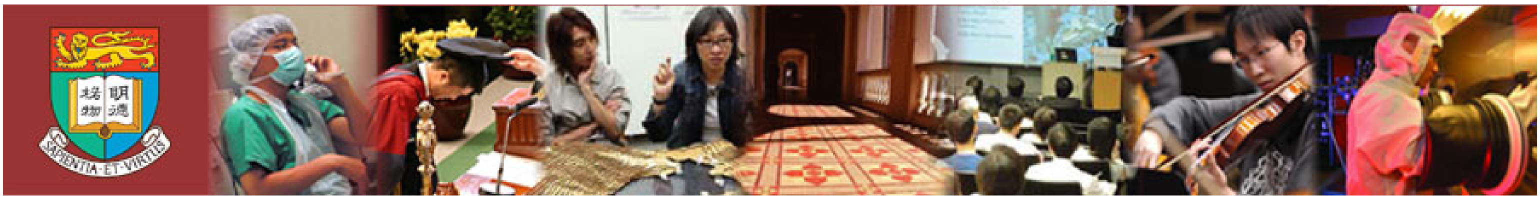

Title	Development of modular green roofs for high-density urban cities
Author(s)	Hui, SCM; Chan, HM
Citation	The 2008 World Green Roof Congress, London, 17-18 September 2008.
Issued Date	2008
URL	http://hdl.handle.net/10722/62257
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Development of Modular Green Roofs for High-density Urban Cities

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Abstract

Many cities are facing problems of urban heat island and lack of greenery space. Green roofs can help mitigate the adverse effects and bring the nature back to the urban area. To apply them effectively, it is important to evaluate the constraints and identify critical factors for planning and designing the green roofs. Modular green roofs have a good potential to suit high-density urban conditions because they can offer better flexibility, convenience and cost optimisation.

This paper presents the research findings to develop modular green roof systems for high-density urban cities. Three different types of modular green roofs, including mat, tray and sack systems, were studied by assessing their designs and characteristics. The urban environment and typical buildings for green roof applications in Hong Kong were evaluated. Useful information was obtained to help design and select modular green roofs that can fit into high-density urban environment.

In Hong Kong, the high-rise buildings have very limited roof spaces. It is usually more effective to apply green roofs to the top of medium- or low-rise buildings/structures or the intermediate podium roofs. For existing buildings, as they often have constraints on roof structural loading, it is necessary to select extremely light-weight systems. Modular green roofs can be designed to achieve this by adopting suitable vegetation and components. They can also provide greater flexibility for instant greening, future modification and maintenance. By optimising the manufacturing, nursery and installation processes, it is possible to reduce the unit cost of green roofs and allow wider spread.

Keywords: Modular green roofs, high-density urban cities, Hong Kong, planning and design.

Introduction

Like many other urban cities, Hong Kong is facing problems of urban heat island and lack of greenery space. In recent years, development of green roofs has attracted much attention in the society of Hong Kong (Hui, 2006; Urbis Limited, 2007). It is believed that green roofs can help mitigate the adverse effects of urban heat island and bring the nature back to the urban area (Kumar and Kaushik, 2005; Liu, 2003; NRCA, 2007).

High-density Urban Cities

Economic and social imperatives dictate that cities must be more concentrated, with high urban density to accommodate the people and to reduce the cost of public services (Hui, 2001). Urban cities often respond to development pressure by setting targets for increased building densities. The result is reflected by high rise cityscape and compact urban settings which may create urban heat island and undesirable local microclimate.

For instance, Hong Kong's urban environment has an extremely high development density pervasively filled by buildings and roads. Population concentrates in the central urban areas surrounding the inner (Victoria) harbour and in some new towns. The most densely populated district, Kwun Tong, has a density of over 54 000 people/km^2; some residential areas may even have over 100 000 people/km^2.

Potential of Modular Green Roofs

Of all the technologies that a city might use to enhance urban greening, it would appear that green roofs offer the most benefits (Urbis Limited, 2007). In order to apply green roofs effectively in high-density urban cities, it is important to evaluate the constraints and identify critical factors for planning and designing the green roofs (FLL, 2004). It is believed that modular green roofs have a good potential to suit the conditions because they can offer better flexibility, convenience and cost optimisation.

This paper presents the major findings of a research project to develop modular green roof systems for high-density urban cities. Three different types of modular green roofs, including mat, tray and sack systems, were studied by assessing their designs and characteristics. The urban environment and typical buildings for green roof applications in Hong Kong were evaluated so as to find out the key factors affecting the planning and design. Useful information was obtained to help design and select modular green roofs that can fit into high-density urban environment.

