



Session Number: Session Title

SUCCESS AND SUCCESSION

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Abstract

A city builds a highway and knows what to expect in terms of maintenance and performance 10 and 20 years from now. It is starting to be recognized that green infrastructure behaves differently, as growing and evolving systems: some of which are quite well characterized, such as urban forests. Green roofs are younger, more dynamic and often highly designed. All of which leaves more questions about their maturation and development largely unanswered in many regions. A retrospective, comprising several of the oldest roofs in North America will be presented, to provide a rich framework within which to consider ecological succession as an ultimate end goal of extensive green roofs. Fundamental issues concerning the post-construction phases of green roof management include the economic and environmental expenses of weeding, fertilization and irrigation of extensive green roofs:

- What happens when the manicured aesthetic ideal is rejected either intentionally or through neglect?
- What is the long term viability of a green roof as a piece of ecological urban infrastructure versus its survival as a horticultural canvas?
- What can we learn from revisiting old projects and how can we design with the evolution of individual sites in mind?

These six case studies are selected on the basis of age (average age ten years), as well as the diversity in terms of design characteristics, subsequent maintenance and stakeholder perspectives. They include a highly sloped sedum roof, a roof with three different compositions of planting medium and a few roofs which have received almost no maintenance or attention since installation.

Introduction

In the City of Toronto, where green roofs are mandated through municipal law, the measure of success is defined:

“The plant selection and design shall be such that within three years of the planting date the selected plants shall cover no less than 80% of the vegetated roof.” (3)

Beyond these early years many green roofs undergo changes due to either deliberate or neglectful behavior by their owners and managers (2). In terrestrial environments complete abandonment would ultimately result in a climax community (8), but even minimally maintained roofs have trees removed once they reach a noticeable 1.8 m. The transition towards a naturalized ecosystem is further confounded by changes in the ownership and management of green roofs and the corresponding changes in the priorities in the use and function. Again this marks green roofs apart from most land based vegetation and plantings.

In addition to the careful selection of the initial planting material, the subsurface components play an important role in the continued development of a system. The percentage of organic matter in the planting substrate has a significant impact in both vegetation health and water holding capacity (1,6,7,9). It has been suggested that organic matter $\geq 25\%$ could cause long term failure of the vegetation through overgrowth and reduced drought resiliency (6). It has also been previously reported that ‘traditional’, low organic matter substrate can accumulate organic matter over a number of years, resulting in physic-chemical changes (4).

Methods

Three complementary studies have been undertaken on a total of eight green roofs on six sites. The green roofs are detailed in Table 1 below.

Table 1 Details of study green roofs in Toronto

	Ref	Construction date	Roof geometry	Shading structures	Organisation type	Surroundings
Earth Rangers: South roof	ERS	2003	Flat	North	Non-profit	Natural
George Vari Engineering, Ryerson University	GVE	2004	Flat	Many	University	Dense Urban
Jackman Avenue School	JAS	2005	Flat	North-East-South	Junior School	Urban
Toronto Botanical Garden: Flat roof	TBGF	2005	Flat	East	Non-profit	Park
Toronto Botanical Garden: Sloped roof	TBGS	2005	Slopes to North	None		
Arts and Administration, University of Toronto	UTSC	2005	Flat	North-West	University	Park
Royal Ontario Museum	ROM	2008	Flat	North	Non-profit	Dense Urban
Earth Rangers: East roof	ERE	2010	Flat	West	Non-profit	Natural



The roofs were selected for study owing to their age, although it is notable that all of the roofs are owned and managed by organizations with an education mandate. Only the George Vari Engineering Building roof is accessible to the community, albeit under restricted conditions. The community gardening group, Rye's HomeGrown CG, have a group of volunteers who regularly farm on the green roof.

