Title

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The Emergence of Suburban Terracing on Coastal Dunes

Case studies along the Perth northern corridor, Western Australia, 1930-2010

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Introduction: city of sand

Founded on traditional Whadjuk country in 1829, the city of Perth is sited on a 25km wide sandy coastal plain that separates the Indian Ocean from the 2.7-billion-year-old Yilgarn Craton plateau. Across the plain, the age of deposition is registered in bands; the oldest, greyest, and flattest sand is nearest the plateau, while the newest, whitest, and steepest sand formations lie closest to the coast. Here, sand and shells cemented together to form a limestone cap that is intermittently expressed as low coastal cliffs, craggy ridgelines, caves, and associated endemic plants. Although Perth is defined by its setting on the Swan River estuary, waterways are rare on the coastal plain; most runoff quickly infiltrates down through the sandy soil to shallow aquifers. Underground flows break the surface in the numerous wetland chains that were originally abundant on the plain and supported riparian habitats (Seddon 1972) (figure 1).

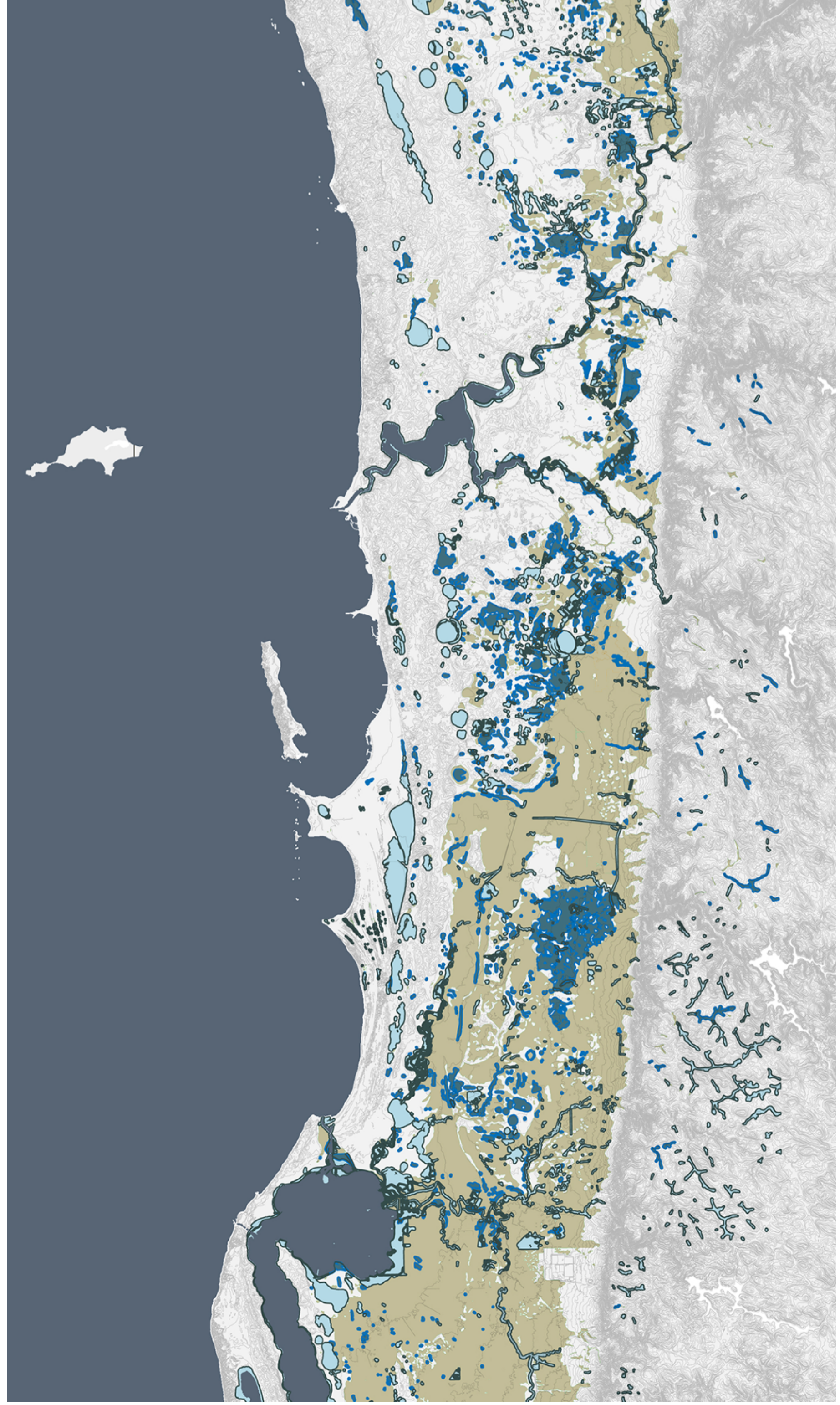

Figure 1: landform (5m contours) and wetlands (indicated by blue areas) of the Swan Coastal Plain (map based on data supplied by the Western Australian Department of Environment and Conservation).

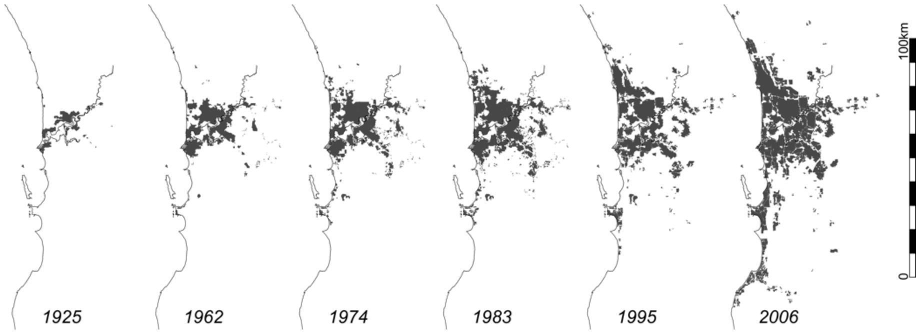

Figure 2: timeline of Perth metropolitan area expansion (map based on data supplied by the Department of Planning and Infrastructure).

Up until WWII, settlement in the Perth metropolitan area was concentrated along the Swan River between the urban centres of Fremantle, Perth, and Guilford (figure 2). With the ocean considered a harsh and difficult environment to access, coastal inhabitation was limited to isolated settlements that accommodated fishermen and holidaymakers but were not considered part of the city. After WWII, accelerating population growth, widespread motor vehicle ownership, and the increasing attractiveness of suburban leisure lifestyles contributed to the reorientation of Perth's growth frontiers towards the coast. In 1970, nascent coastal suburbanization was endorsed in the Perth Corridor Plan, which focussed future growth into two corridors extending inland and two corridors along the coast (MRPA 1970).

The current form of the Perth metropolitan area reflects a distorted realization of the corridor plan, with the inland corridors recording modest growth in comparison with the burgeoning 140km long coastal strip. Despite government efforts to mitigate this uneven expansion by mandating higher densities in new development and transit-oriented densification in older inner-ring suburbs (WAPC 2004a), the northern coastal corridor continues to advance at a rate of approximately 1km per year (figure 3). Since the 1970s, the industrialized scale of suburbanization comprised increasingly comprehensive site manipulation techniques that allowed standardized suburban homes to be established irrespective of local conditions. Persistent casualties of both suburban expansion and densification included the filling of wetlands and removal of indigenous coastal heathland and Tuart woodlands.

By the 1990s, site preparation for suburban developments evolved to the total re-engineering of naturally undulating coastal dune systems into vast expanses of flat lots retained with limestone walls. Although suburban terracing was pioneered in California in the 1950s (see: Banham 1971), Perth's sandy soils offered far less resistance to mining-scaled earthmoving techniques than did the foothills of Los Angeles' mountainous frame. This acquiescence allowed the terrain to be readily manipulated to reflect civil engineering standards for sewerage and streets, real-estate criteria for maximized views and indoor/outdoor space and building industry construction methods.

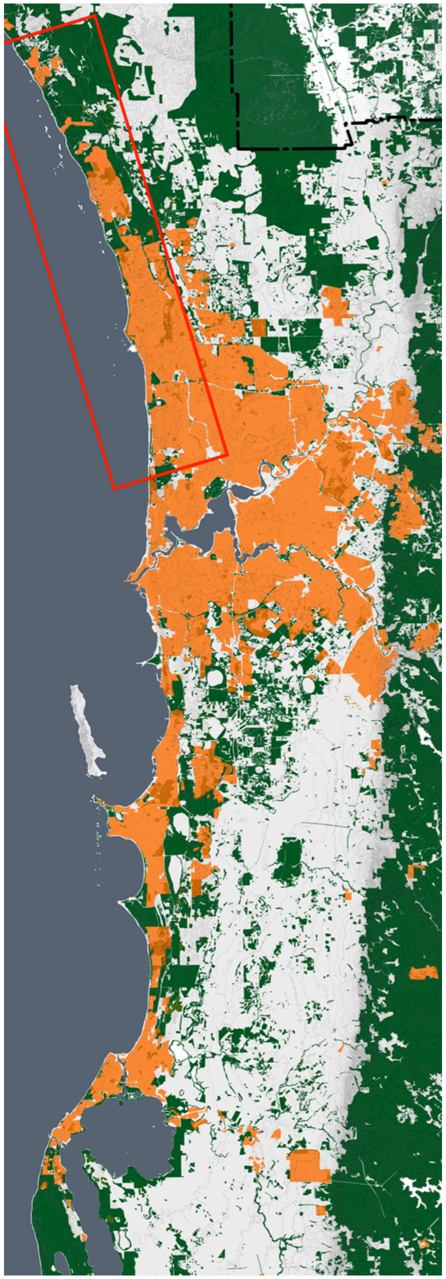

Figure 3: current metropolitan extents (orange) and remnant natural vegetation (green), with the northern corridor study area indicated by red box (map based on data by Department of Agriculture and Department of Planning and Infrastructure).

