

# **TOWARD SUSTAINABLE ROOFS VIA DESIGN FOR HEIGHTENED MAINTAINABILITY AND FUTURE DISASSEMBLY**

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## **ABSTRACT**

Around the globe, designers are grappling with long term issues related to the built environment's impacts upon our health, the drain upon non-renewable resources, the effect of global warming, as well as potential end uses and disposal of spent building materials. Roofing systems and materials require similar examination. In Canada, these concerns are addressed at the federal, provincial and municipal levels of government.

Most designers recognise the significance of the environmental, but few implement designs that consider **R**educing material consumption or waste, **R**eusing existing (in-place) materials or **R**ecycling those components for other suitable uses. In fact, in order to provide a roof to satisfy typical functional requirements (impermeability, wind resistance, fire resistance, and thermal resistance), designers are often drawn away from options that optimally facilitate reuse, recycling and reduction.

A comprehensive view to improving the maintainability, serviceability and the possible disassembly of typical "case" roofing system configurations is described within this paper. The paper also examines the projected incremental investments and examines the economic consequences associated with implementing the recommended procedures.

## **Keywords**

legal requirements, resource consumption, waste management, deconstruction, sustainable design, economic evaluation.

## **INTRODUCTION**

### **Issue statement – World-wide perspective**

Historically, roofs have been built using materials that were available close at hand, with techniques that responded to the demands of the local climate and user customs. In many parts of the world, unique regional roofing practices survive because they continue to be cost effective and meet users' needs. Thatch roofs have been used for centuries in much of the world and are currently undergoing a slight renaissance. Sod roofs continue to be used in many rural areas. A traditional roofing material of India, mud phuska, provides relatively sustainable, thermal protection and waterproofing to a large portion of the residential roofs in the sub-continent (Jaisingh 1998).

As the world's economies have become less insular, many construction materials and methods have been exported to formerly remote markets around the globe. The "new" techniques are often in direct competition with the accepted or traditional practices. Such introduced technologies have had varying impacts on the local roofing industries but in most instances have caused an adaptation and broadening of labour skills, manufacturing capabilities, and technical knowledge. Regulations and standards for roofing construction typically have been expanded to permit the application of these newer "shared" technologies. This is facilitated by the international swing to performance-based specifications; the premise that "what" is to be provided with the application of a construction material or method is more significant than "how" that requirement is met.

With seamless borders and a global economy there has also been a wide international acceptance of each society's responsibility for environmental protection and improvement. In the mid-1980's various initiatives, such as the World Commission on Environment and Development (United Nations' 1988), formalised the desires of the international community for environmental sustainability and preservation. Various authors have identified the need, investigated the potential of designing for disassembly and have laid the groundwork for a general "deconstruction" practice (Rosenberg 1992, Doyle 1994, Kibert 1998, Hassanain and

Harkness 1998, Crowther 1999). Building materials and components may have various possible “end of life scenarios” (Guequierre and Kristinsson 1999) and designers must weigh the environmental benefits relative to the life-cycle economic factors.

Several international technical committees and working groups are currently examining ways to prolong building service life, achieve sustainability and minimise the long term environmental impact of built works. Notable amongst these efforts are: 1) the findings of Task Group 2 of the CIB W.83 / RILEM 166 RMS Joint Committee on Roofing Materials and Systems which has outlined some basic, and yet universal, methods to achieve sustainable roofing practice (Hutchinson and Roberts 1998); and 2) the on-going work of CIB Task Group TG39 examining existing procedures for and impediments to “deconstruction”.

### **Canadian perspective**

The Canadian construction industry has typically considered “use and dispose” to be the norm and the roofing sector has generally followed this practice. While most facilities constructed over the past 40 years were erected with a view to obsolescence, many of their constituent components and basic building materials are capable of providing an extended life or may be put to new usage. The identification and selective harvesting of the durable components in the most efficient and economical manner possible is the current challenge. Traditionally, the environmental benefits of using recycled materials are considered to be significantly greater than the potential economic advantages. This is particularly true if material or component reuse implies a reduced technical performance.

