Title
Towards topographically sensitive urbanism: re-envisioning earthwork terracing in suburban development

Journal
Journal of Urbanism International Research on Placemaking and Urban Sustainability, 8(4)

ISSN
1754-9175

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Publication Date
2015-10-02

DOI
10.1080/17549175.2014.896395

Peer reviewed

Towards Topographically Sensitive Urbanism

Re-envisioning earthwork terracing in suburban development

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2014, *Journal of Urbanism* 8 (4): 331–351

Introduction: topographic defiance

Celebrated world cities sited on or near steep topography respond to their settings with a variety of site-specific strategies. In Hong Kong, slopes of up to 40% gradient are typically built on, with steeper ground artificially stabilized and classified within an engineering database (Figure 2). In Rio de Janeiro, the almost vertical megalithic granite domes serve as spatial and religious orienting devices that are circumnavigated by the official city and appropriated by the favelas. In Sydney, arterial roads tend to track the ridgelines that alternate with forested valleys, with vestiges of exposed sandstone penetrating the urban fabric in between. And in San Francisco the urban grid is renowned for its contrasting expression of the underlying topography (Figure 1). As Florence Lipsky (1999, 154) observes, the urban quality of San Francisco "resides precisely in this incompatibility, an unthinkable defiance of nature."

In these four examples, the underlying geomorphology is sufficiently robust to resist erasure and drive the celebrated identity of each city. However, at the peripheries of many rapidly expanding cities, the delicate balance between urban form and topographic morphology is

Figure 1. Contour signature for north-eastern quarter of San Francisco.

Figure 2. Example of a Hong Kong "registered slope" stabilization technique

disrupted. In California, the supply of relatively level land in Los Angeles and the Bay Area has largely been exhausted, with both metropolitan areas abutting their mountainous frames (SCSC 2001, 2). Unperturbed by this topographic barrier and facilitated by mining-scale "mountain cropping" techniques (after Bronson 1968, 35), suburban sprawl increasingly encroaches into the peripheral foothills (Figure 3). In the southern hemisphere, the naturally undulating sand dune terrain of Perth (Western Australia) does not hinder the rapid suburban expansion of the metropolitan area. The dunes are stripped of all vegetation and remodelled into megalithic 'benched' earthworks of retaining walls and perfectly flat building lots, thus creating a blank canvas that enables the 'great suburban dream' to be pursued irrespective of the natural topography of the site (Figures 4 and 5).

Figure 3. Example of site preparation for new suburban development at Hayward, California.

Figure 4. Example of remodelling undulating sand dune terrain into a large earthwork of retaining walls (demarcated by their shadows) and perfectly flat buildings lots to facilitate rapid suburban expansion in Perth, Australia. 2012.

Figure 5. 12 ft (3.5m) high retaining walls in preparation for residential subdivision in northern Perth. Indigenous remnant heath vegetation and natural topographic landform is visible in the background.

Three urban models: modernism, ecological planning, traditional urban design

From both ecological and urban design perspectives, the examples outlined above frame a flawed template for metropolitan growth. Nonetheless, the three prevailing twentieth century urban models have exerted little influence over the process of mechanized suburban transformation. First, modern urbanism sought to reconstitute cities above the ground on *pilotis* designed to enable the land to flow unimpeded beneath (Vogt 2000). Although successful in isolated projects, when realized on a large scale in post-WWII reconstruction in Europe and urban renewal in the US, decoupling from the ground often had the unintended by-product of devaluing the landscape. The pastoral scenes of many modern visions degenerated into wastelands in the absence of custodians to share and steward the ground. As a result, automobiles routinely appropriated the uncoordinated landscape between and beneath buildings that offered lack of gathering spaces to support urban life (Ingersoll 2006). Consequences included environmental degradation and the dissolution of functioning communities (see Jacobs 1961; Sennett 1990).

Second, ecological planning—as embodied in the ‘suitability analysis’ techniques developed by Ian McHarg (1969)—was more repellent, dictating where development should not occur, such as on steep slopes. An influential McHargian image that illustrates dispersed fully detached housing co-inhabiting a sparsely wooded valley slope clearly demonstrates the environmental limitations McHarg placed on development in particular landscape types (Figure 6). While appropriate in some contexts, given the contemporary pressures on cities to expand it is nevertheless unlikely that every steep slope will be protected from suburban development. In these instances, ecological planning methods risk becoming less effectual once the anti-development argument has been lost.

Third, the currently prevalent model of traditional urban design focuses on reinstating the key formal qualities of pre-modern urbanism. This model is premised on the massing of built form and landmarks, and the legibility of streets as they relate to networks of both movement and lines of sight. As cities were generally historically sited on waterways, traditional urbanism is most efficacious on flat sites. Where it does exist, topography is often positioned in urban design schemes as a non-urban 'other' that takes the form of a park or natural landmark. The seminal *Rural-Urban Transect* diagram by Andrés Duany (2002) illustrates this point. The schematic section taken from the core of a city to the periphery is entirely flat, with topography conveniently relegated to the periphery of the built zones and identified as regional recreational and nature reserves (Figure 7). Although useful as a historical analysis, this idealized model does not accurately reflect conditions at the peripheries of many expanding contemporary cites. As Peter Bosselmann (2011) demonstrates, actual urban cross-sectional profiles reveal a far more complex relationship between topography, urban morphology, and urban legibility than a flat urban core encircled by a hilly wooded periphery. In coastal cities in particular, the appeal of building near the coast—despite typically offering steeper topography than inland river flood plains—further dissolves neat topographically-based urban/rural distinctions.

Figure 6. Illustration of low-density development suitable for sloped woodlands as established through Ian McHarg's suitability analysis. Source: McHarg, I. (1969) Design with Nature. Garden City, NY: Natural History Press, p. 90.

