ROOF AND FACADE GARDENS

Darren Holloway, Peter Ho and Boyd Boxshall

Boughouse

SUMMARY OF

ACTIONS TOWARDS SUSTAINABLE OUTCOMES

Environmental Issues/Principal Impacts

- There is a worldwide trend towards the application of new methodologies that attempt to integrate principles of ecological 'sustainability'. These methodologies can be viewed as part of the 'greening' process in contemporary society.
- 'Urban greening' has evolved as an important discipline to deal with sustainability issues in our built environment.
- The development of roof and facade gardens have considerable potential as mechanisms of urban greening by:
  - Mitigating the urban heat island effect.
  - Improving building performance by reducing consumption of energy.
  - Restoring a diverse ecology to urban areas.
  - Improving air quality through pollution adsorption and oxygen generation.
  - Recycling storm water and grey water.
  - High frequency noise abatement.
  - Improving visual amenity and providing psychological benefits.

Basic Strategies

- Consider the types of function and social interaction that are required. These requirements will be informed and modified by a thorough assessment at the outset.
- Assess the existing natural and built environment to quantify constraints and linkages. What are the limits to plant growth in the area? What are the links to existing ecosystems?
- Assess the building/s to determine structural considerations and optimisations of passive gain applications. What additional structure will be required? Where is the best location for the plant elements in terms of shading or insulation of the building?
- Create opportunities for multiple functions within the planting, to achieve highest overall efficiency.
- Evaluate safety, access, and maintenance at the design stage.
- Integrate assessments and consider most appropriate form of planting.
- A combination of techniques will often be required to achieve a site-specific design solution.

Cutting EDGe Strategies

- Development of an Integrated Plantscape System, creating interfaces between roof gardens and ground-based landscapes with vertical gardens.
- Integrating storm water collection and grey water recycling.
- Purpose designed roofs and facades for garden application.
- Fixing pre-grown modular plant panels to facades.
- Utilisation of passive heat exchange properties of buildings to reduce core temperatures and move fragrances.

Synergies and References

- *BDP Environment Design Guide*: DES 2; DES 40; DES 43; DES 45; TEC 10; GEN 3; PRO 25.
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- Osmundson, T, 1999, *Roof Gardens: History, Design and Construction*, WW Norton & Company Inc, New York.
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1.0 INTRODUCTION

Environmental design is in the broadest sense, the human response to the understanding that we are a part of our environment. This is the design realisation that ecology matters. This area of human endeavour has undergone a rapid transformation in development. For example, the application of vegetation to building facades and roofs has emerged as an important discipline addressing urban greening. This transformation can be articulated as:

1) "a shift from an equilibrium point of view where local populations and ecosystems are viewed as in balance with local resources and conditions, to a dis-equilibrium point of view where history matters and populations and ecosystems are continually being influenced by disturbances; and

2) a shift from considering populations and ecosystems as relatively closed or autonomous systems independent of their surroundings, to considering both populations and ecosystems an 'open' and strongly influenced by the input and output or 'flux' of material and individuals across borders." (Johnson & Hill, 2002)

'Greening' and 'sustainability' have developed as key terms to describe processes and outcomes in environmental design. In the broadest sense, 'greening' describes all of the various measures that societies implement to improve the design of our cities and landscapes. Importantly, these measures may not involve the use of any actual greenery, being purely technological in basis or centred around the internalisation or recycling of existing processes and materials. 'Sustainability' has developed as a field of understanding and definition, able to address the comparative worth of 'greening' measures. However, the meaning of sustainability is highly contested, political, and changing rapidly. Broadly, sustainability is the human response to the two points listed above. In the strictest ecological sense, it is almost impossible to measure the actual sustainability of a particular venture due to the myriad complexity of connections involved. In practical terms, sustainability is a commitment to understanding and integrating the factors in the 'open' system, which relate to our homes and societies. There is an ongoing process of implementation in relation to sustainability. In this respect, there is a wide range of policy and documentation available including triple bottom line, ISO 14004, and life cycle analysis, which can be readily applied to help provide new understanding. Indeed, these systems may in turn be superseded. Roof and facade gardens are measures of urban greening, as they are also elements of restoration ecology. They are tools for the transformation of the built environment.

2.0 DESIGN CONTEXT

2.1 Ecological precedence

Roof and facade gardens have precedence in the natural environment, where interactions of climate and geology have helped create diverse ecological niches. The wide assortment of cliffs, escarpments, gorges, and boulder fields create a range of growing environments approximating those of the roof and facade garden. Many plant and animal species have evolved to exploit these geological features throughout the world, adapting to these environments with specialised abilities. For plants, the actual limiting factors for growth are varied and location specific, but are principally related to soil moisture, soil quality, soil quantity, and extremes of temperature (Hitchmough, 1994; Osmundson, 1999). Coastal plants and rocky shrub land communities have developed mechanisms to exploit poor soil quality and volume, and to maintain growth in the absence of a reliable water supply (Wrigley, 1988). Climbing plants have developed a range of mechanisms of attachment and mobility, including spines, tendrils, suckering, and petiole and stem twining. Xeriscape plants by definition possess one or more characteristics which enable them to survive periods of drought, such as water storage mechanisms, a thick cuticle, stomatal closure or reduction of the transpiring surface (Weier et al, 1982).