Study 1 – Succession in Management

Individuals who own or maintain the case study roofs, were asked to complete a short survey. Two stakeholders per case study were invited to take part. Question 1 established their relationship to the green roof. The second question asked them to rank a number of services or functions which their green roof provides in 2014. The functions included were: Aesthetics, Biodiversity, Community, Identity, Education or research, and Infrastructure. Finally, the simple question 'Is your roof successful?' was asked with three categories of possible response.

Study 2 – Succession of Plant Communities

Assessments of the vegetation diversity were made during visits to the study roofs in 2013, 2014 or in some cases both summer seasons. The number of species were recorded on site, or by later reference to photographs of encountered specimens. In two cases the plant communities had been surveyed in 2008 (5). A summary of the original planting lists is presented in the Appendix.

Study 3 – Development of Substrate

The depth of the planting substrate was recorded on-site using a graduated metal probe. Samples of the planting substrate were air-dried and stored at the laboratory prior to testing. Portions of the substrate (~20 g) were subject to loss-on-ignition (550 °C, 120 minutes) to determine the % organic matter. pH measurements were made using 1:2 (w/v) preparations in reagent grade water, stood for 60 minutes prior to testing (Radiometer PHM92 with Sentix22 probe). Additional suspensions were prepared at 1:5 (w/v) and tested for electrical conductivity (FieldScout EC110).

Results and Discussion

Study 1 – Succession in Management

Question 1 established that three of eight respondents have been with their organization since their roof was constructed and three have joined their organizations since. Four respondents identified themselves as responsible for the upkeep and maintenance of their roof. Question 2 results regarding the importance of various factors, are presented below in Figure 1. In each respondent's polygon, more important functions project further from the centre. Based on mean rankings the key priority was education and research, whilst the lowest average ranking was given to aesthetics. Half of the respondents said that their roof was 'successful' and selected 'somewhat' to this question. Frustrations were expressed about limited accessibility and use of roofs, particularly for educational purposes. This directly reflects the nature and priorities of the organizations. Another comment was made regarding the Toronto bylaw and questioned the effectiveness of green roofs from a sustainability perspective. No concerns were expressed about the upkeep or evolution of their green roof design over time.

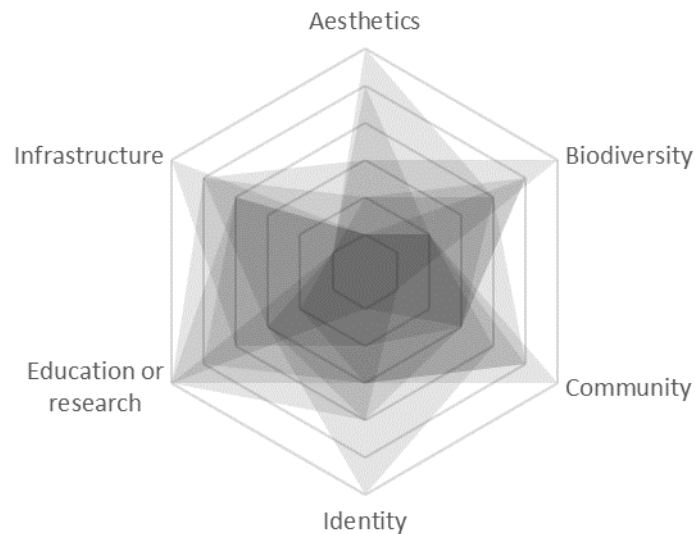


Figure 1 Stakeholder rankings of the importance of green roof functions (n=7).

Study 2 – Succession of Plant Communities

Earth Rangers

This green roof was originally commissioned with a strong interest in the infrastructural benefits in terms of storm water retention and moderating the temperature within the building envelope. Despite these primary motivations, the roof is overlooked from the building's upper storey and is one of the most highly maintained roofs studied. Monthly weeding and occasional manual irrigation results in the visible retention of the geometric design over ten years later (Figure 2). The Southern green roof (pictured) is the most 'traditional' of the study installations, comprising Sedum species planted into a low organic medium. Eight Sedum species were planted with Chives (*Allium schoenoprasum*) and White Clover (*Trifolium repens*) providing additional height and texture. Originally this design spanned three roofs; north, east, and south over the first floor wings of the buildings.

