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Reconceptualizing Suburban Terracing

Topographically responsive development scenarios for a sandy coastal site

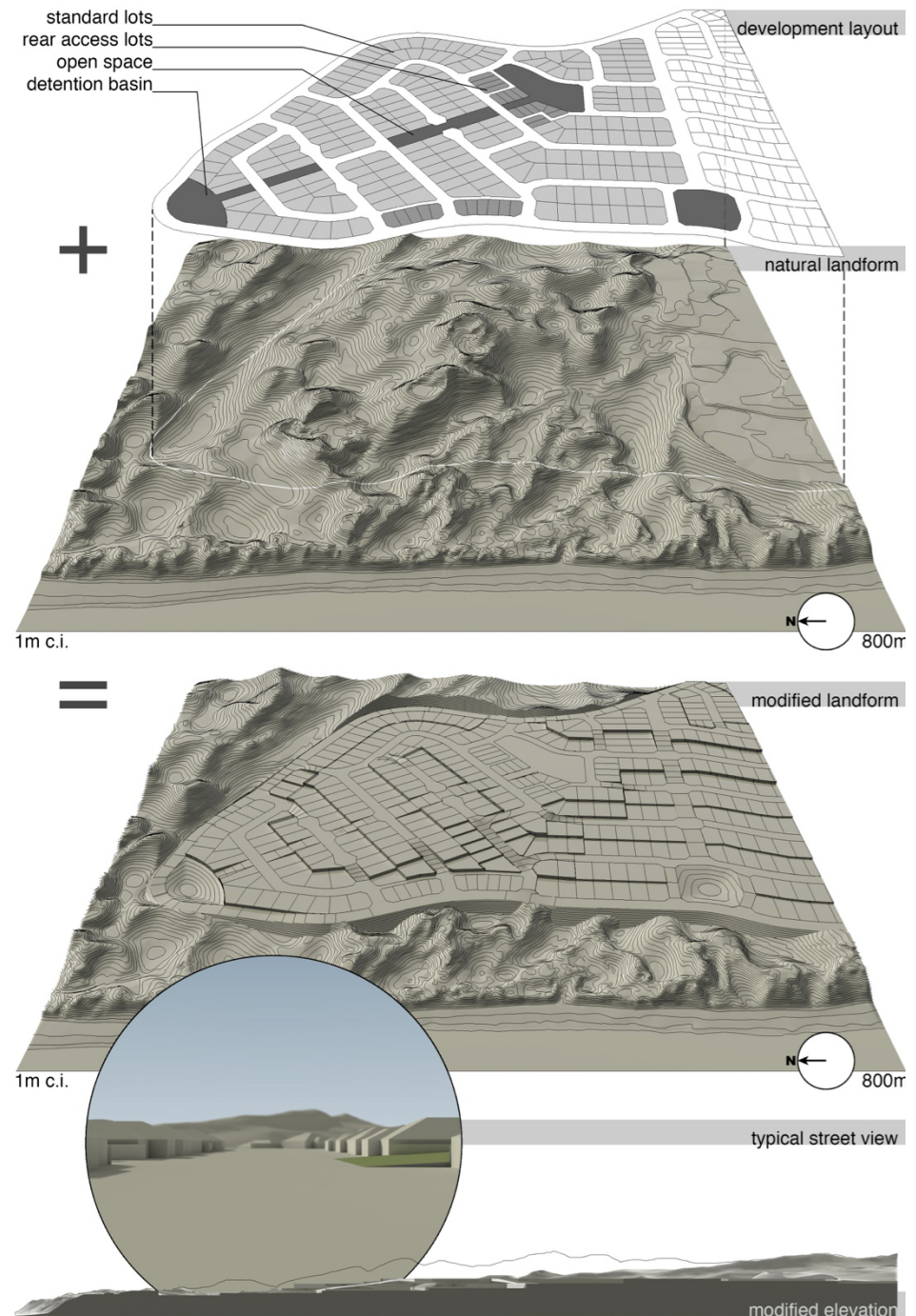
Karl Kullmann

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Introduction: suburban benching

Terraced site works first occurred in California in the 1950s in response to suburban expansion into mountainous areas. Referred to as “mountain cropping” (Bronson 1968, 35), the practice permitted standardized flatland suburban development models to be established irrespective of site conditions (Banham 1971). Following the influence of US suburban ideals and practices, large-scale earth works began to emerge in Australian suburban development in the 1970s.

In Western Australia in particular, mining-scaled earthmoving processes enabled steep coastal sand dune terrain to be readily remodeled to facilitate rapid suburban sprawl. By the mid 1980s, site preparation had evolved to the total re-engineering of natural topography into suburb-scaled systems of level lots retained with limestone block walls. Termed *benching* in the local industry, the practice offers numerous performance advantages over older suburbs subdivided with limited reshaping of the natural terrain. These include the ability to develop steep sites with increased lot densities, larger house footprints, standardized construction techniques, and improved flow between indoor and outdoor entertainment areas.



Additional performance benefits associated with earthworks include more efficient and cost-effective sewerage and storm-water systems, standardized road grades, simplified street layout design, and the capacity to maximize valuable views from each lot (Kullmann 2014a).

While leveling land is integral to the history of human inhabitation (Leatherbarrow 2004; Rykwert 1976), and is convenient for the development industry, the expansive scale of benching in the suburban context produces numerous negative biophysical and experiential consequences. The process of bulk earthworks necessitates removing all native vegetation, which eliminates significant sources of habitat, biodiversity, and human amenity in the suburban environment (Cary and Williams 2000). Moreover, once established soil-strata are disturbed or eliminated, micro-ecologies cannot be readily reconstructed, which has ramifications for soil stability, fertility, and ground water quality (Grose 2010a).

From an experiential perspective, landform is a significant feature of landscape character, which in turn is fundamental to spatial navigation, perception, and place making (Tuan 1974). Terrain exerts substantial agency over the legibility of urban environments, whereby “topographic gradients” (slope) are fundamental to the formation of directional differentiation (Lynch 1960, 96). Where large-scale suburban benching substitutes natural terrain with an artificially re-engineered topographic system, topographic gradients are likely to be obscured. Moreover, suburban benching potentially undermines how residents physically, psychologically, and creatively interface with their environment. Corporeal interaction with complex and variable landscapes acts as a vital catalyst of creative expression, which enhances the establishment of place making (Sennett 1998).

In response to the negative impacts of large-scale earthworks, Western Australian planning policies adopted in the 2000s aim to minimize the impact of benching while simultaneously mandating improvements to a range of standard urban design performance criteria¹ (WAPC 2004a; WAPC 2004b; WAPC 2002). In practice, the



Figure 1. Northern Perth suburb of Jindalee illustrating retaining walls up to 20ft high (© 2012 Google).

two objectives appear incongruent, whereby the application of urban design principles developed in Europe and the US coincides with higher retaining walls in the most recent coastal suburban developments (Kullmann 2014b) (figure 1).

Research Scope: Enhanced Topographic Expression in Suburban Development

Given the apparent incongruity between local terrain and unmodified urban design models imported from abroad, the article tests mechanisms for improving the conservation and expression of natural topography in current coastal suburban development. This objective is explored through design scenarios for a greenfield subdivision development site on the northern periphery of Western Australia’s capital city of Perth.

To be certain, a substantial body of international literature identifies both the vulnerability of coastal landscapes and the environmentally, socially, and economically unsustainable nature of unconstrained

suburban expansion (See Bruegmann 2006). For this reason, Perth's coastal sprawl—which has been officially sanctioned for nearly half a century (MRPA 1970)—will ideally be slowed or stopped. Towards this goal, Government policy of the past decade has sought to limit sprawl through higher densities in new development and transit-oriented densification in older inner-city suburbs (WAPC 2004a; WAPC 2004b). Nevertheless, strong community opposition to coastal high-rise development continues to limit the efficacy of densification policy, with coastal sprawl continuing to expand at a rate of approximately half a mile per year (WAPC 2013). Therefore, the article takes the position that concurrent to improving the effectiveness of urban densification strategies, the ongoing improvement of current design and planning practices in greenfield subdivisions remains valuable for the foreseeable future (See Gleeson 2006).

Although the practice and morphology of suburban benching—along with most of the research on the topic of suburbanization—originates in the US, the Australian context differs in several key aspects. First, suburban growth in Australia is more centrally controlled at the state level than in the US, where planning decisions with regional impact are typically generated at the county, city or even community level (Troy 1996; Gleeson 2006). State government oversight results in a planning process that benefits from consistency across jurisdictions, but conversely is potentially less reactive to local conditions and issues than in the US. Second, undulating coastal landform in Australia tends to be less bimodal than the geomorphology of the Western US (where benching originated), which is typified by distinct demarcations between flatlands and rugged mountain chains. Where competent regional planning potentially restricts development in steep zones, this well-defined topographic/residential demarcation is not as evident in continuously undulating terrain. And third, whereas topographic elevation strongly influences property values and socio-economic patterns in the US, proximity to the ocean is typically more influential over property values in Australia (Fraser and Spencer 1998).