2.2 Plants and urban design

Human societies have valued plants in urban design and culture for centuries. There are a range of perceived benefits to individuals and communities that have influenced the adoption of plantings in an urban context (Alexander et al, 1977). Urban design has incorporated plants in the following ways:

1) Development of mechanisms whereby plants fulfil functional environmental roles; contributing to the diversity, complexity, and connectivity of the ecology at the site level (roof, facade, street); urban level (city); and bio-region (wider landscape). For example, creating a native planting to interact with native fauna.

2) Creation of design principles to guide integration of plantings into the social environment; contributing to the context, interactivity, and aesthetic. For example, selecting plants in relation to their harvesting potential i.e. cut flowers, herbs, fruit; or selecting plants for their potential visual amenity.

3) Appropriate strategies to maximise the economic efficiency of the planting through consideration of the relative costs and benefits. The main benefits are achieved through effective functioning at all levels of application. These strategies are principally related to improving building performance.

The contemporary use of plants in urban design reflects the recognition that quality of life, health and environment are issues that are linked and cannot be neglected. Roof gardens and facade gardens:

- positively influence urban temperatures and microclimates;
- increase biodiversity;
- sequester pollutants;
- recycle storm water and reduce runoff;
- reduce dust and glare and improve soundscapes.;
- screen unattractive sights;
- extend the life of building surfaces;
- provide insulation and shading thus, reducing heating and cooling costs;
- reduce building anonymity and increase property values.

(Bass, 1999 & 2000; Mason, 1985; Peck, 1999; Simson & Straus, 1998; Ulrich, 1979)

2.3 Urban perspectives

The introduction of green spaces within a city has been shown to have a positive effect on the city's microclimate. When integrated across the urban environment, rooftop and facade gardens can decrease a city's heightened temperatures via the shading of reflective surfaces, absorption of incoming solar energy as latent heat, and plant evapotranspiration (Bass et al, 1999 & 2000). The incorporation of these gardens in urban areas will reduce the urban heat-island effect and ameliorate the impacts of other urban environmental problems, which will be exacerbated under climate change. This will in turn reduce the energy demand for air-conditioning, fossil fuel production, and hence greenhouse gas emissions (Bass et al, 1999 & 2000; Meier, 1991). A recent study completed on behalf of the city of Chicago indicated that the greening of city roofs could save up to US $100 million per year. This is equivalent to 720 mega watts of power generation, the equivalent output of one small nuclear power plant (www.greenroofs.com, 2002).

Research has consistently demonstrated that vegetation shading lowers building wall and roof surface temperatures. In one study, Meier (1991) illustrates a drop of approximately 17%. Importantly Meier also found that subsequent air conditioning costs were reduced by between 25% to 80%. Yeang (1996) goes further in his studies calculating the area of vegetation necessary, suggesting that an estimated 8% cooling load saving could be expected from a 10% covering of vegetation. Modern high-rise buildings typically intake air into their ventilation systems from the roof where ambient temperatures are very high. This in turn puts excessive energy loads on air cooling, adding significantly to the cost. Shading air conditioning units and air vents with vegetation will assist their functioning, keeping motors cooler and most importantly helping to pre-cool air to be conditioned. Bass (1999) suggests that vegetation shading and evaporative cooling can maintain a stable reduction of summer rooftop temperatures in the order of 30–50°C.

There are significant potential benefits in relation to capturing storm water. Roof and facade gardens are elements of source control, and with careful design, are capable of significantly reducing peak storm flows and modifying water quality (Lloyd, 2000). In the USA, storm water management fees are now being charged on the amount of impervious surface per parcel of land, and roof gardens constitute a credit in utility fees (Taube, 2003).

It is important to note that building facades constitute a significant percentage of the total surface area in the urban environment, in comparison to that of the street or rooftop. Subsequently, the function of the widespread placement of facade gardens has significant potential to absorb urban air pollutants and to mediate the urban wind tunnel effect (McPherson et al, 1994). Further energy reductions and cost savings are achieved through the protection of the building facade from weather and acid rain (Peck et al, 1999).

The use of vegetation as a building component is not a new concept. Their aesthetic, insulation, and agricultural value have made them vital parts of cities throughout history (McKay, 1975; Harvey, 1981). Like the contemporary city, ancient cities had similar problems of densely built-up areas, leaving little room available for green space. Many cultures have addressed this shortfall of the city, turning time and again to the use of green roofs and walls to improve the quality of urban life (Peck et al, 1999). Precedents include the Hanging Gardens of Babylon, the Villa of the Mysteries in Pompeii, and the Ziggurats of Ancient Mesopotamia (McKay, 1975; Osmundson, 1999).