While economical for the housing sector, large-scale suburban terracing carries several negative biophysical and spatial-cognitive side effects. The process of shifting, removing, and adding new sand requires removing all existing vegetation, which eliminates important sources of habitat, biodiversity, and human amenity in the suburban context (Cary and Williams 2000). In the earth-grading process, the endemic topsoil is replaced by un-stratified artificially reformed sand. The upper strata of organic soil matter can be extremely old and can provide a window into past environmental conditions that may recur or impact the present (Grose 2010). Once this topographic record is disturbed or eliminated, the micro-ecologies within endemic soil-strata cannot be easily repatriated. This in turn has ramifications for many soil-specific criteria, including stability, fertility, and ground water quality.

Suburban terracing also impacts how people cognitively map, orientate and create a sense of place in their environment. Kevin Lynch (1960, 9697) explored the role of landform in shaping the legibility of the urban environment. Lynch notes that when navigating the city, people imbue their route with a sense of directional differentiation, for which slope is an important underlying influence. In natural landforms, water networks usually form the bases of these topographical gradients. However, when a landscape is artificially re-engineered, these inherent directional gradients are often obfuscated. Furthermore, terracing impacts how people physically, psychologically, and creatively interact with their environment. Richard Sennett (1998) argues that physical contact with complex and variable environments provides an important catalyst for creative expression, which forms a foundation of place making. By rarefying the rough nuances of the natural terrain into flat planes and vertical walls, terracing diminishes the phenomenological connection between mind, body, and ground.

International context

The renowned multidisciplinary scholar George Seddon (1979; 1986; 1990; 1998) generated the most sustained critique of topographic modification in Perth's suburban development. Seddon abhorred the practice of suburban terracing for destroying the innate sense of place and urged planners and designers to study and build in sympathy with the landform rather than levelling it. Terracing was also harshly critiqued in the US, with early suburban terracing in California decried as emblematic of environmental wastefulness in industrialized society (Bronson 1968; Blake 1964). Beyond these concerns, contemporary literature specifically addressing the phenomenon of suburban terracing is limited, with most analysis emanating as a by-product of botanical and ecological studies (see: Williams et. al. 2005; Rokich et. al. 2001).

This dearth of investigation correlates with the low priority assigned to topography in general within international design and planning discourse (Kullmann 2014). For example, the influential New Urbanism movement focuses on the relationship between built form and the legibility of streets and urban spaces. Given that many of the historic cities that New Urbanism is derived from are sited on flat river floodplains, topography is typically positioned outside the urban zone as parkland or countryside (see: Duany 2002). While relevant to many inland cities, this conception of urban landform disregards the complex overlapping interaction between topography and expanding coastal cities in the real world (see: Bosselman 2011).

Within planning, the mapping techniques pioneered by Ian McHarg (1969) and subsequently advanced through GIS, provided a template for establishing the suitability of slopes for development. While these methods mounted compelling cases for repelling or lowering residential densities in numerous locations in both the US and Australia, they were also often neutralized by commercial development pressures at the peripheries of expanding cities. Within architecture, investigations into topographically sensitive design have also had a mixed legacy, with most efforts remaining isolated experiments for affluent clients on large lots, with limited applicability to the suburban context (see: Paolella and Quattrone 2008; Serraino 2006). The modern architectural aspiration to touch the earth lightly has been particularly ineffectual in the suburban context (see: Ingersoll 2006).

Research scope

Through analysis of the evolving treatment of topography in suburban Perth, the article illuminates the converging factors that drove the emergence of suburban terracing in a coastal setting. Understanding the scale-integrated factors that underpin suburban terracing provides a foundation for the development of suburban design practices that are more sensitive to the ecological and cultural value of existing sand dune topography. To be sure, urban infill policies that aim to accommodate 60% of Perth's population increase within existing metropolitan boundaries by 2030 remain essential to sustainable growth initiatives (WAPC 2004a). Nevertheless, as is the case with many expanding cities around the world, urban densification will not accommodate all of Perth's future population increase. Peripheral green-fields suburban development will consequently continue to require management through sustainable design and planning techniques (Gleeson 2006).

Developing more sustainable coastal suburban development practices is internationally pertinent, with population coastalization now a global phenomenon. Indeed, Perth's suburban expansion model is significantly driven by international population flows, with UK migrants comprising up to 43% of the population in the northern most suburbs (Salt 2012). This process is repeated in sunbelts around the word, where increasingly mobile and older populations seek lifestyles associated with beachside living (Engelman 1997).

Case studies: Perth northern corridor

Exhibiting a contiguous pattern of coastal suburban development, the northern corridor provides a consistent case study area for tracing the evolution of subdivision design and construction techniques in Perth. Arranged chronologically and generally northwards, the eight case studies are representative of the treatment of existing topography in the creation of new suburbs in each decade between 1930 and 2010 (figure 4). The cases consider the three suburban scales of houses, lots and street layouts in relation to the overall landform strategy. Resources include current and historical 1m contour data, ultra high-resolution orthogonal and axonometric aerial imagery, and (where available from the state archives) historical bird's eye and street level photographs. For consistency across numerous local government jurisdictions, all area and density calculations were derived from planimetric and cadastral data supplied by the state government mapping agency (Landgate) for this study. 500x500m sample areas for each case study are compiled into a diagrammatic matrix comprising natural contours, modified contours, parcel layout and dwelling footprints (figure 5). The matrix is referenced throughout the article.

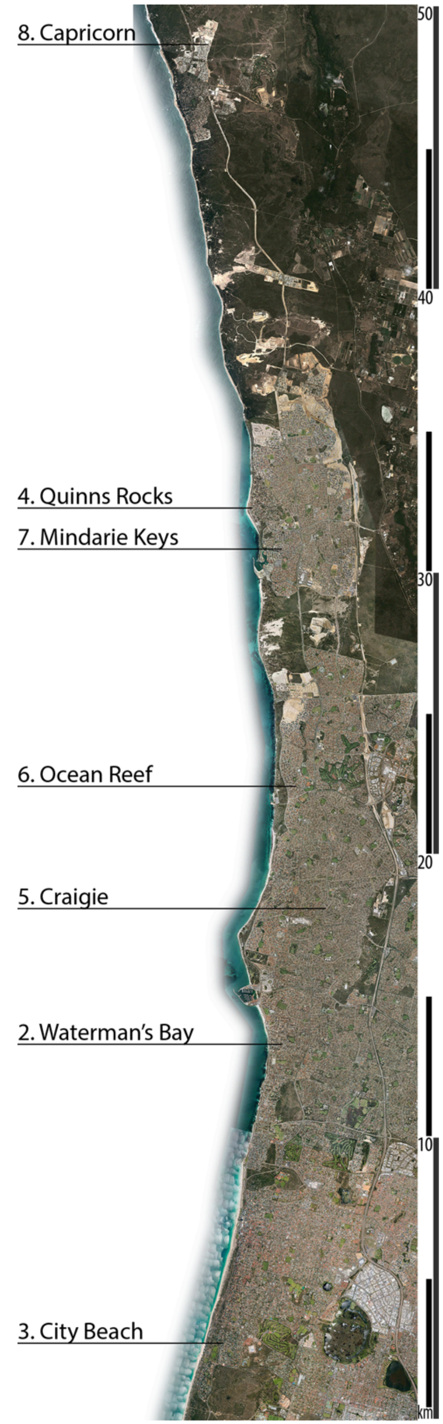

Figure 4: location of case study sites in the Perth northern corridor, excluding Wedge Island located 100km north.