After six years, this system had not developed significantly and lacked the dynamism that the owners wanted to promote green technology awareness and to integrate the roof into the natural surroundings. So the Eastern roof was replaced in 2010 to support a variety of native and ornamental perennials in a substrate with higher % compost. Due to the maintenance, this roof has also remained largely unchanged since installation although some areas of geraniums (*Geranium maculatum*) and all of the Tickseed (*Coreopsis* sp.) were lost in the winter 2013/2014. In the winter of 2013/2014 a weir was installed to measure the output flow from the entire green roof (South-East and a North wing). This is the final data stream for the building owners, Earth Rangers, to track their entire water balance (both indoor and outdoor uses) on a continuous basis.



Figure 2 Earth Rangers Southern roof: 2005, after 2 years establishment (left), and 2013 (right).

George Vari Engineering Building, Ryerson University

In contrast, the green roof of the George Vari Engineering building at Ryerson University was originally conceived as a monoculture of daylilies (*Hemerocallis* 'Catherine woodbury') and was equipped from the outset with a suite of hydrological and climatological sensors for research purposes. This roof received minimal maintenance for over eight years, with just woody species being removed to prevent membrane damage. For many years there was no irrigation system installed.

After just four years the number of species had risen to thirty-nine, as many volunteer species colonized (5). Some *Hemerocallis* remain still in 2014, although, until 2013, this urban ecosystem continued to evolve into more of a prairie meadow with *Aster* sp., *Asclepias tuberosa*, *Linaria vulgaris* and *Vicia cracca* prevalent amongst the grasses. A dramatic change in the management of this roof occurred between 2013 and 2014, as a group of community gardeners took control of the space and turned much of the area to vegetable production (Figure 3). With this new function the space is accessed twice per week through the summer months and now receives automatic irrigation and regular soil amendments in addition to weeding care.



Figure 3 George Vari Engineering Building roof, 2013 (left), and 2014 (right)



Jackman Avenue School

This 90 m² roof was designed in partnership with the school community who were and still are concerned primarily with the potential for evaporative cooling to affect air flow coming across the installation and in through adjacent windows. A palette of eleven native species was selected according to the sheltered and shaded position. The roof is not accessible under usual circumstances and it is explained to the young students as being a 'roof' rather than a 'garden'. Weeding maintenance is provided infrequently (approximately annually) and irrigation is not provided. Since installation the total number of species has remained similar (11 originally). The original design intent has been largely obscured due to the relative success of the planting and some replacement with volunteer species.

Toronto Botanical Garden

This roof, of two parts, was intended to fit within the overall botanical garden theme of a curated garden landscape. The largest part of the roof (60 m²) is sloped to the north on a curve, from 22 to 30°. This area has battens to retain the planting substrate and was planted with four varieties of Sedum. The slope restricts maintenance, as access requires the use of harnesses and steel lines to climb the loose surface (Figure 4). Although this is the second Sedum roof examined, the slope, the composition of the original planting substrate (high compost content), lower maintenance and higher vegetation coverage have led to a very different outcome. A thick layer of haircap moss (~10 cm) has formed an understory, resulting in a wetter environment at the substrate surface which supports fruiting fungi in the late summer.

The local seed bank is diverse and ornamental compared to other green roofs, leading to the establishment of Penstemon, Coneflower (*Ratibida pinnata*), Jerusalem Sage (*Phlomis tuberosa* 'Amazona') in addition to the more common Golden rod (*Solidago* sp.) and the seemingly ubiquitous Black medic (*Medicago lupulina*).



Figure 4 Toronto Botanical Garden sloped section, 2006 (left) and 2014 (right).

University of Toronto, Scarborough, Arts and Administration Building

Installed at the time of the building construction, this roof was originally seeded with a wildflower mixture, with a nurse crop of Annual Rye (*Lolium multiflorum*). The clients were clear that they required a minimal maintenance system and did not provide irrigation beyond the first season.