Canada is amongst the highest per capita generators of waste in the developed nations. Figures from the late 80’s indicate that Canadians produce about 30 million tonnes of waste annually, or more than one tonne per person per year (CANMET 1993). Projections based upon a survey of Canadian landfill indicate that approximately one quarter of Canada’s solid waste originates from construction and demolition (CANMET 1993). Many of the products used in Canadian roofing construction

have a high percentage of recycled materials but these materials are generally not available for further recycling after use in roofing systems.

The typical configurations of Canadian building stock have been categorised relative to occupancy and usage domains. The largest, and most diverse as far as construction types and materials are concerned, is Industrial, Commercial & Institutional (ICI). Buildings of this category tend to be fairly low structures, an average of 3 storeys for the institutional component and only one storey being expected in the industrial and commercial segments. The walls are typically constructed of brick or stone masonry while the roofs are generally low-slope, most likely to be BUR with progressively smaller percentages of Modified Bitumen, EPDM and PVC membranes being employed. On institutional buildings reinforced concrete slabs are the norm and galvanised steel decking is the typical design choice for industrial and commercial applications. The use of vapour barrier and the amount of insulation to be found in both walls and roofs generally reflects the cost of energy immediately preceding the construction date.

### Greening of Government initiatives

In 1990, "The Green Plan: A National Challenge" (Environment Canada 1990) informed Canadians of the serious environmental problems facing the country and the world. It outlined the federal programs, laws, and other actions in place to address these issues and made a commitment to clean air, water and land as well as sustainable use of renewable resources. Another five years passed until these commitments became a matter of public policy with the "Greening Government" Guide and Directions (Environment Canada 1995a, 1995b). This policy requires all federal government departments to establish and maintain a Sustainable Development Strategy. The Canadian government's highest environmental priorities focus on reducing energy consumption as well as the emission of greenhouse gases. Public Works and Government Services Canada (PWGSC) as the primary construction contracting agent and provider of office space and facilities to the federal public service, recognised one of their largest potential contributions to the success of these initiatives to be in the area of waste reduction. PWGSC put a

comprehensive Waste Management Strategy in place and current efforts are concentrating on waste management infrastructure requirements for construction, retrofit and demolition projects (Boyle et al. 1999).

The responsiveness of the Canadian provincial authorities to greening their operations and legislative requirements is spotty. Ontario is the only province that has formal regulations governing solid waste management. Municipalities or regional municipal bodies are responsible for landfill management in most provinces and many have imposed sorting requirements and/or material bans.

### **Role of emerging information technologies**

The capability to manage and assess information on the various aspects and efficiencies of roofing performance and phases of the life-cycle is relatively new and continually evolving. The available computer technologies and data structures permit the sharing of CAD details as well as design and material specifications developed by others in far-flung reaches of the world. The Internet permits the forewarning of, and sharing of solutions for, potential pit-falls to material application or design oversights. Practitioners are becoming steadily more informed about proven maintenance practices, international design standards and expected environmental performance criteria. With the increased benefit of rapid communication and information dissemination comes the increased threat of misinformation. Users must be confident of the validity and continued integrity of their information resources.

### **Scope of paper**

This paper attempts to evaluate the sustainability of low-slope roofing system configurations without professing to examine all the environmental concerns. The included work examines typical Canadian ICI low-slope roofing designs and construction as well as proposing modifications to enhance the sustainability of these systems by facilitating maintainability, disassembly and decommissioning. The paper further assesses the economic and environmental consequences of the recommended design modifications.

## **Sustainability objectives**

In order to make roofs more sustainable, decisions must be made on which environmental aspects are most critical and on how to best meet competing technical requirements. Each project is unique, and in dealing with one environmental aspect we may, in fact, create other problems. In addition, roofing construction is constantly shifting: new materials and techniques are being developed, and new regulations and standards are introduced.

The “3R’s,” reduce, re-use and recycle, are the cornerstones of sustainability. Improvements in roofing design would considerably extend the life of the roofing systems themselves and by extension, the buildings they serve. At the moment, there is little specific, organised information on where and how the most common current roofing system designs can be adapted to meet these objectives.

## **Sustainable design**

A truly sustainable roof is designed to permit material separation or refurbishment and re-use or recycling at the end of its life.

