Reforesting the Built Environment - a Practical Feasibility Case Study in Christchurch

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Abstract

As the demand for infill housing increases in suburban areas, more land becomes sealed and impervious to water. The demand on the storm water systems increases, along with an increase in the detrimental effects of erosion and water pollution. Green roofs can assist in managing the demand on storm water systems as well as provide increased thermal insulation, improving air quality, providing habitat for insects and birds, and enhancing the aesthetic appearance of increasingly dense urban areas. This paper describes a small scale modular retrofit green roof system that is suitable for installation over existing roof systems. Initial observations indicate the green roof system is able to retain a high percentage of the rain fall and therefore reduce the demand on the storm water system.

Introduction

Our current urban form has changed the natural environment significantly, and has detrimental effects beyond the city limits. We are now beginning to recognise the importance of caring for, and creating systems that are synchronised with the natural environment. There has been an increasing interest by individuals, communities and regional authorities to enhance the urban environment by returning parts of it to a more natural state.

Today's urban form has resulted in local natural cyclic systems being replaced by throughput systems. One example of this systems change is rainfall, where in a natural system the water is locally valuable and utilised, but in a throughput system is collected and discharged as storm water. Sealed or impervious surfaces generate rapid and complete water runoff, which is directed into the storm water system and from there into receiving waters. This process of discarding a resource results in negative impacts on the natural environment in the form of surface pollution runoff, erosion of stream banks, and increasing the level of suspended silt/sediment. In areas where there is a high percentage of impervious surfaces, runoff can exceed the capacity of the storm water system resulting in surface flooding, severe erosion of land and stream banks, and sewage system infiltration and pollution of water ways.

If storm water runoff can be spread out over a longer time period and some of the water retained on the surface where it falls, these negative impacts can be greatly reduced. A green roof is able to reduce the rate of water runoff by retaining water in the soil/substrate and allowing slow drainage. These and other benefits of green roofs have been well studied and documented. Van Woert et al 2005 examine the ability of different roof surfaces to delay rain water runoff after the start of a rain fall event and the amount of water retained on the surface where it falls. Niachou et al 2001 examine the thermal performance of energy savings gained with green roof systems.

The study by Van Woert et al (2005) examined the storm water runoff delay and rainfall retention of three roof coverings, gravel ballast, a green roof system without vegetation, and a fully vegetated green roof. The rainfall events were categorised into light, medium and heavy events. The green roof without vegetation and the fully vegetated roof both significantly delayed the start of water runoff from the roof after the start of the rain event, and retained a high percentage of the rainfall. The start of water runoff was delayed by 5 to 55 minutes, depending on the rainfall category and vegetation cover on the green roof.. Overall for all rain fall events, the fully vegetated roof had a mean rainfall retention of 82.8%, while the green roof system without vegetation retained 80%, and the gravel ballast 48%.

A significant increase in thermal performance can be achieved using a green roof where the substrate and vegetation cover act as (additional) insulation. Niachou et al. (2001) measured the surface and indoor temperature of buildings with and without green roofs. The indoor temperature of buildings with green roofs was found to be more consistent, having an average daily variation of 4^{o}C compared to 7^{o}C for a standard roofed building.

In addition to reducing the demand on storm water systems and increasing the thermal performance of buildings, green roofs offer the opportunity to increase the green space of the urban environment; a landscape that can be predominantly built or paved. Additional benefits include improved aesthetic appeal, providing a habitat for fauna and improving air quality.

A varying degree of positive impacts can be realised depending on the type of green roof and whether the roof is designed in conjunction with the building or as a retrofit. In this case study the green roof is to be installed on an existing building, so a retrofit solution is required. Retrofit examples in New Zealand, such as that by Fassman et al. (2008), have been permanent, involving a complex installation. This paper presents a retrofit solution that can be easily installed requiring no change to the existing roof. The retrofit roof system can also be completely removed and moved to another location without destroying the green roof.