The system is still dominated by the rye grass with other abundant species including yarrow (*Achillea millefolium*) dog strangling vine (*Cynanchum rossicum*) (Figure 5).



Figure 5 Arts and Administration green roof, University of Toronto, 2005 (left) and 2013 (right).

In addition to the noted herbaceous changes, all of the roofs had saplings of woody species observed or reported as recently removed. The most common among which were the Chinese elm (*Ulmus parvifolia*) and the Manitoba maple (*Acer negundo*).

Royal Ontario Museum

Although one of the youngest roofs studied, this green roof (519 m²) has a number of remarkable features. It is located to the South of an overhanging reflective aluminium fascia, which results in a very hot dry area directly alongside the only observation point, a restaurant window. The majority of the installation is suspended 1.2 m above the existing roof with deeper recesses to support ornamental trees. The original planting comprised Sedums – 8 main varieties with about 16 different cultivars, and Hens and Chicks (*Sempivivum* sp.), chives and horsetail grass (*Equisetum* sp.). The spray irrigation system is programmed to deliver twice a day during the summer due of the low storage volume of the planting substrate depth. In the first two years there was an attempt to maintain the design intent with weeding and replacement of dead sedums. But with the spread of the chives and the horsetail grass into the highly designed sedum fields it was seen as an impossible maintenance endeavor and after the two year warranty period all routine attention ceased. Over time it has acquired a diverse look from the original highly stratified design of white, yellow and pink Sedum areas. The design intent was fraught with unrealistic expectations from the start – form beat function to the detriment of good horticultural practice or practicality. One area which suffered particularly is beneath the overhang, the intense heat and light eradicated the Hens and Chicks leaving an opening, which was occupied by Quick Weed (*Galinsoga quadriradiata*) in 2013. This is an annual weed, which failed to germinate by June 2014, resulting in the exposure and erosion of the planting substrate, and subsequent damage to the irrigation line, exacerbating the problems (Figure 6).

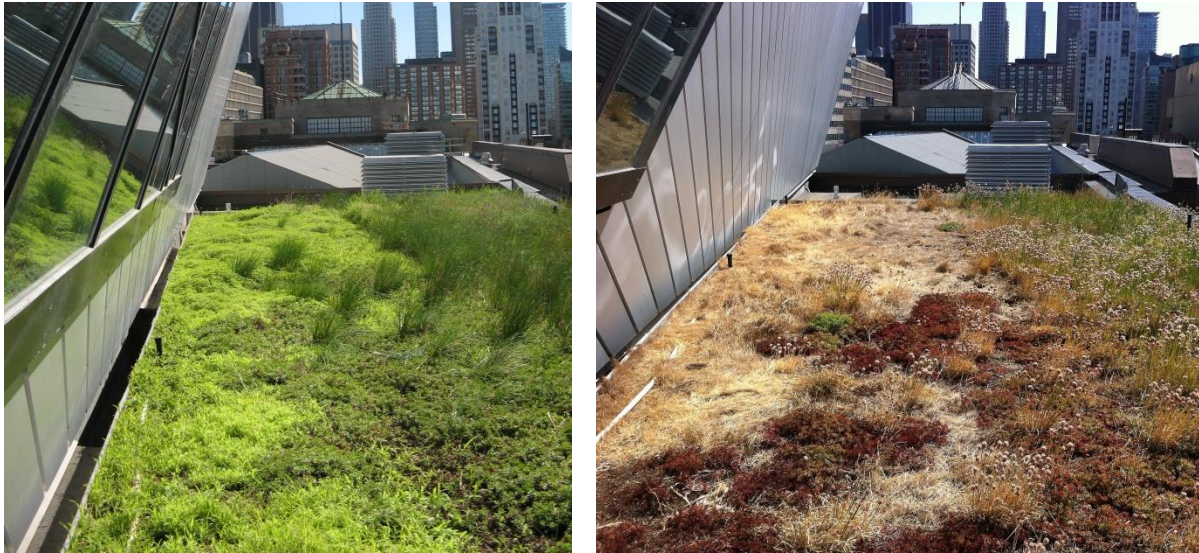


Figure 6 Royal Ontario Museum scorched section detail, 2013 (left) and 2014 (right)

Study 3 – Development of Substrate

Based on the depth measurements, none of the planting substrates have demonstrated significant bulk compaction since installation (Figure 7).