In designing for sustainability, life-cycle economic performance should be considered. Relevant items include the costs of maintenance and repairs, anticipated life span as well as the costs and potential revenues associated with decommissioning and disposal or recycling of roofing materials.

Designing for disassembly recognises that buildings do not last forever, and anticipates when they will be either renovated or dismantled. It is an important aspect of sustainable design, because it allows for easier renovation of existing assemblies, less waste material, and the easy separation of discarded materials for re-use or recycling. Designers must consider the potential reuse and recycling of constituent materials and components as well as the long-term interactions and incompatibilities of the air and vapour barriers, insulation and membrane.

The basic principles of designing for disassembly (Catali 1998) are:

- allow the primary material properties to remain unchanged over its expected life;
- simplify design to facilitate disassembly;
- keep material assemblies independent to minimise potential damage to adjacent assemblies during their removal, repair, and disassembly;
- obtain information on each component or material of an assembly (ingredients, composition), this will help to identify future reuse and recycling as well as waste management scenarios;
- expose connections or plan for easy access wherever possible to facilitate disassembly; and
- position materials or components with the shortest anticipated life-cycle in most accessible locations.

Despite the sound intent of sustainable design objectives, it may not always be possible to simplify the design of roof details due to restrictions or limitations imposed by building code requirements or insurance agencies.

### **Can it be built?**

Innovation in design is successful only if people, working under less than ideal conditions, can easily execute it in “real life,” on real buildings. For this reason, it is essential that any modifications to existing “proven” systems be designed with ease of construction in mind. Physical limitations of people and materials must be addressed, and the sequence of construction must be carefully planned in order to design systems that work in practice as well as in theory.

To assure co-ordination of building envelope continuity issues, it is important to identify the responsibilities of each party involved with its construction. The building’s air barrier system is particularly susceptible, since the system typically depends on the connection of many different materials by many different trades throughout the construction process. When there are many participants in a project, scheduling becomes very important - particularly if one team member is depending on another to complete a portion of the work before the other can continue.

## **Can it be maintained?**

The effectiveness and longevity of a roofing system depends on the level of maintenance. The level of maintenance is linked to the historical practices of the building maintenance staff, the available budget, and the ease of inspection and access possible with any particular design. Preventative maintenance is generally more cost-effective than post-failure repairs, because expensive repairs to water-damaged building interiors are avoided. Roofing systems that are easily maintained and repaired will save money and materials in the long run. Preventative maintenance will enhance the possibility of maintaining roofing materials in a recyclable or reusable condition later in their life-cycle.

An easily dismantled roofing system will be easier and less costly to repair, since it will be possible to remove and replace damaged portions without adversely affecting sections that are still intact or performing adequately. By using this approach in a pro-active manner, a roof that is easy to dismantle would allow worn materials to be removed and replaced before roof failure, allowing the life of other roof components to be prolonged.

## **Can materials be reused or recycled?**

On decommissioning, a roof that can be easily dismantled allows for simplification of material recovery, and the potential reuse and recycling of materials. This can save money and resources if salvageable materials are re-used for the roof reconstruction. Less material will enter the waste stream, yielding environmental benefits as well as potential cost savings through reduction or elimination of tipping fees at landfill sites.

Recovery and reuse or recycling of roofing materials after renovation or decommissioning, as well as selection of environmentally sound products, is an important aspect of roofing sustainability and toward the reduction of environmental impact (Hendriks and de Hoog 1998). The infrastructure for recycling roofing materials is not yet well developed in Canada, most used roofing materials are disposed of in landfills despite the fact that the technologies exist to recycle most of these products. Since the average life span of a low-slope roof in North America ranges from twelve to twenty years (Marcellus



and Kyle 1998, Cash 1997, Wilson 1998) this can add up to an enormous amount of waste over the life span of a building. For the purposes of this study, it is assumed that recycling will become more feasible as the demand for these services grows and makes it economically viable.

Re-use of materials with little or no further processing is preferred wherever possible. If unprocessed re-use is not practical, materials should at least be separated from each other for reprocessing. If they cannot be separated they are considered to be contaminated and can not be recycled. The separation of materials is one of the greatest obstacles to overcome in sustainable roof design.