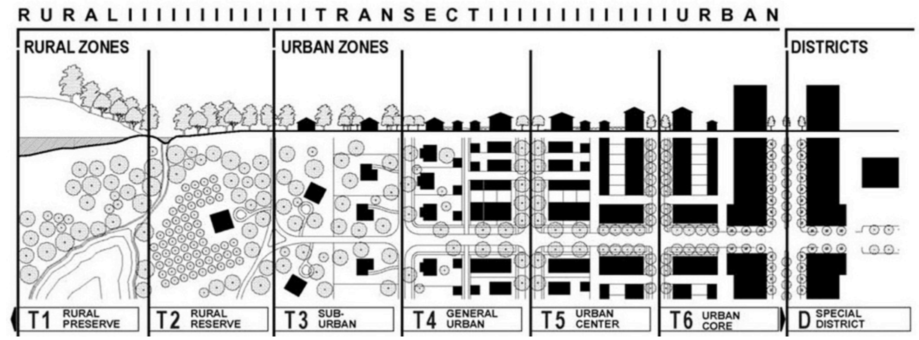


Figure 7. Rural–urban transect illustrating assumption of flat urban core and hilly wooded periphery. Source: Duany, A. (2002) Introduction to the Special Issue: The Transect. Journal of Urban Design 7(3), p. 256.

Research aims, methods and definitions

Modernism, ecological planning, and traditional urban design provide robust urban models for many aspects of cities. These include organizing urban cores, conserving areas of ecological value, maximizing community interaction, and integrating infrastructure. Nevertheless, there is limited research within the disciplines concerned with the design qualities of cities into the role of topography in enhancing urbanism. Although numerous researchers and observers have identified the troublesome nature of suburban expansion into hilly terrain, these concerns tend to emerge as a by-product of other research in specific disciplinary arenas, including history, biology, ecology, landscape architecture, architecture, urban planning, and urban design. Responses tend to be polarized between the implicit position that this kind of development should be stopped altogether, and site-specific experiments that address individual typological situations in isolation from the overall urban structure. As cities continue to expand due to population growth and may need to retreat to higher ground due to the impacts of climate change, developing a more holistic framework becomes increasingly important.

To create a contextualizing framework, the article synthesizes relevant perspectives and methods from the range of disciplines that are invested—either through opposition or participation—in the practice of suburban benching on steep sites. The argument for fostering more topographically responsive suburban design is structured in three parts: (1) outlining the post-WWII transformations that have driven the suburban benching phenomenon; (2) articulating the inherent worth of retained topographic form; and (3) examining how the key building blocks of suburbia may be reinterpreted to achieve more topographically responsive suburban morphologies. The article includes analysis of examples from Perth (Western Australia) and the Bay Area (California), both of which exhibit significant expansion into distinct types of hilly terrain.

Although Australian suburban growth is more controlled than the US development model (Troy 1996; Gleeson 2006), the engineered benching morphology that typically results is similar. In both California and Western Australia, suburban benching is constructed across average hillside gradients ranging anywhere from of between 2% and 30%. Localized slopes within the original landform of up to 75% the foothills of the Bay Area, and 70% in the sand dunes of Perth, are typically smoothed out during the re-grading process. Within this very wide gradient range, slope does not impact the prevalence or general engineering of suburban benching, with only the relative height of the retaining walls or embankments between lots increasing in proportion to steepness. On slopes averaging above 30%, suburban benching remains uncommon, with low-density pile/stilt construction housing forming the dominant housing type on very steep slopes in the Bay Area. In Perth, long slopes averaging over 30% are rare and generally not developed for suburban housing. In addition to the influence of slope, suburban benching ranges in scale from an area as small as two residential lots, through to the development of entire suburbs of 150 lots in the Bay Area and over 500 lots in Perth.

Figure 8. Longji (Dragon's Backbone) Terraced Rice Fields, Guangxi, China.

Framing the problem: levelling the ground

Levelling out an area of ground when establishing a camp represents a primeval act of inhabitation; for eons levelness has allowed humans to gather readily around a cooking fire and to sleep comfortably. The act of cutting and filling does not erase or create earth but rather carves functionality from the ruggedness of the world. Indeed, the very notion of levelness equates to usability across a very wide range of programs that encompass dwelling, making, agriculture and recreation (Figure 8). Conversely, land that is out-of-level has tended to be perceived as useless and is thus attributed lower, or merely scenic, value. Interestingly, differentiating the ruggedness of wild terrain from the cultivated usability of the terrace represents a relatively contemporary dichotomy, with ‘terrain’ and ‘terrace’ actually sharing equivalent etymological origins (Leatherbarrow 2004).

Throughout history, levelness is equally important in the founding of cities. Roman surveyors typically preferred sites on flood plains, and the *Groma* (Roman survey apparatus) was plumbed to sit perpendicular to the level ground, with this vertical orientation a precondition of the accurate functionality of the instrument (see Rykwert 1976, 50). Even in instances where urbanism was topographically sited primarily for defence—as in the case of the southern European medieval hill towns that followed the withdrawal of Roman stability, and the Incas' retreat at Machu Picchu (Peru)—levelness was still a determining factor, albeit in heavily restricted proportions atop knolls or cols. On this need and capacity to create levelness in even the most extreme environments, landscape theorist Anne Whiston Spirn (1984, 91) termed humans "geological agents." Spirn observed that the topography of settlements is constantly modified as "hills are levelled" and "low-lying basins are filled."

Constructing level sites in even the most precipitous settings is thus a timeless activity in inhabitation, agriculture, and the building of civilizations. The incorporation of 'making level' into benched suburban site-works may therefore be interpreted as historically consistent. To differentiate site terracing on a suburban scale from historical types of levelling, the following section identifies the convergence of factors driving the emergence of suburban benching.