Learning Objectives:

- Know the types and characteristics of modular green roofs
- Understand the major design factors and benefits
- Appreciate the green roof applications in Hong Kong

Modular Green Roofs

At present, most green roof systems have a series of components that must be installed in layers on a roof surface. They are referred to as built-in green roofs. Traditional built-in green roofs were first developed in Europe and are still widely adopted in the market (Weiler and Scholz-Barth, 2006; Zinco, 2000). These green roofs are more complex, permanent and expensive than modular systems because of the time and costs needed for installation. They have certain limitations including complicated installation logistics, excess weight (about 180 to 450 kg/m^2), lengthy installation schedules and complexity of maintenance. Once a built-in green roof is put in place, it cannot be changed easily.

Modular green roof technologies are becoming more and more popular in some countries (Velazquez, 2003). Modular systems retain all the benefits of the green roof while addressing the limitations of a built-in system. They are different from planting in freestanding containers placed on top of a roof because the containers are not integrated in the roof system.

Types of Modular Green Roofs

Basically, modular design tries to subdivide a system into small standard parts that are easily interchangeable. For green roof systems, modular designs are often self-contained pre-planted blocks giving an instant greening effect and greater design flexibility. Modular green roof systems can be divided into three main types:

- Mat system
- Tray system
- Sack system

The vegetated mat system is shown in Figure 1. They are normally pre-grown, then rolled up and transported as a complete system. It is a very light weight system with a thickness of about 45 mm (Doshi, *et al.*, 2005).

Figure 1. Vegetated mat system (Source: Elevated Landscape Technologies, www.elteasygreen.com)

Figure 2 shows an example of tray system. Nowadays, tray systems are the most commonly found modular green roofs in practice. Often, plastic interlocking containers are filled with a drainage system, growing medium, and vegetation prior to installation (Dunnett and Kingsbury, 2004). As the growing medium is completely contained in the tray, it can easily be removed or replaced without affecting the original structure or other plants.

Figure 2. Tray system (Source: LiveRoof, www.liveroof.com)

Figure 3 shows one example of the sack system. Sack systems are flexible modules that can easily conform to irregular and radius areas. The growing media remains sealed within the fabric module until openings are made ready for planting after positioning them on the roof.

Figure 3. Sack system (Source: Green Paks, www.greenpaks.com)

Major Characteristics

Usually, modular green roofs take less time to install and are less expensive than built-in systems due to their ease of installation, simple design, and flexibility. They are often utilized for extensive green roofs with a soil depth of 25 to 150 mm, and they can achieve a very light weight (about 70 to 220 kg/m^2). The installation process takes several days to a couple of weeks depending on the green roof's size. The plant species is limited to drought-resistant and weather tolerant plants such as sedums and grasses because they require less maintenance and cultivation.

The placement of the modules can be rotated seasonally, moved for maintenance, or repair at any time. Growing medium usually contains sand, gravel, peat, organic matter, crushed brick, lightweight expanded clay aggregate and some soil. The modular green roof can be installed any time of the year because the vegetation is commercially available, pre-planted, and established before installation occurs.

Table 1 gives a comparison of the characteristics of the three types of modular green roof systems. Depending on the building conditions and client requirements, these systems can be selected and designed to suit the specific needs.

Table 1. Characteristics of three modular green roof systems

Mat System (Source: Elevated Landscape Technologies, www.elteasygreen.com)	
Size :	1 m^2/module (vegetated area)
Saturated weight :	39 - 73 kg/m^2 (soil depth ≤ 40 mm)
Materials :	High density polyethylene (50% post-industrial recycled materials)
Handling :	Modules must be installed within two days after being palletized
Installation :	Interlocking panels are placed on top of root barrier. Overlap two pockets on the panel and fasten by polyethylene rivets.
Tray System (Source: LiveRoof, www.liveroof.com)	
Size :	0.18 m^2/ module (0.3 m x 0.6 m)
Saturated weight :	73 - 130 kg/m^2 (soil depth = 75-100 mm)
Materials :	100% post-industrial recycled polypropylene
Handling :	18 modules/pallet, 54 pallets/truck
Installation :	Ergonomically designed modules can be installed by just one person. They are placed on root barrier and needs to be watered immediately after installation.
Sack System (Source: Green Paks, www.greenpaks.com)	
Size :	0.48 m^2/module
Saturated weight :	83.2 kg/m^2 (soil depth = 100 mm)
Materials :	Woven fabric knitted of high density polyethylene
Handling :	42 modules/pallet, 20 pallets/truck
Installation :	Modules can be stored prior to installation. They are placed on root barrier and cut slits in the fabric module to insert plant plugs or seeds.