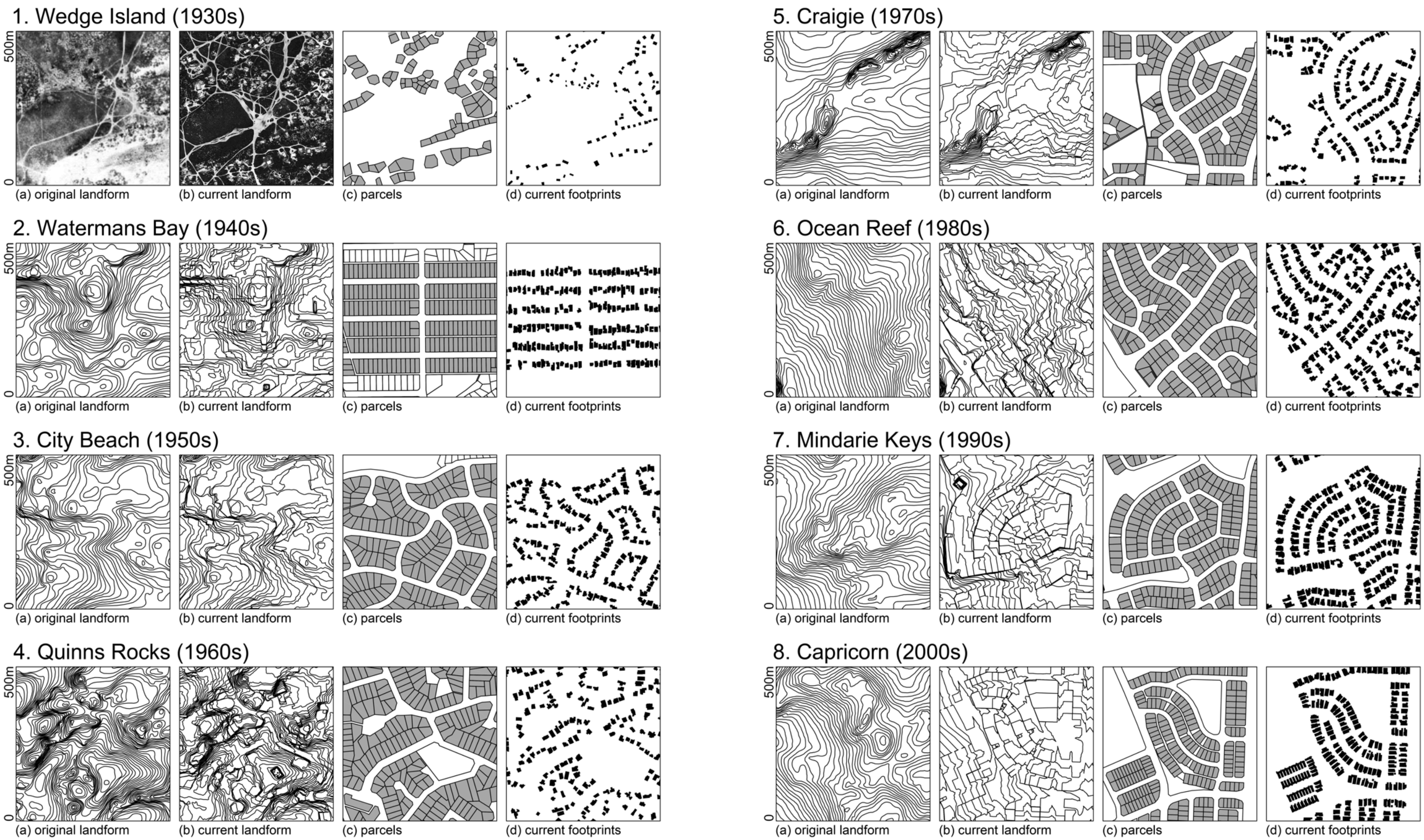

Figure 5: 500x500m sample area of each case suburb as labelled, indicating (a) unmodified landform prior to development, (b) modified landform following development, (c) parcel layout, and (d) building footprints (base maps supplied by Landgate, except: 1(a) courtesy of Wedge Island Progress Association; 1(b) © 2013 Google Earth, © 2013 Digital Globe; 1(c), 1(d), and 8(d) traced from aerial imagery, 6(a) from Foulds 1982, 7(a) from EPA 1985; and 8(b) courtesy of Capricorn Village).

1. Wedge Island: 1930s shack settlement

Situated 100km north of the current Perth city limits, the isolated coastal settlement of Wedge Island is representative of the squatter's shacks that predated official suburban development in numerous locations along the Perth Northern Corridor. Between the 1930s and a moratorium on new structures in the late 1990s, 320 corrugated iron shacks were constructed by fishermen, farmers and later by vacationing Perth residents (GML 2012).

With no planning, infrastructure, or mechanisms for land ownership in place, decisions made by individuals led to an organic settlement pattern that closely follows the natural lay of the land (figure 5.1.a). Older shacks were generally sited along the primary and secondary swales while more recent structures are clustered on secondary and tertiary dunes (figure 6). The pattern of settlement also reflects the dynamic nature of the coastal ecosystem, with new structures following the successional re-vegetation of barren sand dunes to the north and west. A web of single-vehicle sand tracks interlink each shack and provide access to the beach, which until recently served as the only 'highway' connecting Wedge Island to the outside world (figure 5.1.b). The isolation is demonstrated by the absence of infrastructure, with the settlement reliant on electricity from portable generators, long-drop dry toilets, and water captured off roofs and drawn from nearby bores.

Based on areas that are visibly in use and associated implied private space, the hypothetical lots around individual shacks range 400% in area between approximately 250m^2 and well over 1000m^2 (figure 5.1.c). The average parcel size of 630m^2 equates to a net residential density of 15 dwellings per hectare, although when the undeveloped areas are included as hypothetical road reserves and public open space, the gross density dilutes considerably to 5 dwellings per hectare. The small 95m^2 average footprints of the shacks further offset the impact of the net density (figure 5.1.d). As with the high diversity of the hypothetical parcels, dwelling footprints also exhibit a very high 375% range between 40m^2 and 150m^2.

Figure 6: oblique aerial view of Wedge Island settlement (courtesy of Wedge Island Progress Association).

In addition to small dwelling footprints, significant factors driving the low level of topographic modification include lack of private yards, narrow access roads, large reserve areas, and limited physical capability to re-grade topography. Moreover, the lack of concern for key urban design principles—such as legible circulation, balanced streetscapes and hierarchy of spaces—enables the settlement pattern to respond solely to site and environmental factors. Nonetheless, the topographically derived layout of Wedge Island fulfils other metrics for good urban environments, including high pedestrian permeability, human scaled development, and community interaction.

2. Watermans Bay: 1940s grid suburb

Watermans Bay was originally subdivided in 1918, but not significantly developed until after WWII. The grid layout reflected the standard template for land subdivision in Perth in the early 20th century, and contrasted with the irregularly arranged shack settlements that

Figure 7: circa 1950 oblique aerial view of Waterman's Bay. The straight streets appear to distort in response to the undulating coastal terrain. Original dune vegetation is evident on both undeveloped areas and some developed lots (courtesy of City of Joondalup Local History Library).

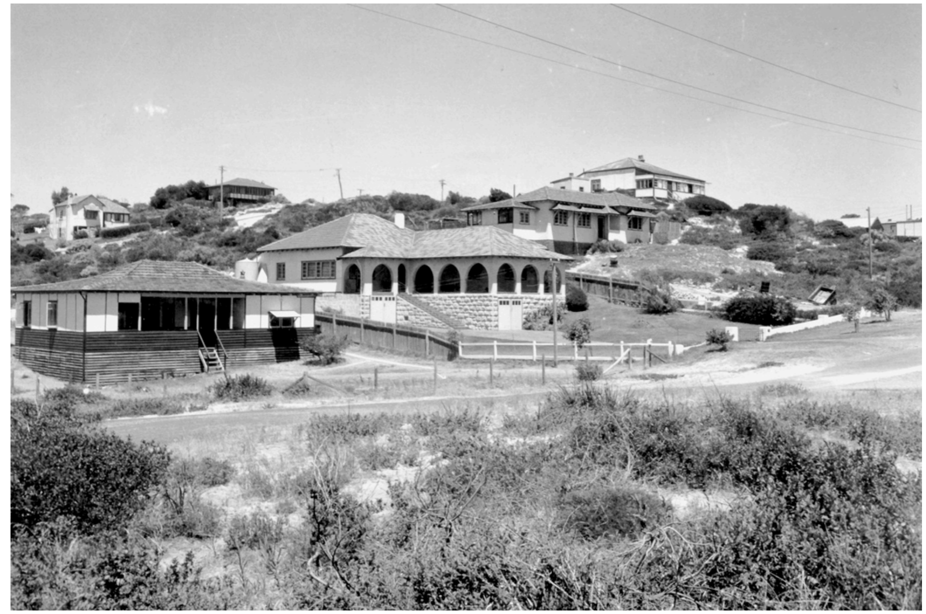

Figure 8: ground-level view of circa 1950 streetscape. The first building on the left is timber-framed stilt construction with enclosed verandas, while the second house from the left is double-brick wall construction set on limestone plinth. The houses to the right are sited further back on their lots to accommodate steeper topography and maximise views. Original dune topography and vegetation is evident on several lots (courtesy of State Library of Western Australia)

were eventually displaced from this section of coast. The suburb is based around twelve identical 240 x 100m blocks serviced by 20m wide road easements that provide high levels of urban legibility and permeability. 6m wide rear laneways persisted in this layout, despite septic systems having already superseded their original purpose for night soil (human waste) collection at the time of development. At the coastal terminus of each east-west street, unfiltered storm water runoff was originally discharged directly into the ocean. Further inland, lots situated on natural low points in the terrain were excavated to form deep sumps for storm water detention and infiltration.

With no site-works undertaken prior to subdivision, the street grid was draped directly over the existing coastal terrain (figure 5.2.a). The disjunction between the landform and the grid necessitated short, steep inclines up the fore dune, and where necessary, minor road-cuts into the limestone ridgeline to accommodate vehicles (figure 5.2.b). In several instances where the topography proved too steep, roads and laneways were left as disconnected easements that were appropriated as *de facto* public spaces. Even when positioned adjacent to road-cuts or disconnected roads, individual parcels were sold in an unmodified state and vegetated with indigenous coastal heath (figure 7). The 400 identical lots were gazetted with 15m frontages and an area of 710m^2, which equates to a net density of 14 dwellings per hectare, and gross density of 10 dwellings per hectare with rights of way included (figure 5.2.c).

