Innovation in Sustainable Roadside Tree Management
City of Winnipeg Regional Street Case Study

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ABSTRACT

The socio-economic benefits to society, both tangible and intangible, from healthy urban forests are varied and remarkable. These benefits are difficult to place a widely accepted financial value upon.

Many jurisdictions make significant investments in trees over their lives. They represent important fixed assets with substantial book value. Proper life-cycle management is necessary to protect and enhance this investment.

Many trees in urban areas are planted adjacent to roadways and other paved areas which are very difficult for trees to thrive in particularly in climates with wide variations in temperature like many parts of Canada.

Traditional engineering and construction in most paved urban areas require replacing good planting soils with compacted sands/gravels and quickly directing runoff to sewers. It is difficult for trees in these areas to access the soil volumes and moisture necessary for vibrant root development.

As a result of such difficult conditions the City of Winnipeg replaces trees in many areas every 7 to 10 years with some as often as every three. This frequent replacement leads to perpetually immature trees that providing only a tiny fraction of the benefits of fully mature.

Various methods have been employed over the years in Winnipeg to increase the soil volume available for tree root development. The newest generation system tried by the City of Winnipeg was an innovative underground framework of fiberglass/ polypropylene structural “cells”.

This system was used in an experimental project on the busy and historic Broadway in downtown Winnipeg in 2007. The installation of this type of system is straightforward but a long term and more widespread evaluation of its effectiveness and life-cycle costs is necessary.

Introduction

The Value of Urban Forests

The Canadian Urban Forest Network (CUFN) considers the urban forest to be: trees, forests, greenspace and related abiotic, biotic and cultural components in and around cities and communities. It includes trees, forest cover and related components in the surrounding rural areas (peri-urban forests)[(1)].

The socio-economic benefits to society from healthy urban forests are varied and remarkable[(2,3,4,5)]. They include both tangible and intangible benefits that make it difficult to place a widely accepted financial value upon them. Examples of the benefits include:

1. Moderating Climate – Mitigating the extreme effects of sun, heat, wind, precipitation, etc. on adjacent infrastructure and the environment (pavements, buildings, adjacent trees and other plantings, wildlife, and people)

2. Energy and Carbon Dioxide Conservation - Trees can contribute to energy conservation because they help to reduce the cost of heating and cooling nearby buildings

3. Air Quality
    - Exchanging gases with the atmosphere;
    - Capturing particulates that can be harmful to people
    - Potential for cities to claim credits for air pollution reduction as air pollution trading markets develop (e.g. trading markets already exist for several criteria pollutants such as Particulate Matter (PM_{10}), Nitrogen Dioxide (NO_2), Volatile Organic Compounds (VOCs) and have been proposed for Carbon Dioxide (CO_2)).

4. Urban Hydrology
    - Reducing the rate and volume of stormwater runoff;
    - Reducing flooding damage;
    - Reducing stormwater treatment costs and water quality problems.

5. Ecological - Promoting ecological stability by providing habitat for wildlife, conserving soil, and enhancing biodiversity. Although the value of these benefits is seldom quantified, they are important to many urban dwellers and to the long term stability of urban ecosystems.

6. Social – The presence of urban trees and forests can make the urban environment a more pleasant and even healthier place to live, work, and spend leisure time. Studies of urbanites' preferences and behavior confirm

the strong contribution that trees and forests make to the quality of life in urban areas.

7. Economic Development and Real Estate – Creating a sense of community well being and spurring demand for well maintained properties. Trees can attract sales and rental premiums for adjacent properties when the trees are healthy and vibrant.

Many jurisdictions make significant investments in urban forests over their lives. As they mature, they increase in value and represent fixed assets with substantial book value. The more mature and large the urban forest, the higher the value. Unlike traditional infrastructure that starts depreciating once it is installed, trees actually appreciate in value as they age and grow. Based on these facts it follows that proper life-cycle management of trees will protect and enhance the investment in them.