Motivation

The suburban landscape in New Zealand has typically had relatively large areas of green space, with sections around each house supporting a garden. Rising demand for housing in existing suburban areas has led to increased infill housing; primarily achieved through subdivision of existing sections. Subdivision significantly reduces the green space due to the land required for new housing, access ways, garages, and vehicle manoeuvring areas. Much of the land dedicated to vehicles is required by regional laws (CCC, 2005a, 2005b, 2006). With a reduction in green space from additional built and paved areas, the level of impervious surfaces greatly increases.

Figure 1. shows the change of green space to impervious surface on the case study section. The section has been subdivided into three titles, with the original house at the front, and two new town houses at the rear. Table 1 shows the change in land cover due to the section subdivision. It should be noted that although the original house and garage layout was obtained (CCC, 2007), and the back of the section garden was known to be grass, the exact layout out of paths and access ways had to be inferred.

Subdividing the section has increased the area of impervious surfaces, (buildings, paths/patios and access ways) from 277 m^2 to 630 m^2, or from 35 % to 80 % of the area of the original title. Converting the entire roof space of the original house and new (front) garage to a green roof would decrease the impervious surfaces by 135 m^2 or 17%, bringing the total impervious surface area to 63%.

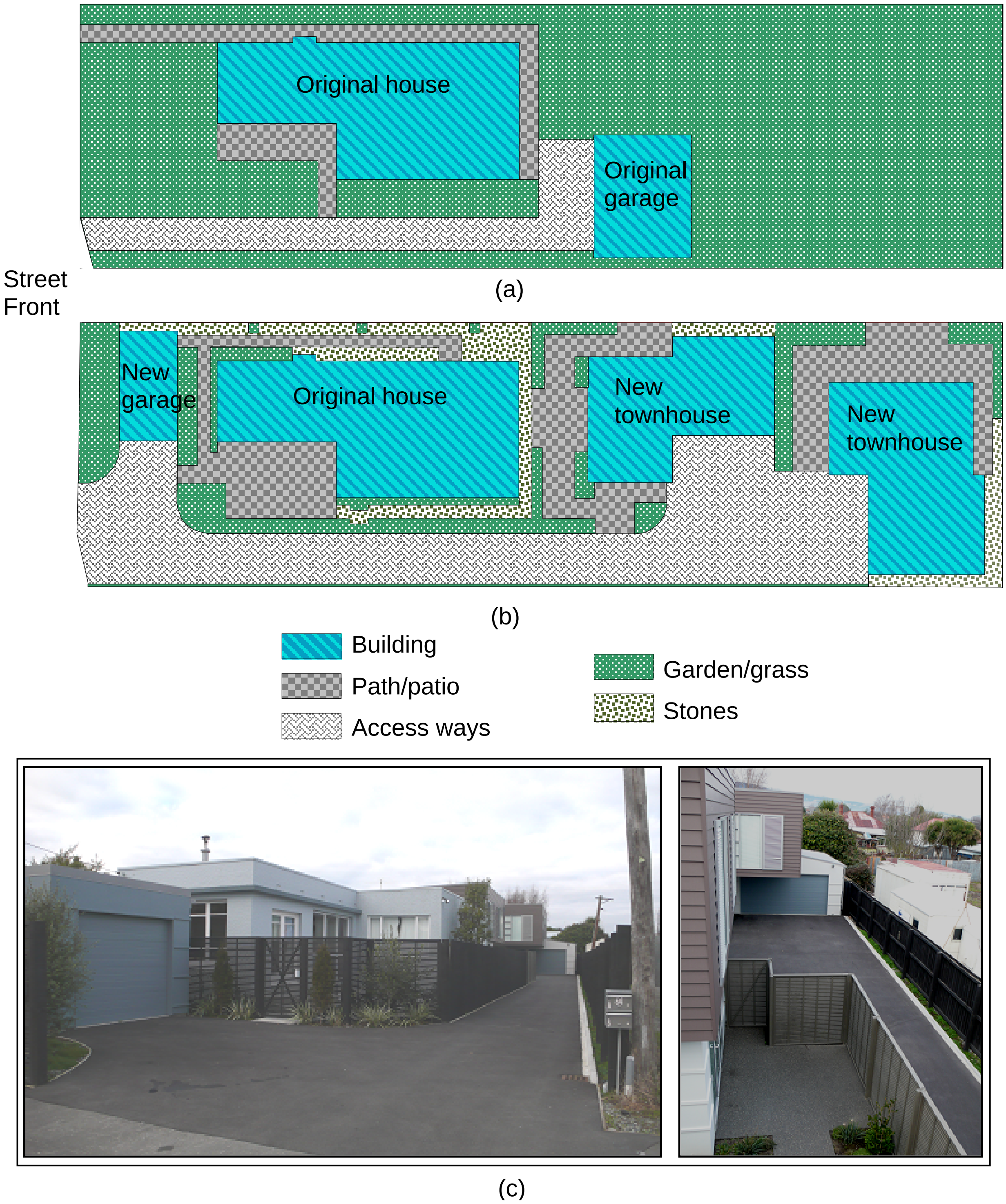


Figure 1. Property shown before (a) and after (b) the original back garden was subdivided into two additional titles, each containing a new townhouse. Photos of the completed subdivision shown in (c).

An additional motivating factor for the green roof is to serve as a demonstration to the local community on what individuals can do to enhance natural environment. The street in which the house is located has already undergone extensive street renewal and landscaping, consisting of road narrowing, new street plantings, and a section wide planting strip that runs through three blocks. Installing a green roof demonstrates that individuals as well as local authorities can make a valuable contribution to the appeal of the urban landscape.

Table 1. Surface cover change due to subdivision on test case section

Surface cover		Original Section		After subdivision		Change in surface cover
		m^3	%	m^3	%	%
Impervious surfaces	Building	153	19	284	36	+17
	Path/patio	53	7	136	17	+10
	Access way	71	9	210	27	+18
Pervious surfaces	Garden/grass	515	65	104	13	-52
	Stones	0	0	58	7	+7
	Total	792	100	792	100	

Project aims

- Develop a retrofit green roof system that can be installed on existing houses and buildings.