If there is no market for recycled materials or no opportunity for storage until they are needed, it is unlikely that materials will actually be re-used. Likewise, if there are no recycling facilities nearby, or if recycling is not cost-effective, recycling of roofing materials will also be unlikely.

### **Typical roofing system configurations**

The following typical roofing systems were investigated in this study:

- Configuration 1 – Conventional Built-up Roofing System, mopped down insulation on steel deck;
- Configuration 2 – Mechanically Fastened PVC membrane on steel deck;
- Configuration 3 – Loose Laid & Ballasted EPDM on steel deck; and
- Configuration 4 – Protected Assembly, Modified Bitumen membrane on a cast-in-place concrete deck.

Detailed descriptions of the roofing configurations examined are included in Appendix A.

Various methods of applying the sustainable design principles were investigated. Considerations were: increased compartmentalisation; an examination of the effect and interaction of fibreboard and insulation; the potential benefits of better maintenance records and training; and a comparison of

re-roofing vs. recovering. In addition, new trends in roofing, such as component modularization, turn-key roofs, material advancements and roof-top gardens, were examined relative to their impact on sustainability.

### **Suggested improvements**

Roofing systems provide impermeability as well as resistance to wind, fire and thermal loads. Despite the untested nature of the recommendations contained in this paper, it is the premise of this study that implementing any of the proposed design modifications will not compromise basic roofing functional requirements.

Modifications to typical design and specification practice that have potential environment benefit, and are common to all of the design configurations being considered, are outlined in Table 1. As appropriate, these items are indicated in the modified configurations of Figures 1 to 4.

<b>Design/specification Modifications</b>	<b>Environmental Benefits</b>
Specifying the use of reversible mechanical fasteners/connectors	Increased ease of maintenance, maintenance, deconstruction and greater opportunity for recycling/reuse
Specifying higher quality galvanisation or other rust-proofing in steel components	Increased component life and potential recycling or re-use
Designing the wall-roof interface with a durable, rigid material (eg. sheet metal or plywood), providing connection point for continuity of air barrier	Increased ease of deconstruction and independence of one system's air-barrier from that of the other
Specifying a proactive maintenance program	Increased roofing system life

**Table 1: Desired modifications to design/specification practice**

The “configuration specific” design alterations, while being environmentally beneficial, are dependent upon economic factors as well as the maturity of the existing construction and

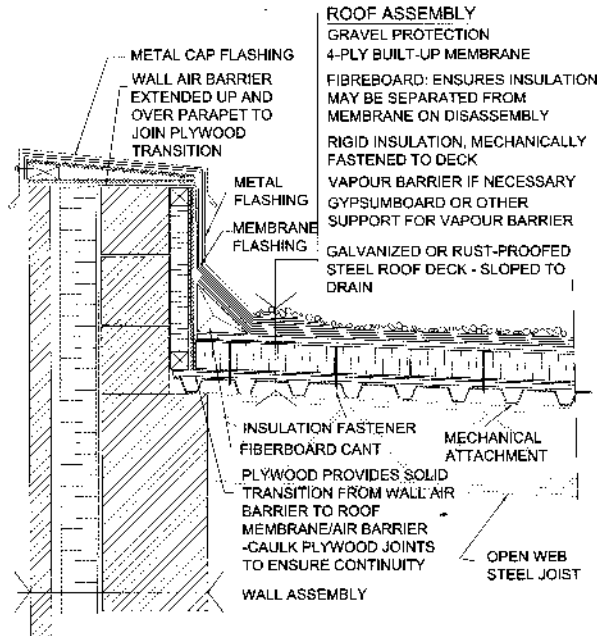
waste management infrastructures. Suggested improvements to each of the four roofing configurations are described below. An assessment of their potential economic impacts, resulting from the proposed deconstruction actions, is included in the following section.

### Modified Configuration 1 - BUR

- Use a slip-sheet/buffer material between insulation and asphalt to help separate materials and make them easier to recycle.
- Use mechanical fasteners at both the insulation & fibreboard connection to deck as well as the deck attachment to the open-web steel joists to help separate materials and make them easier to recycle.