A discussion of the value of trees in urban environments would not be complete without mention of some of the downside associated with them. Some of the characteristics of mature urban forests in urban environments also include(2,3,4,5)

i. Root damage to sewers and adjacent pavements;
ii. Pollen production;
iii. Hydrocarbon emissions;
iv. Green waste disposal;
v. Water consumption.
vi. Higher general maintenance requirements;
vii. Potential conflicts with overhead utilities and signage (power lines, light standards, commercial and traffic signs, etc.);
viii. Darker streets at night depending on specific canopy and illumination characteristics in an area;

The abundance of existing trees in North American municipalities provides testimony that trees are not only highly valued by communities, but they must be maintained in a healthy and vibrant condition. As public sector infrastructure stewards, solutions must be found to minimize conflicts with traditional infrastructure and how it is designed and constructed.

Maintaining Trees Adjacent to City Streets and Paved Areas

The need to protect investment in tree assets is very important. Many jurisdictions face budgetary constraints and/or priority decisions that reduce routine tree maintenance programs in favour of higher profile infrastructure assets. This often manifests itself in lengthened pruning cycles, more tree removals than replacements, and the inability to quickly address public safety hazards. These maintenance impacts and others lead to the slow degradation of the urban forest in terms of size, health and other characteristics.

However, there are a series of other factors besides fiscal constraints that contribute to the degradation of trees in urban areas. A great number of trees in urban areas are planted adjacent to roadways and other paved areas such as sidewalks, bicycle paths and parking lots. These environments are very difficult for trees to thrive in particularly in climates with wide variations in temperature like many parts of Canada. Factors contributing to this harsh environment include:

i. Poor soil conditions (e.g. lack of quantity and quality of soils with proper nutrients);
ii. Pavement impacts (tree and roots exposed to extremes of temperature from pavement conduction and reflection);
iii. Repeated exposure to materials like salt and other de-icing materials;
iv. Damage from vehicle collisions;
v. Damage from underground and overhead construction (e.g. utilities);
vi. Vandalism;
vii. Adjacent development and land use that alter a trees exposure to heat/wind/elements, etc.

There ability to be creative with tree maintenance is limited since trees are living organisms that must be dealt with as their health issues arise. Pruning, watering and inspection are fundamental activities that cannot be avoided or deferred too long without risk to the tree.

Planting Trees Adjacent to City Streets

Trees require large soil volumes to grow. As a tree grows larger in diameter and height, more soil is required for its growth. It is difficult for trees in paved urban areas to reach sufficient soil volume necessary for full and rapid root development. Many traditional tree “pits” in urban centers hold less than $2m^3$ of soil. It is believed that nearly 15 times that volume of soil is needed to grow a 400+mm diameter tree (say 10 to 12m high) with full crown(6).

Traditional engineering and construction standards and practices in most paved urban areas require replacing good planting type soils with compacted sands and gravels. Runoff is typically managed by guiding it quickly and efficiently into catch basins off to land drainage sewers underground. The priority given to constructing compacted pavement structures and whisking away runoff is often at odds with the needs of a municipality’s urban forest.

The City of Winnipeg replaces trees in many areas every 7 to 10 years due to the environmental difficulties and engineering practices described above. Some survive only three years on busy regional streets where the City places a high priority on maintaining trees. The frequent replacement leads to perpetually immature trees that provide only a tiny fraction of the benefits of mature trees.

Various methods have been employed over the years in Winnipeg to increase the soil volume available for tree root development. These methods include soil vaults, raised beds, and a new blended gravel/soil backfill ("structural soil") concept yet to be tried.

The newest generation system the City tried is an underground framework of "structural cells" made from a fiberglass/ polypropylene blend able to support traffic above while providing loose soil below (**Fig. 1**).

Figure 1 – Structural Cells Used on Downtown Winnipeg Sidewalk Project 2007

This innovative system was used on the busy and historic Broadway sidewalk project in downtown Winnipeg in 2007, the largest of only 3 known trial installations in North America at that time with the others being in Redwood, California and Kelowna B.C.

City of Winnipeg - Broadway Sidewalk Renewal Project

Background

During the summer of 2007 the City of Winnipeg Public Works Department (Transportation Engineering and Parks & Open Spaces Divisions) decided to alter an existing downtown sidewalk renewal contract by replacing the specified "structural soil" item with a newly developed "structural cell" system. The original contract item called for replacing the existing sidewalks and trees on a busy downtown street. The tree wells were to be excavated and filled with approximately granular base course combined with 20% planting soil. The 20% soil would provide the base course with nutrients and porosity for promoting tree root growth with the base course intended to carry the pavement and traffic loading of the sidewalk above.