- Investigate plant varieties that are suitable to grow in shallow substrate depths and the potentially harsh conditions on an exposed roof surface (hot to cold temperatures, dry to wet moisture levels).
- Begin to re-establish eco-systems thereby improving and supporting the natural environment.
- Provide a demonstration site to illustrate a non-conventional use of roof space.

Method and Results

An experimental auxiliary system has been designed, constructed, tested and located on a residential garage roof in Christchurch. The auxiliary system was designed in a modular fashion to allow easy construction and installation. In addition, the modular system allows tailoring of the green roof to the load bearing capacity of the existing roof structure.

The case study house was constructed around 1920 and has a Rimu wooden frame construction, with concrete block and plaster cladding. The roof has a slope of 3.1^o and a total area of 114 m^2. The load bearing capacity of the roof was determined by a building inspector to be at least $50kg/m^2$. Thus, a full coverage of a retrofitted green roof was not possible as the saturated roof could potentially exceed the load bearing capacity of the roof and building structure. Therefore, the modular system was designed to have only partial substrate coverage, and ground covers that are able to cover the areas of the roof without substrate coverage. Although the design on the green roof was dictated by the house construction, initial installation was on the garage due to ease of access and public visibility. The garage roof has a slope of 4.5^o and a total area of $21m^2$

An important consideration of the retrofit system is to ensure the existing roof is not detrimentally affected by the installation of the green roof. To this end, the modular system was designed to completely prevent moisture from reaching the existing roof surface and the choice of construction materials was limited to those that had no potential to react with or damage the roof surface in any way. Preventing moisture from reaching the surface removes the danger of the plant roots infiltrating the existing roof system. Preventing any damage allows the existing roof to retain its integrity should the modular green roof be removed.

Two experimental green roof modules were designed and constructed. Each module has a total area of $0.61m^2$ and 50% substrate coverage. The saturated mass of each module is 11kg, resulting in a distributed mass of $18kg/m^2$, significantly below the recommended maximum capacity of $50kg/m^2$. As a comparison, other retrofit systems have a saturated mass of 70-200 kg/m^2 (Fassman et al 2008). A metal mesh container holds the substrate in position. It is envisaged that once the plants have established, the ground covers will envelope the mesh containers and further assist in containing the substrate.