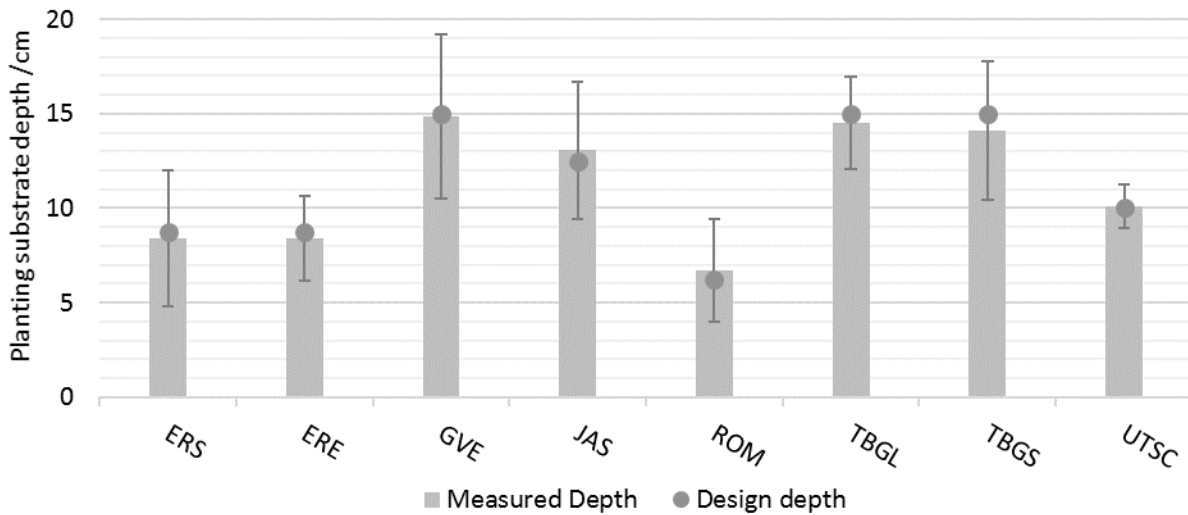


Figure 7 Depth of planting substrate on eight green roofs

The planting substrate used in the Earth Rangers South roof contains ~7% organic matter, which is within the range on the supplier’s current specification for a similar product (5 - 10%). This material was distinct from the remaining study roofs which contained a mean of 53% organic matter ($\sigma = 8\%$). The substrates had neutral pH, with mean $pH_{1:2H_2O} = 6.8$ ($\sigma = 0.5$). The electrical conductivity of the soil solution indicates the total dissolved solids and is related to

the osmotic potential. Electrical conductivity appeared to reduce with age, although the small sample size resulted in Pearson's $r = 0.75$, and $r = 0.68$ with the exclusion of the Earth Rangers South roof.

Conclusions

Stakeholders who inherit or commission green roofs may expect a zero-maintenance, but the emergence of tree seedlings on all of the roofs forces the minimum of an annual inspection for even the most disinterested owners. The sparsest vegetation was observed in the north section of the ROM roof and across the southern roof at the Earth Rangers site. In both cases the roofs are exceptionally hot and dry due to their southern aspect and unusual substrate configurations. When applied ≥ 10 cm deep, the substrates containing around half organic matter were stable after ten years and successfully supporting a range of native, ornamental and/or sedum species.