1. Lack of available flat land

The exhaustion of flat land suitable for building contributes pressure to develop steep terrain that had previously been considered off-limits due to the prohibitive cost-engineering challenges of preparing this land for development (see Corner and MacLean, 67). This process is more complex than internal population increases exerting pressure on 'full' cities to expand outwards, since a concurrent reduction in residential densities at the metropolitan core often accompanies growth at the peripheries of cities. This 'hollow city' phenomenon can take several forms. At one extreme is the highly visible socio-economic retreat from inner-suburban blight that characterizes many US cities to varying degrees. At the other, is the subtler but nevertheless statistically powerful process of gentrification. As occurs in all major Australian cities, socio-economic displacement results in a reduction in numbers of residents per dwelling in first-ring suburbs.

Both blight and gentrification displace residents and services to the periphery, even before the pressure of actual overall population increase is considered (Bruegmann 2005). In this context, on-going planning, and design initiatives to revitalize potential infill areas within existing urban boundaries represent an essential component of sustainable cities. Nevertheless, while some observers place hope in the capacity for "genuine centre-based diversity and density" to contain sprawl and "stop ecologically destructive growth at the edge" (Fishman 2006, 3), it appears unlikely that urban infill will accommodate all of a given city's future population increases. By extension, peripheral green-fields expansion—that in many instances impinge into steep terrain—is likely to be an inevitable condition of twenty-first century urbanism that requires management through sustainable design and planning techniques (Gleeson 2006, 10).

2. Growth in building footprints

The floor areas of single-family fully detached dwellings increased markedly after WWII. In Australia, typical floor areas of around 1,000 sq ft (90m^2) in the 1940s grew to 1,600 sq ft (150m^2) by the mid-1980s, and further to 2,300 sq ft (210m^2) by the mid-2000s (Hall 2007). In the US, house sizes increased from an average of 1,000 sq ft (90m^2) after WWII, to 2,400 sq ft (220m^2) by 2010 (Sarkar 2011). On both continents, this expansion represents a more than doubling of living space in just half a century. Throughout this period, larger dwellings have been marketed as necessary to accommodate the post-WWII prosperity-driven culture of lifestyle features that include chef's-kitchens, activity-rooms, home-theatres, and large foyers (Flanagan 1998). The simultaneous reduction in actual numbers of inhabitants per dwelling mirrored the increase in physical living space. In the US, average household size shrank from 4.60 people per house in 1900, to 3.68 in 1940, and 2.59 in 2000 (Hobbs and Stoops 2002). Similarly, in Australia, average households declined from 4.6 people per dwelling a century ago, to 3.6 people in the 1950s, 2.6 in 2006, and are expected to decline further to 2.4 by 2031 (de Vaus 2004; ABS 2010).

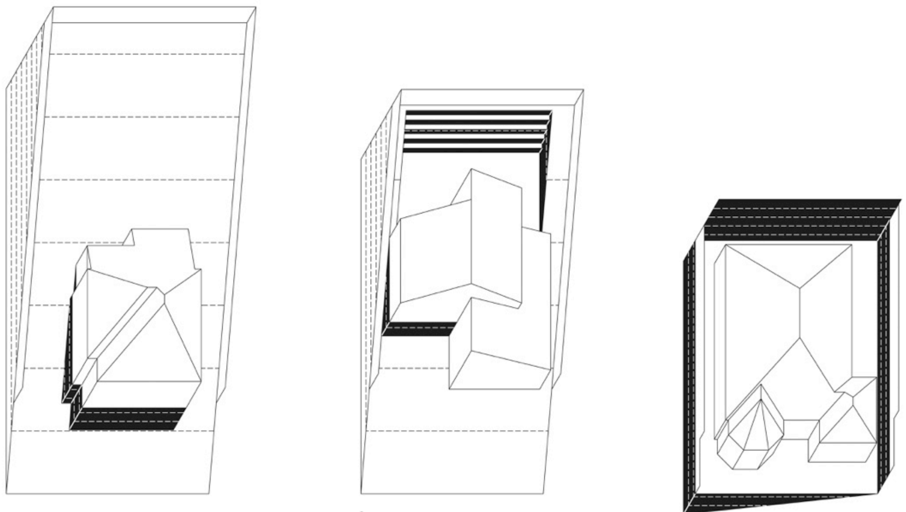
3. Shrinkage of building lot sizes

A proportional reduction in average lot sizes compounded the marked historical increase in the footprints of suburban housing. In Australia, typical single-family residential lots decreased from 11,000 sq ft (1020m^2) in the 1930s, to 8,000 sq ft (740m^2) in the 1950s, 6,000 sq ft (560m^2) in the 1970s, and down to 4,500 sq ft (420m^2) in the 2000s, with some single family residential 'cottage' lots below 2,500 sq ft (230m^2) (Kupke et al. 2011). In the US, lot shrinkage has not been as dramatic, but has nonetheless been decreasing since reaching a maximum average of 14,000 sq ft (1,300m^2) in the 1990s (Sarkar 2011). The initial period of downsizing from large ¼ acre lots can be attributed to the widespread installation of sewage infrastructure, which eliminated the need for spatially extensive onsite septic tanks. Smaller lots also provided the higher yields necessary to offset increased development costs associated with installing sewers. Following the initial impact of sewage systems, the decrease in building lot sizes can also be ascribed to both supply and demand. On the supply side, the exponential increase in land values in many cities has been connected to increased access to credit that reached a peak in before the Global Financial Crisis of 2008 but originates in the returned serviceman home loans that were a feature of both US and Australian post-WWII societies (Morris 2005, 186; Hayden 2004, 4; Chow 2002, 22–25). The trend towards smaller lots partially offsets the affordability issues associated with increases in the cost of land. On the demand side, increased preferences for indoor and offsite leisure activities improved the marketability of 'low maintenance' smaller lots.