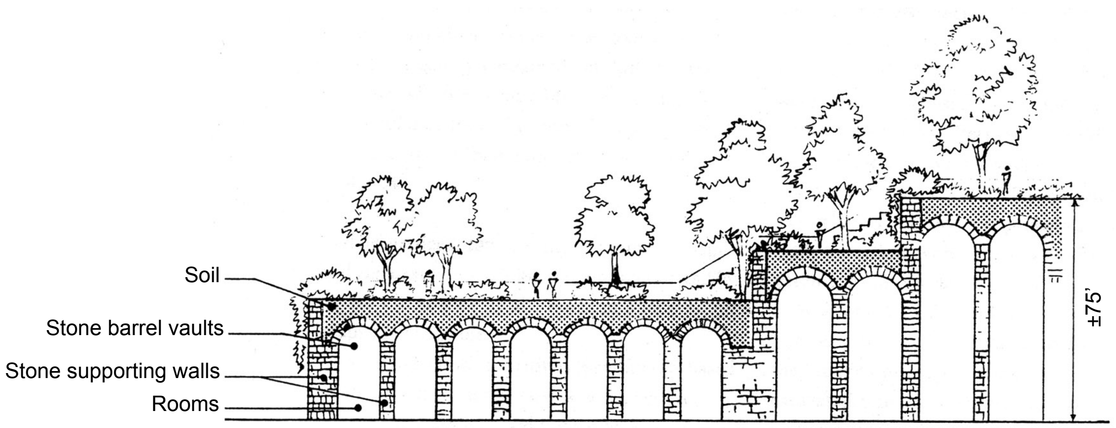

Figure 1. The Hanging Gardens of Babylon (Osmundson, 1999)

Developments in Roman architecture enabled a greater understanding of the construction issues of loadings and drainage. This formative basis encouraged a wide adoption of balcony gardens and terraces throughout Renaissance Europe. Meanwhile grass roof huts and garden courtyards have been valid design responses to climatic extremes in equatorial zones particularly in North America, Africa and the Middle East (Harvey, 1981).

2.4 Overseas trends

There has been a modern revival in the articulation of urban planting forms, with the inclusion of vegetation and more specifically roof and facade plantscape structures within architectural design. This concept, often referred to as 'biotecture', has over time, made more and more appearances in architectural literature (Minke, 1979). Biotecture has been a trend since Le Corbusier and Arthur Wiechula in the early 1920's. A major theme in their work was to incorporate nature into the lives of city dwellers, leading to an interest in rooftop gardens because of their aesthetic and practical value to such communities (Curtis, 1986).

This revival has centred in Europe and North America as a coherent response to building energy efficiency in cold climates (Dahinden, 1971; Doernach, 1979). In a variety of European municipalities the widespread adoption of roof gardens is a modern phenomena encouraged by advanced forms of planning requirement and legislation (Prinz, 1981). Typically, the introduction of tax subsidies and storm water and pollution emission taxes are used to support this legislation. Each new industrial building in Berlin for example must incorporate a green roof. To encourage the installation of roof gardens in Vienna, private property owners vie for green roof grants. The ongoing maintenance of the roof garden can be ensured with a long-term schedule of part payments (Kuhn, 1998).

The contemporary development of roof garden principles, new materials and methodologies, in Northern Europe, has further enhanced the lightweight construction options for facade-mounted greenery (Yeang, 1996).

Urban populations in Asia have also witnessed an increase in urban greening measures, with the 'biotectural' skyscrapers of Hamzah and Yeang (Richards, 2001). And in Tokyo, planning laws stipulate that all new buildings on plots over a quarter acre should dedicate at least 20% of the roof surface to a garden (Brooke, 2002).

While many contemporary architects and designers do not entirely embrace the concept of biotecture the central intent of much of their work is to restore a sense of 'place' to the urban environment, emphasising the need to change the fabric of our cities .

3.0 DESIGN ASSESSMENT

In consideration of the feasibility of a roof or facade garden, it is helpful to table the issues that will affect the design outcomes. In this approach, there is a range of critical, measurable factors to assess in relation to the natural and built environments. A coordinated approach to the assessment of these factors allows an effective analysis of different planting options.

3.1 Assessment of natural environment

Planting design involves working with natural and constructed elements in an integrative approach. The specific plants chosen need to reflect the constraints of the site, or the design will need to accommodate the extra sensitivity of these plants. There is a range of climatic variables specific to each site that can be recorded and used as an aid to the selection of species, watering and maintenance regimes. Knowing the limiting climatic variables will allow the designer to manipulate the structural elements to aid the planting. For example, designing structures that shade the sun or buffer the wind on exposed rooftops. In effect, microclimates are created which support the growth of selected species.

Issue		Consideration
What are the natural elements affecting design?		Record or measure existing elements to inform the new design
Climatic Inputs	Rainfall	• Total rainfall and monthly averages. Peaks and droughts. • Consider the water demand through the critical period of summer.
	Sunshine	• Totals, averages and range. • Seasonal extremes of the year.
	Wind	• Prevailing, averages, extremes.
Geology	Soil	• Quality, volume and depth. • Assess nutrient requirements of intended plant selection.
Flora		• Compile a selection of local species. • Investigate listed weed plants. • Investigate implications of selected non- indigenous species.
Fauna		• Compile a general selection of local and introduced species. • Investigate feeding and nesting requirements.
Linkages		• Modes of access to existing green spaces.

Table 1. Assessing the natural environment

3.2 Assessment of built and social environment

Assessment of the built environment will assist in making relevant decisions for the design and construction process. Social function must be considered at this point as human movement and perspective may be a critical determinant of current and future design (Table 2 and Table 3).

4.0 ROOF AND FACADE GARDEN DESIGN

As noted, the important preliminary stages in the design are in the assessment of the existing environmental factors, and the assessment of the existing or proposed building and associated functions. Sophisticated roof garden systems developed in countries other than Australia will generally require some adaptation to local conditions and plant varieties.

Issue	Consideration
What are the social elements affecting design?	
Context	• Consider the meaning of the planting in terms of its overall effect, and the new relationships formed with adjacent streetscapes.
Interactivity	• Consider how the planting can interface with human activity providing food or fragrance. Special consideration to placement of thorny species.
Aesthetic	• Consider seasonal changes and flowering times for intended species. Visual and aural effects such as wind through reeds, and complementary colours.
Function	• Consider the movement of people through the space.