### Possible Demolition Alternatives

- Separate, reuse and / or recycle membrane, insulation and deck.



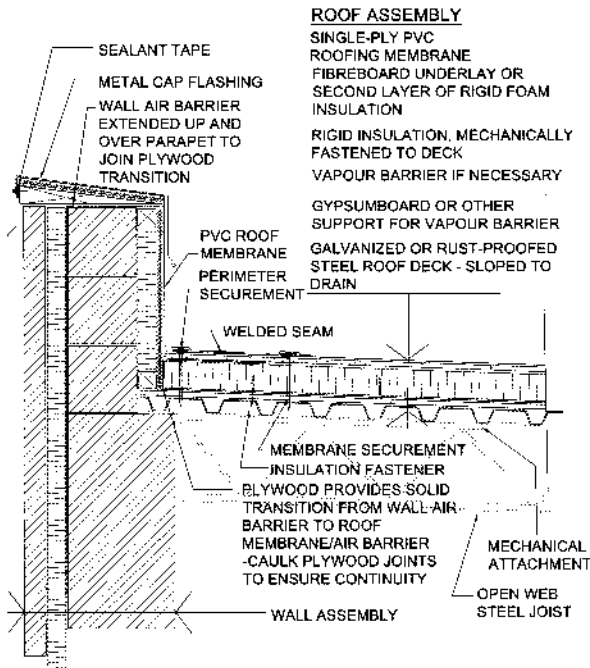
**Fig. 1: Modified BUR Assembly**

## Modified Configuration 2 - Mechanically attached PVC

- Use mechanical fasteners at both the insulation & fibreboard connection to deck as well as the deck attachment to the open-web steel joists to help separate materials and make them easier to recycle.
- Compartmentalise large roofs.
- Consider eliminating vapour barrier.

### Possible Demolition Alternatives

- Separate, reuse or recycle membrane, insulation and deck.
- Apply a new membrane over the old without replacement.



**Fig. 2- Modified Mech. Attached Assembly**

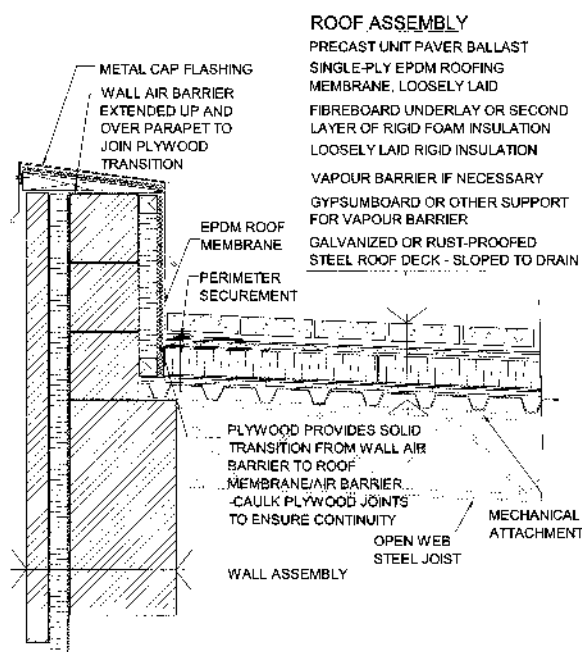
## Modified Configuration 3 - Loose-laid & Ballasted EPDM

- Use mechanical fasteners at the deck attachment to the open-web steel joists to help separate materials and make them easier to recycle.

- Compartmentalise large roofs.
- Consider eliminating vapour barrier.
- Use pavers rather than stone ballast.

