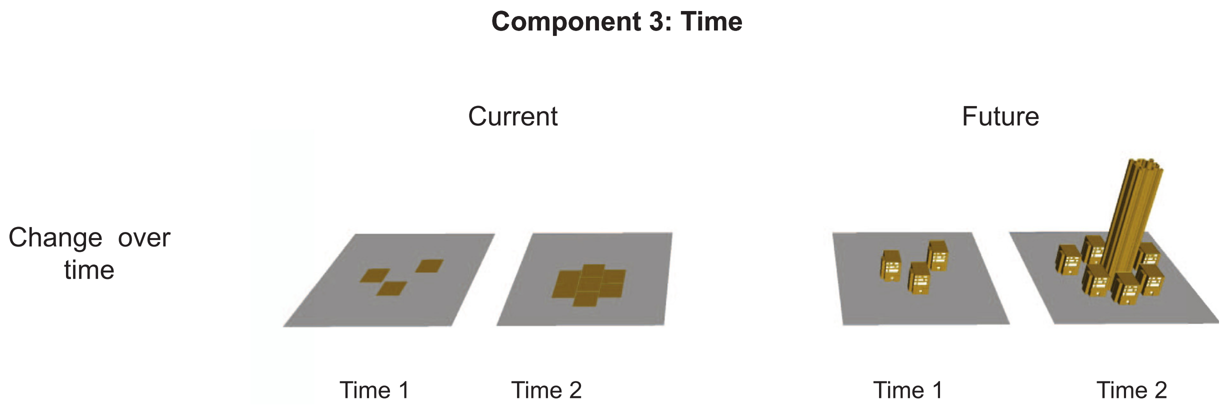

Fig. 4. The time component of urban form and how it is currently represented in urban studies and how it could be represented in the future.

timeframes. There are gaps in the literature linking remotely sensed imagery to local and global impacts and implications within the larger urban system (Wentz et al., 2014). Linking remotely sensed imagery with other data sources, such as sensor technology or household energy usage, will allow researchers to tease out the more nuanced relationships between emissions, urban form, flows, and social structure.

The urban form represents the visible objects of a city (e.g., buildings, roads, vegetation, water) as well as how they change over time. It provides the functional space for urban activities – and either facilitate or limit interaction. Geographical distances, connectivity, shape, and pattern are metrics used to assess the level and quality of interaction. For example, compactness and higher complexity of urban form is associated with reduced carbon emissions due to the flows through the system (Fang, Wang, & Li, 2015; Makido, Dhakal, & Yamagata, 2012). Similarly, the embedded spaces in which biological energy and nutrient processing occur in cities can be significant contributors to carbon sequestration, water infiltration and storage, processing of contaminants, mitigation of heat extremes, and the support of human wellbeing in various other ways (Gardiner, Burkman, & Prajzner, 2013; McPhearson et al., 2014; Nowak, Greenfield, Hoehn, & Lapoint, 2013) There are few tools for analyzing urban form from this perspective and the level of impact across domains remains unclear (Biljecki, Ledoux, Stoter, & Zhao, 2014).

The six aspects framework has notable limitations. First, we acknowledge that reducing urban materials to the aspects of constructed, soil-plant continuum, and surface water does not capture all of the material manifestations of urban form. Absolute aspects of form are challenged by features or scales that fail to be represented by one and only one category, such as green roof structures, abandoned brownfields, and urban wetlands. Second, all material aspects of urban form are temporally dynamic at differential rates of change, such as periodic and seasonal meteorological events that impact the soil-plant continuum and the appearance and disappearance of surface water. Wetland features, for example, can serve physical processes of both the soil-plant continuum and water, and their function may change over time as the drivers of rainfall, horizontal water flow, and evapotranspiration change seasonally or annually (Bois et al., 2017). A third challenge is that each of the three aspects invariably may be disaggregated into more detailed categories of constructed, biological and water. For example, "low density residential," a common land use category, would likely contain one or more building structures, landscaping, and in some cases water features such as swimming pools. Finally, each of the material aspects has associated attributes (e.g., the albedo of constructed materials, vegetation type, measurements of water quality), which are not specified in this framework. These attributes critically link urban form to urban social and ecological processes.

While less of a limitation and instead an observation, the six aspects of this framework are restricted to urban form at-or-above-the-surface. This means we did not include important subsurface (notably key infrastructure, including subway systems, buried utilities, groundwater, sewer) or atmospheric materials (water vapor, air pollutants), which interact with the at-surface urban form in significant ways. As examples of this relationship of below ground processes to urban form, the soil-plant continuum and water materials biochemically interact with molecules in the air, potentially reducing the effects of pollution (Yang, Yu, & Gong, 2008). Similarly, the 3D urban form, including a combination of buildings and trees, influences air flow and dispersion or concentration of air pollutants (Baik, Kim, & Fernando, 2003). This introduces the idea that urban form is layered – ultimately creating what we described as 3D urban form. While we restrict the 3D to volume, other data can be introduced to address a layering form. This concept of layering urban form extends current considerations in substantive ways. Adding layering of material aspects to the assessment of 3D configuration provides a way forward, although it requires additional sources of data or elevation segmentation of urban materials.

5. Conclusions

The need met by this paper is fundamentally conceptual, and in part, a call to action. Ultimately its impact will be measured by how much it can further our understanding and measurement of urban areas, which in turn will be served by technological and analytical advances in remote sensing data collection and analysis, spatial statistical techniques and models, and visualization approaches. These methodologies then lead to the ability to address the critical open questions in studying the dynamics and complexity of urban form and land use/cover change in cities globally. Knowledge on the influence and interaction of the drivers and consequences of land use/cover change are needed to identify hot spots, triggers, and tipping points of land use/cover change. Urban form is costly to transform and leads to path dependence of neighborhoods, cities, and regions, which generates long-term implications, as well as reduces the ability of communities to transform. It is a needed and relevant framework as municipalities decide how to approach and build smart cities, best utilize resources from the combination of authoritative data sources along with newer forms of data collection, and ultimately reach global sustainability development goals.

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