Table 2. Assessing the social environment

Issue	Consideration
Existing and proposed structures	
Structural	• Examine the structural engineering, specifically loadings for the nominated roof/facade. • Note positions of bearing walls and columns for positioning heavy items such as planter boxes at the final layout stage. • Examine existing waterproofing system and roof/ facade substrate for future assessment of compatibility with the new design. • Record existing roof/ facade drainage system and silt trap details. These elements will need to be augmented or made easily accessible for future maintenance. • Examine joint and flashing details. Note that exposed and open seams will require protection from vigorous plant species.
Energy efficiency	• Consider principal issues of human comfort within the existing building and how plantings can facilitate improved levels of comfort. • Shading is a key factor to consider. Create shadow diagrams to determine hot and cool areas of building and surrounds. Use plantings to shade or filter key hot areas such as roof, western facade, glazed areas. • Examine current system of building insulation. Consider plantings for insulation when used as a 'blanket' on exposed areas. • Measure energy consumption of existing building. Compare with modelled efficiencies for design options.
Water	• Investigate options for distribution, collection and storage of storm-water within the design. • Investigate potential for grey-water recycling.
Planning	• Examine building height and overhang restrictions with respect to plant growth over time. • Review the relevant planning guidelines and permits related to building works, setback and height requirements, and heritage Acts. • Consider issues of overlooking and overshadowing of adjoining building. • Examine existing building maintenance systems for future modification. • Record exiting access requirements (including disabled access). • Consider safety issues of parapet and guardrail design, fire alarms, exit and emergency lighting. • Investigate requirements to maintain insurance cover for the intended design.

Table3. Assessing the built environment

4.1 Roof garden systems

The current imperative for roof gardens is to address the acres of exposed roofs that already exist in urban areas. These retrofit designs require working within the limitations of the original building design to a large degree. Most roof constructions are either flat concrete decks or sloping metal and tile profiles. Major alteration of the basic roof system is generally a significant cost. Many roof structures are engineered to withstand additional loadings, or can do so with the lesser cost of augmentation of the support members. Design loadings need to consider the weight of additional waterproofing materials, soil profiles at saturation and future growth of plant material and associated wind loadings. The limiting factor of roof angle is predominantly an issue with sloping metal deck roofs. It is possible to plant out roof decks with slopes of up to 15%, with few problems. Roof pitch angles of up to 30% have been planted out, but there is a requirement for additional landscape retainers and surface containment fabrics. In these situations, there is reduced opportunity for significant additional loadings. Concrete roofs are themselves limited by being too flat, requiring careful attention to waterproofing and drainage to prevent ponding and pooling. Alternatively, a wetland ecosystem is possible with correct design.

4.1.1 Intensive roof gardens

Intensive roof gardens utilise:

- Deeper soil profiles.
- A wider range of plant species enabling structural diversity in the planting.
- Spaces designed for social interaction.

Intensive roof gardens are most applicable when:

- There is adequate structural capability for increased loadings.
- The roof space is designed to include regular human foot traffic.
- The project budget is available, usually due to adequate existing structural capability.

Intensive roof gardens capitalise on the capacity of the roof to withstand additional loadings. Soil profiles are generally in the range of 10-30cm deep, with an increased ability to mound soil and place planter box structures at bearing walls and columns. There is generally a significant maintenance load due to an increased range of plant species with variable requirements. Many contemporary buildings have an arrangement of different roof types , including concrete deck and metal deck, integrated into one roof system. It is common practice to use a combination of intensive and extensive methods to achieve significant coverage in these situations.

4.1.2 Extensive roof gardens

Extensive roof gardens utilise:

- Shallow soil profiles or, artificial soil media.
- Shallow growing plants such as grasses, herbs, and succulents.
- Plants that have a minimum requirement for watering and maintenance.

Extensive roof gardens are most applicable when:

- Structural issues limit the opportunities for extra loadings.
- The roof space is essentially non- trafficable.
- The project budget is limited.

Generally, roof profiles that are not designed for regular human access, or with little opportunity for additional loading, may be considered for an extensive garden design. The basic components of extensive roof gardens are lightweight, shallow growing profiles of amended soil or artificial growth media. These media are not designed to accept compaction from typical human foot traffic. The shallow growing volume is significantly more susceptible to rapid water loss/desiccation than in deep soil profiles. As a limiting factor, designers must pay careful attention to selection of suitable plants.

4.1.3 Waterproofing membranes

Contemporary waterproofing systems involve the application of concrete additives, the layering of sheets and fabrics, and the application of liquid membranes. The type of membrane used reflects the project design limitations. The most common commercial membrane materials are rubberised asphalt, thermoplastic sheet or liquid rubber and plastic solutions. Within all systems, it is possible to develop a specification for steel, concrete or wood substrates.