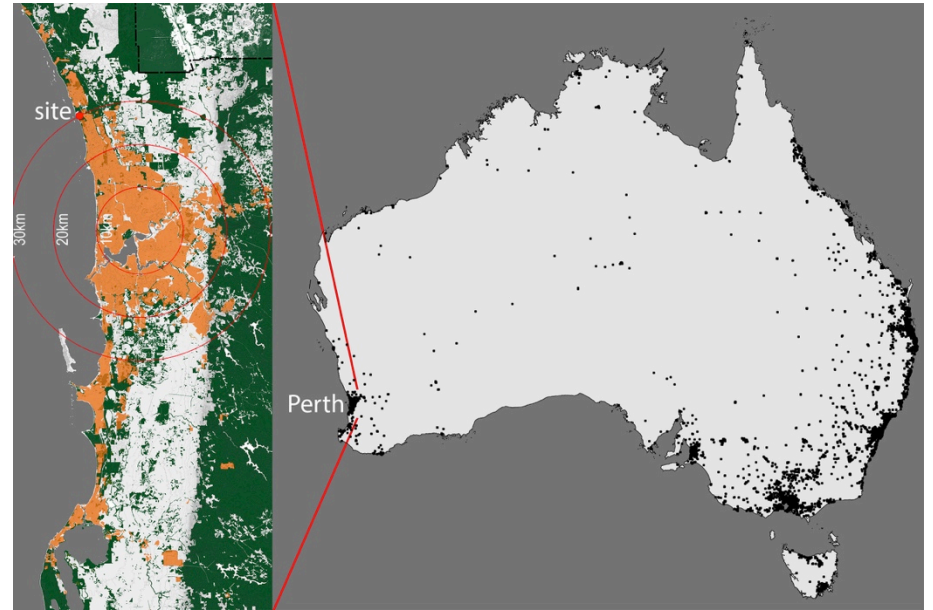


Figure 2. Location of the Burns Beach study site in the context of Australia and Perth (orange = metropolitan area, green = indigenous vegetation). Coastal settlements patterns are evident in the map of Australia (each dot represents 500 people).

Design Study Site: Burns Beach Northern Residential Precinct

Originally platted in the 1920s as an isolated coastal settlement 19-miles north of Perth, metropolitan suburban sprawl leapfrogged Burns Beach in the 1990s (figure 2). Since 2005, coastal heathland immediately to the north of the original settlement has undergone phased development for suburban housing. As is typical of current practices along the Perth coastal plain, development necessitates the complete clearing of virgin heathland and installation of large-scale earthwork benching prior to the sale of individual lots.

Designated as the Northern Residential Precinct (NRP), the final phase of the Burns Beach development is planned for a particularly steep area of stable secondary dunes (figure 3). The topography of the 62-acre site is generally characterized by a diagonal ridgeline that separates lower areas in the southwest corner from the highest points in the northeast. Aeolian depressions and knolls are dispersed



Figure 3. Burns Beach with the Northern Residential Precinct (NRP) development site demarcated in red. Areas of exposed white and yellow sand are undergoing development (© 2012 Daryl Jones).

complexly throughout the site, with slopes on the steepest sand formations reaching the natural angle of repose of 73%. Although the impact of uncontrolled recreational off-road vehicles results in some dune degradation, the indigenous coastal heath and grasses remain mostly intact ahead of the forthcoming development (author's field survey, July 2014).

Development Framework: Aspirational Guidelines Versus Entrenched Practices

The Adopted Structure Plan for the NRP acknowledges the extremely steep topography of the location. As directed by state government planning policy, the key development objective is defined as providing "quality residential outcomes" whilst "retaining the general landform of the site" (CoJ 2007, 27). To retain the general landform while providing residential lots "developed upon a standard manner," the Structure Plan states the need for retaining walls that "stabilize" and "retain the general slope and height of the 'original' landform" (CoJ

2007, 27). To achieve this compromise, development is to be benched up to the natural high point in the center of the site. To minimize visual impact from the street, retaining walls are capped at 13ft high, and are limited to the rear boundaries of lots (CoJ 2007).

The Adopted Design layout for the NRP claims to spatialize these objectives. The layout is structured around a narrow linear park that forms an axis between the highest point in the center of the site and a low point in the northwest corner of the site that is used for storm water detention (figure 4). Streets running perpendicular to this spine establish a stepped sequence of benches with equal distribution of ocean views. In the southern portion of the site, the residential streets rotate parallel to the coast to match the street grid established in earlier phases of the Burns Beach development.

In practice, this structure accommodates a subdivision layout typical of recent development in Perth's northern suburbs. The 233 conventional street access suburban lots fall within a narrow size range of between 5,920ft² and 8,070ft², for an average of 6,940ft². When combined with the 27 smaller rear access lots of around 3,770ft², the 260 lots range 210% in size. All lots average 6,670ft² to achieve an overall net density of 6.5 dwelling units per acre (du/ac) and gross density of 4du/ac including road reserves and parks. Based on dwelling footprints in the initial phases of the Burns Beach development, houses in the NRP are assumed to average 3,880ft² on street access lots, and 2,690ft² on rear access lots. When dwelling footprints are expressed as a percentage of lot area, site coverage averages out at 55% for the conventional lots and 70% for the compact rear-access lots.

Three-dimensional modeling demonstrates that the 48,980,000ft³ of re-grading required to support the Adopted Design heavily modifies the original terrain (figure 4). In the most general sense, the plan retains the higher and lower areas of the site, which represents advancement over nearby contemporaneous developments where entire fore-dune systems have been completely leveled for suburban

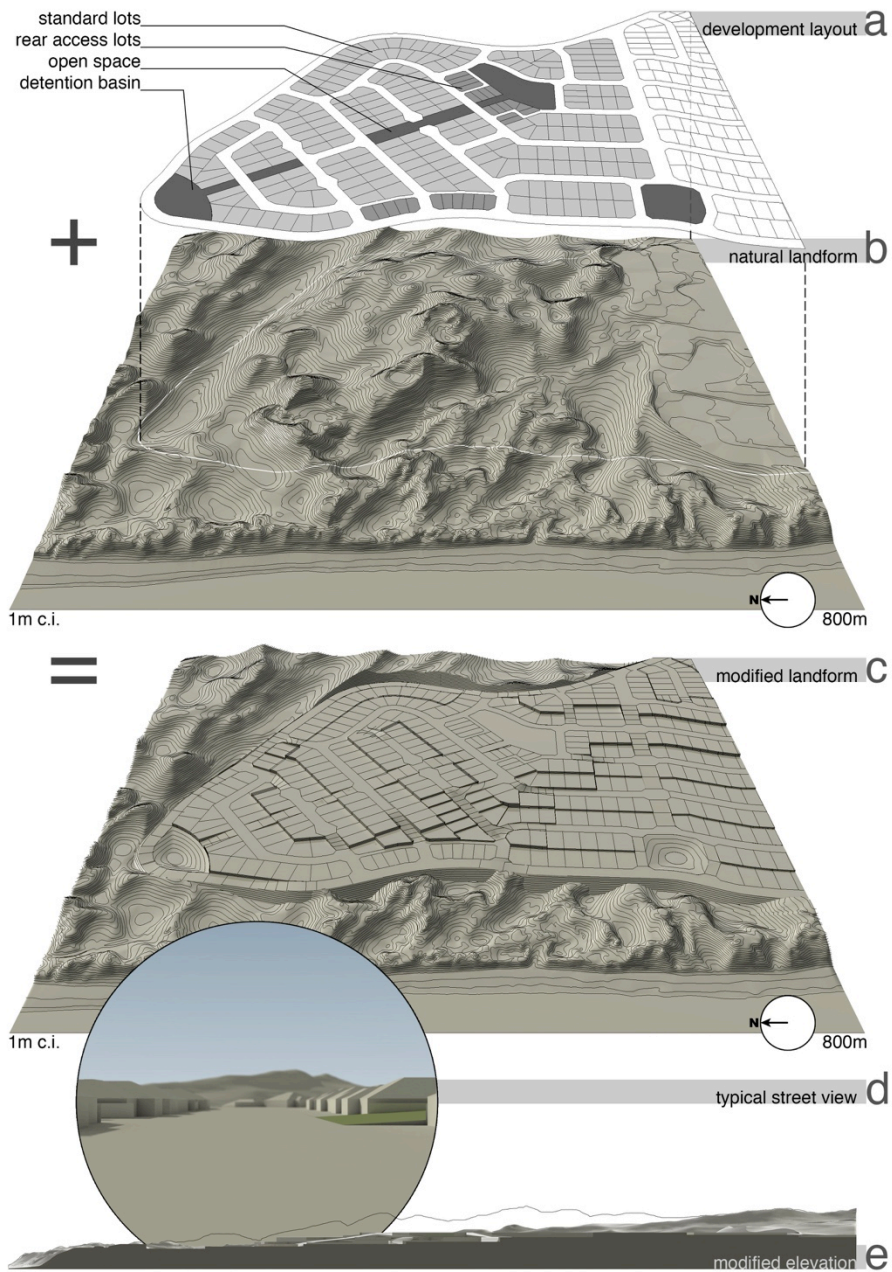


Figure 4. 3D model of the NRP Adopted Design, placed above a 3D mesh of the site's natural topography.



Figure 5. Northern Perth suburb of Alkimos, illustrating the elimination of retaining walls through the total leveling of sand dune topography. The dunes visible in the background originally covered the entire site (author 2014).

development (figure 5). Nevertheless, the restrictive system of benching eliminates all indication of the topographic nuances in between the highest and lowest points. This result indicates that coastal sand dune terrain is too complex and intricate to be retained under the conventional development model.