The typical floor area of houses constructed in the original land release averaged 90m^2, although the enclosure of front and rear verandas with fibre-cement panelling and glass louvres often provided an additional 10-20m^2 of usable indoor space. The first houses were timber framed and elevated on stilts to accommodate variations in topography within the site and enhance cooling in summer. Subsequent dwellings constructed with double-brick walls and suspended timber floors were set on plinths formed of quarried limestone. In downslope areas the plinths were often high enough to incorporate under-croft garages, which were frequently converted into additional living space. Houses were also often set further back within the lot to accommodate particularly steep topography and maximise views (figure 8).

Despite the rigidity of the grid, the medium sized lots, compact houses that negotiated slope within their footprints, and limited use of yard space reduced the need for extensive topographic modification within each lot. While current zoning codes prohibit lot subdivision in Watermans Bay, the increase of average dwelling footprints to 235m^2 in replacement housing stock has raised typical plot ratios from 13% in the 1940s to 38% today (figure 5.2.d). As a result of these newer, larger houses using concrete slab construction and incorporating outdoor entertaining areas, the underlying topography continues to be modified at the lot level.

3. City Beach: 1950s garden suburb

Initially subdivided in the 1930s but developed mainly in the 1950s, City Beach was the first coastal subdivision in Perth to use a curvilinear street layout in place of the traditional grid (figure 9). As a local interpretation of the garden suburb, the streets were designed to meander in three dimensions by curving both over and around ridges and swales in the undulating terrain (figure 5.3.a). The pattern of 20m wide road easements frame very small blocks containing as few as 15 parcels, separated by four-way and three-way intersections. With no cul-de-sacs, the layout provides good levels of urban permeability and legibility as the curving streets generally traverse the suburb and maintain sufficient overall direction (as defined by: Lynch 1960).

Figure 10: ground-level view of circa late 1950s City Beach house and front yard with combination of plinth, low onsite retaining walls, and embankments to negotiate level change between street and house (author 2013).

Except for some minor re-grading to accommodate road cross-falls, no other site preparation was undertaken; lots were sold with dune topography and vegetation intact (figure 5.3.b). The parcels average 1015m^2, which equates to a net density of 10 dwellings per hectare, and a gross density of 7 dwellings per hectare when road areas are included. However, unlike the identical parcels at Watermans Bay, the 250 lots in City Beach range 250% in size from 750m^2 to 1900m^2. This high degree of lot diversity appears to be dictated more by the geometries formed within the curving blocks, and less by site-specific variations in the landform (figure 5.3.c).

With City Beach marketed as a middle-class community, the first generation of houses typically covered 150m^2, which was larger than average Perth house footprints of the era. Timber-framed houses on stilts did not feature in City Beach, having already been stigmatized in Perth as an impermanent and fragile construction method associated with shack settlements. Rather, houses were constructed in the preferred method of the time, with suspended timber floors set on quarried limestone plinths that were often significantly elevated to accommodate sloping site conditions. Where high enough, the established tradition of fitting a garage or under-croft in the foundations was continued. Individual owners often incrementally added retaining walls and embankments within the lot to improve the accessibility (figure 10).

Overall, the lack of site grading, topographically responsive alignment of roads, small to medium sized homes, and large to very large lots all contributed to the low level of topographic manipulation. With City Beach's continued reliance on septic tanks (and no sewerage infill currently planned) backyard subdivision is not permitted, in turn limiting the potential for increased topographic manipulation to accommodate densification. Nonetheless, the replacement of most of the original housing stock with much larger modern homes with footprints of up to 500m^2 has driven plot ratios up from 15% in the 1950s to 40% at present (figure 5.3.d). This increase, combined with the addition of pools and tennis courts, has resulted in widespread ground levelling within individual lots throughout City Beach.

4. Quinns Rocks: 1960s site-specific suburb

Quinns Rocks originally comprised an isolated settlement of squatter's shacks similar to Wedge Island. The first subdivision in 1959 necessitated removing the shacks, although the occupants were given first choice of lots, and many shacks were relocated onto newly gazetted parcels (Arthur and Hunt-Smith 1994). This unique arrangement infused the suburb with an eclectic variety of vernacular building styles and a readymade community with strong connections to the location. Rainwater tanks and backyard ground water bores enabled the first residents to be water self-sufficient until water infrastructure was introduced in 1968.

Figure 11: 2012 oblique aerial view of Quinns Rocks (© Daryl Jones, 2012).

By the late 1960s, over 700 residential lots had been subdivided around a web of long kinked streets terminating in three-way intersections with numerous short cul-de-sac offshoots. Natural low points were retained as reserves for storm water detention and infiltration. While these features reflected subdivision standards of the era, the overall layout of Quinns Rocks was dictated more by the steep sand dune terrain than by the imposition of imported styles or application of urban design principles (figure 5.4.a). As a result, from plan view, the layout appears disorganized with poor legibility and permeability (figure 5.4.c). However, when experienced on the ground, the structure appears more legible, as roads generally follow the lay of the land along natural swales and circumnavigate around larger sand hills (figure 11).

With no earthworks undertaken prior to subdivision, lots were sold in an unlevelled and un-cleared state. Large lots averaging 1010m^2 gave an overall net density of 10 dwellings per hectare but were surveyed in a very wide variety of sizes. Ranging between 760m^2 and 2500m^2,

Figure 12: ground-level view illustrating disorganized Quinns Rocks streetscape, with long steep driveways and varied building positions and construction methods (author 2013).

the high 330% diversity of lot sizes generally responded to the characteristics of the terrain; on the more rugged sites, larger lots provided ample space to locate building envelopes within the varied terrain, with long steep driveways typically connecting houses perched on dune tops with the street below. The high diversity of lot sizes also influenced the wide range of dwelling footprint sizes, which ranged from under 100m^2 for the first shacks through to 160m^2 for the first generation of suburban homes. Since the 1960s, the replacement of housing stock has resulted in a steady increase in footprints, with some 400m^2 houses now amongst the largest found along the coast. Current dwelling footprints average 230m^2, with plot ratio ranging from under 10% for some remaining shacks through to 50% for the newest McMansions (figure 5.4.d).

Despite housing renewal, an eclectic range of topographically sensitive building techniques remain, including timber-pole, steel frame and concrete-slab-on-plinth construction (figure 12). As a result, topographic modification remains moderate, with the general dune morphology remaining intact and remnant dune vegetation still evident on some lots. Only a moderate degree of levelling for new house pads is evident, and this is typically contained well within the boundaries of each parcel (figure 5.4.b). A key factor in the low degree of topographic modification is the continued reliance of septic tanks prohibiting lot subdivision. However, with vacuum-sewerage infill soon to enable rezoning to up to 60 dwellings per hectare (City of Wanneroo 2010), the distinctive sand dune character of Quinns Rocks may be impacted over coming decades.

5. Craigie: 1970s large-scale suburban expansion

Fuelled by iron ore exports to Japan, Western Australia's 1970s mining boom led to increased prosperity and population growth in Perth (DTF 2004). Extensively planned suburban expansion to the north accommodated the demand for new housing. Spacious lots, modern dwellings set exclusively on concrete pads, and up-to-date amenities presented an attractive lifestyle alternative to older inner-ring suburbs. Influenced by mining practices, suburban development was conceived for the first time as a large-scale integrated engineering project. The requirements of sewerage, storm water, and underground electricity were incorporated into suburban layouts at the design phase, enabling improved infrastructural performance over systems retrofitted into older suburbs.

The suburb of Craigie is typical of northern suburban expansion of this era. Set sev`eral kilometres away from the coast to take advantage of the gently undulating terrain, the suburb is structured around an internal loop road with numerous cul-de-sacs and crescents joined by three-way intersections. Although subsequently critiqued for encouraging automobile reliance (Newman and Kenworthy 1999), cul-de-sacs were viewed at the time as a socially enabling design feature that transferred the "intimacy of personal contacts" found in higher density urban areas to the suburban context of single detached houses (TMCB 1975B, p. 6). In addition to

Figure 13: 1972 oblique aerial view over the subdivisions of Cragie and Kallaroo. Extensive clearing and grading for roads and infrastructure left lots mostly vegetated. Clearance of remaining natural vegetation was left to individual landowners. The initial clearing of road easements directly into the native vegetation in the foreground indicates limited re-grading of the natural topography (Courtesy of Aerial Surveys Australia).

eliminating through-traffic and encouraging neighbourly interaction, cul-de-sacs also offered the added advantage of reducing the total road area, which increased overall residential yields. With no street trees, footpaths, or power lines competing for space in local streets, road easements were narrowed to 18m, which facilitated addition yield gains.

During the development process, re-grading occurred along road easements to accommodate the gravity-falls required by sewerage and storm water infrastructure (figure 13). While significant, more extreme manipulation of the landscape was avoided by designing the street layouts around low points and ridgelines, which were left in semi-natural sates as public open space (figure 5.5.a). Although the

Figure 14: aerial view of back yard terracing to accommodate level outdoors entertainment area on sloping site, Kallaroo (2013).

infrastructural earthworks necessitated some re-grading of lots, many parcels were sold partially vegetated, with land clearing and site-works the responsibility of individual landowners (figure 5.5.b). Averaging 755m^2, parcels were smaller than earlier coastal subdivisions, but still significantly larger than typical inner-ring suburban lots (figure 5.5.c). Within this net density of 13 dwellings per hectare, lot sizes between 680m^2 and 1100m^2 fall within a relatively tight 160% range.