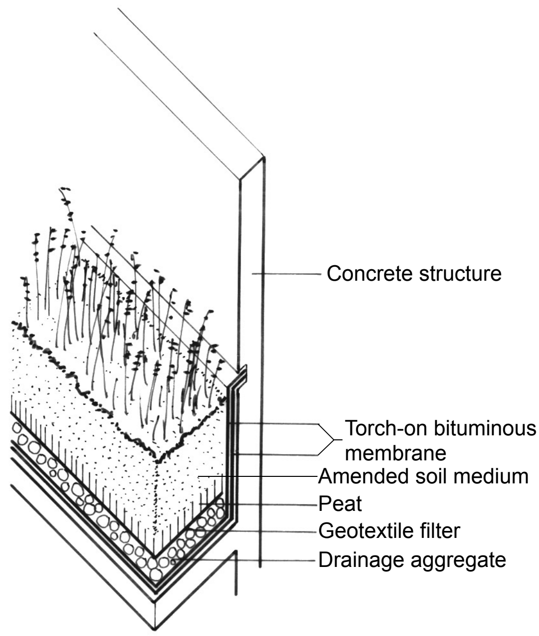

Figure 2. Intensive roof garden with bituminous membrane (example of proprietary system)

- Rubberised asphalt or bituminous membranes are generally torch-on sheet systems, applied with full overlaps, being bonded to the roof or underlying protection layer (Figure 2). Intensive roof gardens and areas receiving heavy foot traffic require double layer torch-on systems. Single layer torch-on and self-adhesive bituminous sheet systems are adequate for planter boxes and some types of intensive roof garden.

- Thermoplastic sheet membranes are also a common component of many roof garden systems, generally applied as a single thickness sheet within a multi–layer system (Figure 3). The membrane can be glued or mechanically fastened to the roof substrate or insulation layer. In areas where wind loadings are not critical, the membrane may be ballast set, loading it with roof garden materials. A thermoplastic membrane system is in place on one of the world's largest roof gardens, the Chicago City Hall, USA (Figure 4).

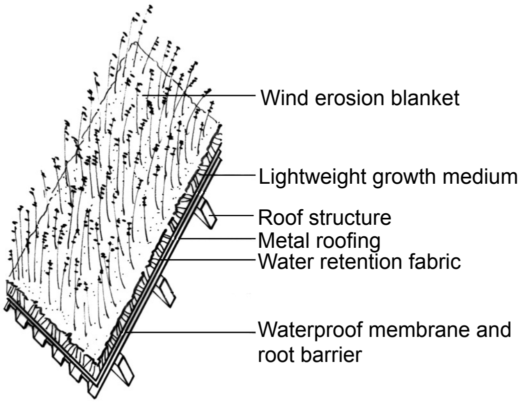

Figure 3. Extensive roof garden with thermoplastic membrane (example of proprietary system)

Figure 4. Chicago City Hall (Chicago city council. www.ci.chi.us)

- Applied liquid polyurethane and liquid bituminous membrane systems are also available for planter boxes and intensive roof garden solutions.
- The application of additives to cement, to create a waterproof concrete, is another potential option. In this instance, plasticisers and water repellent agents are additional elements in the pre-mix. This has the advantage of simplified detailing for joints and pipe projections, elimination of membrane repair and replacement, and reduced construction time. This technology is relatively new and not in widespread use within roof garden design (Figure 5). Before implementing this method of waterproofing it is advisable to research performance of roof gardens which have used cement additives.
- Gravity as a draining agent should not be overlooked as an aid to waterproofing. There are reliable examples of roof gardens with an additional, thin poured concrete slab, directly above the existing flat roof to provide an enhanced drainage profile. Alternatively, tapered insulation may be applied to the roof deck to create a positive slope.

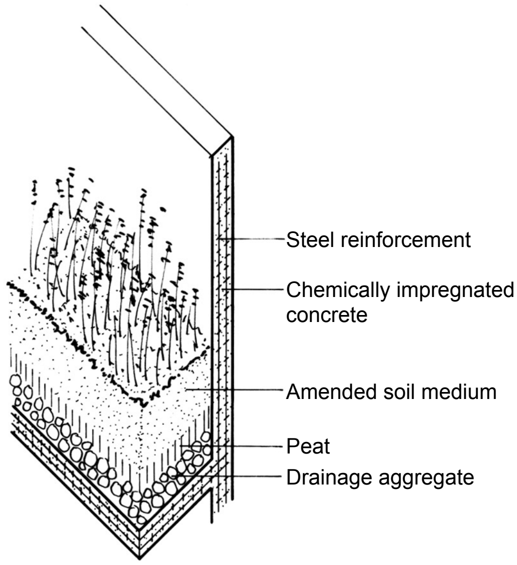

Figure 5. Chemically impregnated concrete roof garden (Boughouse, 2003)

To ensure continuity of insurance and a waterproof roof, it is necessary to complete the project using pre-selected contractors and auditable installation methods. This level of sophistication may not be required for the roof of the family garage!

4.1.4 Waterproofing support layers

A number of additional layers are regularly sandwiched into the roof garden substrate profile. Other layers include insulation, membrane protection, drainage, and surface covering/protection. Insulation layers such as extruded polystyrene sheet are laid down under, or above the waterproofing membrane, depending on the system used. Insulation is an effective part of a design solution for cold climate areas. Membrane protection layers protect the membrane both from penetrative root action and from impact damage from above. Root resistant additives may be included in the membrane or a geo-textile root mat laid down over the membrane for protection. In the event that a drainage cell system and filter mat is used, it is possible to dispense with the membrane protection fabric.