In many of the case studies examined, the original aesthetics had been eroded through abandonment and the design intent lost to nature. Benign neglect provides a window of opportunity for the development of alternative, biodiverse urban ecosystems which retain all of their other original functions. As the current custodians place a relatively low priority on the aesthetics of their green roofs, the mantra 'form follows function' may be good advice for enduring green roof design. In most circumstances where the roof is not accessed or even overlooked the designers and clients are advised to work towards a shared understanding of how a roof with minimal maintenance will evolve to ensure the perception of success for the lifetime of the installation.

Acknowledgements

The authors would like to thank the custodians of the green roofs at the organizations: Earth Rangers, Ryerson University, Jackman Avenue School, Toronto Botanical Garden, University of Toronto and the Royal Ontario Museum. We value their support both in terms of physical access and facilitation and in sharing their insights and opinions. Thanks also go to the Natural Sciences and Engineering Research Council of Canada for funding this work.



References

- (1) Buist R, Friedrich C. The Organic Question. Living Architecture Monitor 2008 Winter 2008:17-20.
- (2) Growing resilience: Long-term plant dynamics and green roof performance . Cities Alive - 11th annual green roof and wall conference San Francisco: Green Roofs for Health Cities; 2013.
- (3) Council of the City of Toronto. Green Roofs. Toronto Municipal Code 2009 2009-05-27;Chapter 492.
- (4) Getter KL, Rowe DB, Andresen JA. Quantifying the effect of slope on extensive green roof stormwater retention. Ecol Eng 2007;31(4):225-231.
- (5) E. Hahn. Urban green roof vegetation assemblage demography, classification and design recommendations Ryerson University; 2009.
- (6) Nagase A, Dunnett N. The relationship between percentage of organic matter in substrate and plant growth in extensive green roofs. Landscape Urban Plann 2011;103(2):230-236.
- (7) Rowe DB, Monterusso MA, Rugh CL. Assessment of Heat-expanded Slate and Fertility Requirements in Green Roof Substrates. Horticultural Technology 2006;16(3):471-477.
- (8) 100 extensive green roofs: lessons learned. Greening rooftops for sustainable communities Washington: Green Roofs for Health Cities; 2005.
- (9) Yio MHN, Stovin V, Werdin J, Vesuviano G. Experimental analysis of green roof substrate detention characteristics. Water science and technology: a journal of the International Association on Water Pollution Research 2013;68(7):1477.



Appendix – Selected planting details study 2

Genus only identified where the species is unknown (in a proprietary seed mixture) or where multiple species have been used.

	ERS	ERE	GVE	JAS	ROM	TBGF	TBGS	UTSC
Achillea millefolium				X				
Allium schonaprasum	X	X			X	X		
Aquilegia canadensis							X	
Aster sp.						X		
Calendula sp.								X
Carex sp.				X				
Centaurea sp.								X
Coreopsis grandiflora 'Early Sunrise'		X						
Coreopsis lanceolata						X		X
Coreopsis tripteris						X		
Cosmos sp.								X
Equisetum hymale					X			
Erysimum sp.								X
Geranium maculatum				X				
Geranium psilostemon 'Rozanne'		X						
Hemerocallis 'Catherine woodbury'			X					
Leucanthemum x superbum								X
Liatris spicata		X		X				
Lobelia siphilitica				X				
Lolium multiflorum								X
Lupinus polyphyllus								X
Monarda fistulosa				X				
Monarda punctata						X		
Panicum virgatum		X				X		
Papaver rhoeas								X
Penstemon digitalis				X		X		
Pycnanthemum tenuifolium						X		
Rudbeckia hirta						X		X
Rudbeckia nitida 'Herbstsonne'				X				
Rudbeckia laciniata 'Goldquelle'				X				
Saponaria officinalis								X
Schizachyrium scoparium				X				
Sedum sp. (#)	8				8		4	
Sempervivum sp.					X			
Silene sp.								
Symphytotrichum novae-angliae				X		X		X
Trifolium repens	X							