To conserve more of the natural shape of the terrain, the developers claim to have considered alternatives to benching with retaining walls on lot boundaries. They conclude, however, that these unspecified alternative design and construction practices require lot sizes to be significantly larger than the compact lots that government policies presently mandate with the aim of limiting suburban sprawl (See WAPC 2004a; WAPC 2004b). The developers argue that the provision of very large lots "to accommodate level rises without ... retaining walls" would lower residential yields and as such "directly conflicts with government sustainability objectives" (CoJ 2007, 31).

Topography and Urbanism: International and Australian Perspectives

Reconciling the apparently divergent objectives of economically viable urban densities and topographic conservation is problematized by the politicized, impassive, or nostalgic nature of relevant critiques, models, and precedents. Although the earliest examples of suburban benching in the US were critiqued for perpetuating the environmental destruction typical of industrialized society (See Banham 1971; Bronson 1968; Blake 1964), the practice has more recently been aestheticized from the air as type of infrastructural land art (See Light 2015; Corner and MacLean 1996).

Limited explicit integration of topography into key contemporary urban models exacerbates the problematic relationship between urban/suburban development and landform in practice. As a defining model of twentieth century urbanism, *modern urbanism* consolidates the city into towers floating above the terrain that flows unhindered beneath and between buildings (Vogt 2000). Although sound in theory, when realized on a large scale in post-war reconstruction in Europe and urban renewal in the US, decoupling urbanism from the ground unintentionally diminished stewardship of the landscape (Ingersoll 2006). As a result, the pastoral ideal that characterises modernism regularly deteriorated into automobile dominated wastelands (Sennett 1990; Jacobs 1961).

Ecological planning addresses this deficiency by integrating topography into the planning of residential density and distribution at the regional scale (See McHarg 1969). Although the suitability-analysis techniques of ecological planning successfully repelled developments and lowered residential densities on steeper terrain, the commercial returns from developing desirable locations often outweigh this reasoning. Moreover, suitability analysis has been criticized for actually accelerating sprawl by dispersing suburban development (Hill 1992).

Taking a more compact approach to cities, *traditional urbanism* systematically positions topography as a scenic rural/natural backdrop

or as a parkland landmark within the urban zone. As the widely adopted Rural-Urban Transect illustrates, framing landform in this way is most relevant to cities sited on flat river floodplains and deltas (See Duany 2002). By contrast, expanding coastal cities often exhibit a far more complex interaction of topography and suburbanization (Bosselmann 2011).

In the Australian context, numerous architects continue to pursue the modernist ideal of 'touching the earth lightly' at the lot scale through topographically sensitive design (See Paoletta and Quattrone 2008). Although providing compelling architectural solutions, these prototypes generally remain as isolated projects for privileged clients on spacious peri-urban lots with limited application to the mass-suburban context. Current literature directly addressing suburban benching in Australia is limited to incidental negative discussion in botanical and ecological studies (See Williams et al. 2005; Rokich et al. 2001).

As such, the most sustained critique of topographic modification in suburban development remains the work of George Seddon (1979; 1990), who criticized the earliest examples of suburban benching for extinguishing the character associated with the nuances of natural topography. As a public figure and internationally significant multidisciplinary scholar of the humanities, sciences, planning and landscape architecture, Seddon synthesized typically disconnected biophysical and cultural perspectives on the environment. From this position, Seddon advised planners and designers to build sympathetically with the natural landform, and used suburbs platted prior to the 1960s as examples to be emulated in good practice.

The Evolution of Suburban Development Standards

Although the older coastal suburbs that Seddon references are indeed characterized by limited modification of the natural topography, their development standards differ markedly from present day standards. Comparison of the NRP with the 1950s Perth coastal 'garden suburb' of City Beach illuminates these distinctions. First, the landforms underpinning the two subdivisions are dissimilar. Whereas City Beach

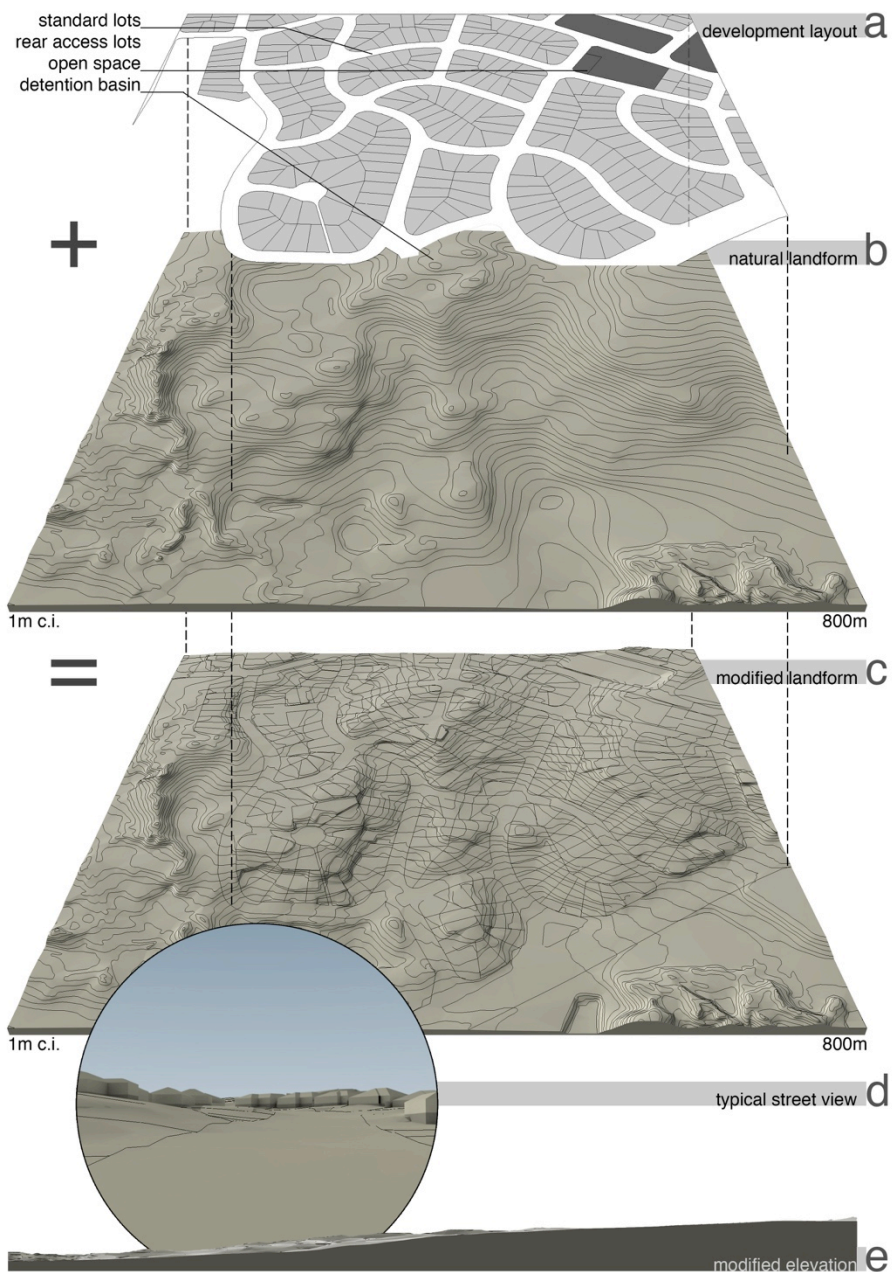


Figure 6. 3D model of the 1950s Perth coastal suburb of City Beach, illustrating low degree of modification between original and current topography.

is sited on undulating terrain with the steepest landforms set-aside as bushland reserves (figure 6), the NRP is sited on steep fore-dunes that will be fully developed (figure 4). Second, planning metrics between the two suburbs are divergent. Lots at City Beach are on average 60% larger and 20% more diverse in size than those at the NRP. Furthermore, site coverage at the NRP is up to ten times higher than City Beach, which equates to three times more un-built space in the older suburb with which to accommodate changes in topography. And third, infrastructural performance differs markedly; while the NRP is optimized for efficient gravity-fed storm water and sewerage systems, City Beach remains dependent on outdated soak-wells and septic tanks. The natural depressions in the terrain complicate the retrofitting of modern infrastructure and necessitate expensive vacuum systems.

Since the 1950s, changing construction techniques also interacted with higher site coverage ratios to transform suburban development. In the first coastal settlements, shacks were constructed of wood frames set above the original landform on stilts. In affluent suburbs such as City Beach, double-brick construction with suspended wood floors predominated. Typically, this technique included a limestone foundational plinth that absorbed variations in topography with minimal disturbance of the original landform (figure 7). The widespread adoption of concrete slabs supplanted both building techniques in the 1960s. Cost efficiencies dictated that each slab came to be set on a level sand pad significantly larger than the footprint of the dwelling. By the 1980s, space limitations required that sand pads be retained with walls at the lot boundaries. Since the 1990s, site coverage ratios above 40% resulted in level sand pads filling out the entire lot (figure 8).



Figure 7. Circa 1950s houses set on limestone plinths that accommodate variations in topography without major earthworks (author 2015).

Design scenarios: alternative suburban layouts

Real world factors that drive current high lot densities and large dwelling footprints limit the applicability of alternative and historical suburban design practices. Although government policies, developer yield expectations, and owner lifestyle expectations are unlikely to shift significantly in the near term, other design factors remain more flexible. Here, scenarios are used to explore the potential for factors as diverse as suburban layouts, construction techniques, distribution of lot sizes and public open space to conserve natural landform at typical suburban densities. The scenario methodology permits equitable detailed comparison of the impacts of diverse planning approaches (Chakraborty et al. 2011).