### Possible Demolition Alternatives

- Separate, reuse or recycle pavers, membrane, insulation and deck



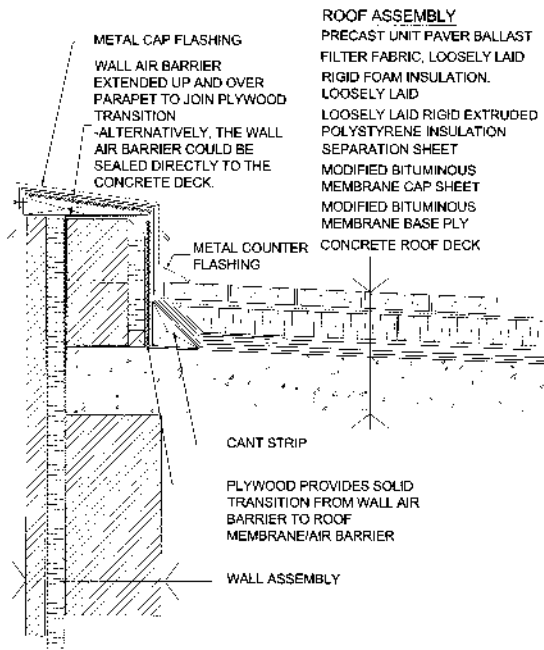
**Fig. 3-Modified Loose-Laid Assembly**

### Modified Configuration 4 - Protected Modified Bitumen

- Use a drainage layer or slip sheet between the insulation and membrane to help separate materials.
- Use pavers rather than stone ballast.

### Possible Demolition Alternatives

- Separate, reuse or recycle pavers, membrane, insulation and deck



**Fig. 4-Modified Protected Assembly**

## **Environmental and economic assessment**

### **Infrastructure and material recovery**

For the environmental benefits of any of the recommended design or specification changes to become significant and economically viable there must be adequate infrastructure in-place. A basic assumption of the following assessment is that such infrastructure does exist and that all of the sorting and processing facilities to deal with the various materials found in the considered roofing configurations.

Rigid insulation can account for as much as 75% of the volume of roofing waste. Reuse of rigid insulation may be possible in some roofing configurations, such as protected membranes where the insulation is held in place by ballast, but in others it is complicated by the fact that insulation boards are attached to other materials by either adhesives (asphalt) or mechanical fasteners. When insulation is coated in asphalt, it normally is neither recoverable nor recyclable. Some foam insulations lose

part of their insulative value over time and their value in reuse scenarios is diminished. Moisture content must also be considered when deciding whether to re-use insulation. Re-use also depends on availability of storage facilities. All types of insulation may be damaged with prolonged exposure to the elements.

If uncontaminated, most types of plastic foam insulation are recyclable. Facilities must be in place to collect and process the materials and adequate demand for the finished (recycled) products must exist. Labelling and coding of the chemical composition of these materials must become standard practice. Thermoplastics such as polystyrene can be melted and reformed, while thermoset plastics (eg. polyisocyanurate and polyurethane) can not.

Roof ballast materials, in particular pavers, lend themselves easily to re-use in either roofing or other applications. Stone may also be reclaimed for use as ballast, fill or aggregate if economically feasible. Commercial vacuuming systems now exist for the removal of gravel from roofs for recycling (Roodvoets 1994).

Metals are readily recovered and recycling them is generally cost-effective. A 1992 survey conducted by the National Roofing Contractor's Association (NRCA) environmental committee, found that metal was the most commonly recycled roofing material (Ujka 1993). An Iowa roofing company has developed a system of metal recovery by separating the edging from the rest of roofing materials at the job site, and sorting them later at the plant. The metals are separated according to type, and sold to a metal-salvage company (Schroeder 1997).

Plastics such as those found in vapour barriers, drainage layers/fabrics and in PVC membranes are able to be recycled and can also be reused if uncontaminated. If recycling is the intent, facilities must exist to collect and process the materials and adequate demand for the finished (recycled) products must exist. As is the case for insulating materials, for the cost effective recycling of plastics to become a reality, labelling and coding of the chemical composition of these materials must become standard practice.

Membranes made from thermoset polymeric compounds, including EPDM, are more difficult to recycle since they have been changed during the polymerising process and cannot be changed back. They can, however, be ground and added to new materials for other purposes - for example, to manufacture rubber flooring. Roofing membranes may also be used as protection layers and walkways at job sites. Asphalt-based roof membranes including modified bitumens also have the potential to be recycled, but only if other materials such as plastic, wood and nails have not contaminated them. Although not yet common practice, test facilities are attempting to recycle these products for use in road pavement and another technique involves cutting, grinding, heating and filtering asphalt roofing waste to produce a bitumen powder (Russo 2000). The powder may then be used to manufacture roofing felts, shingles, bituminous adhesives, protection boards and admixtures for road asphalt. Depending on the final product, between 10 and 90% recycled bitumen content may be used. Another process of thermal recycling is used to separate the bitumen from the carriers for the production of a ready-mix of recycled and new bitumen. This process results in a waste residue that may be incinerated (Hendriks and de Hoog 1998).