The substrate is slightly different to that used in other green roof systems due to the limited load bearing capacity and hence has a shallow substrate depth of 70mm. Instead of having very defined layers as is typical with non-retrofit green roof systems (more extensive, deeper systems) the substrate is comprised of only three materials. Firstly, a layer of sphagnum moss covers the bottom of the mesh container, as shown in Figure 2a. This sphagnum layer forms a mat that acts as a filter for the substrate above. The plants were then placed on the moss layer and the gaps around the plant root balls filled with a mixture of palm peat and coarse potting mix, as shown in Figure 2 b &c.

The palm peat serves a double purpose. Firstly, the water retention of palm peat is greater than potting mix thereby increasing the water retention capacity of the system. Secondly, the palm peat assists in binding the potting mix together, reducing substrate loss particularly during the period of plant establishment.

The top layer of sphagnum moss covers the peat and potting mix, as shown in Figure 2d. This top layer of moss once again acts as a mat layer. The interlocking nature of the moss reduces the loss of substrate due to wind and by lowering rain drop velocity and spray. Reducing substrate loss is particularly important during the plant establishment period.

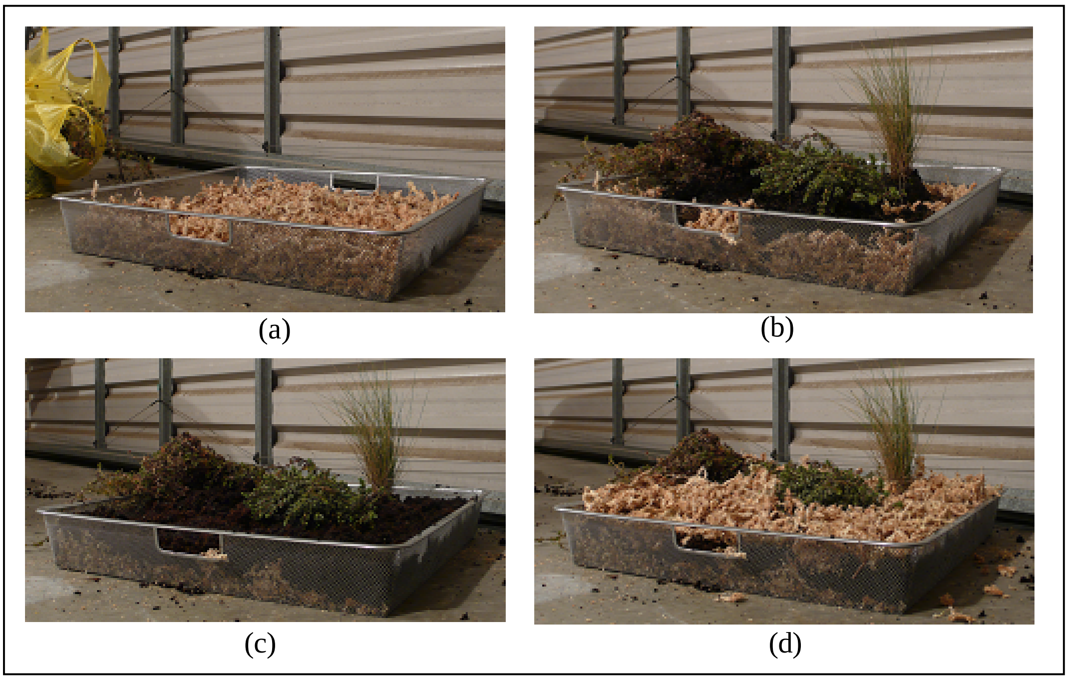


Figure 2. Planting of mesh containers filled with the substrate consisting of (a) sphagnum moss, (b) three plants, (c) a layer of palm peat combined with coarse potting mix, (d) a final layer of sphagnum moss.