Drainage layers are a component of most roof garden systems where there is adequate depth in the planting profile. The purpose of the layer is to provide a horizon of free drainage above the membrane. This is an anti-ponding mechanism, but can also be the basis for a sub-surface irrigation system. This layer is the target of root growth for plants in the profile, and this can be encouraged in shallow profile systems, or discouraged with anti-root fabrics (e.g. near drainage penetrations). Rigid plastic drainage grids of 2-6cm depth are a commonly available product. Traditionally, drainage layers include large diameter stable aggregates such as gravel, crushed brick, and volcanic stone. It is common practice to lay a filter fabric over the drainage layer to limit movement of soil. Roof sites with shallow growing profiles and/or wind affected positions, commonly use a fabric layer on the surface of the soil profile as a method of retention of soil. These perforated fabrics are suitable on roof gardens with a steep roof pitch and perform many of the functions of a protective 'mulch' layer.

4.1.5 Nutrient supply/soil media

Due to the relative weight of normal soils, roof and facade gardens commonly use amended soil blends or artificial growing media to reduce the overall loadings. Successful design involves matching the substrate choice with the nature of the site and the management regime. Specific issues include drainage, oxygenation, nutrient supply, water retention, compaction, and volume loss. Synthetic soil-less media are commonly used to add depth and structure to the growing profile with reduced weight. Synthetic media generally have excellent oxygenation and drainage characteristics, with a diminished ability to retain nutrients and water (Hitchmough, 1994).

In addition, a lightweight artificial planting media has reduced capacity to anchor larger shrubs and trees within the planting. Soil profiles suited to roof gardens are commonly amended by the addition of materials, which improve the limitations of the media in a containerised situation. Additions of natural media, such as sand (for drainage), clay (water retention) and, bark (oxygenation and volume) allow organic site-specific solutions. Designers must pay specific attention to AS 4419 *Soils for landscaping and garden use*.

4.1.6 Irrigation

There is a wide range of choices in the delivery of water to the garden. Designing within the environmental constraints of the site allows selection of species that require little additional irrigation. However, clients typically desire divergent solutions, necessitating an irrigation system that must enhance the site-based limitations of the planting profile. Commonly used systems include drip/capillary irrigation, sub irrigation and sprinklers. Drip/capillary irrigation methods include the use of 'tensiometers', devices buried in the soil profile, which measure the tension at which water is held in the soil. The tensiometers can be distributed throughout the planting area, providing individualised watering responses.

Sub irrigation systems are typically used for shallow profile applications. Many extensive roof gardens have soil profiles of 5-10cm, and are potentially subject to desiccation. Sub irrigation of these shallow profiles is effected through supply of water below the growing media at the level of the membrane or drainage layer. The result is to encourage plant roots to grow down at the bottom of the profile, thus reducing the potential for water stress. Specific issues include the potential for waterborne pathogens, de-oxygenation of the lower profile, and difficulty in observing irrigation system faults. Surface irrigation involves the use of sprinklers, and is generally not suitable for roof garden applications, an exception being the irrigation of turf. Apart from the desiccation issues outlined above, it is difficult to ascertain actual soil wetting after a watering event and rooftop wind levels may disperse water away from the planting.

4.2 Facade garden systems

Facade gardens consist of vegetation covering vertical and inclined surfaces of buildings, as a simple layer or as a complex and integrated ecology of many species. These 'inverted topographies' (Sitta, 1983) can offer plant life where horizontal space is either not available or at a premium. Facade gardens utilise:

- Plants grown on or adjacent to a building facade.
- Supporting structures such as mesh or cables to train and direct plant growth.
- Plantings may be out of the ground or containerised.

Facade gardens are most applicable when:

- The facade can sustain the projected loadings.
- There is an opportunity to provide functional benefits such as shading, insulation, pollution absorption, and fragrance production.
- There is the opportunity for linkage between existing landscapes.

While modern building facades are, as a rule, not designed to incorporate facade gardens, there is a range of retrofit options that can be implemented. These solutions primarily involve planting out existing horizontal surfaces such as balconies, terraces and parapets. Current applications make extensive use of tiered balcony plantings to effect a wall of plants (Figure 6). Alternatively, ground-based facade gardens are an effective measure for the remediation of many urban issues associated with major roadways and construction works, screening unattractive sites, covering graffiti, trapping dust and attenuating sound (Figure 7).

Figure 6. Kuala Lumpur airport (courtesy of Ronstan International, 2002)

Figure 7. Freeway noise attenuation wall (courtesy of Transurban 2002)

Purpose-designed facades for vertical gardens are a relatively new concept. In principle, what is required is an effective arrangement of horizontal 'bedding' surfaces throughout the vertical profile of the facade. These may be in the form of structural sub-frame elements such as terraces or ledges, and suspended plantings that utilise tensioned cable systems. The positioning of structural and planting elements is specifically related to the project requirements and the potential benefits of the vertical garden. Other options include 'through wall' plantings, where the growing media and root ball are located inside the building, the plant growing out through a pipe penetration to hang free of the facade (Figure 8).