Low diversity of lot sizes also impacted dwelling footprint diversity. While average footprints of 220m^2 continued the post-WWII trend towards larger homes, the narrow 170% range between 150m^2 and 250m^2 reflected the mass-produced template of double-brick houses set on concrete slabs (figure 5.5.d). While brick or limestone plinths were used to ground the earliest examples of concrete slab construction, economies of scale mandated flat sand-pads larger than the building footprint. As sites were not terraced prior to sale, levelling to accommodate concrete slabs occurred on lot-by-lot basis.

22% plot ratios ensured enough space remained inside individual lot boundaries to accommodate changes in level with embankments and retaining walls. Split-level concrete slabs that were popular at the time were also able to accommodate some site level changes, although interior step-downs were generally designed to separate living areas in model homes, rather than in response to external site conditions.

Over time, many homeowners undertook small scale terracing within their sloping lots to accommodate level entertainment areas (figure 14). Even when reproduced over many lots, the very localized scale of this landscaping work and cost effectiveness of balancing cut and fill on site mitigated its impact. Overall, re-grading to accommodate streets, infrastructure, house pads, and back yards resulted in some topographical disturbance, although the original landform generally remains legible. Given that the relatively square lot proportions, the absence of rear laneways, and limited backyards all prevent suburban infill around the current housing stock, the current level of topographic modification in Craigie is likely to remain stable until significant housing renewal occurs.

6. Ocean Reef: 1980s total suburb clearing

Established in several phases throughout the 1980s, Ocean Reef is illustrative of a significant transitional period towards suburban terracing. Whereas previous infrastructure-oriented earthworks left residual patches of native vegetation, at Ocean Reef the total clearing and re-grading of the entire development site created a *tabula rasa* for subdivision (figure 15). In the initial phases of development, re-grading smoothed out the natural roughness of the terrain without necessarily levelling it. This necessitated some additional site-works on individual lots accommodate concrete pads. In areas of Ocean Reef developed later in the decade, long limestone retaining walls were incorporated behind some lots prior to the sale of land. These first retaining walls were used to moderate the slopes of steeper lots rather than to create completely level parcels (figure 16). The novelty

Figure 15: 1980 oblique aerial view over Heathridge and Ocean Reef. Total clearance and smoothing of the site without retaining walls prior to construction of streets and houses is evident (courtesy of State Library of Western Australia).

of planning for the first retaining walls is revealed in their description in a nearby contemporaneous subdivision as “enhancing visual aspects of the development by adding points of interest” (TMCB 1975A, p. 4).

By the late 1970s, the coast was established as a legitimate alternative to Perth’s traditional riverside locations for upmarket housing. Due to its prime location, Ocean Reef was laid out with generous proportions that went against the general trend towards more compact subdivisions. 20m wide road easements were set in branching patterns of long cul-de-sacs that created the impression of semi-privatized enclaves. The general alignment of local roads parallel to the slope constructed a grandstand effect to maximize the highly valuable ocean views of each lot (figures 5.6.a and 5.6.b). Within this layout, parcels average 860m^2 in size, resulting in a low net density of 12 dwellings per hectare (figure 5.6.c). With the increased residential

Figure 16: 1987 oblique aerial view of Ocean Reef. Retaining walls are evident behind, but not between, lots (courtesy of City of Joondalup Local History Library).

yield that resulted from the high number of cul-de-sacs and associated poor street permeability, gross density was maintained at 9 dwellings per hectare. With parcels ranging in size from 780m^2 to 1100m^2, lot diversity is relatively low at 140%.

Dwelling footprints average 280m^2, although the popularity of double story homes in Ocean Reef frequently result in significantly larger floor areas. Two story dwellings also account for the high 310% diversity of dwelling footprints that range from 150m^2 for compact multilevel Mediterranean-style homes to 470m^2 for sprawling bungalows (figure 5.6.d). In addition to the expansive level pads required to construct double-story brick houses on concrete slabs, significant retaining and levelling is evident within individual lots to accommodate ancillary structures, entertainment areas, swimming pools, and even tennis courts. When combined with average plot ratios of 32%, the degree of topographic modification in Ocean reef is high on individual lots, but lower on road easements that generally follow the lay of the land.

Figure 17: 1993 oblique aerial view of the development of Kinross (left background), illustrating the first extensive use of retaining walls between all lots. By comparison, the mostly developed suburb of Currambine (right middle-ground) does not include retaining walls along property boundaries (courtesy Aerial Surveys Australia, State Library of Western Australia).

7. Mindarie Keys: 1990s total suburb engineering

By the early 1990s, retaining walls evolved from slope mitigation devices incorporated behind particularly steep lots, to comprehensive infrastructural systems that framed every lot within a suburban development (figure 17). The use of retaining walls to totally re-engineer the natural terrain into perfectly level building lots streamlined the suburban development process at all scales. The absence of site slope enabled increased standardization of house design and construction, irrespective of the topographic conditions of the location. Comprehensive earthworks also facilitated more efficient storm water and sewerage systems, and enabled roads to be set to standardized radii, grades, and profiles. Additionally, the mass movement of earth enabled filling of the natural swales that are common in coastal sand dune terrain. This eliminated engineering

Figure 18: axonometric aerial view of Mindarie Keys illustrating retaining wall system creating terraced plinth to maximize ocean views (2013).

Figure 19: ground-level view of Mindarie Keys streetscape illustrating division created by 4.5m high combination retaining wall/boundary wall between adjacent lots (author 2013).

complications associated with draining gravity-fed storm water and sewerage from low points.

While originally established on more undulating terrain, this development model readily adapted to steeper sites. The mid-1990s development of Mindarie Keys is typical of this fully re-engineered suburban development model on steep terrain. Established in phases around an artificial recreational harbour, Mindarie Keys is laid out in precincts containing approximately 200 lots each. In response to critique of automobile dependency associated with the extensive use of cul-de-sacs in 1980s suburban development (Newman and Kenworthy 1999), local streets connect to three and four-way intersections. Circular traffic systems and limited points of entry to each precinct re-create the neighbourhood environment provided by cul-de-sacs whilst offering improved permeability and legibility.

Extensive earthworks undertaken prior to subdivision created a completely artificial topography unrelated to the pre-existing terrain (figures 5.7.a and 5.7.b). With boundary retaining walls exceeding 6m in some instances, each precinct is essentially placed on a grandstand-like plinth that is designed to equally distribute ocean views to each lot (figure 18). With low points also eliminated by the large-scale earthworks, the location and typology of large parks became less topographically predetermined by their need to double as storm water detention basins. At Mindarie Keys, more numerous smaller parks and linear parks take advantage of this increased freedom and offer improved pedestrian catchments and non-vehicular connection.

Within the layout, lots average 710m^2, which equates to a net density of 14 dwellings per hectare. Ranging in area between 500m^2 and 970m^2, lots exhibit a relatively high diversity of 195%, with the largest parcels associated with the prime positions for unobstructed 'front row' ocean views (figure 5.7.c). Dwelling footprints average 315m^2, with a 190% range between 230m^2 and 430m^2 (figure 5.7.d). As in Ocean Reef, the predominance of double storey dwellings at Mindarie Keys result in actual floor areas that are up to double the footprint size.

The very high average 45% plot ratios that result from building large structures on medium sized lots leave little space within each parcel to accommodate slope variations. Within these confines on steep sites, strategies used in previous decades — including positioning the house within the lot, small-scale landscape terracing, or split-level homes with under crofts — are less effective. In this regard, the creation of terraced flat parcels prior to the subdivision of Mindarie reduces the potential for site work complications between neighbouring properties. Nevertheless, the placement of retaining walls along each property boundary frequently results in significant level differences between adjoining lots (figure 19). In these situations, overshadowing of outdoor areas and the potential for overlooking are likely unintended side effects. Moreover, the over-the-fence backyard interactions that have historically been a feature of suburban life are unlikely to persist over a 4m high retaining wall topped with a 1.8m high boundary fence.

8. Capricorn: 2000s liveable neighbourhood

Capricorn is situated at the northern most extents of coastal development activity in the Perth metropolitan area. The subdivision was governed by new design guidelines established in response to growing critique of the negative social and economic impacts associated with commuter suburbs developed since the 1950s. Drawing on alternative approaches to conventional low-density suburbs that emerged in international discourse on Smart Growth and New Urbanism in the 1990s (Jones 2012), *Liveable Neighbourhoods* mandated higher densities, diversity, walkability, permeability, legibility, community interaction, commerce, and streetscape quality (WAPC 2004b). Influenced by founding New Urbanists Peter Calthorpe and Andrés Duany (who have both provided structure planning and

Figure 20: axonometric aerial view of Capricorn, illustrating retaining wall system creating level rear-access lots on sloping terrain (2013).

suburban design services in Perth's Northern Corridor), the very prescriptive guidelines favoured traditional gridded street layouts focussed on activity nodes.

The impact of the *Liveable Neighbourhoods* design guidelines on Capricorn is evident at several scales. The layout of gridded and parallel curving streets connected with four-way and three-way intersections are significantly more permeable and legible than the internalized layouts of cul-de-sacs and loops that characterized suburban design up until the 1990s (figure 20). 16m wide roadway easements continue the general trend since the 1970s towards narrower streetscapes than the historical 20m standard.

Within this structure, lots average 470m^2, which equates to a net density of 21 dwellings per hectare. Individual parcels range 190% in area from 340m^2 to 640m^2, with approximately one third of the smaller lots serviced from the rear via 6m wide laneways (figure

Figure 21: ground-level view at Capricorn through empty terraced lots. House under construction in background is setback the minimum 1m distance from retaining walls on lot boundary (author 2012).