Plants

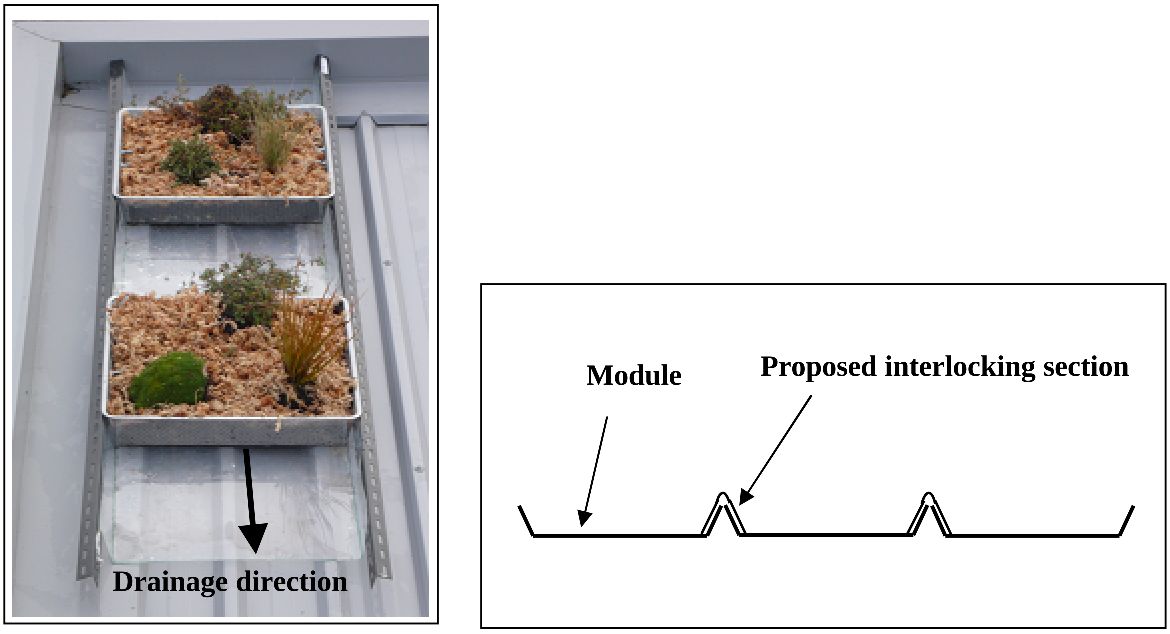
One of the aims of this experiment is to begin to re-establish eco-systems that were lost when the land was cleared and houses subsequently built. Thus, the plants were selected based on their native origin, as well as showing potential to survive in shallow soils and harsh condition. Plants that are native to the flat areas of Christchurch were looked at first, followed by Canterbury and Banks Peninsula plants, followed by New Zealand natives.

Each green roof module contains three plants, two ground covers and a grass or grass like plant. The grasses provide height and visual impact to the green roof. One of the ground covers used in both modules, acaena caesiiglauca, readily grows roots on the shoots in contact with the substrate. It is intended that this ground cover will rapidly spread and cover areas of the substrate not already covered by the other plants. The grass like plant with reddish leaves (foreground of Figure 3a.) libertia peregrinans, spreads by way of suckers off the main roots of the parent plant. Therefore, this plant should propagate throughout the container and any additional suckers can be transferred to other substrate areas.

Modular support structure

A modular system recognises the tradeoffs that exist between gaining the many benefits of green roofs with the ability of an existing structure to maintain the extra loading created by a green roof installation. Varying the percentage cover of the substrate allows the green roof to be tailored to the load bearing capacity of the roof structure.

The modular design of the green roof system allows ease of installation and varying sized roofs to be covered. Figure 3a shows two modules installed on the roof. Figure 3b illustrates how the modules interlock next to one another. The modules on the high side of the roof surface drain into those below them, while the sideways interlocking ensures all rain fall is collected on either the substrate or clear module sections in between the substrate areas.