Set on the NRP site, the five scenarios aim to maintain the total yield of the Adopted Design layout (260 dwellings) and are limited to locally accepted suburban densities of between 3 and 12 du/ac (for reasoning refer to Research Scope). These densities are manifested



Figure 8. Circa 2010s house set on sand pad that fills out the entire lot and is retained at the property boundaries (author 2014).

predominantly as fully detached, front access, single and double story houses with 20ft (car length) street setbacks. This standard template is augmented with medium-density fully detached, rear access, double story houses (and in one scenario with low-density front access bush-lots). Additionally, contiguity between suburban houses and their private outdoor spaces are maintained in this study. This contrasts with residential patterns common in Northern European cities where dwellings and private gardens are often located in different parts of the city.

As per the Adopted Design, each scenario interfaces with the existing street grid on the southern side and maintains the perimeter road with mandatory 600ft coastal setback. As government policy dictates, approximately 10% of the site is designated as public open space in each scenario, with open space retained in the northwestern corner of all scenarios for storm water detention. Where included in the

scenarios, retaining walls are capped at 13ft for consistency with the Adopted Design. 50ft road easements and 20ft laneway standards are also maintained. By contrast, whereas road grades in the Adopted Design and other contemporaneous suburban subdivisions rarely exceed 10%, maximum road grades for the scenarios are increased to 15%. This adjustment acknowledges that far steeper grades are incorporated into older coastal suburbs without significant reductions in usability.

The topographic expression of each scenario is evaluated using earthwork volumes and criteria drawn from the subjectivist framework for visual landform character analysis collated by Tveit, Ode and Fry (2006) and Ode, Tveit, and Fry (2008). This framework offers a range of criteria adaptable to the specific characteristics of the Perth northern coastal heathland environment, which include visual fragmentation, vulnerability to anthropomorphic disturbance and variation in topographic complexity. To apprehend these key characteristics, the following criteria were selected for their applicability to the morphology of the study site: (a) *imageability* (the contribution of landmarks and other topographic elements to a strong visual image); (b) *disturbance* (the deviation of topographic features from the original context); (c) *complexity* (the diversity and richness of topographic features). In addition to this visual framework, landform is also perceived and evaluated kinesthetically (through the body while in motion) (See Lynch, Appleyard and Meyer 1964).

Scenario 1. Adopted Layout with Earthworks Limited to Roads

Pre-1970s, Perth suburbs were established with minimal modification of the original landform prior the subdivision and sale of individual lots. Site works were generally limited to minor re-grading to accommodate street profiles and storm water detention sumps. Suburban lots were sold mostly vegetated, with site clearing the responsibility of individual landowners. This practice—combined with low site coverage ratios and low-impact dwelling construction techniques—resulted in significant retainment of original topography and native vegetation. The first scenario tests the historical practice of

limited earthworks at current densities and site coverage ratios. For comparison, the Adopted Design layout is retained in planform and superimposed over the original topography (figure 9). Earthworks are limited to localized cut and fill to accommodate street grades of up to 15%. With the provision of flat lots removed, each dwelling and associated private outdoor space negotiates topographic variations on site.

Urban performance. With 226 lots, the residential yield of this scenario is 15% lower than the identical Adopted Design layout with benching. This yield loss results from several factors. First, storm water detention basins displace lots situated on natural low points. This arrangement is common in suburbs constructed prior to the 1960s, and while improving local infiltration, creates less effective overall drainage infrastructure. Retaining the natural depressions also complicates modern sewerage infrastructure, with complex vacuum-sewerage systems required to counteract gravity. Second, additional yield loss results from lots rendered inaccessible and undevelopable due to a high proportion of slopes set near the steepest natural angle of repose of 70%. And third, road alignments originally designed for benching are not topographically optimized, resulting in cuts up to 40ft deep and encroaching up to 80ft into adjacent lots.

While numerous retained natural high points enable panoramic views from the highest lots, views are distributed less equally overall than in the Adopted Design. Vehicular permeability for this scenario is also slightly lower than in the Adopted Design as vehicular roadways are discontinued in several instances where road easements exceed the 15% grade limit. While pocket parks with staircases could potentially occupy the road reserve in these locations, vehicular access to adjacent lots remains impacted.

Topographic expression. The 8,300,000ft³ of earthworks required to accommodate the layout equates to 17% of earth movement volume of the Adopted Design. In comparison with the original landform, the

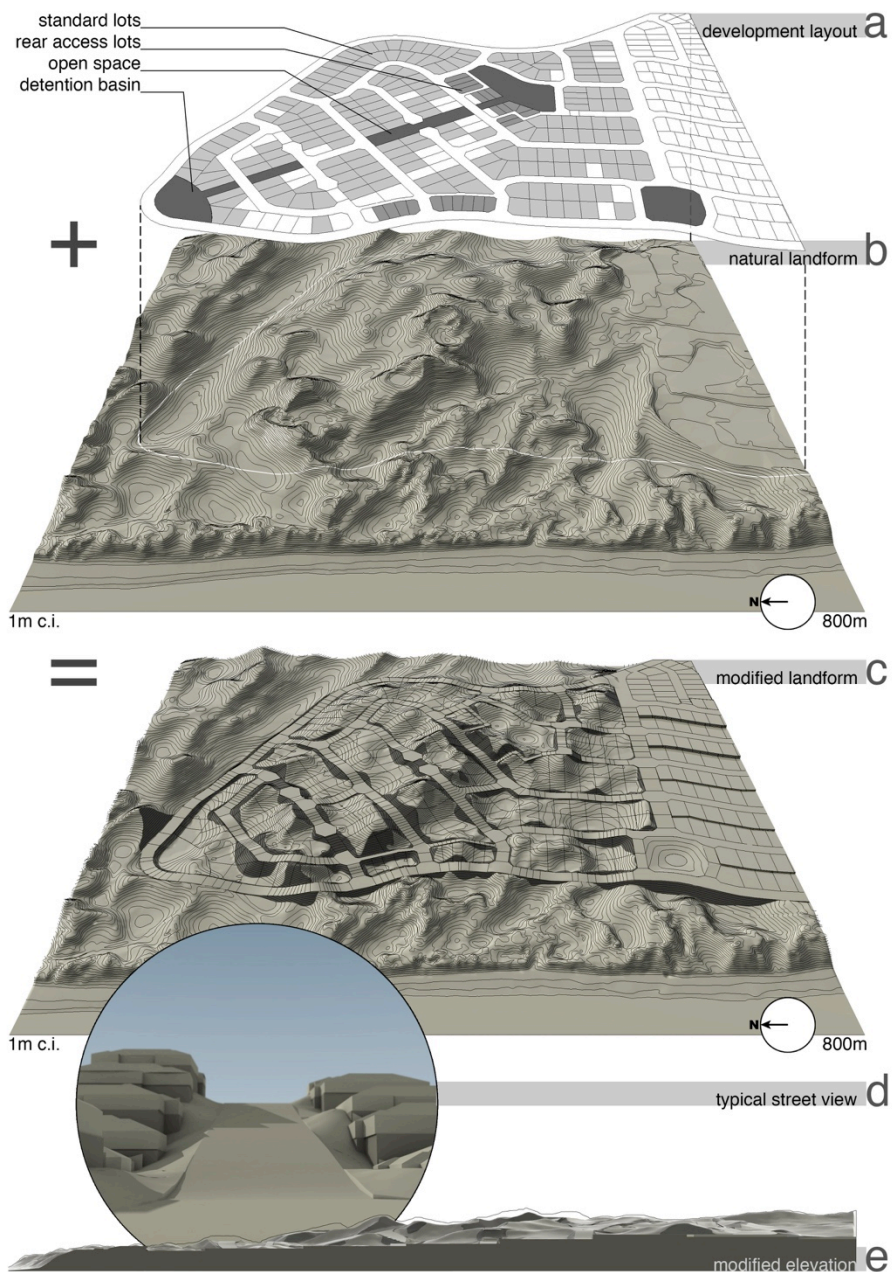


Figure 9. 3D model of scenario 1, illustrating the topographic impact of the Adopted Design with only minimal topographic modification to accommodate road profiles.

overall topographic imageability of the scenario is moderate. The road cuts dissect significant portions of the main ridgeline, which diminishes the legibility of the remaining landform from a distance. The road cuts also create a high degree of landform disturbance, although conserved fragments of complexity elsewhere in the development counterbalance this impact. Even though each dwelling covers more than half of each lot, enough of the natural landform is retained in front, behind and along the street to convey a coherent image of the original topography. Houses elevated on plinths or framed structures act as datums within the landscape that enhance that image. Furthermore, the physical barriers that discontinued streets create on the steepest slopes ensure that topography actively influences legibility and wayfinding in the suburb.

Design challenges. In contrast with floating wood floors typical in pre-1970s suburban housing, dwellings constructed on concrete slabs require substantial sand importation to backfill each plinth. Given that contemporary suburban houses are approximately 80ft long, the finished floor level of dwellings set on the steepest slopes of 70% are elevated up to 66ft above ground level. Typically, 3ft setbacks from the side property boundaries result in 7ft wide chasms between adjacent houses with little natural light or amenity. Moreover, private open space is likely to be set significantly higher than the finished floor level of the house, which complicates the indoor/outdoor flow that is typical of contemporary suburban homes.