4. Plot coverage ratios and indoor/outdoor continuity

The net result of expanding dwellings and shrinking lots has been an increase in plot coverage ratios (percentage of a lot covered by buildings). In Australia plot ratios rose from as low as 10% on the ¼ acre (1020m^2) lots that were typical prior to WWII, to 60% and above in the 2000s (Hall 2007). Increased plot ratios substantially diminish the quantity of un-built land available on individual lots for negotiating differences in topography. Three archetypal situations from the undulating topography of the Perth suburban fabric illustrate this point. In a typical 1940s situation, the generous proportions of the lot, diminutive footprint of the dwelling, and lack of 'lifestyle' programming for the yard left ample space for accommodating the natural landform (Figure 9a). In most instances, the dwelling was set above the lay-of-the-land on a plinth constructed either of timber stilts, or a cut-limestone block foundation that precisely traced the footprint of the house. Additionally, the positioning of the house was frequently fine-tuned to the localized topography of the site by rotating or shifting the footprint away from the street.

By the 1960s, burgeoning floor areas and decreasing lot sizes required more proactive site-based solutions to the challenges posed by slopes (Figure 9b). Terraced retaining walls set back from property boundaries emerged as a technique for facilitating increased demand for flat outdoor entertaining areas set level with the internal floor of the house. With origins in Californian modernism, the popularization of fluid leisure space between indoors and outdoors represented a significant shift in attitudes that continues to influence present-day suburban design. Within this new architectural paradigm, the garden came to be viewed as an extension of the house, displacing the old arrangement of the house constituted as an internal private world set between a decorative front garden and functional backyard. Split-level floor plates also became a common feature in dwellings of this era, with the change in level demarcating living and entertaining areas within the house, but also having the additional advantage of accommodating any changes in site topography within the footprint of the building.



a. b. c.

Figure 9. Axonometric diagrams illustrating the effect of shrinking suburban lots and growing house areas on landform treatment with regards to steep sites:
(a) 1940s 1,250 sq ft (120m2) house on 8,000 sq ft (740m2) lot with site grade negotiated using a limestone plinth foundation for house.
(b) 1970s 1,750 sq ft (160m2) house on 6,000 sq ft (560m2) lot with site grade negotiated using a combination of split-level construction, external retaining walls, and terraces near property boundaries.
(c) 2000s 2,500 sq ft (230m2) house on 4,500 sq ft (420m2) lot with site grade negotiated using retaining walls on all property boundaries to create level lot.

In many suburban developments through the 1990s and into the 2000s, expanding building footprints and shrinking lots surpassed the critical threshold of plot coverage ratios of 50-60%. At this point, the relationship between house and land fundamentally inverted from a *house set within a lot* to the *lot constituted as a narrow buffer around the house.* In this new standard, the lot plays a supporting role to the house, essentially taking over the function of the building foundations typical of the 1940s. In hilly locations, the site grade is negotiated using retaining walls that have been displaced outwards to the property boundaries to create a perfectly level lot (Figure 9c). In a logical evolution of this practice, the retaining walls became the official demarcation of the parcel boundaries, replacing the role of six ft. high boundary fences found in older suburbs. This in turn necessitated an infrastructural-scaled approach to site preparation that differs markedly from the piecemeal homeowner-scaled operations that characterized site manipulation up until the 1980s.

The effects of these transformations on the post-WWII suburban landscape are clearly illustrated in a series of topographic samples taken from the Perth suburban fabric. In each 500m (1640 ft.) squared frame, the contour signature of the suburban residential area is compared with adjacent terrain that has been preserved in its natural state (Figure 10). In a 1940s development, the large lots, small building footprints, and compact building foundation plinth, leave the underlying landform virtually unmodified. In a similar 1950s development on a very steep slope, repositioning houses within the lots minimized contour manipulation. In a 1970s development undergoing renewal with backyard infill development, a moderate degree of topographic modification and some retaining walls are evident. In a 2000s development, the indigenous landform has been totally substituted for an artificial landscape of terracing and retaining walls.

5. Technology and standardized models

In economic terms, increased land values and more efficient mining-scale earth-moving techniques to allowed formerly unprofitable sites to be levelled for suburban development. Additionally, the post-WWII shift to mass-produced concrete slab ‘tract homes’ and superficially customized ‘model homes’ necessitated that suburban residential development sites be standardized to accommodate pre-determined buildings, as opposed to the buildings adapting to the site. With origins in the late-1940s planned community of Levittown (Long Island, New York), this culture of mass production reflects the same top-down models associated with product manufacture. Initially, the developer of a given suburban project identifies their potential market, defines the lifestyles around which the identity of the project will be created, and finally programs the site to fulfil this vision (Chow 2005, 54).