(a) (b)

Figure 3. (a) Two modules in location on the garage roof. (b) Cross-sectional view of modules indicating sideways locking (mesh substrate containers not shown for clarity)

Preliminary rain fall test

Rainfall retention and runoff delay properties of the substrate section of a module were investigated by rainfall simulation. The module was completely saturated three days prior to the test, with intervening days being mostly sunny (no rainfall) and having temperature highs around 12°C and lows of around 1°C. The rain fall was simulated by sprinkling water over the substrate at a rate of 100ml/minute for 14 minutes. This equates to a total rain fall of 4.63mm, at a rate of 19.8mm/hr. In the last six months, the greatest daily rainfall in Christchurch was approximately 41mm (ECAN, 2008), thus the simulated rainfall represents a medium to heavy rainfall event. The water runoff was initially measured at 1 minute intervals, with measurement intervals decreasing as runoff decreased. The results are shown in Figure 4.

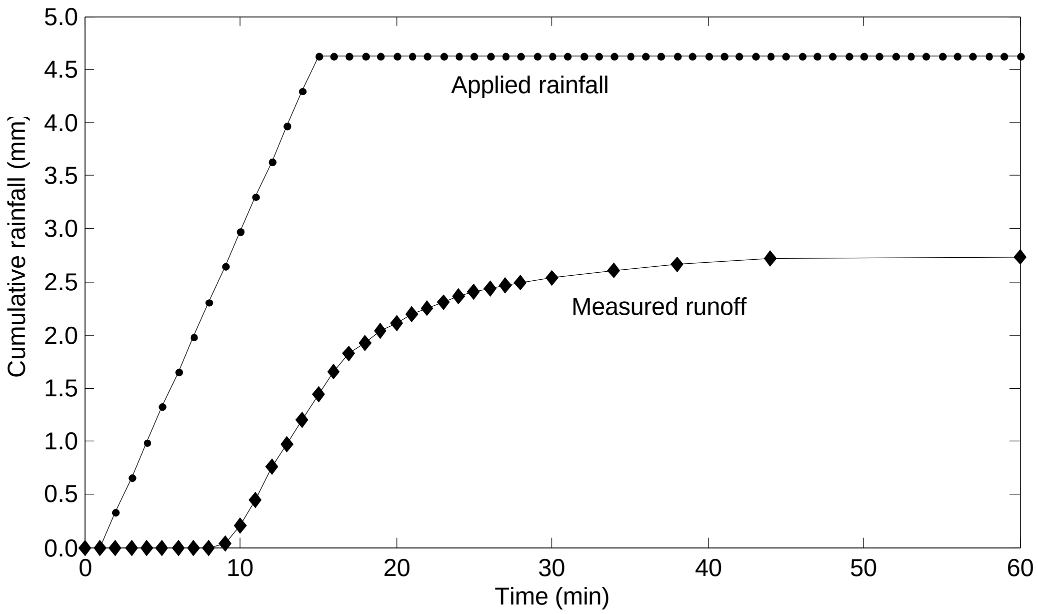


Figure 4. Rainfall test of the planted section of the module

The module was found to significantly absorb and delay runoff. The delay in runoff was measured to be 8 minutes. Runoff had completely stopped by 60 minutes, with a measured retention of 1.90mm of the 4.63mm applied. The runoff was observed to contain a small amount of substrate, thus an additional filter layer will be installed in future modules. Considering the substrate was completely saturated three days prior to the test, and the simulate rain fall represents an intense shower, the green roof system has shown to offer good retention and runoff delay properties.

Conclusions

A light weight modular green roof system was designed, built, tested, and retrofitted to and existing suburban dwelling. The modular construction and ease of instillation and removal makes this system potentially more attractive as no alterations of the existing roof and building structure is required.

The modular green roof system shows the potential of a retrofit system to achieve a proportion of the benefits offered by green roofs. Initial results show that the modular system is able to retain and extend the rain fall runoff time period. This is important due to the increase in demand on the storm water systems in urban areas from the case study section and other similar subdivisions.

Future Work

Based on the performance of the first two modules, imminent work includes:

- Covering the entire roof in modules
- Additional retention and delay runoff tests with different rainfall rates

Systems for green coverage of vertical surfaces are being developed for retrofit of the residential house. Observation of the plant growth behaviour, in the shallow substrate depth, will assist in determining whether any of the plants are suitable for vertical applications. Temperature and humidity data loggers are currently installed throughout the house, enabling thermal properties of a retrofit green roof to be tested in the future if desired.

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