To reduce excessively high plinths, houses may be partially excavated into sloping sites, and/or set over two or more split-levels. Challenges associated with these methods include increased complexity of the concrete slab and diminished internal accessibility due to level changes within the house. While substitution of brick on slab construction with lightweight framing methods eliminates bulky plinths, this construction technique does still impact the ground plane, with the space underneath the house typically devoid of sunlight and requiring artificial stabilization.

Scenario 2. Grid Layout with Partially Leveled and Split-Level Lots

Prior to the mid-century introduction of curvilinear layouts, Perth coastal suburbs were generally platted into east-west grids without regard to the local landform. Despite this apparent disjunction, many older gridded suburbs involved minimal topographic modification. Although low site coverage ratios were clearly a factor, the structure of the grid is also significant, whereby the repetitive geometry creates a set of parallel section lines that trace variations in the ground (figure 10). Following this historical precedent, the second scenario extends the existing parallel streets at the southern end of the NRP into a grid layout across the site (figure 11). Street grid intersections are set close to the natural contour and long streets are matched to the natural contour at three equidistant locations and smoothed to the maximum gradient of 15%. Each lot is benched using conventional retaining walls at the side and rear property boundaries but not at the front. In contrast to the Adopted Design, where lots are set to match the road level on both sides of the street, each lot level is set to the natural contour at its center. On steep slopes that would necessitate retaining walls higher than 13ft, lots are split into two benches set 9ft apart.

Urban performance. The grid layout delivers residential yield equal to the Adopted Design. However, with 50 compact rear access lots supplementing 210 front access lots, this yield is contingent on the inclusion of nearly double the number of compact rear access lots included in the Adopted Design. A result of higher total road area compared to the Adopted Design, this yield loss is counterbalanced by improved urban permeability. Pedestrian permeability is higher than vehicular permeability due to the conversion of side streets to public open space. While the yield target dictates this configuration, converting side streets to parks is common in pre-WWII grid suburbs and has the advantage of distributing public open space evenly throughout the neighborhood.

Topographic expression. 16,740,000ft³ of earthworks are required to accommodate the layout, which equates to 34% of earth movement volume of the Adopted Design. Although the grid totally modifies the

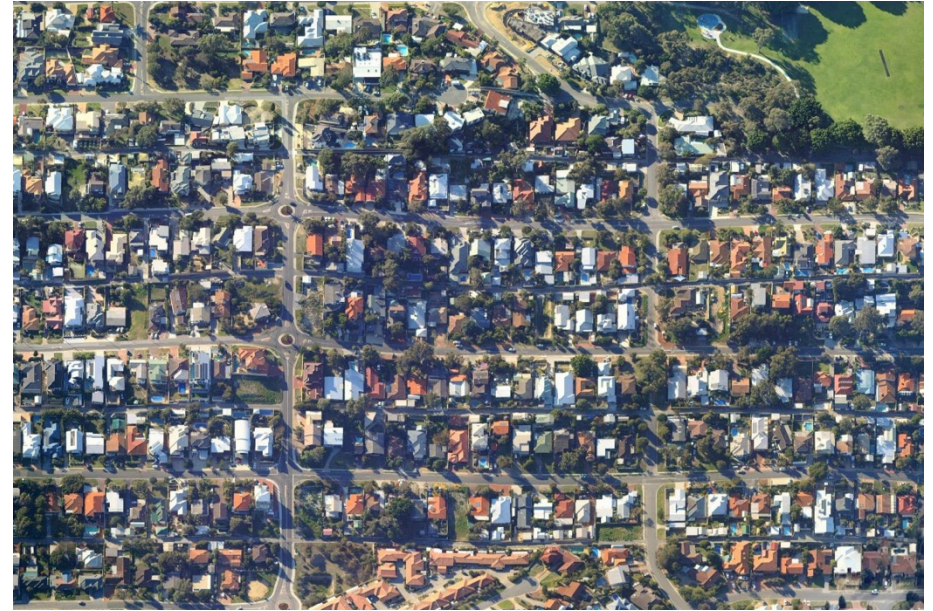


Figure 10. 1940s Perth coastal suburb of Watermans Bay, illustrating warped street grid expressing topographic undulations (© 2013 Google).

original terrain, the general features of the landform are maintained, resulting in a moderate visual expression of the main topographic features from a distance. The grid and wall system creates a pixelated version of the original topography that lacks complexity. However, while the steepest slopes and more intricate sand dune features are eliminated, the overall topographic impression retains key traces in the landform. The imageability of these traces is amplified along parallel streets, which lead directly up and over topographic features, and offer revelatory views at hillcrests. Views out of the suburb are widespread and are incorporated into private lots, public space, and streets. The setback of retaining walls 20ft into the lots also reduces their visibility from the street, although vertical drops of up to 13ft continue to dominate the interface between adjacent lots.

Design challenges. Numerous disjunctions between the arbitrary grid and the natural topography occur along the southwest facing slopes of the main ridgeline through the site. In several locations the street

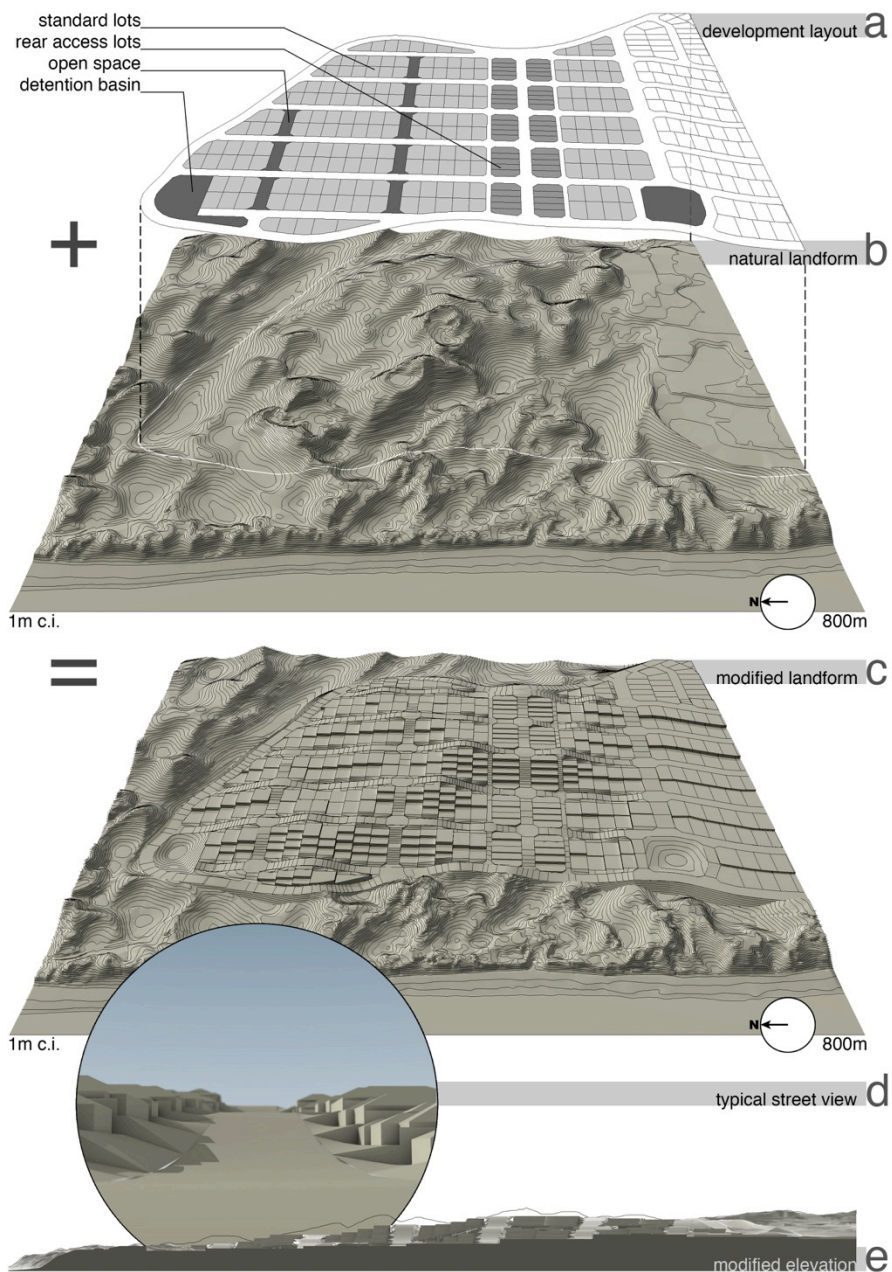


Figure 11. 3D model of scenario 2, illustrating the topographic impact of the grid layout with partially leveled lots.

grid encounters natural slopes of up to 60%, which is almost four times the maximum permissible road grade. Furthermore, the natural levels between parallel streets frequently significantly exceed the maximum retaining wall height of 13ft. Lots situated in areas that remain excessively steep after slope moderation are bisected with 9ft high retaining walls. This split-level configuration enables back-to-back lots to transcend almost 40ft in elevation difference between parallel streets without breaching the retaining wall maximum height of 13ft. The 9ft step-down is calibrated to accommodate a partial ground floor, either at the front or rear of the house depending on the direction of the slope. Advantages of this configuration include relocating level changes from the edges to the center of a lot, and the potential for dwelling floor plans that make innovative use of the dual levels. Disadvantages include reduced access between the front and rear levels of a split-lot, and increased design and construction costs in comparison with conventional level lots.