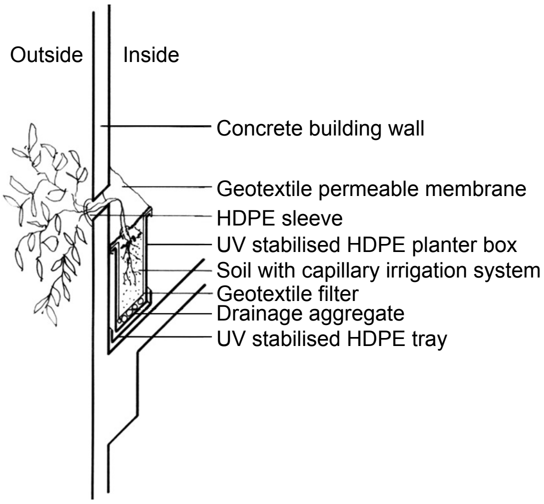

Figure 8. Through wall planting (Boughouse 2003)

In an Australian context, there are a number of native plant species with the capacity to duplicate many of the qualities of the introduced species. Climbing vines represent the most promising group for further experimentation, although a complex ecology of many species may ultimately provide a more diverse and resilient planting than mono-cultural solutions. It is important to note that many climbing vines if left untended, have a tendency to grow out at the top of the vine, lower sections becoming more woody and bare of leaf. In this respect, maintenance requires careful seasonal pruning and espaliering of the plant to effect an even spread of growth. Alternatively, secondary species may be added at a latter stage to fill out the lower, bare sections of a planting.

4.2.1 In-ground facade gardens

Facade gardens can be grown from an in-ground level planting. Plantings of this type are the most cost-effective solution. The principal issue is the limits to upward growth for the species. Careful selection of woody and long-lived species will enable the planting to reach three or four storeys in height. The more vigorous species tend to be derived from tropical environments, although there are several temperate zone options. Suckering species require a firm substrate to grow upon, with considerable potential to invade building seams and weaknesses. Species that utilise twining or tendril mechanisms of mobility inevitably require a support substrate such as mesh, lattice or cables.

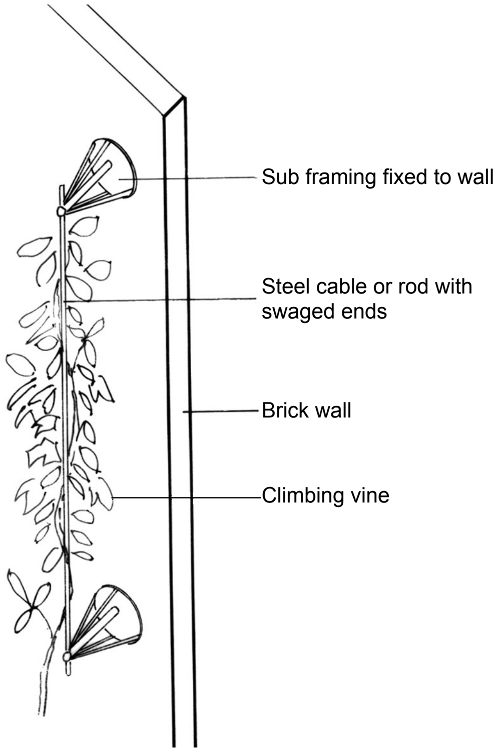

Figure 9. Cable wall planting (Boughouse, 2003)

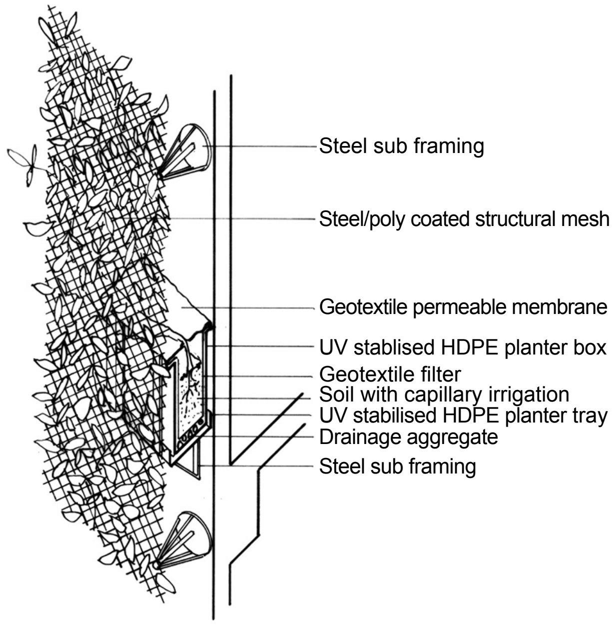

Figure 10. Blanket cover mesh wall planting (Boughouse, 2003)

In-ground plantings are generally low-maintenance, without the issues of limited soil volumes and ongoing moisture stress. The domestic use of in-ground facade gardens can enable a multi-functional result, giving shade, insulation, sound, and glare reduction to exposed facades of a family home. In addition, these garden types are well suited to the utilisation of fragrant and fruiting species, as the issues of access and public risk are minimised. The widespread use of deciduous species on pergolas illustrates a design understanding of in-ground plantings.

4.2.2 Containerised facade gardens

Alternatively, suspended plantings are comprised of engineered support structures and support systems overlaid by living plant elements (Figures 10 and 11).

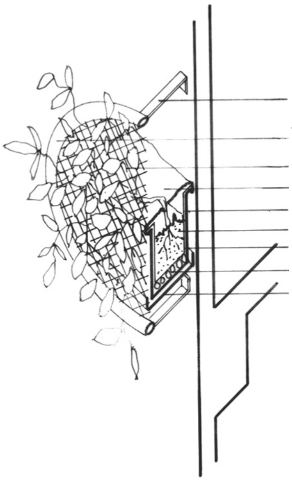

Figure 11. Modular mesh wall planting (Boughouse, 2003)

The structure is designed to hang free of the wall, avoiding direct plant contact with the building and effectively extending the building's outer insulation layer. Furthermore, the space created between the facade and planting structure can accommodate the requirement of access for maintenance. In practice, it is an effective methodology to pre-grow plant 'modules', each unit comprising a mesh substrate, attached sub-frame, containerised plant and irrigation element. These modules can be grown off-site and transported to the building facade at a later date. The modules have no specific size requirements, what is critical is the relationship between the container volume, the species chosen, and the anticipated canopy/leaf area.