Figure 22: ground-level view of Capricorn streetscape created by level rear-access lots, where the rear lane is set 2m higher than the street (author 2013).

5.8.c). The reappearance of laneways following a six-decade absence from Perth suburban development represents one of the most visible impacts of the *Liveable Neighbourhoods* guidelines; narrower lots permit more spatially efficient dwelling layouts and cleaner streetscapes unobstructed by driveways. Despite the prevalence of compact rear access lots, plot ratios of over 50% result in dwelling footprints averaging 250m^2 (figure 5.8.d) The tendency to build out to the maximum plot ratio results in dwelling footprints that match the lot size diversity of 190% and range between 180m^2 to 350m^2. The mandatory incorporation of the *Liveable Neighbourhoods* guidelines in the design of Capricorn resulted in modest increases urban density, diversity, and permeability.

Nevertheless, the conservation of natural topography did not improve, despite the design guidelines stating that "lot size and dimensions should enable dwellings to be sited to … minimize earthworks and retaining walls on sloping sites" (WAPC 2007, p. 3:9). In reality, Capricorn was established using the same site engineering techniques as pioneered in 1990s subdivisions, with the total clearing and terracing of the landform undertaken prior to the sale of lots (figures 5.8.a and 5.8.b). With entrenched construction techniques continuing to dictate flat sites, and buildings covering over half their lot, few opportunities exist for maintaining natural topography between dwellings and lot boundaries (figure 21). Additionally, the rear access lots actually increase the visual impact of terracing; when set on a hillside, high retaining walls on the street boundary are required to match the level of the rear laneway, creating a fortified streetscape of blind frontages (figure 22).

Analysis: factors influencing eight decades of increasing topographic manipulation

This section distils establishes the primary drivers of the historical trend towards increased topographic manipulation in the suburban development of the Perth northern corridor. Ten key metrics and factors are distilled from the case studies and graphically collated for comparison.

1. Pre-development original landform

Most case study sites are located within 500m of the coast; only Capricorn and Craigie located a little further inland at 1.5km and 2.5km respectively. Despite all being situated on the same coastal geological classification, the morphology of each site prior to development varied significantly. This variation is quantified by ranking each site according to the steepness and degree of topographic complexity (defined by the prevalence of depressions and knolls) of the original landforms (figures 5.1.a to 5.8.a). The earliest three case study sites all exhibited low original topographic steepness and complexity, with Wedge Island (1930s) ranked second, Watermans Bay (1940s) fourth, and City Beach (1950s) third. Conversely, the newest three case study sites all exhibited high original topographic steepness and complexity, with Ocean Reef (1980s) ranked seventh, Mindarie Keys (1990s) fifth, and Capricorn (2000s) sixth. Two sites in the middle of the case study period disturb this general trend to developing steeper sites over time; Quinns Rocks (1960s) exhibited the highest degree of topographic steepness and complexity, and Craigie (1970s) the lowest.

2. Post-development landform modification

The relative degree of topographic modification undertaken in the development of each study site is established by evaluating residual evidence of the original landform in recent topographic data captures (figures 5.1.b to 5.8.b). With virtually no impact on the dune formations, Wedge Island (1930s) exhibits the lowest degree of topographic manipulation (figure 5.1.b). With the original dune formation clearly visible beneath some minor road and lot re-grading, City Beach (1950s) ranks second lowest (figure 5.3.b). While the gridded road cuts at Watermans Bay (1940s) are clearly visible in recent topographic captures, the overall form of the terrain remains intact, resulting in the third lowest degree of topographic manipulation (figure 5.2.b).

In subsequent years, each new decade of development corresponded to increased topographic modification. At Quinns Rocks (1960s), cut and fill into the slopes of individual lots are highly visible on the modified contour signature, but are mitigated by the influence of roads that follow natural swales (figure 5.4.b). At Craigie (1970s), the impact of bulk earthworks prior to development are moderated by the undulating nature of the site and the preserving of steeper areas as parkland (figure 5.5.b). At Ocean Reef (1980s), retaining walls create long terraces that roughly trace the original contours (figure 5.6.b). At Mindarie Keys (1990s), the main ridgeline is completely re-graded to reorient to the ocean, with linear parks set along the natural swales the only legible reference to the original landform (figure 5.7.b). And finally, Capricorn (2000s) exhibits the highest degree of topographic manipulation, with no discernable correlation between the modified landform and its original state (figure 5.8.b).

3. Lot densities

Over the study period, average densities of the case study areas decreased from around 14 net dwellings per hectare in Watermans Bay (1940s), to a low of 10 dwellings per hectare in City Beach (1950s) and Quinns Rocks (1960s) (figures 5.1.c to 5.8.c). From this historically low average density characterised by quarter-acre (1011m^2) suburban lots, densities increased, with the Craigie (1970s) and Ocean Reef (1980s) averaging 12 to 13 dwellings per hectare. At 14 dwellings per hectare, Mindarie Keys (1990s) equalled the density established half a century earlier Waterman's Bay. Averaging 21 dwellings per hectare, Capricorn (2000s) established the highest average densities of the case studies. Over the eight decades, the gap between net and gross densities generally contracted, as narrower streets, increased use of cul-de-sacs, and reduction in leftover areas considered unsuitable for building, helped to increase residential yields.

4. Diversity of lot sizes

Lot size diversity trended more variably across the case studies. The most extreme highs and lows occurred in the first two decades of the case study period, with over 400% variation in the socially implied lots around beach shacks in Wedge Island, and 0% variation in the identical lots of the 1940s grid of Watermans Bay. Lot diversity then increased to 250% and 330% in the looser layouts of City Beach and Quinns Rocks respectively, before reversing and declining to 160% at Craigie and 140% at Ocean Reef. Following this low point in the 1980s, lot size diversity increased again to around 190% following the incorporation of larger 'premium' lots in Mindarie Keys, and smaller rear-access lots at Capricorn.

5 & 6. Dwelling footprint sizes and plot ratios

Average dwelling footprints increased linearly in each decade between the 1930s and the 1990s, ranging from under 100m^2 at Wedge Island, to 315m^2 at Mindarie Keys (figures 5.1.d to 5.8.d). Following this uninterrupted tripling of building footprints over seven decades, Capricorn registered the only decline, with 250m^2 average dwelling footprints finally impacted by the trend towards smaller lots. As the expression of dwelling footprints as a percentage of lot size (density), plot ratios place this data in context. Both Watermans Bay and City Beach exhibited plot ratios of 7%, with the larger lots at City Beach neutralized by larger original housing stock. From this low mark in the 1950s, plot ratios rose marginally at Quinns Rocks in the 1960s, before increasing by approximately 10% in each decade up to the 1990s. In the 2000s, Capricorn reached the significant threshold of 50%, whereby each dwelling covers half of its lot.

7. Street layouts and design

Across the study period, the design of suburban street layouts fall into three general categories. The most distinctive is the transposing of the urban grid from its traditional inner-city environment to a coastal setting at Watermans Bay (figures 5.1.c to 5.8.c). The second category includes site-derived layouts that closely follow the natural lay of the land. Wedge Island is the purest embodiment of this category, whilst the swale-tracking roads of Quinns Rocks are its closest approximation amongst the officially designed suburbs. City Beach also follows this pattern, albeit with added formal refinement of the street curves. Facilitated by increasing degrees of site engineering, the layouts of the newest suburbs of Craigie, Ocean Reef, Mindarie Keys, and Capricorn are influenced less by their respective sites and more by superimposed planning — and later urban design — principles. This third category of suburban layout design is characterized by a tension between socially based theories for community building, and pressure for higher residential yields to capitalize on increasing land values.

Since the 1940s, road easements decreased from 20m to 15m wide in the most recent suburban developments. While narrower streets theoretically result in a lower topographic disturbance, in practice this was offset by the need for more streets and laneways to accommodate smaller lots and higher yields. Permeability of street intersections decreased from the 1960s, with the elimination of the four-way intersections that dominated the Watermans Bay and City Beach layouts. The widespread use of cul-de-sacs is first evident in Quinns Rocks, and peaks in Ocean Reef, before a return to three and four-way intersections at Mindarie Keys and Capricorn.

8. Infrastructure

Of the range of utilities that serve modern suburbs (electricity, phone, water), sewerage had the most impact over suburban morphology in the Perth northern corridor. The incorporation of gravity-sewerage into the development of Craigie in the 1970s marks a clear break from earlier septic systems. In Craigie — and later in Ocean Reef, Mindarie Keys, and Capricorn — the integration of sewerage is registered through higher densities, smoothly graded street falls, and elimination of topographic depressions that are more difficult to service by gravity. Storm water follows a similar pattern, with the integration of detention basins into parks replacing localized soak wells and sumps in natural low points. From the development of Craigie onwards, this has tended to result in the consolidation of public open space into the lowest point in a suburb.

9. Building construction techniques

Three main construction techniques prevailed at various stages in the development of the eight case study suburbs. Timber framed structures clad in either corrugated iron or asbestos sheeting formed the original beachside construction method. Shacks at Wedge Island and Quinns Rocks were constructed in this way, as were the first official houses at Watermans Bay. With stumps or stilts placing the building above the terrain, timber framing required the lowest degree of topographic modification. The second construction technique comprised double brick walls, set on a foundation plinth made of locally quarried limestone blocks, with suspended hardwood floors. Most of Watermans Bay and nearly all of City Beach were developed using this technique. Moderate degrees of topographic disturbance were limited to the on-site digging required to establish the foundations. On particularly steep sites, tall foundation walls placed the finished floor level of the house up to one storey above the ground.