Scenario 3. Roads Along Swales with Earth Smoothing

In sandy terrain, swales normally provide the most level routes for traversal. Consequently, circulation patterns in unplanned coastal shack settlements traditionally follow swale lines. Similarly, in the 1950s, the first coastal suburban layouts to depart from the time-honored grid used curvilinear streets aligned to swales. Placing roads in swales creates a funneling effect along the streetscape, with houses generally sited above the road on both sides (figure 12). Swale lines also generally simplify storm water engineering and reduce the amount of cut and fill required to accommodate road profiles when compared with roads that contour along hillsides. In the third scenario, local streets set at maximum 15% grades are designed to follow the natural swale lines at the NRP site. Bulk earthworks are used to smooth back the natural terrain to establish a balance between retaining the topographic form and ensuring that lots are sufficiently moderated to be buildable. During the bulk grading process, the steepest slopes are smoothed back to 50%, and depressions are raised to match the street level. As per scenario 1, houses are set on solid plinths or lightweight sub-structures.



Figure 12. 1960s Perth coastal suburb of Quinns Rocks, illustrating streets set along swale lines with houses set on ridge lines on both sides of the street (© 2013 Google).

Urban performance. The swale-based lot layout of this scenario comprises 227 front access lots and 27 compact rear access lots for a total yield of 256 lots (figure 13). While the overall yield and allocation of lot sizes is comparable to the Adopted Design, greater variability of lot sizes and geometries occurs within this range. As a consequence of following alignments dictated by the landform, the street and lot layout necessitates several cul-de-sacs and numerous looping roads that significantly change direction along their length. In two-dimensional plan view, this configuration appears to provide lower urban legibility and permeability than the grid-based systems of previous scenarios. However, the layout is more legible when perceived three-dimensionally within the context of the dune structure. By framing the streetscape on both sides and setting houses set above the street, lots sloping up from the street level also assist urban legibility. Additionally, the swales create a funnel effect that supports standard of gravity fed storm water and sewerage infrastructure.

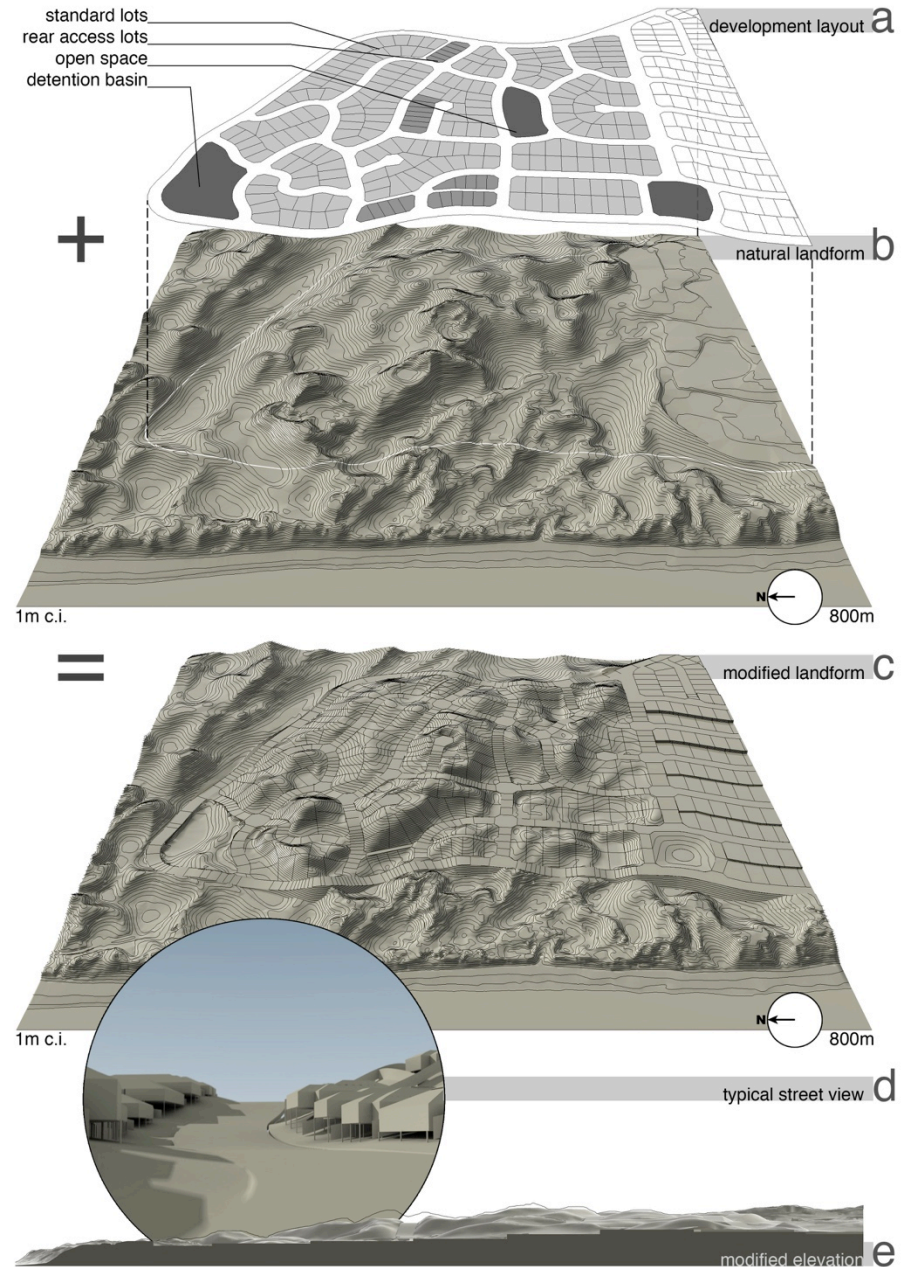


Figure 13. 3D model of scenario 3, illustrating the topographic impact of aligning roads along swales and light smoothing of terrain on residential lots.

Topographic expression. The 7,130,000ft³ of earthworks required to accommodate the layout equates to 15% of earth movement volume of the Adopted Design. Despite some rounding off of knolls, the smoothed landforms remain highly imageable. With road alignments closely calibrated to the original swales, site circulation approximates the natural desire lines that exist in the unmodified landscape. Following swale lines minimizes changes in elevation, particularly at the ends where natural saddles represent the most efficient location for cresting ridgelines. Situating roads along swales and over saddles also amplifies the sense of topographic immersion, which contrasts with the panoramic external views of scenario 2. Although the most pronounced dune formations are diluted, the consistently moderate level of topographic disturbance across the site mitigates this impact. Consequently, a general sense of the complexity of the original topography is present throughout the modified landform.

Design challenges. As distinct from the long, contiguous, and parallel swales that characteristically separate primary and secondary dune systems, the NRP site comprises many short, disconnected swales and gullies. Fitting standardized lot sizes and roads into this highly variable and intricate dune structure results in complex lot geometries. Given site coverage ratios above 50%, these irregular lot shapes directly impact dwelling layouts and reduce the capacity for standardized housing design. Furthermore, although houses elevated slightly above the street are ideal from the perspective of real-estate ‘street presence’, many dwellings are set more than a full floor above street level. Reintroducing the undercroft garages that were common in vernacular architecture up until the 1960s is one method for utilizing this street-front level differential between house and lot.

Scenario 4. Conserved Ridgeline with Unmodified and Conventional Benched Lots

Even when occupying a comparatively proportion of a site, the high visibility of ridgelines amplifies their influence over the topographic character of a neighborhood (O’Shea and Ross 2007). In Perth coastal suburbs established prior to the 1980s, the steepest dune ridgelines typically remained as undeveloped bushland reserves (figure 14).



Figure 14. 1970s Perth coastal suburb of Kallaroo, illustrating dune ridgeline conserved as bushland (author 2014).

Since the 1980s, development yield pressures, escalating land values, and earthmoving technology led to increased residential development of ridgelines. Furthermore, the shift to combining parks with storm-water detention basins displaced public open space from ridge tops to the lowest elevations. The fourth scenario aims to reserve this trend by conserving the most elevated areas of the site (figure 15). To achieve this goal while the meeting residential yield targets, all public open space not essential for storm water detention is situated on the ridge, with the remainder of the ridge platted as large ‘hill’ lots. These lots are developed under the caveat that minimal earthworks are undertaken for dwelling construction and the remainder of each lot remains vegetated with indigenous coastal heath. The remaining lowlands are benched as per current conventional practice.