### **Economics of deconstruction versus demolition**

With standard demolition practices there is only a limited potential to reuse roofing materials on-site as well as a possibility of modest revenue from scrap material. If deconstruction is the chosen tack, the possibilities for cost avoidance increase significantly. More material may be reused, either on-site or through resale. As more materials are salvaged for roofing projects recycling becomes more significant and may drastically reduce haulage and tipping costs associated with the standard practices. Deconstruction does, however, imply increased labour and management costs linked to the material separation, classification and storage; these incurred costs have been included in the assessment.

The tables below summarize the economic impact of deconstruction/dismantling and the suggested roofing configuration modifications discussed in this paper. All figures are in CA\$/sq.ft. . The area of Toronto, Ontario is the assumed location and costs are reflective of the current rates at this



location as well as relevant construction cost data (RSMMeans 1996) and recent trade estimates.

Table 2: presents the costs (-) and benefits of applying deconstruction and dismantling procedures to complete roofing replacement projects. The net benefits are illustrated for the initial configurations as well as the recommended design alterations. The demolition costs found in Table 2 include the cost of complete roofing system and deck removal, cartage as well as small revenue associated with the sale of some of the galvanized steel deck used in configurations 1 to 3. The deconstruction figures are assuming varying percentages of salvage materials from the various configurations, an avoided haulage as well as costs associated with implementing the design modifications (mechanical attachments and pavers) and disposal.

### **Roof Removal**

Configuration	Initial Configurations			Modified Configurations			
	Demolish	Dismantle	Net Benefit	Dismantle w/pavers	Net Benefit w/o pavers	Dismantle w/pavers	Net Benefit w/o pavers
<b>1 BUR</b>	-\$2.21	\$0.23	\$2.44		\$0.53		\$2.74
<b>2 Mech.Attach PVC</b>	-\$1.12	\$0.33	\$1.45		\$0.55		\$1.67
<b>3 Loose-laid EPDM</b>	-\$1.31	\$0.33	\$1.64	-\$2.05	\$0.55	-\$0.74	\$1.86
<b>4 Protected Assembly-Mod.Bit.</b>	-\$6.77	-\$3.33	\$3.44	\$5.93	-\$3.33	\$0.84	\$3.44

**Table 2: Cost / Benefits for Complete Roof Removal**

For the configurations 1 to 3, the benefits are largely derived from the possibility of reusing and recycling the galvanized steel deck. The net benefit for Modified Configurations 1 to 3 is increased with the additional recycling potential provided by the mechanical attachment to the deck. In the case of the Modified Configuration 1, the mechanical attachment of insulation provides a potential material recovery benefit. In both the Modified Configurations 3 and 4, there is an additional cost due to the purchase expense of the pavers. Despite this additional cost the Modified Configuration 4 has a positive net benefit due to reduced disposal costs.

Table 3: presents the costs (-) and benefit projections for roofing renewal projects where the deck is left intact. In this table, the demolition costs reflect the roof waterproofing and insulation system removal and disposal. No scrap revenue is generated. The deconstruction figures are assuming heightened percentages of salvageable materials from the various configurations and avoided haulage. As in Table 2, the design modifications columns include the costs associated with implementing the design modifications (mechanical attachments and pavers) and disposal.

In all of the Configurations presented in Table 3, the net benefits are derived from additional materials being available for reuse or recycling. For Modified Configurations 2 to 4 there is no increased net benefit; the addition of pavers to Configurations 3 and 4 was not effective for roofing renewal scenario. In Configuration 1, the benefit of deconstruction is modest. But, by having implemented the design modification, mechanically attached insulation, the net benefit increases appreciably.