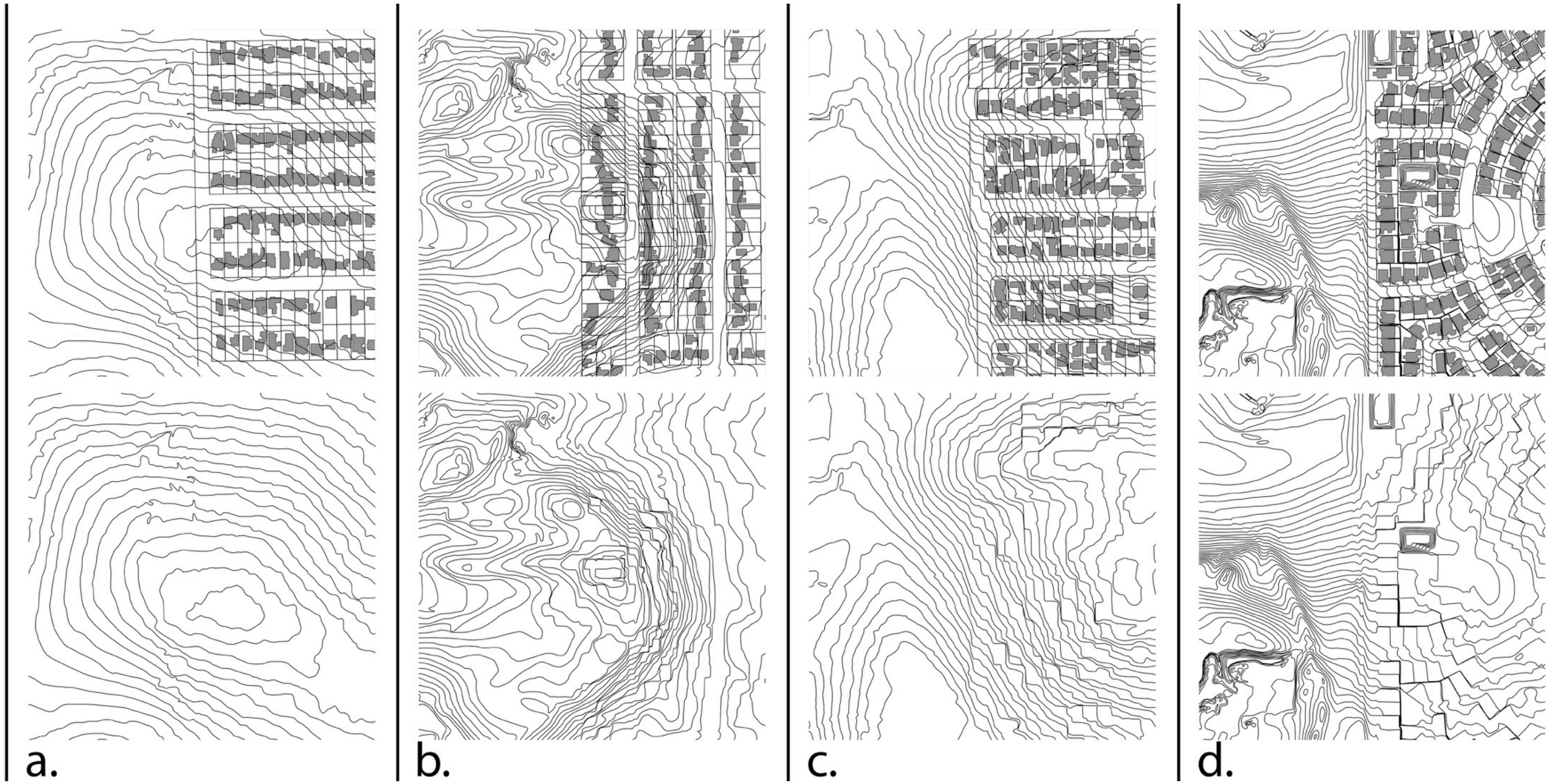


Figure 10. 500m (1640 ft) square samples of four suburbs with adjacent unmodified landform covering the left portion of each plot. Top row includes topographic, cadastral, and building footprint data. The topographic signature for each square is isolated on the bottom row:

(a) 1940s development (Nedlands) showing underlying landform virtually unmodified.
(b) 1950s development (Mt Claremont) showing some calibration of building footprint within lots on steepest slopes.
(c) 1970s development (North Beach) with some infill development underway showing moderate contour modification.
(d) 2000s development (Kinross) showing total substitution of indigenous landform with artificial terracing.

In the process, standardizing assumptions drive the design of model homes, with each assumption increasing the specificity of spaces for prescribed activities. The placeless, universal nature of this process results in structures that are conceived from the inside out with indifference to the setting. While such inflexible, standardized units may suit the mass-manufacture and marketing of consumer products, this process is less sensitive when applied to the uniqueness and variability of different landscapes. As the architectural historian Reyner Banham (1971, 85) observed, the economics of a tract home "imply a flat building surface, not a sloping one; and those economics are demanding enough to ensure that the site will be a flat one by some means or other."

Reasons for conserving topographic form

The geographer and historian George Seddon (1979, 69) viewed suburban benching as a flawed practice, advising planners and designers to avoid destroying the existing landscape by "studying the landform and building in sympathy with it." Looking beyond the nostalgia for the lost natural landscape that permeated Seddon's writing, this section discusses four key biophysical and psychological benefits of maintaining the original ground that is otherwise erased through the process of levelling steep sites for suburban development.

1. Remnant vegetation

Retaining vegetation in the suburban context has been demonstrated to be an important source of faunal habitat, floral biodiversity, and human amenity (Cary and Williams 2000). The process of shifting, removing, and adding new soil necessitates the elimination of existing vegetation, which is typically highly sensitive to even minor degrees of root disturbance (Figure 11). Consequently, newer benched developments typically exhibit greatly reduced occurrences of remnant pre-existing vegetation when compared with older suburbs. In Perth for example, Tuart trees (*Eucalyptus gomphocephala*) are endemic to the narrow coastal belt of sand dune and sub-coastal plains that significantly overlap with the greater metropolitan area.

Figure 11. Example of limited extent of retained indigenous vegetation as a result of land modelling in preparation for a suburban development in southern Perth.

With only 5% of the original distribution remaining, a significant proportion of extant mature Tuart occur in private residential lots within older suburbs (Beard and Sprenger 1984). In the newer benched suburbs situated at the northern and southern extents of the city, the distribution of mature Tuarts has been extensively reduced because of the earthwork process, with remnant trees typically limited to occasional local parks and road shoulders.

In addition to the highly visible upper canopy of large trees, remnant vegetation typically includes understory vegetation. In settings that comprise low oak woodlands (western slopes of hills in the Bay Area), coastal heath (Southern California and Western Australia), and native grasslands (Melbourne, Australia), retaining indigenous vegetation is problematic given the incompatibility between these vegetation associations and suburban housing. Unlike the McHargian ideal of low density residential co-existing with wooded slopes of taller trees, understory vegetation is highly susceptible to fragmentation and degradation in the suburban context (Williams et al. 2005; Noss 1995). By maintaining the original topography in the suburban development process, the potential for disturbance or elimination of existing flora is reduced.