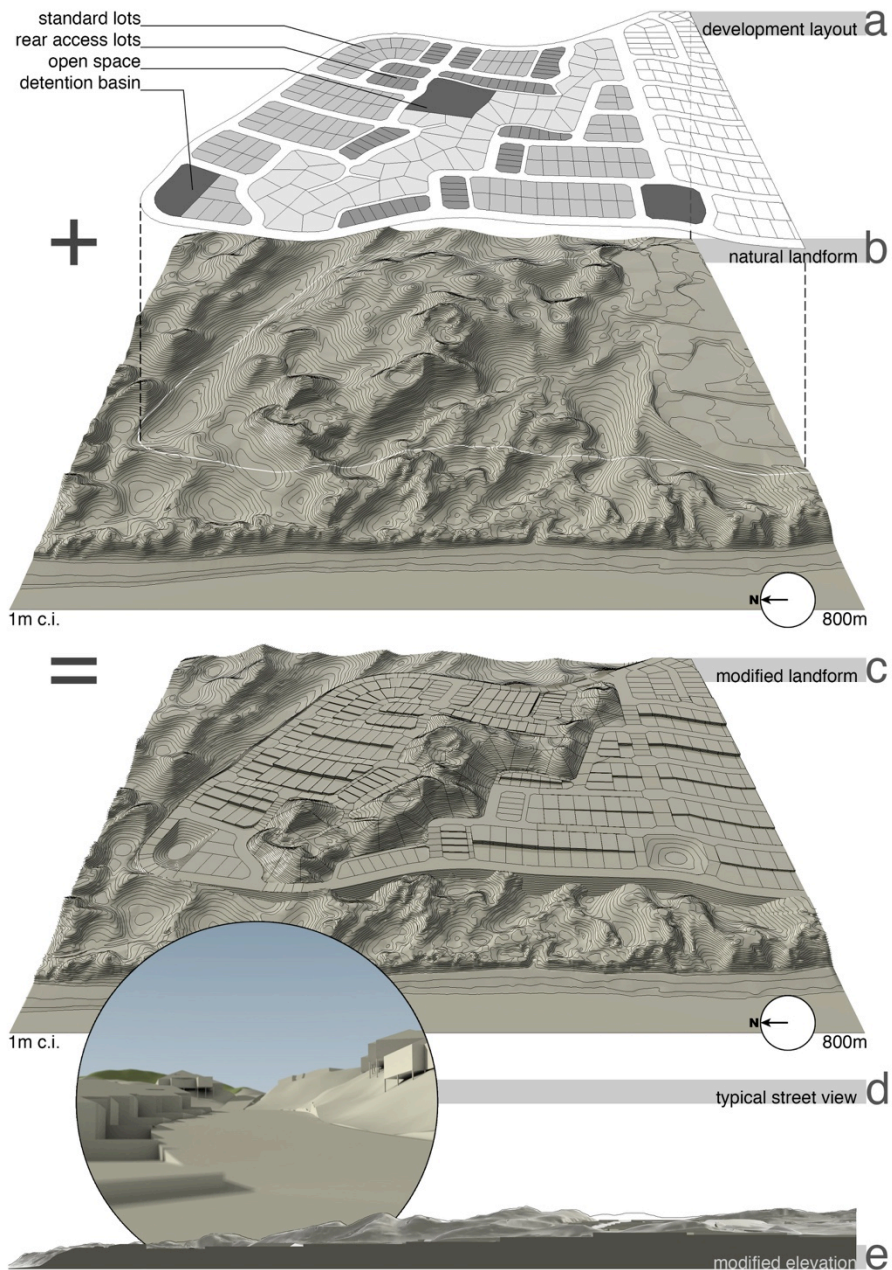


Figure 15. 3D model of scenario 4, illustrating the topographic impact of siting large lots and public open space on the highest areas of the site.

Urban performance. With 254 lots, the total yield for scenario 4 is close to the Adopted Design yield. In addition to 128 regular front access lots, the scenario comprises 54 hill lots, which average 12,920ft² or 3 du/ac. However, 72 compact rear access lots are required to offset this area of low-density development, which equates to 2.5 times more compact rear access lots than in the Adopted Design. Moreover, while the 430% range between the smallest and largest lots indicates high overall lot diversity, actual size variation within each of the three lot types is minimal. Urban permeability is low, with the lack of roads through the topographically unmodified hill lot area on the ridgeline restricting urban connectivity across the site. Conversely, the elevation of the ridge and the elimination of natural depressions amongst the leveled lots facilitates efficient storm water and sewerage infrastructure.

Topographic expression. 15,400,000ft³ of earthworks are required to accommodate the layout, which equates to 31% of earth movement volume of the Adopted Design. As is consistent with the twofold development strategy, the topographic expression of the scenario is bimodal. The ridgeline is visible from many parts of the surrounding development and conveys the topographic silhouette of the site. With numerous streets terminating at the base of the ridge, this central elevated position amplifies the topographic imageability of the ridge within the suburb. Along the ridge, dwellings scattered at low densities with retained natural vegetation maintain a high degree of complexity. Furthermore, the hilltop park allows the ridge to be physically experienced, rather than only visually registered from a distance. In contrast to the high imageability of the ridge, natural topographic character is entirely eliminated in the conventionally benched lowlands. These areas, which comprise most of the development area and residential yield, exhibit very high degrees of topographic disturbance and very low degrees of imageability and complexity.

Design challenges. To maintain overall residential yield, more compact rear access lots are required to offset the significant number of large hill lots. Although additional compact lots align with

demographic shifts towards smaller, time-poor households (ABS 2010), the conventional benching required to accommodate both compact and conventional lots eliminates direct interaction with landform for 80% of the residences in this scenario. Privatizing the desirable ridge outlook to 20% of households creates clear segregation from the higher density leveled lots in the lower areas of the site. The incorporation of public open space on the ridgeline is therefore essential to offset the impression of the ridge as a privatized and segregated barrier that bisects the suburb. To ensure that topographic conservation is maintained, hill lots necessitate clear urban guidelines that define building envelopes and construction methods, and limit indigenous vegetation clearing and earthworks in the remainder of each lot. While these controls are straightforward to define and enforce during the initial permitting and construction phase, the piecemeal site modifications that individual homeowners make over time are far more difficult to police. The incremental clearing of vegetation and leveling of slopes to accommodate ancillary structures and entertainment spaces is therefore likely to erode the topographic advantages of hill lots over time.

Scenario 5. Conserved Depressions with Conventional and Split-Level Benched Lots

Due to the absorbent substratum, the action of wind—rather than water—predominantly shapes sandy terrain. The numerous depressions that result from this process connect the ground surface with the underground water table. Despite this important hydrological role, low-lying areas have been filled in and built over throughout the history of Perth’s settlement. Although environmental policy now mandates that larger wetlands be conserved during suburban development, they continue to be degraded through poor design integration and parkland maintenance regimes (Davis and Friend 1999) (figure 16). Moreover, smaller depressions are routinely eliminated during the site engineering process to simplify gravity-fed storm water and sewage infrastructure. The fifth scenario retains all but the smallest depressions and their natural vegetation on the NRP site (figure 17).



Figure 16. Local park in the Perth coastal suburb of Craigie, illustrating a depression retained as a poorly integrated storm water detention basin (author 2014).

To minimize degradation of natural systems through direct adjacencies with residential lots, a street or laneway buffers each depression. A meandering grid of streets connects the depressions amongst suburban lots developed using conventional benching practices.

Urban performance. With 247 lots, the total yield for scenario 5 falls 5% short of the Adopted Design yield. This shortfall results from the increased area allocated to retaining the depressions, which produces 40% more open space than the Adopted Design. To compensate, 70 compact rear access lots are incorporated in the yield, which is more than double the compact lot allocation in the Adopted Design. The meandering street layout that links the depressions creates moderate lot size diversity. The absence of cul-de-sacs in the street network facilitates high urban permeability. As a result of conventional benching, sewerage and storm water infrastructure efficiency is good, albeit with the important environmental caveat that retained depressions are not converted to storm water detention in the future.

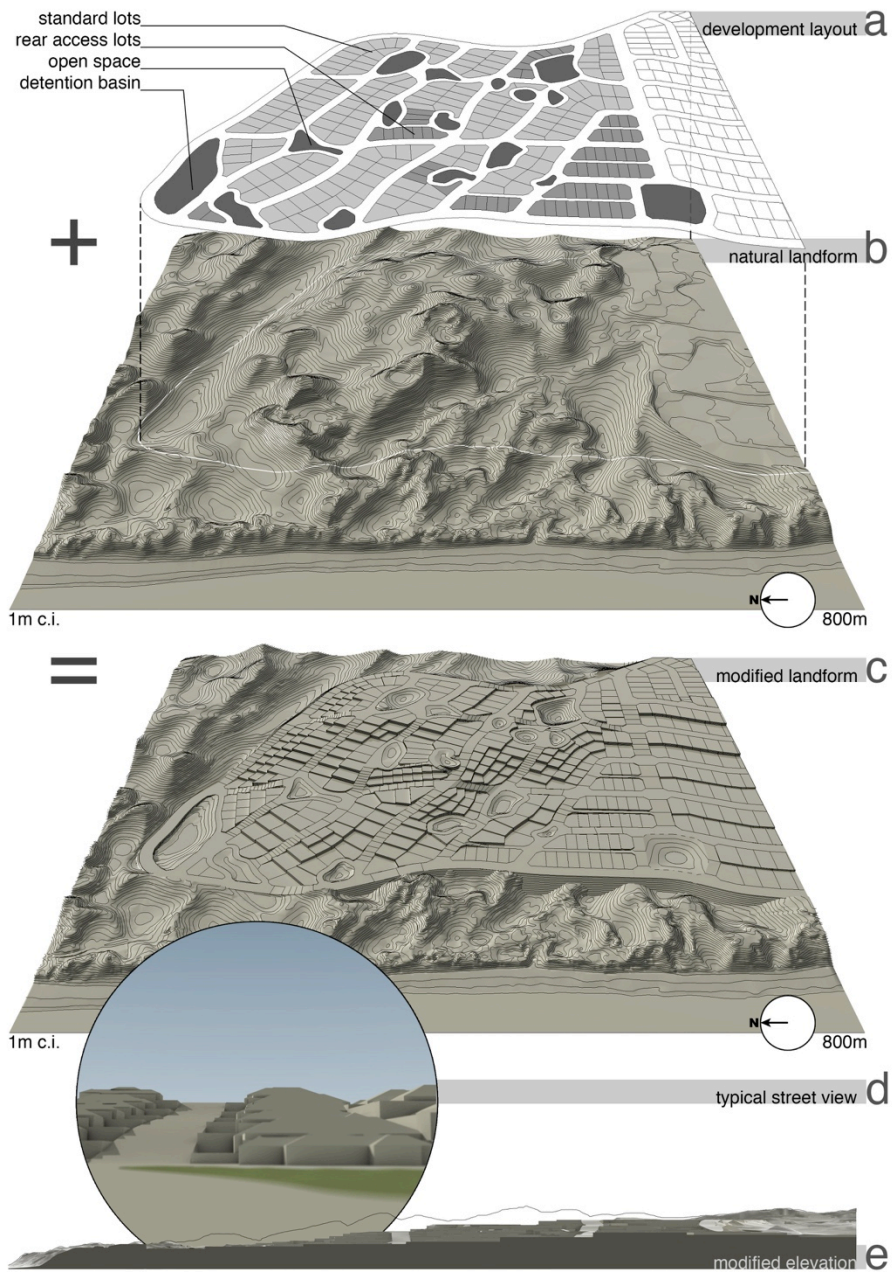


Figure 17. 3D model of scenario 5, illustrating the topographic impact of retaining depressions within conventional benching practices.