Advantages of the Modular Approach

It is believed that modular green roofs can offer the same benefits to that of traditional built-in green roofs in terms of system performance and environmental impacts. As compared to the built-in green roofs, modular systems are extremely lightweight and can be easily installed in a wide array of configurations and customization (Velazquez, 2003). Moreover, they can provide building designers and owners a wide range of advantages as shown in Table 2. The most notable benefits of using a modular approach to green roof construction are simplicity and flexibility. This design flexibility and installation efficiency can help to lower the cost of a modular green roof. It also allows a building owner to modify the layout or add other modular features at any time in the future. As the plants are prepared ahead of time, this provides them with a higher rate of survival and overall success of the green roof.

Table 2. Advantages of modular green roofs

Advantages	Description
Simple and quick installation	The installation time can be reduced as the modules can be grown off-site, and placed directly on the roof at any time of year.
Instant greening	Fully pre-grown modules can provide an instant aesthetic benefit for the owner and neighbour.
Greater variation	Modules are self-contained and can provide a mean for mixed type design which allows greater diversity of vegetation.
Further adjustments	Physical flexibility is possible with minimal disruption of other plantings or roof structure.

System Design and Analyses

The main goal of green roofs is to reduce the environmental impact of buildings and maintain a stable living ecosystem (Earth Pledge, 2005). When developing and designing suitable green roof systems for high-density urban cities, it is important to consider the design criteria and constraints in a holistic and pragmatic way.

Design Criteria and Concept

Eight key design criteria have been identified to form the basis of our design concept. Table 3 shows the key design criteria for our modular green roofs. The criteria can provide a framework to select suitable green roof system and configuration for a particular project.

Table 3. Key design criteria for our modular green roofs

Design criteria	Description
1. Flexibility	Adaptation to different soil depth and types of roofs and buildings
2. System weight	Limited by the roof structural loading. Depends on soil weight
3. Manual handling	Ergonomic design with optimum size and weight
4. Transportation	Transportation tools and packaging that come with the design
5. Installation	Ease of installation and removal determines part of the cost
6. Maintenance	Reduce maintenance work by proper design and components
7. Durability	Depends on the material used for each component
8. Costs	Includes: manufacturing, transportation, labour, maintenance

System Components and Prototypes

For urban cities like Hong Kong, green roofs are often considered for existing buildings which often have space limitations, roof load and other constraints. The design of our green roof systems is aiming at low-weight, high-flexibility and low-cost module designs.

Mat and tray systems are chosen in this study since they can give the best solution to cope with weight and space limitations as well as offer high flexibility in adapting to different range of soil depth for different plants. Figure 4 shows a prototype of the mat system developed for our modular green roofs. Figure 5 indicates the test units of tray system prepared in our laboratory.

Figure 4. Prototype of a mat system for modular green roof

Figure 5. Test units of tray system for modular green roof

The selection of plants is crucial for green roof systems (ASTM, 2006). Since different plants have different characteristics, it is essential to identify the need for each plant and its function (Snodgrass and Snodgrass, 2006). For low maintenance extensive green roofs, it is more suitable to use hardy plants such as sedums that can adapt to the local climate.

Technical Design Analyses

In order to evaluate the critical factors for designing modular green roofs and to develop practical information for building designers, the following technical analyses have been carried out.

- *Soil substrate analysis*. This includes estimation of system weight and structural loading for typical soil substrates, as well as their effect on plant growth. Useful data on system weight and plant growth conditions were obtained.
- *Plastic materials analysis*. It aims to assess the durability of plastic materials commonly used for green roof systems. The effects of outdoor climatic conditions (like temperature, solar radiation and rainfall) and pesticides were considered.
- *Thermal performance analysis*. Assessments were done to study the thermal performance of different types of green roof modules. Figure 6 gives an example of the analysis on aluminium panels using infrared thermography. An option of raised floor system for the modular design was studied.