2. Continuity of natural soil processes

The substrata of natural landforms undergo processes of leaching and sorting over geological timeframes. In contrast, the artificially reformed soil associated with suburban benching is un-stratified. This has ramifications for many soil-specific criteria, including stability, soil-fertility, and ground water quality (Rokich et al. 2001). Moreover, the upper strata of organic soil matter can be extremely old and can act like an ice core sample as a historical litmus, providing a window into past conditions that may recur or impact the present, including fire regimes and climate change (Grose 2010). Once this topographic history is disturbed or eliminated during the bulk earth re-grading process, the micro-ecologies within endemic soil-strata cannot be easily repatriated. The expedient solution to this loss of biotic material has been to import processed fertilizers and organic matter that are often unsuited to indigenous flora, but readily support exotic garden species.

This new implanted suburban ecology has consequences for surface and subsurface hydrology, which can become eutrophied due to increased nutrient loads derived from heavily fertilized gardens flushed with irrigation systems (Mallin et al. 2006). To be certain, older suburbs without disturbed topographies are also prone to nutrient leaching from exotic gardens. The difference in newer benched suburbs is that there is little alternative to implanted artificial garden ecologies, since no vestiges of the endemic, self-supporting soil and vegetation typically remain (see Hogan 2003). Maintaining landform in the suburban development process allows endemic soil profiles to be retained along with myriad environmental and historical benefits.

3. The phenomenological value of 'rough' landform

The complexity and variation typically inherent in natural terrain bears innate value in terms of how humans physically, psychologically, and creatively interact with their environment. Drawing on the philosophies of Martin Heidegger, the sociologist Richard Sennett (1998, 20) extensively explored this phenomenon, observing that physical contact with the "roughness, hardness and difficulty" of the environment has meaningful value, since creative expression is most likely to occur in rough terrain. By contrast, the smooth, flat surfaces associated with many urban situations reduce the inherent roughness and resistance of the landscape. In modern cities, the creation of smoothness has been viewed as essential to the articulation of everyday urban life (Cache 1995, 26). While smoothness provides clear practical advantages in cities, rarefied surfaces also inadvertently reduce the phenomenological connection between the body and its environment. As Paul Carter (1993, 91) notes, the erasure of "ups and downs" in cities causes movement to be similarly "flat, droning, listless." Consequently, when traversing artificially flat environments, pedestrians are vulnerable to small aberrations in the ground preying on their inattentiveness (Tuan 1974). The tendency to trip on small cracks in otherwise flat pavements is symptomatic of this phenomenon.

By rarefying the rough nuances of the natural terrain into flat planes and vertical walls, the artificial ground of suburban benching also contributes to this diminished phenomenological connection between mind, body, and ground. While this disconnection is unlikely to have a catastrophic impact on the fabric of urban life, over time it may weaken the sense of meaning that people invest into particular places (Cache 1995, 152). Conversely, maintaining a greater sense of the original topography in suburban development potentially enables the creation of more meaningful and expressive urban environments. For example, the affinity that many people hold for medieval hill towns is partially a response to the intimate reciprocity between the urban form and rugged site.

4. The orientating value of topography

Underlying topography has a profound influence on how urban dwellers cognitively map and orientate in their environment. Kevin Lynch (1960, 96–97) observed the importance of landform in shaping the legibility of the urban environment. Lynch noted that when navigating the city, people cognitively endow their route with a sense of directional differentiation, for which gradient or slope is an important underlying influence. This topographical gradient is inbuilt in certain types of natural terrain. For example, in a dendritic landscape—as characterised by the branching creeks and rivers in the San Francisco Bay Area—following the converging waterways downhill leads to a major river, estuary, or coast, which in turn is likely to facilitate transport networks and urban density. Conversely, in an endorheic landscape—as characterized in the convex and concave wind-formed sand terrain of Perth—a downhill journey will lead into a topographic hollow that is likely to contain a park or other public reserve associated with a wetland or local storm-water detention basin. In this context, an alternative navigational strategy is required, with a journey that involves moving between hilltops more likely to be navigationally useful than following waterways downhill.

Artificially constructed suburban benching that smothers the indigenous terrain structure diminishes the visibility of the underlying site-specific topographical gradients. This in turn eliminates the readymade topographical basis for orientation that Lynch identified as so important to effective and fulfilling navigation in the urban environment. To be certain, while a visitor is unlikely to become completely lost in suburbia given the pervasiveness of signage and other navigational clues, Lynch demonstrated that even persistent minor disorientations could have a destabilizing effect on a person's individual cognitive map (Lynch 1960, 5). Maintaining greater evidence of natural topographic gradients in suburban projects potentially enables a higher degree of intuitive orientation that is less reliant on augmentation with signage and electronic navigational devices.

Potential mechanisms for maintaining topographical form

Suburban morphology comprises three essential components that simultaneously operate at distinct and interlinked scales: (1) buildings, (2) lot parcels, and (3) urban layout. Using these three scales to frame discussion, this section establishes initial operating parameters for re-envisioning suburban design in more topographically responsive terms.

1. Building technology and typology

Individual houses form the building blocks of suburban structure. Decisions made in individual dwellings are repeated *en mass* and reverberate throughout the overall structure of the suburb. Consequently, building technology and typology form essential components of topographically responsive approaches to suburban design. In the early twentieth century up until WWII, various permutations of the Californian Bungalow were prevalent in both California and Australia (Lancaster 1995; Butler 1992). Suspended timber floors raised a few steps above exterior ground level typify this housing typology. Following the rationalist success of mass-production in Levittown, slab-on-ground construction began to replace timber floors in the post war era (Monteyne 2004).