Double brick walls set on a concrete slab represent the third major construction technique. Like the timber floors they replaced, the first concrete slabs were set up on plinths encased by limestone or brick. Some dwellings in City Beach and most houses in Quinns Rocks were constructed in this manner. From the development of Craigie onwards, concrete slabs were poured onto a level sand pad that needed to be at least 1m larger than the dwelling footprint to account for erosion and the natural angle of repose of the sand. Given that most dwellings are set back 1m from the side fence, expanding sand pads needed to be retained with walls on the property boundary. With this technique, the traditional limestone plinth essentially migrated from the outer wall of the house to the boundary of the lot. The practice of establishing each lot as a plinth was enlarged at Mindarie Keys to encompass the elevation of entire suburban precincts onto plinths.

10. Diversity of dwelling sizes

Due to limited relevant historical records, diversity of dwelling sizes is a difficult metric to measure in the older case study areas that have undergone housing stock renewal. Based on the footprints of the few remaining original houses, it is reasonable to assume that Watermans Bay and City Beach exhibited low dwelling footprint diversity when first developed. With an unusual combination of relocated shacks and suburban houses, Quinns Rocks exhibited a higher degree of original diversity. In all these cases, higher diversity of dwelling sizes emerged over time as the original housing stock was enlarged through renovating or rebuilding. With originally low plot ratios that provided ample space to expand within each lot, the four oldest case studies now exhibit the highest diversity; Quinns Rocks ranks highest with a 400% range, followed by Wedge Island (375%), City Beach (330%), and Watermans Bay (230%).

In the newer case study areas, the diversity of the original dwelling footprints is lower. With single density zoning throughout, Craigie exhibits the lowest diversity (170%). Despite mandated housing diversity through the inclusion of compact rear access lots, the range of footprint sizes in Capricorn (190%) is actually only marginally higher and equal to Mindarie Keys. Only Ocean Reef (310%) exhibits high diversity, although this is largely attributable to a mix of sprawling single story bungalows and more compact double story dwellings with similar total floor areas. Moreover, when renewal of the original housing stock does start occurring in these newer suburbs, the higher plot ratios are likely to limit significant increases in dwelling diversity.

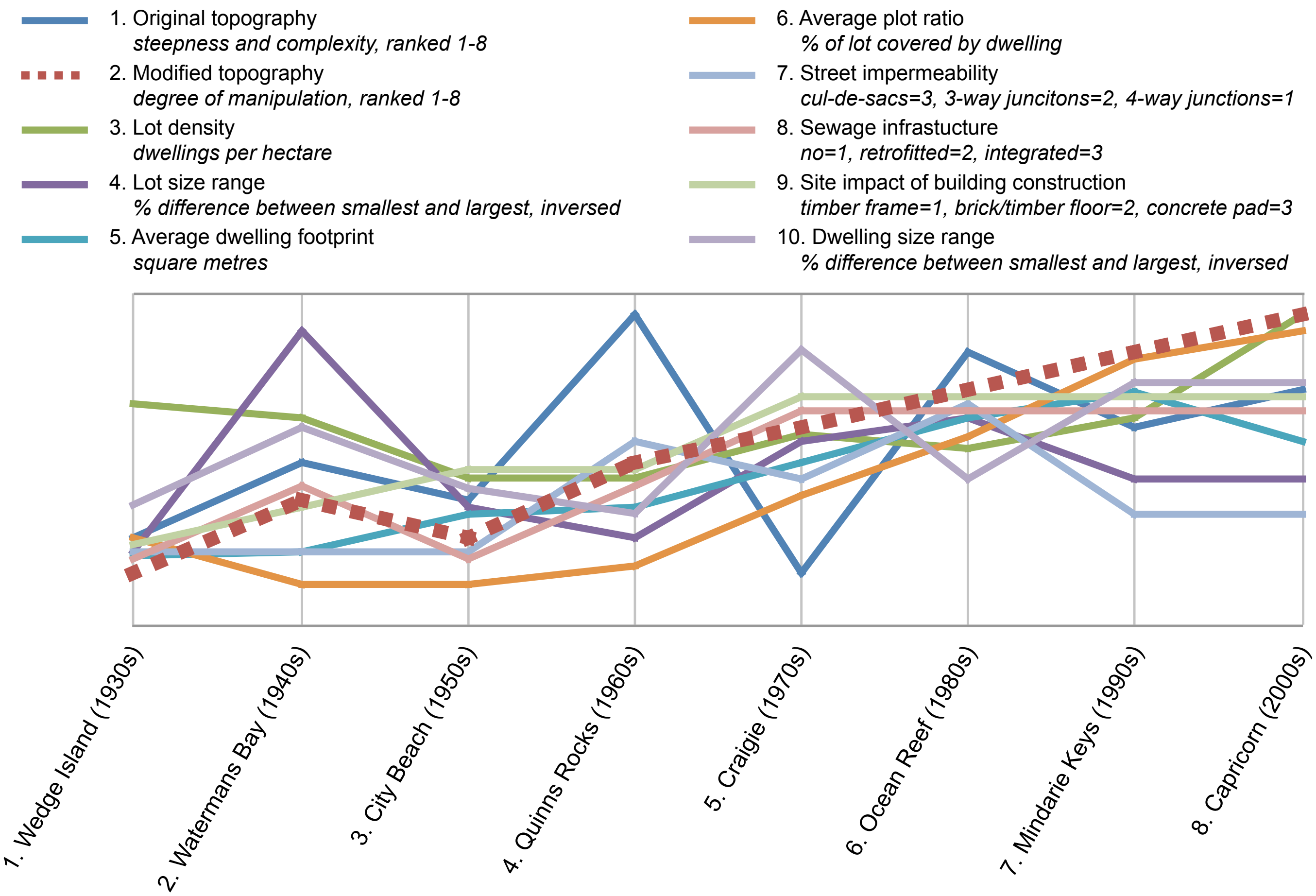

Figure 23: relative comparison of changes in suburban development metrics over the case study period.

Comparative analysis

To establish their relative impact on landform modification, the ten factors distilled in the previous section are superimposed into a single visual representation (figure 23). The native units for each metric in the graph (m^2, %, rank) are proportionally scaled for comparison against the base (factor 2) ranking the degree of topographic modification in each case study site.

Of the factors, the correlation between street permeability (factor 7) and diversity of lot sizes (factor 4) with the emergence of topographic terracing are lowest. High permeability is associated with the older suburbs that exhibited low topographic modification, and declining permeability correlates with increasing topographic modification up until the 1980s. Nevertheless, a return to improved permeability in the newest suburbs does not impact the continued increase in topographic modification. Similarly, decreasing diversity of lot sizes between the 1950s and 1980s correlates with increasing topographic modification. However, this correlation is absent from the 1940s grid, where zero variation in lot sizes is associated with lower topographic modification. Moreover, the reintroduction of a range of lot sizes in the most recent developments has not resulted in a decrease in topographic modification.

Dwelling diversity (factor 10) and steepness of the original landform (factor 1) correlate moderately with topographic modification across the study period. The range of dwelling sizes is generally higher in the oldest, less topographically modified suburbs, and lowest in the newest terraced suburbs. Nonetheless, in a significant variation to this trend between the 1970s and 1980s, a sharp improvement in diversity has no impact on increasing topographic modification over this timeframe. The steepness and complexity of the original landform also exhibit a similar pattern of influence over topographic modification. In the oldest suburbs, the lowest degrees topographic modification correlate with the most undulating sites, while in the newest suburbs, the highest degrees of topographic modification correlate with steep sites. The case studies from the 1960s and 1970s abruptly interrupt this trend, with low topographic modification on a steep site, and higher modification on an undulating site.

The impact of construction techniques (factor 9) and sewerage infrastructure (factor 8) correlate more consistently with topographic modification in the older suburbs, although their influence diminishes over time. The shift from timber framing to brick with timber floor construction and finally to concrete slabs correlates with increasing topographic modification. Nevertheless, slab construction techniques subsequently remained largely unchanged for four decades while topographic modification continued to escalate. Similarly, while the introduction of integrated sewerage infrastructure correlates with increased topographic modification in the 1970s, the technology has not significantly changed in the time since.

Of the all the factors, lot densities (factor 3), dwelling sizes (factor 5), and their combination as plot ratios (factor 6) correlate most consistently with increasing topographic modification over eight decades. The historically largest lots of the 1950s correlate with low topographic modification, while the smallest average lots of the 2000s correspond with the highest degree of topographic modification. Similarly, the historically consistent increase in average dwelling sizes also consistently correlates with progressively higher topographic modification. When average lot and dwelling sizes are combined, the resultant plot ratios closely track increases in topographic modification in each decade.

Discussion: plot ratios, policy, mechanisms

Plot ratios in the eight coastal suburbs increased more than seven-fold since the 1950s. The halving of average lot sizes and tripling of house footprints over this period drove this increase. The trend to smaller lots in the case studies correlates with the findings of Grose (2010), who demonstrates the declining size of usable outdoor space during the 20th century across a range of mainly non-coastal Perth suburban residential lots. Moreover, the trend to larger houses is reflected in the Australia-wide research of Hall (2010a; 2010b), who identifies the proportionally higher rate of increase in dwelling footprints compared with shrinkage of lot sizes. Hall also observes a rather sudden elimination of usable outdoor space in the early 1990s, which corresponds with the emergence of suburban terracing in the case studies.