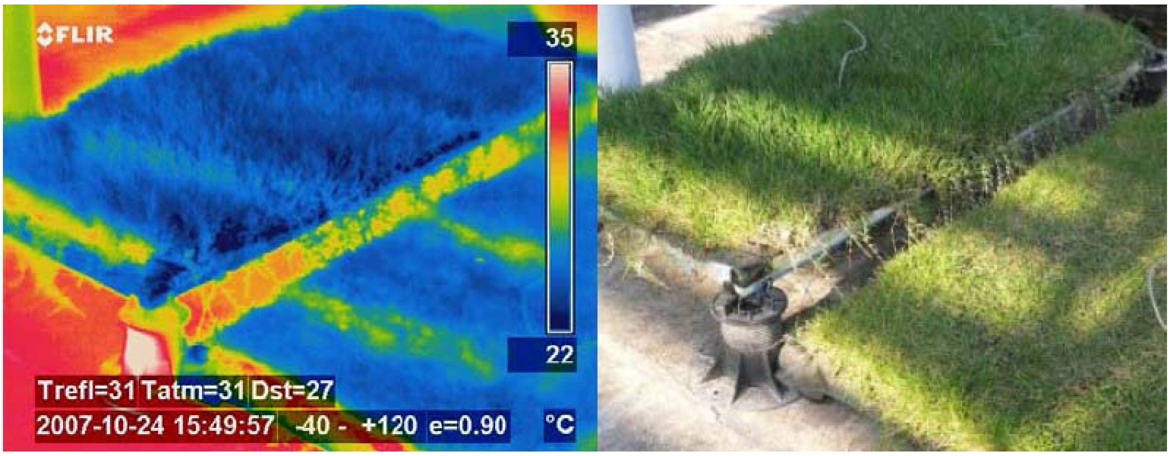

Figure 6. Infrared photo of aluminium panels used for modular green roofs; one with raised floor (left) and one placed directly on rooftop (right)

Application Studies in Hong Kong

Green roof designs are unique from one building to another. It is essential to identify the site conditions for a green roof system to be well designed and constructed. In this research, efforts have been made to study some existing green roof projects in Hong Kong, with the aim to learn more about the practical considerations of green roof construction and evaluate the key factors affecting the planning and design of modular green roof systems. A brief summary of the research findings and their implications are discussed in the following.

Green Roof Projects Studied

The projects that have been studied in this research include traditional built-in systems and some new initiatives for modular designs. Table 4 gives a summary of the projects and their major characteristics identified. Figure 7 shows some pictures of the projects.

Table 4. Green roof projects studied and their major characteristics

Projects (location)	Major characteristics
Government bldg. (To Kwa Wan)	Built-in system with crushed bricks and a brown appearance
Primary school A (Diamond Hill)	Built-in system with 2 types of sedums grown on an existing building
Primary school B (San Po Kong)	Built-in system with large variety of plants put on a new building
Site office A (Tsing Yi)	Modular system with large galvanized steel tray on a sloping roof
Site office B (Pokfulam)	Roof garden with some tray modules made of different materials
A technology centre (Tseung Kwan O)	Modular raised floor system with aluminium panels and an appearance like built-in system

Figure 7. Green roof projects studied in Hong Kong (1: Government bldg.; 2: Site office B; 3: Primary school A; 4: Primary school B)

Planning and Design Factors

In Hong Kong, the high-rise buildings have very limited roof spaces. It is usually more effective to apply green roofs to the top of medium- or low-rise buildings/structures or the intermediate podium roofs. By doing this, the occupants from surrounding tall buildings can enjoy the green roof and appreciate the application. Examples include those primary schools being studied, which are surrounded by residential towers.

The roof structural loading is a main factor determining the viability and cost of a green roof installation (ASTM, 2005). For a new building having a green roof included in its initial design, the additional roof loading can easily be accommodated, thus the cost could be minor. However, for an existing building, the design will be limited to the loading capacity of the existing roof unless a higher initial cost is paid to upgrade the structure. Retrofitting an existing roof may not be feasible if the structural capacity of the roof is not adequate. Therefore, the weight of a green roof system is of vital importance and it is necessary to select extremely light-weight systems.

The local climatic factors also affect green roof designs in Hong Kong. The most important climatic factors include:

- *Typhoons*. The strong wind might blow away the vegetation and soil. Modules and plants must be well secured and protected.
- *Heavy rainfalls*. They are quite common in rainy seasons. The green roofs should be able to hold and drain the rain water without creating pools of stagnant standing water.
- *High temperature*. High temperature might affect some plant species.
- *Strong sunlight.* Strong solar and UV radiation might cause problems to the green roof materials and components.

Supplemental irrigation systems can be problematic and must be designed for site-specific requirements. Repair and maintenance of the underlying roof can be cumbersome and costly since peeling back or replacing large sections of green roof may be required.

Lastly, it is observed that as the green roof market in Hong Kong is still developing and not mature yet, insufficient attention has been paid to optimise the manufacturing, nursery and installation processes of the green roof systems. This will affect the price level and cost-effectiveness of the green roof systems.

Conclusions

The Hong Kong Government is now trying to improve the quality of urban environment and living through promoting better urban greenery, and by maximizing the greening opportunities during the planning and development of public work projects. There is an urgent need to investigate and promote effective green roof technologies for both public and private sectors in our society. The experience and knowledge gained will also be useful to other cities in the world.

Modular green roofs have a good potential to suit high-density urban conditions. By adopting suitable vegetation and components, they can be designed to achieve simplicity and ease of installation. They can also provide greater flexibility for instant greening, future modification and maintenance. By optimising the manufacturing, nursery and installation processes, it is possible to reduce the unit cost of green roofs and allow wider spread of the green roof technologies in urban cities.

Key Lessons Learned:

- The types and characteristics of modular green roofs
- Major benefits and design factors of the modular approach
- Current green roof applications and trends in Hong Kong

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