If the selected species grows beyond the module and container size limits, as designed, it will be difficult to maintain water and nutrient requirements for that module. Reducing the overall leaf area of each plant, as in a modular unit, is an effective strategy to limit the growth as the limited soil volume places an imperative on effective irrigation and nutrient supply. When maintained in this manner, containerised plants will be less affected by reduced soil volume. In many respects, the issues of plant selection, soil profile, and irrigation system are the same as for roof gardens.

5.0 CONCLUSION

Contemporary landscaping methodologies have not been able to articulate a cohesive, functional plantscape for urban spaces. An integrated plantscape system is the creation of landscapes that are connected by roof and facade gardens, incorporating an authentic attempt to support ecological values, independent of potential human benefits. Roof and facade garden materials and methodologies are at a preliminary stage, and there is a need to develop authentic Australian examples of these systems. There has not been an extensive research and development process, despite the potential Australian market. Government agencies must seek a greater understanding of the potential benefits of roof and facade gardens, with a commitment to regulatory policing of building energy inefficiency, and a more comprehensive incentive scheme for emerging 'greening' measures.

Modern buildings are becoming more complex and responsive in providing solutions to human comfort issues. Yet, the challenge for designers is in the provision of hybrid systems, where technological solutions for building design are integrated with biological mechanisms. For example, 'twin facade' systems are an ideal opportunity to utilise facade gardens in the outer building fabric. In future, roof and facade gardens will be an integral part of a solution to climate-controlled HVAC buildings with their high-energy usage, and occupant health issues. There have been few convincing attempts to improve the urban environment with plants, even when it is very cost-effective to do so. There is

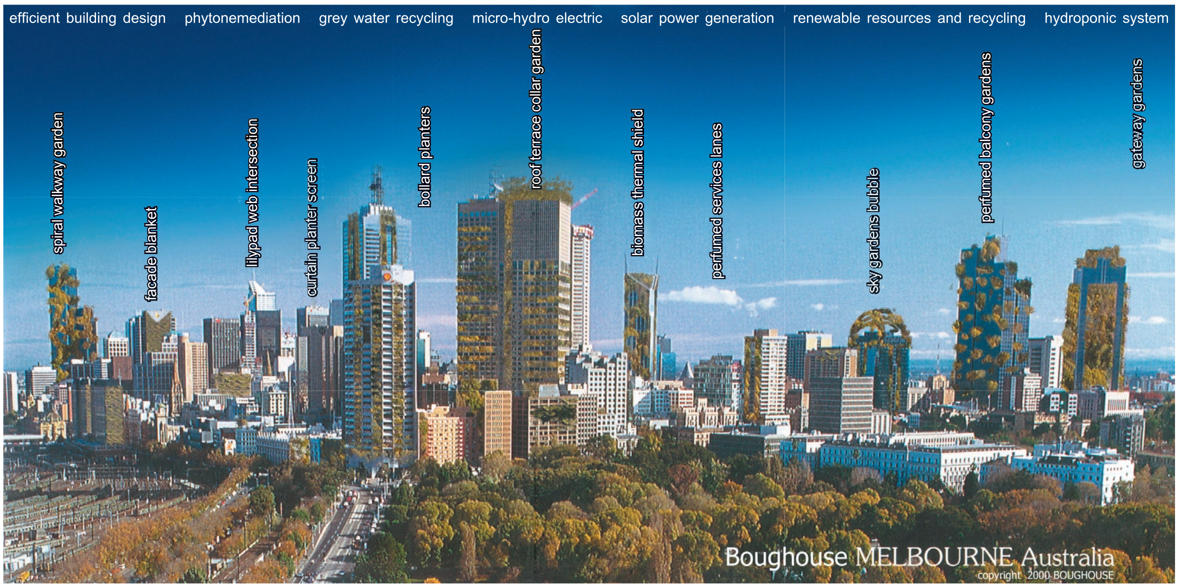

Figure 12. Hanging Gardens of Melbourne (Boughouse 2000)

considerable opportunity to improve odours, reduce glare, and screen unattractive sights with in-ground facade plantings, at little cost.

This article has not examined the considerable issues of human health and well-being in relation to roof and facade gardens. It is difficult to evaluate the social worth of a ‘green’ city, in terms of cohesiveness, connectedness, and pride for the inhabitants, as well as the possibility of improved health for all citizens. Against the backdrop of our current urban environmental issues, it is clear an ecological solution is the preferable option.

Designers must explore more thoroughly, the impulse to create centralised urban spaces, and the skyscrapers that fill them. It is clear that increasing levels of centralised development are creating social and ecological issues, through the inability of planning and construction processes to reconcile complex issues of sustainability, such as the need for cities to internalise recycling. In addition, designers must develop a process of integrating new ideas on sustainability. In terms of embodied energy of production, planting solutions are at the forefront of sustainable technologies. It is increasingly true that there are no longer any technological barriers, which prevent our natural and built environments from merging into the hybrid forms of a green future!

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