The nature of the project was primarily sidewalk renewals on a six lane (3 lanes each way) divided tree lined downtown street. The outside lane in both the east and west directions is used for parking during off peak hours. The project included the replacement of 7 American Elms on the north side of the street.

Structural Cell Design

The tree planting was done on two separate blocks with 2 trees on one and 5 on the other. Different soil volumes were planted on each of the two blocks. The first block was completely excavated to the property line while the second block was excavated only in between the row of trees. The first block provided approximately 30 cubic meters of soil per tree while the second block provided approximately 20 cubic meters of soil per tree. The structural soil cells were designed to be stacked on a compacted subgrade and gravel base. The first section was approximately 0.80m deep (2 cells) by 3.25m wide (5 cells) by 22.95m long (18 cells) and the second section was 0.80m deep (2 cells) by 1.95m wide (3 cells) by 62.6m long (49 cells).

The cells consist of a fiberglass/polypropylene blend frame (600mm W x 1200mm L x 400mm H) with legs intended to be fit into one another as they are stacked like typical household storage containers. Once the desired number of frames is stacked for height, a solid cover is placed on top to receive the ultimate pavement structure. The large voids created by the framework of adjacent stacked cells house the desired planting soil type while the legs of the frames create pillars through which the pavement and traffic loading above are transferred to the compacted subgrade below (**Fig. 2**).

Figure 2 – Structural Cells Being Stacked on Each Other in Winnipeg

Construction Methods

The method of constructing the structural soil cell tree installations consisted of normal sidewalk removal, excavation, backfill, and sidewalk construction. Normal subgrade and granular bedding compaction methods were used. (**Fig. 3**).

Figure 3 – Typical Construction Methods Used (bedding compaction shown here)

Hand placement of the structural cell frames, geotextile wrap, desired soil fill and frame covers followed the subgrade and bedding compaction (**Fig. 4**).

Figure 4 – Structural Cells Being Wrapped, Filled and Covered in Winnipeg

Drainage and irrigation pipes were also placed in among the network of frames as appropriate to provide positive lateral drainage and watering for the trees respectively. Further, viewing ports (vertical plastic tubes) were installed in two locations and capped for future access so the system could be visually monitored as needed in the future.

The monitoring could include viewing to establish subsurface water level in the system, insertion of a small video camera to examine the development of roots and consolidation of soil, and sampling of subsurface soil and water as desired.

Anticipated Benefits

The anticipated benefits from employing the structural cells include:

i. Improved dispersal and earlier root development;
ii. Better annual tree growth;
iii. Enhanced subsurface soil drainage;
iv. Longer tree life;
v. More mature trees;
vi. Longer tree replacement cycle;
vii. Normal excavation, backfilling and compaction methods can be used;
viii. Normal sidewalk pavement construction can be accommodate; and
ix. More complete realization of socio-economic benefits.

Project Considerations

A number of considerations arising from this particular test project are worthy of note and should be thought about in planning future projects in Winnipeg and elsewhere.

i. The General Contractor on this project was not familiar with the structural cell components or their placement for this project so was not as efficient as he could be after several installations.
ii. This project happened to be the General Contractor's first project as a General Contractor on a City of Winnipeg project. This added uncertainty to his pricing, work planning, traffic control, etc. These factors lead to a higher level of effort in administering the contract.;
iii. Despite the product/system inexperience of everyone involved on the project, the installation went relatively quickly with the proper number of labourers and materials on hand;
iv. There were no special handling requirements for the structural cell system materials although it is relatively easy to damage frames and covers if loaded laterally or twisted too much;
v. Ensuring a level working base is important for installation, structural integrity, and fit within confined excavation areas;

vi. Not having a local frame supplier will make it necessary to order extra components in case of damage;
vii. One legacy of the structural cell system is the large framework of cells under the sidewalk which may impede future utility works or become damaged by unsuspecting construction crews (again the need for local supplier or buying extra stock of components up front could be important);
viii. Compacting the soil within the soil cells was done by foot as it is not really practical to use conventional compaction equipment such a jumping jack for fear of damaging the frames. Although the frames were topped up with soil before the covers were placed on them, there is a high likelihood that the soil will consolidate over time leaving a noticeable void that can not ever be practically filled. Aside from the lost potential volume of soil that could be placed in the void there is little other anticipated issues with this;
ix. The per tree soil volumes used in this experimental installation was significant but may not be optimal. Longer term evaluation of the installations is necessary to help determine an appropriate soil volume.