In the decades that followed, slab-based construction became the dominant housing foundation in both California and Western Australia, albeit with differing structures above the slab. In California, standard building methods comprise mostly double story, timber-frame on concrete-slab construction, with rendered chipboard exteriors. From an international perspective, Western Australia is more unique, with standard building methods comprising mostly single story, load-bearing double clay-brick cavity walls on concrete-slab construction. Despite these differences in height and building methods, establishing the slab determines the site-works in both cases, with cost-sensitive contractors mandating a flat layout area larger than the final footprint of the house. As a result, the pervasive use of the concrete pad and its construction contingencies contribute significantly to the practice of suburban benching.

Running in parallel to the popular legacy of the 'grounded' California Bungalow and its post-war derivatives is the alternate architectural vision of buildings on framed sub-structures that seek to 'touch the ground lightly.' By avoiding remodelling the ground plane, this ethos tacitly avoids disturbing the ecological and/or spiritual sacredness attributed to the earth. To be sure, levitating as a means of leaving the lay-of-the-land intact was a core tenet—and later core criticism—of modern urbanism. Additionally, touching the ground lightly has been questioned from a landscape design point of view. In an influential textbook Norman Booth (1983, 65) defines the "level terraced site" as the landform "that makes a building appear stable and most strongly connected to the site." In contrast, buildings appear the "least stable and comfortable when located on sloped sites." Done without care, placing buildings on sloped sites readily devolves into what Banham (1971, 86) lamented as the ill-conceived perching of "standard developer's tract-homes [...] in mid-air on steel uprights."

These caveats notwithstanding, regional modernist movements operating at the residential scale have produced significant legacies of site-sensitive structures designed in tune with the landform. From the late 1930s, proponents of the California modernist school created numerous houses that used appropriate lightweight construction, and careful layout and positioning to harmonize with their steep sites. Extant examples by Harwell Hamilton Harris and Vernon de Mars in the Berkeley Hills epitomize this school of thought (see Serraino 2006). In the 1970s and 80s in Australia, a locally adapted modern 'bush vernacular' that also valued sensitivity toward the site emerged in the work of architects Richard Leplastrier, Glenn Murcutt, Peter Stutchbury and others (Paolella and Quattrone 2008).

Although many of these regionally adapted examples hold potential lessons for everyday suburban design, they have tended to remain bespoke residences for privileged clients on generously proportioned lots. In this regard, forging affordable templates for everyday suburban design is a more encompassing undertaking than the refinement or revolution of building technology and design. Given the complex interwoven economy of skills, supplies and real-estate norms that have accrued over time around a particular mode of construction, viable alternatives must confront the hegemony of entrenched perceptions and practices. Without such a comprehensive approach, the best architectural intentions and innovations in site-sensitive building design will remain exclusive experiments with little impact on the industry of levelling landscapes for suburbia.

2. Diversity of lot sizes and housing types

The preference for uniformity and repetition in subdividing land was originally perfected by the Romans through *centuriation*, rediscovered in the Enlightenment and later refined by the modern professions of surveying and cartography (see Romano 2003; Rykwert 1976). When parcelling off land, the equal division of lots suited the Cartesian idea of space as inert and uniform and accommodated emerging societal ideals of equality. These ideals were most vividly registered in the 1-mile (1.6km) Jeffersonian grid that parcelled out farmland and town-sites with remarkable consistency across the American Mid-West and West (Corner and MacLean 1996). In the design of neighbourhoods, uniformity was also embraced with historical consistency, with eighteenth century row-housing, high-density modern towers, and traditional urbanism all privileging consistency over diversity. Additionally, the suburban plans that resulted from McHargian land-suitability analysis tended to be conceived as monolithic blocks, with blanket residential densities and typologies tied to general landscape conditions (see McHarg 1969). Indeed, across the many incarnations of urbanism throughout Modernity, to lack uniformity has been viewed as devolution into the randomness of medieval village morphology. In the present day, irregular urban form is predominantly viewed as the purview of nostalgic theme parks and counter-culture communes (see Sorkin 1992).

Urban uniformity was further entrenched with the advent of exclusive land-use zoning in the early twentieth century (Kaiser and Godschalk 1995). By consolidating similar uses together, land-use zoning reduced the likelihood of incompatible adjacencies. Density zoning further subcategorized residential land-use into areas of equivalently sized lots and dwellings. Although enabling suburban communities to appear egalitarian, rigid single-density zoning has been extensively critiqued for lack of diversity, both in terms of cultural interaction and the provision of varied housing options (Ellin 2006). Additionally, orthodox zoning practices have a particularly mixed legacy on topographical sites. While single-density older suburbs were often porous enough to allow the landform to be left largely intact, the inflexibility of single-density zoning increases with the more compact morphologies of large houses on small lots that typify contemporary suburban developments. In these instances, the disjunction between rigidly constrained lot sizes and dwelling types, and the variability of the underlying topography, is manifested as retaining walls and embankments between lots. Even in instances where housing types are not explicitly defined, designated lot widths and building setback distances from the street often implicitly prescribe the construction of standardized suburban housing typologies.

In the latter twentieth century, the alternatives of *performance-based zoning* (sets performance objectives rather than land-use restrictions) and *form-based code* (prescribes building locations and form) emerged as more place-specific mechanisms for establishing appropriate function and form (Ellin 2006). The flexibility inherent in these models provides a precedent for establishing topographically variable approaches to designating suitable land-use densities. Such an approach potentially involves calibrating lot sizes and housing typologies to existing terrain variations. In contrast with the fixed single-zone approach, topographic zoning involves establishing a diversity of lot sizes and housing typologies at the local scale. A potential drawback of variable density is the likely reduction in streetscape uniformity; overcoming this fundamental urban principle of consistency and repetition presents a significant challenge. Moreover, the variable model also confronts the entrenched industry of standardized homes and real-estate norms that resist customisation or uniqueness for fear of over- or under-capitalizing a property.