The fact that the net benefits, for initial configurations in both the removal (Table 2) and renewal (Table 3) scenarios, were positive is encouraging. It simply takes the awareness that the benefits do exist and a willingness to invest the small extra effort required realizing them. In the case of the latter two assemblies, the modification of using pavers in place of ballast does not result in appreciable benefits but in fact, requires additional investment which does not have a resultant benefit in terms of the parameters of this study.

### Roof Renewal

Configuration	Initial Configurations			Modified Configurations			
	Demolish	Dismantle	Net Benefit	Dismantle w/pavers	w/o pavers	Net Benefit w/pavers	Net Benefit w/o pavers
<b>1 BUR</b>	-\$1.72	\$0.01	\$1.74		\$0.23		\$1.96
<b>2 Mech.Attach PVC</b>	-\$0.63	\$0.78	\$1.41		\$0.78		\$1.41
<b>3 Loose-laid EPDM</b>	-\$0.82	\$0.60	\$1.42	-\$2.00	\$0.60	-\$1.18	\$1.42
<b>4 Protected Assembly-Mod.Bit.</b>	-\$0.93	\$0.86	\$3.44	-\$1.75	\$0.86	-\$0.81	\$1.79

**Table 3: Cost / Benefits for Roof Renewal**

## **Conclusions**

For the four roofing configurations examined, deconstruction is a viable economical alternative to demolition, providing net benefits for both complete system removal and for roofing renewal scenarios.

For the particular study location and the haulage and disposal costs foreseen, the use of paver as ballast material was not a cost effective design modification.

Loose-laid and ballasted or mechanical fastened assemblies provide the best deconstruction opportunities since they are more readily dismantled than fully adhered systems.

The current obstacles to the design of sustainable roofs are insurance and building code requirements, lack of coordination of the trades, lack of developed infrastructure for deconstruction, and perceived cost-effectiveness at the initial capital cost stage. Education is the key to overcoming all of these obstacles.

## **Recommendations**

For roofing retrofit projects, deconstruction should be considered as an alternative to the traditional demolish and dispose phase of project execution.

Although the infrastructure for recycling of roofing materials is still in its infancy, it is important to design with recycling in mind. The availability of easily separated and non-contaminated materials is a key element in supporting the growth of this industry.

## **Appendix A - Roofing Configurations Examined**

### **Configuration 1 - Conventional Built-up Roofing System**

Gravel aggregate surfacing in a flood coat of asphalt  
4 plies Type IV adhered with type 2 asphalt  
12.7 mm (½") fibreboard roof insulation  
46 mm (1.8") polyisocyanurate roof insulation (1.2 m x 1.2 m boards)

- polyisocyanurate and fibreboard are mopped-down
- 22 ga. rigid galvanized steel deck welded to open web bar joists.

### **Configuration 2 - Mechanically Fastened Single Ply**

1.2 mm reinforced **PVC** membrane,  
● fastened in side laps at 305 mm (12") o.c. with side laps spaced at 1.9 m (73") in the field of the roof  
● increased by 50% in perimeter areas and 75% in corners  
50 mm (2") rigid polyisocyanurate insulation  
● mechanically affixed to deck with screws at the rate of 1 screw every 0.36 m<sup>2</sup> (4 sq. ft.)  
● boards are 1.2 m x 2.4 m.  
22 ga. rigid galvanized steel deck welded to open web bar joists.

### **Configuration 3 - Loose Laid & Ballasted Single Ply**

Ballast surfacing (38 to 50 mm diameter stone)  
● average rate of 50 kg/m<sup>2</sup>  
0.45 (1.5 mm) **EPDM** membrane  
● assumed sheet size - 15 m x 30 m  
100 mm (4") expanded polystyrene insulation, loosely laid  
6 mil polyethylene with taped seams  
22 ga. rigid galvanized steel deck welded to open web bar joists.

### **Configuration 4 - Protected Membrane Assembly**

Ballast surfacing (38 to 50 mm diameter stone)  
average rate of 50 kg/m<sup>2</sup>  
Permeable fabric  
100 mm (4") loosely laid extruded polystyrene insulation  
One (1) layer of 250 g/m<sup>2</sup> torched on modified membrane  
One (1) layer of 180 g/m<sup>2</sup> torched on modified membrane  
200 mm (8") cast-in-place concrete deck.

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