Project Economics

The overall success of the structural cell system concept as well as the City of Winnipeg's specific project should be based on many factors. These factors include not only the tangible and intangible environmental and socio-economic impacts described earlier but also more straightforward economics factors. One fundamental economic factor is the life-cycle cost of such installations. Although a detailed cost-benefit analysis was not intended to be part of Winnipeg's experimental installation, we have provided some high level financial analysis here to give the reader and other municipal jurisdictions some degree of context when considering undertaking similar projects in the future.

Our experimental project experienced relatively high initial per tree cost compared with more conventional and well established planting methods in Winnipeg. Our approximate installation cost was approximately $17.0K per tree vs. $6.3K for the gravel/soil mix originally bid vs. a more typical <$1.0K conventional "pull and plug" approach. Factors contributing to this high initial capital cost include:

- Some of the materials, methods and contract terms were a first for this particular General Contractor;
- There existed little or no past experience with this system for most of the parties involved in this project (owner, engineering company, contractor, supplier);
- Few meaningful efficiencies were anticipated or realized in design, specification, pricing, installation or contract administration. The method was new and a late replacement for an already awarded contract item;

- Material supply costs for our limited volume shipment of components over a long distance were higher than would be expected if the system becomes more routinely implemented;

We believe the per tree capital cost of installations similar to those of our project will very likely come down over time and have used an assumed capital value of $12,000 for economic analysis later in this section. Similar to other new technologies or construction methods, as the experience of the industry and number of material suppliers grows, more efficiency will be realized, economies of scale will come into play and perceptions of risk by contractors will diminish.

Even at our relatively high capital cost, the life cycle cost for a small number of adjacent tree plantings would need to be examined more fully before economic conclusions should be drawn about the system in general. That is, replacing fully mature trees with young ones once every 40 years or so provides much different cost/benefit ratio than replacing immature trees many times in the same period.

In order to provide a rough idea of what the comparative life-cycle cost might be for trees planted every 5 or 8 years versus every 40 years we have provided a very simplified Net Present Value (NPV) financial analysis to illustrate the point (see Tree Replacement Cycle Comparison Tables). The analysis includes three tree replacement methods for comparison:

1. Basic "Pull and Plug" method (root ball plus minimal new soil);
2. "Structural Soil" method (using a gravel/planting soil mixture);
3. "Structural Cell" method (using underground plastic framework).

In our example the NPV of a basic tree replacement every 5 or 8 years is approximately $9,000 better per tree than installing the Structural Cells and replacing the tree at 40 years given the assumptions in the analysis (see Tables 1, 2 and 5). Reducing the discount rate by a percentage point (which is plausible since many municipalities with good credit ratings can obtain borrowing rates very near those of the chartered banks' lowest rates) or reducing the structural cells capital costs within a range of %15 – 30% (due t increasing efficiency and economies of scale over time) does not materially change this difference. The NPV of the "Structural Soil" is much closer to that of the "Structural Cells" (see Tables 3, 4 and 5) with the same sensitivity to discount rate and capital cost. Similar to discount rate and capital cost as described above, altering the theoretical salvage values does not change the relative results in a material way.

Even though we have provided a very simplified financial analysis here, more rigorous Discounted Cash Flow (DCF) analyses need to be performed with factors such as intangible ongoing socio-economic benefits and terminal values reasonably quantified and qualified. Boiling the value of mature urban forest versus immature urban forest down to a simple NPV without thorough quantification of these important variables is inappropriate and likely misleading.

In other words, this analysis does not account for the value of the intangible benefits to a community provided by the tree as it grows to maturity and beyond. If trees must be replanted every 5 to 8 years, the much greater benefits from the tree growing much larger are never realized.