Nevertheless, a persuasive demographic rationale counters these ingrained practices. Adhering to the uniform application of standardized five-bedroom-by-three-bathroom homes on 5,000 sq ft (460m^2) lots fails to accommodate increasingly divergent living arrangements in both US and Australian populations. For example, in Australia, persons living alone presently account for around 25% of all households, with this number projected to increase to 30% within 20 years (ABS 2010). Consequently, in the suburbs, a lack of living options between the extremes of large single family-homes and apartment blocks represents a significant issue for those whose household size does not fit the typical suburban profile (Wuff et al. 2004). To address this void, it has been argued that the development industry must diversify beyond the small number of standardized real estate product types (Leinberger 2005). The variable density model potentially facilitates this diversification. As illustrated in a design experiment in Perth, a hypothetical example includes a four-bedroom freestanding house adjacent to a single bedroom studio unit, which in turn is sited alongside a pair of two-bedroom terraces (Figure 12). In this experiment, higher densities are tied to steeper slopes in order to form smaller terraces that reduce the height (but not necessarily the extent) of site retaining walls.

3. Street and block layout

Historically, the identity of suburban developments resides largely with the plan-view layout of streets and blocks. Consequently, the age of a suburb can be deduced from the street layouts that typically reflect the dominant formal agenda of the era. Suburban layouts typically reflect concessions between the economics of yield (to maximize return on investment) and the principles of sound urban form that include connectivity, community, legibility, and access to transport, commerce, and public open space. In hilly areas these factors tend to be reduced to a compromise between maximizing available views for individual lots and negotiating the engineering of street grades, slope geo-technics, and sewage and storm-water infrastructure requirements.

In terms of aesthetic design criteria, the layouts of suburban developments on hilly sites are frequently loosely conflated with ecological outcomes. For example, streets that contour along slopes are commonly described as harmonizing with the natural landform, despite requiring more cut-and-fill earthworks than roads that climb up and over hilly terrain (see Booth 1983). Similarly, the politically charged field of visual impact assessment appropriated ecological language to reinforce the notion that higher density developments 'naturally' belong down-slope while lower densities belong up-slope. This assessment opposes the established architectural principle of building on high ground to accentuate—rather than neutralize—the underlying topography. Pseudo-ecological design doctrines—combined with contemporary engineering standards, the desire for views, and the economy of overall yield—continue to drive the formal agenda for suburban development on hilly sites.

Figure 12. Design experiment on undulating coastal terrain in the suburb of Ocean Reef (Perth) testing the objective of reducing retaining wall heights by tuning variable residential lot sizes to topography. Smaller lots are associated with steeper slopes. By Nicola Anastas in consultation with the author.

Developing suburban templates that are more topographically sensitive requires moving beyond such aesthetic assumptions. It also requires recalibration and inevitably some compromise between the often-contradictory objectives of good urban form, site engineering standards and associated infrastructure. As an example, present-day automobiles can negotiate steeper road grades with ease, which in turn potentially significantly shifts the overall layout parameters of a development. Pedestrian circulation may then be woven into secondary networks that align to more pedestrian friendly inclines. Moreover, the potential of such scenarios is inextricably tied to the suburban building-blocks of individual lot parcels and houses, and indeed innovations at those scales will have the most profound influence at the larger suburban layout scale.

Conclusion

Whereas many of the most topographically expressive world cities were laid out in deference to the strength of their underlying geomorphologies, the expansionary pressures facing many hilly cities reverse this relationship. Fuelled by demand and an apparent lack of options, suburban peripheral expansion increasingly encroaches into steep terrain. The standard twentieth century urban models of modern planning, ecological planning and traditional urban design exert negligible influence in this environment, where industrial earthmoving techniques continue to facilitate unmodified flat-land suburban morphologies irrespective of the site.

The result is highly engineered 'benched' landscapes of flat building pads and high retaining walls or embankments. The forces motivating this practice include the increasing rarity of flat land, the post-WWII increase in building footprints, the concurrent decrease in lot sizes, and shifts in construction technology, social expectations, and cultural habits. Despite levelling land being an ancient component of place making, performing this operation at the scale of an entire suburban development has profound effects on the biophysical and psychological environment. Negative consequences include loss of existing vegetation and soil profiles, as well as the phenomenological roughness and orienting features inherent in natural topography.

The contextual framework for re-envisioning topographically sensitive suburban design comprises three key scales: (1) buildings, (2) lots, and (3) overall layout. At the smallest scale, economically viable building technologies that work in deference to the underlying landform and provide convincing alternatives to standardized building industry products on concrete slabs are essential. At the largest scale, re-evaluation of priorities between the various elements of design, site engineering and real estate standards that influence the overall layout are required. In between, injecting demographically supported diversity into lot sizes and housing typologies potentially permits the development of more variable suburban morphologies.

With the aid of contemporary digital mapping and modelling techniques this variable morphology may be calibrated to the nuances of local topography. The trade-off of street-scale uniformity that has been such an enduring feature across the history of planned urbanism is a major hurdle for this kind of innovation. Consequently, the resultant urbanism will most likely not adhere to all the traditional criteria of urban design. Viewed through another lens, topographically calibrated urbanism may contribute to emergence of what has been referred to in the suburban context as "good scruffiness" (Gleeson 2006). Here, scruffiness may be understood as the physical manifestation of topographic complexity rather than an inconvenient truth to be engineered out.

While Seddon's (1990, 5) planning ideal of "surveying the site, orienting the proposed building in relation to the topography, keeping the trees, and maintaining the landform, rather than flattening it" may nostalgically reference the era of large lots and modestly sized homes, these objectives remain the key mechanisms for approaching topographically sensitive design. Actualizing these enduring criteria within the realities of the contemporary suburban context requires a holistic and trans-disciplinary approach that bridges the design, planning, construction technology, site engineering, ecology, and real-estate fields.

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