Topographic expression. The 23,450,000ft³ of earthworks required to accommodate the layout equates to 48% of earth movement volume of the Adopted Design. Since depressions are naturally distributed across a wide range of elevations and locations throughout the site, their retainment inherently restricts the extent to which the site's natural landform may be leveled out. The depressions are brought into view as public spaces that are encountered regularly along the streets, thus contributing to the topographic local character of the neighborhood. Nevertheless, on account of their position below ground level, the depressions cannot be seen from a distance, and are therefore unable to function as imageable landmarks in the same capacity as ridges and knolls. Moreover, the elimination of highpoints and other complex topographic features remove the natural topographic context of the depressions. When experienced in isolation, the conserved depressions contribute minimal information to the imageability of the original landform, which is highly disturbed across most of the development.

Design challenges. Expressing the site's natural depressions within the suburban development presents several design complications. Unlike development in dendritic terrain—in which creek lines typically form the basis of public open space—the fragmented non-linear distribution of depressions does not support integrated open space systems. Moreover, small, fragmented remnant depressions are highly vulnerable to ecological degradation because of high perimeter-to-area ratios (Stenhouse 2004). In addition to improving general imageability, encircling depressions with roads minimizes weed ingress and prevents incremental privatization from adjacent private property. Nevertheless, road buffers may position depressions as an inconvenience to motorists and unintentionally perpetuate their historical devaluation. For this reason, the implementation of effective long-term land management policies is essential to prevent the conserved depressions becoming depositories for waste or being incrementally leveled and grassed to accommodate active recreation.

Evaluation: reconciling landform and urban performance

The relative performance of the five scenarios and the Adopted Design across key quantitative and qualitative criteria are summarized in table 1. To reflect the broadly opposing values of conservation and development, performance metrics are grouped into *landform expression* and *urban design and development* criteria.

All the scenarios express the site's pre-development landform more comprehensively than the Adopted Design, which ranks last across all landform criteria. Ranked second last, scenario 5 is the least effective of the scenarios, with the conserved depressions and conventional benching generally exhibiting poor landform expression across most metrics. At the other end of the spectrum, scenario 3 is most effective, with the system of topographic smoothing and swale-aligned layout ranking first in most landform expression criteria. Scenario 4 exhibits the second most effective expression, with the bimodal strategy of ridgeline conservation and conventional benching ranking highly in most criteria.

Overall, all of the scenarios exhibit decreased urban design and urban development performance in comparison with the Adopted Design. Scenario 2 ranks second highest overall, with only low lot diversity and lower storm water and sewage infrastructure performance undermining the generally high urban performance of the traditional grid layout. Scenario 4 ranks a close third, with the combination of ridgeline conservation and conventional benching rating well across most urban metrics. Significantly, scenario 4 substantially outperforms the Adopted Design in the criterion of lot size diversity through the inclusion of large hill lots and increase in compact rear access lots. At the other end of the range, scenario 2 exhibits the lowest overall ranking. In this scenario, the translation of the Adopted Design layout onto a non-benched landform strategy compromises all urban metrics.

When both landform expression and urban design and development are evaluated together, scenario 4 exhibits the highest and most balanced overall performance across both groups of metrics.

	ADOPTED DESIGN	SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4	SCENARIO 5
Landform Expression Criteria	Rankings					
Lowest volume of earthworks	6	2	4	1	3	5
Landform imageability	6	3	4	1	2	5
Lowest landform disturbance	6	4	5	1	2	3
Landform complexity	6	2	4	1	3	5
Distant landform legibility	6	4	3	2	1	5
Streetscape landform legibility	6	1	2	3	4	4
Lot-scale landform legibility	6	1	4	3	1	4
Average of rankings by scenario	6	2.4	3.7	1.7	2.3	4.4
Overall landform criteria	6	3	4	1	2	5
Urban design / Development Criteria	Rankings					
Highest diversity of lot sizes	5	6	4	3	1	2
Urban design performance	2	6	1	5	3	3
Infrastructural performance	1	6	4	5	2	3
Private view distribution	1	3	2	3	5	6
Deviation from standard practice	1	5	2	6	3	4
Average of rankings by scenario	2	5.2	2.6	4.4	2.8	3.6
Overall urban / development criteria	1	6	2	5	3	4

Table 1. Scenarios ranked against selected landform expression and urban design / development criteria. 1 = best performance, 6 = poorest performance.

Somewhat counter-intuitively, segregating urban development areas from landscape conservation areas within the development site achieves this balance. Two other scenarios also rate highly in the combined rankings, albeit with significant compromises from divergent priorities. The grid strategy of scenario 2 scores highly in urban criteria and satisfactorily in landform expression criteria for a high combined performance. The central function of retaining walls in structuring this scenario suggests the potential for benching to be reconfigured for improved topographic responsiveness. From the alternate perspective, scenario 3 exhibits a similarly high combined performance. With a very strong expression of original landform

offsetting comparatively urban poor performance, this scenario suggests the potential for foregoing performance in certain urban criteria to achieve high overall landform expression.

Conclusion: site specificity

The development scenarios for the NRP site demonstrate that government-mandated suburban densities can be reconciled with improved design responsiveness to natural sand-dune topography. First, conserving major ridgelines with open space and low-density housing offers a satisfactory counterbalance to conventional practices elsewhere in the development. Second, retaining walls can express terrain if laid-out on a grid in small enough units, including within individual lots. This assessment demonstrates that improved topographic expression is not necessarily contingent on eliminating or reducing the height and extent of retaining walls. And third, aligning roads to swales and moderately smoothing the landform requires the least earthworks and conveys a consistently strong image of original landscape character across a wide range of scales.

Integrating elements of the scenarios into current suburban development requires significant re-evaluation of industry conventions and urban design policies. First, adopting increased road grades and slower, tighter road curves enable suburban street networks to respond more closely to natural variations in topography. To achieve this, engineering standards that are closely linked to statewide infrastructure criteria require recalibration. Second, increased diversity of lot and dwelling sizes improve opportunities for suburban form to respond to topographic variation. To achieve this, the suburban monoculture of similarly sized houses requires augmentation with smaller and larger dwellings, which have the added benefit of accommodating increasing demographic diversity (ABS 2010). Third, alternative housing construction techniques enable lots to be developed without first being leveled. To achieve adoption, the industry-perpetuated cultural-bias against lightweight construction must be overcome. This represents an opportunity for residential architects, who currently design an insignificant percentage of suburban housing stock (Dunham-Jones 2000). Last, looser urban

structures enable street networks to incorporate natural landform more effectively. To achieve this, rigid imported urban performance criteria may be relaxed to allow variations in topography to distort neat, ordered urban structures.

These innovations require policy innovation to refocus an industry that is entrenched around bulk earthworks and benching as the most economic and expedient model for suburban development. Given the strong link between ocean views and property value in Perth, poorer view distribution represents a major obstruction to widespread acceptance of lower topographic modification in coastal suburban development. With ocean views now more valuable than the cost of moving sand, extensive topographic modification has a strong economic rationale. This imperative will need to be systematically addressed by reorienting perceptions towards the value of inland views and lots that are sheltered from the elements. The suburban layouts most capable of expressing the topographic character of coastal dunes are likely to be more variable than the formulaic plan-oriented templates that currently drive development patterns. Most critically, this research indicates that expressing the topographic character of sand dunes necessitates a profoundly site-specific approach to suburban development.

To be certain, with Perth projected to add 2 million people by 2056—and current government urban densification objectives proving difficult to realize in practice (WAPC 2010)—the sheer extent of ongoing suburban sprawl is likely to overwhelm any topographic improvements at the subdivision scale. That this sprawl is planned to extend into dune systems that are steeper than the more moderate topographies of older coastal districts to the south further exaggerates this disjunction. In this topographic and demographic context, extending the scope of future research beyond established low/medium suburban densities is required. Calibrating higher urban densities and novel dwelling arrangements to landform potentially offers further improvements of topographic expression whilst concurrently demonstrating the positive qualities of urban density.

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Notes

¹ Urban performance criteria typically include: *density* (number of dwellings per unit of area); *diversity* (range of dwelling sizes and types); *legibility* (ease with which an urban landscape can be comprehended and navigated at ground level); *permeability* (degree of public accessibility and connectivity); and *walkability* (comfort and proximity of the pedestrian experience) (See Carmona 2010).