While plot ratios in the Perth Northern Corridor case studies increased relatively linearly from the 1950s, the crossing of the 50% threshold marks a tipping point in the relationship between built and un-built space on a lot. From a mathematical perspective, a 50% plot ratio leaves half the lot as un-built outdoor space, which in the case of a 500m^2 lot would appear ample. However, in fully detached suburban housing, a significant portion of outdoor space is absorbed in the narrow setbacks between the external walls of the house and the lot boundary, leaving little or no useable outdoor space (Hall 2010a; 2010b). The narrow and fragmented nature of resultant leftover spaces is also less conducive to absorbing topographic variation within each lot. On sites with sloping street frontages in particular, 1m setbacks on both sides of the dwelling eliminate any possibility of absorbing topographic variation. Due to the generous front setbacks persist in new suburban developments, lots that slope away from the street (up or down) may possess greater capacity for absorbing topographic variation on site.

Influence of planning codes on plot ratios and topographic modification

Plot ratios are governed by Western Australia's residential codes (R-codes), which control density, streetscapes, boundary setbacks, open space, site works, building bulk, overlooking, and climatic considerations. Following a shift from a prescriptive basis to a more performance-based criteria in 2002, the codes are considered to be amongst the most progressive in Australia. Prior to 2002, maximum plot ratios were not specified for residential densities fewer than 35 dwellings per hectare, with only the setback provisions controlling maximum coverage (TPBWA 1985; WADPUD 1991). Following major revisions in 2002 that acknowledged the trend to larger houses on smaller lots, site coverage limits were specified at all densities. As reflected in the case studies, these requirements range from 40% at densities of 10 dwellings per hectare, to 55% at 40 dwellings per hectare (WAPC 2002). In subsequent editions of the R-codes, 1m minimum setbacks between single story buildings and property boundaries remained consistent, although the introduction of performance based-criteria in 2002 also enabled the introduction of 0m setbacks in some instances.

In addition to the introduction of plot ratio and setback requirements, subsequent editions of the R-codes addressed topographic conservation increasingly directly. In the 1982 codes, no reference at all was made to site conditions or topography (WARCAC 1982). In 1985, topography was only briefly addressed with regards to how sloping sites affect building heights and setbacks (TPBWA 1985). The 1991 edition expanded this reference slightly, acknowledging that the subdivision of a topographically irregular site may require some lots to be "significantly larger than others to accommodate slope to be workable" (WADPUD 1991). The 2002 R-codes were far more explicit, noting that "variations in topography" make an "important contribution to local character." The codes observe that "respecting the natural topography" enables potential views out of the locality to be optimised by the maximum number of dwellings. Major interference with the "natural ground level" should therefore be avoided (WAPC 2002). When levelling is necessary, excavation is suggested as less-visually obtrusive alternative to building up the levels on a lot.

With regards to conservation of natural topography, the R-codes appear most effective in single-lot redevelopment within established older suburban areas. Development is required to "respond to the natural features of the site" and "require minimal excavation/fill" (WAPC 2013). In support of this policy, retaining walls higher than 0.5m are required to be treated as though a building and be set back from the property boundary on a sliding scale proportional to height. Nevertheless, slope is still assumed to be constant across a site. Where variable, convex, or concave terrain exists, "the natural contours should be interpreted to… smooth out such anomalies" (WAPC 2003). Under this definition, the "deemed natural ground level" (WAPC 2013) of a site is reduced to a simplified surface linking spot heights at each corner of the lot.

Moreover, in new subdivisions, "natural ground" is defined even more artificial terms as the level established prior to the erection of buildings (WAPC 2002). Under this definition, large-scale suburban terracing and associated retaining walls are effectively 'naturalized' into the landscape (WAPC 2013). The degree of cut and fill across a subdivision is proposed by the developer and vetted on a case-by-case basis through the framework of the *Liveable Neighbourhoods* design guidelines (WAPC 2004b) by the local government with oversight by the state planning body (WAPC 2003). As a result, the R-codes exert very little real influence over the degree of topographic modification in new developments. At best, the codes serve to ameliorate potential overlooking or overshadowing issues between adjacent properties, whose levels are already set.

Over the past three decades, the R-codes addressed plot ratios and topographic conservation in progressively more direct terms. Nevertheless, the case studies demonstrate that this period corresponds with the most extensive topographic modification of new suburbs in the Perth Northern Corridor. This reveals a disjunction between the conceptual intent of the codes and the reality of what minimum metrics actually permit on the ground when repeatedly probed and optimized by development and construction companies in ways that were not originally foreseen. In this context — much as Hall (2010a; 2010b) observes across Australia with regards to shrinking backyards — the R-codes do not explicitly encourage terracing, but neither do they actively prevent it. Rather, planning policy appears to consistently lag behind powerful market forces dictating larger dwellings and the engineering capabilities for total site remodelling.

Reducing topographic modification in future development

Entrenched development frameworks, government policies and economic forces dictating smaller lots, and consumer expectations for large fully detached houses are all unlikely to change significantly in the near term. Therefore, retaining more natural topographic character in future suburban developments require reconciling these realities with the nuances of coastal sand dune terrain. Towards this goal, discrepancies between the intent of planning policies and the constructed reality should be narrowed. Existing R-codes that are reasonably effective at retaining topographic form and character in established residential areas should exert similar levels of control over new suburban developments. Terming an obviously artificial terraced landscape "natural ground" is convenient in planning terms but deeply problematic for landform conservation.

Historically, conserving and celebrating natural landform contributed to the creation of vibrant local communities. Along the coast of Western Australia, a degree of urban disorder informed the characters of vernacular settlement patterns (such as Wedge Island), which tended to be dictated by the lay of the land. This looseness persevered in the layouts of some older suburbs such as Quinns Rocks, and in the vernacular architecture and dwelling position of more ordered older suburbs such as Watermans Bay. However, in newer developments the focus of the design guidelines on urban order, hierarchy and legibility often outweighs these opportunities. Therefore, the present focus of the *Liveable Neighbourhoods* design guidelines (WAPC 2004b) on largely imported New Urbanist values should be rebalanced towards accommodating local site factors, even at the expense of some urban coherency.

While exhibiting larger lots and smaller dwellings, the case studies of older suburbs provide numerous additional cues to loosening suburban design in new developments. Average dwelling floor areas are unlikely to change, but other factors may be able to be unstitched from this historical narrative of progressively increasing topographic modification and alternatives sought. For example, streetscapes, construction techniques, and dwelling diversity all have potential to be reimagined and influence more topographically sensitive urban design and planning practices. Whereas lots on the newest engineered suburbs are typically matched to symmetrically engineered street profiles (WAPC 2013), older suburbs tend to exhibit asymmetrical streetscapes. Streets running across slopes tend to have high and low sides resulting in some houses being set partially below street level. Allowing the street shoulder space and front setback space within lots to absorb more topographic variation may reduce or eliminate retaining walls behind lots in new developments.

To combat the continued domination of brick-on-concrete-slab construction, 'floating' steel-framed homes that reference the original coastal beach shacks have been tested in several new developments. While yet to be tested *en mass*, pole construction techniques have demonstrated low topographic impact and high degrees of amenity. Furthermore, greater use of two storey dwellings could theoretically increase the amount of outdoor space available for accommodating level changes within a lot. Nonetheless, returning to larger outdoor spaces on suburban lots is not essential. While Grose (2009) and Hall (2010a, 2010b) convey the ecological and cultural benefits offered by the large backyards found in older suburbs, busy modern lifestyles lead primarily in indoors or in dedicated recreational facilities limit the attractiveness of maintaining a yard for many people. Moreover, changing demographics have resulted in a reduction in the number of stereotypical nuclear suburban families, for whom a significant portion of family life was played out in the backyard (ABS 2010). This shift to smaller households provides a rational for designing alternative suburban models containing greater variation of housing types between large fully detached houses at the one extreme and shared housing at the other (Wuff et al. 2004; Leinberger 2005). Highly variable housing types and associated lot sizes could potentially be calibrated to variations the topography, resulting in a more flexible suburban model. By embodying what Brendon Gleeson (2006) refers to in the Australian suburban context as "good scruffiness," variability is the physical manifestation of topographic complexity.

Conclusion: terracing results from incremental changes

The eight case studies provide coherent account of the historical transformations in coastal suburban development in the Perth Northern Corridor. In each decade since the 1950s, topographic modification steadily increased due to a range of factors. These include decreasing lot sizes, increasing dwelling footprints, changes in construction techniques, changes in the use of outdoor space, incorporation of more efficient infrastructure, tighter road engineering standards, greater physical capacity to manipulate the ground, and development of more rugged sites. In the 1990s, these factors converged to a tipping point where suburban terracing emerged as the apparently logical extension of incremental changes to site preparation. In the 2000s, following concerns with regards to the visual and ecological impacts of large-scale site engineering, planning codes and design guidelines sought to reduce terracing. However, the unintended result was more retaining walls, not fewer. Incorporating greater topographic sensitivity in future suburban developments requires elevating the importance of respecting site conditions in urban policy, even if this results in less ordered layouts. While exhibiting lower densities, numerous characteristics of older suburbs also remain instructive for new development, including construction techniques, streetscape profiles and dwelling and lot variability.

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