Jurisdictions must develop their own DCF models to help evaluate what tree planting methods are best for them but the sustainability of the assets and the intangible benefits they provide to the community must be appropriately weighed by decision makers in their analyses.

Summary

Mature urban trees (and hence forests) pose both benefits and some problems to the urban environment and community. It is believed, on balance, that the benefits outweigh the problems by a measurable margin. Therefore the need to protect municipalities' investments in their urban forests is very important. A large part of tree investments is the initial installation cost and a large part of tree sustainability is the method used to install and maintain them.

The technical concept of the structural cell installation method appears sound. The construction is very straightforward with essentially conventional labour, equipment and materials required. The City of Winnipeg's experience with the method could be considered good overall.

The City's rationale for trying the structural cell method experiment on its Broadway streetscaping project in 2007 was based on the anticipated sustainability of the trees planted. This sustainability rationale appears defensible but long term tree monitoring and more rigorous economic and DCF analyses need to be done to quantify its true life-cycle cost more accurately than presented here.

Additional similar projects need to be added to the body of data required to determine what "normal" capital costs might be. Further, a long term examination of the trees and the overall installation area itself is necessary to more fully assess the effectiveness of the project on the development of the trees and there full benefits and impacts on the street and broader environment/community.

At the time of writing this paper, the City of Winnipeg had been contacted by a number of other jurisdictions considering similar trial installations of structural cells including the Cities of Calgary and Toronto.

TABLES

Table 1: Basic Tree Replacement Method (8 yr cycle) vs. "Structural Cell" Method

Tree Replacement Cycle Comparison			
	Basic	Structural Cells	Difference
Replacement	8 yr Cycle	40 yr Cycle	32 yrs
Capital Cost	($1,000)	($12,000)	$11,000
Salvage Value	$1,500	$20,000	($18,500)
Trunk (mm)	150	500	(350)
Crown (m)	4.0	8.0	(4.0)
Discount Rate	6.0%	6.0%	-
NPV	($183)	($9,376)	$9,193

Table 2: Basic Tree Replacement Method (5 yr cycle) vs. "Structural Cell" Method

Tree Replacement Cycle Comparison			
	Basic	Structural Cells	Difference
Replacement	5 yr Cycle	40 yr Cycle	35 yrs
Capital Cost	($1,000)	($12,000)	$11,000
Salvage Value	$1,200	$20,000	($18,800)
Trunk mm)	120	500	(380)
Crown (m)	3.0	8.0	(5.0)
Discount Rate	6.0%	6.0%	-
NPV	($410)	($9,376)	$8,967

Table 3: "Structural Soil" Method (8 yr cycle) vs. "Structural Cell" Method

Tree Replacement Cycle Comparison			
	Structural Soil	Structural Cells	Difference
Replacement	8 yr Cycle	40 yr Cycle	32 yrs
Capital Cost	($8,000)	($12,000)	$4,000
Salvage Value	$1,500	$20,000	($18,500)
Trunk (mm)	150	500	(350)
Crown (m)	4.0	8.0	(4.0)
Discount Rate	6.0%	6.0%	-
NPV	($9,321)	($9,376)	$56

Table 4: "Structural Soil" Method (5 yr cycle) vs. "Structural Cell" Method

Tree Replacement Cycle Comparison			
	Structural Soil	Structural Cells	Difference
Replacement	5 yr Cycle	40 yr Cycle	35 yrs
Capital Cost	($8,000)	($12,000)	$4,000
Salvage Value	$1,200	$20,000	($18,800)
Trunk mm)	120	500	(380)
Crown (m)	3.0	8.0	(5.0)
Discount Rate	6.0%	6.0%	-
NPV	($11,462)	($9,376)	($2,086)

Table 5: Comparative Net Present Values of Tree Replacement Methods

	Net Present Value		
Tree Replacement Method	**5 Year Cycle**	**8 Year Cycle**	**40 Year Cycle**
Basic "Pull and Plug" Method	($410)	($183)	-
"Structural Soil" Method	($11,462)	($9,321)	-
"Structural Cell" Method	-	-	($9,376)
	Benefit of Method Over "Structural Cells"		
Basic "Pull and Plug" Method	$8,967	$9,193	-
"Structural Soil" Method	($2,086)	$56	-
"Structural Cell" Method	-	-	$0

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