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Journal

Choosing the Right Paver System for Rooftop Amenity Spaces

Tai Mahmuti, PE

Since the industrial revolution, the United States has been rapidly urbanizing. The most recent census data shows that approximately 80% of Americans live in an urban or suburban location, and that number is on the rise. Cities house nearly 63% of the U.S. population, while comprising just 3.5% of total land area. With space at a premium, cities are rapidly losing public greenways for their citizens, as demand for the built environment continues to drive development.

Incorporating an outdoor recreation area into a roof capitalizes on existing space and creates a desirable building feature. A blend of pavers and turf creates a dynamic feel to this terrace.

One area in which pertinent data exist that can inform future change is the increasing proliferation of green roofs. Access to outdoor spaces, whether built out of hardscape or biological materials, provides building tenants with a respite from city life, access to fresh air, and a place to gather.

As of 2016, New York City contained 60 acres of green roofs, which account for less than one-tenth of one percent of the city's 1 million rooftops, or around 40,000 acres of underdeveloped and underutilized space. For an example of a city that is much further along in its mission to provide this amenity to citizens, look no further than Singapore, which has made a conscious effort since 2005 to incorporate finished and green roof spaces into the built environment. Singapore currently contains more than 2,100 distinct green roofs, contributing 15,000 acres of green space, which is over 25% of the total built-up area.

The COVID-19 pandemic has laid bare shortcomings that a lot of American cities struggle with, when access to outdoor spaces is not only an amenity, but a necessity. For those fortunate enough to live in a building that provides outdoor space, the decision to stay home was made all that much easier. As the availability of vaccinations and evolving health guidelines allowed people to resume gatherings outside, demand for open-air facilities

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increased, and with it the conversion of any usable terraces, roofs, and landings into impromptu areas to congregate. An increase in accessibility to outdoor spaces has now been demonstrated to be a priority that will long outlast the current crisis.

Building owners should take advantage of this high demand and, where possible, provide outdoor amenity spaces. By retrofitting existing roofs and terraces, owners can capitalize on unseemly or inaccessible locations throughout a property and present an attractive and lucrative design solution for their tenants.

Roofing Assemblies: The Basics

Most low-slope roofs are what is referred to as ***traditional assemblies.*** This means that the roofing membrane, which provides waterproofing, is visible and exposed as the topmost layer, with the insulation (if any) beneath. Leaving the roofing membrane exposed may allow for easier access and repairs, but it also leaves the roof in a vulnerable situation. Debris, cycling of precipitation and drying out, exposure to ultraviolet radiation, and foot traffic all contribute to the deterioration of the roofing membrane. A common solution is to cover the roof with an "overburden," traditionally of stone ballast, most often a thin layer of river stone loose-laid directly on the roofing membrane. However, loose aggregate surfacing may be prohibited by code, notably for buildings in hurricane-prone regions and for taller buildings in certain wind speed and exposure categories. Another solution is to place walkway pads on top of the membrane to allow maintenance staff to access equipment without treading directly on the roof; however, this does not alleviate the issue of the exposed membrane.

An ***inverted system,*** also referred to as an ***IRMA*** (inverted roof membrane assembly) or ***PRMA*** (protected roof membrane assembly) system, is installed in the reverse order of the traditional assembly. The roofing membrane is loose-laid, adhered, or anchored directly to the structural deck, with a drainage mat and insulation installed atop the membrane. Inverted systems were also traditionally capped with stone ballast, but because of the updated building code, they are now frequently covered by a paving system. The IRMA system allows for greater protection of the roofing membrane, as it is not exposed to ultraviolet radiation, debris, or wear and tear, and it provides more flexibility in terms of energy performance, as insulation may be added without having to remove the membrane. Furthermore, roof pavers are a better walking surface than ballast and ultimately may allow the roof to be occupied.

> "Access to outdoor spaces provides building tenants with a respite from city life, access to fresh air, and a place to gather."

Engineering Considerations

Converting unoccupied roofs into occupied terraces requires consideration for not only amenities like furniture and greenery, but also structural capacity, access/egress and safety, wind uplift resistance, insulation and energy performance, and appropriate situation-specific detailing, among other concerns. In transforming a bare-bones roof covering into a usable space, owners should be aware of the modifications that might be necessary before a roof designed to support little more than its own weight can safely bear plantings, furnishings, and people.

Load Capacity

A licensed structural engineer must evaluate the structural capacity of the existing roof deck and compare roof load capacities with code requirements for occupied terraces. Roofs that were not originally designed as occupied terraces may not meet building code live load requirements, and structural reinforcement of the roofs may be necessary.

Furthermore, if the design of the occupied terraces includes dead loads such as planters, pergolas, furniture, etc., the existing roof structural deck must be able to withstand the additional load. Structural reinforcement to withstand required loads may vary from reinforcing the existing structural members, such as beams, columns, and deck, to providing additional beams, to replacing the entire structural deck and framing.

Occupancy and Accessibility

As part of the conversion of a roof to an occupied terrace, other factors to consider include determining maximum occupancy load, obtaining an occupancy permit from the governing agency, providing appropriate lighting and exit signage, and providing proper guardrails of adequate height and load resistance.

Barrier-free accessibility to occupied roof terraces must also be considered during design. This includes accessibility from the building interior to the outdoor space, as well as accessibility throughout the terrace. The slope of the terrace, position and height of handrails, turn radius, doorway clearance, threshold design, and automatic doors must all meet Americans with Disabilities Act (ADA) requirements.

Roof Geometry

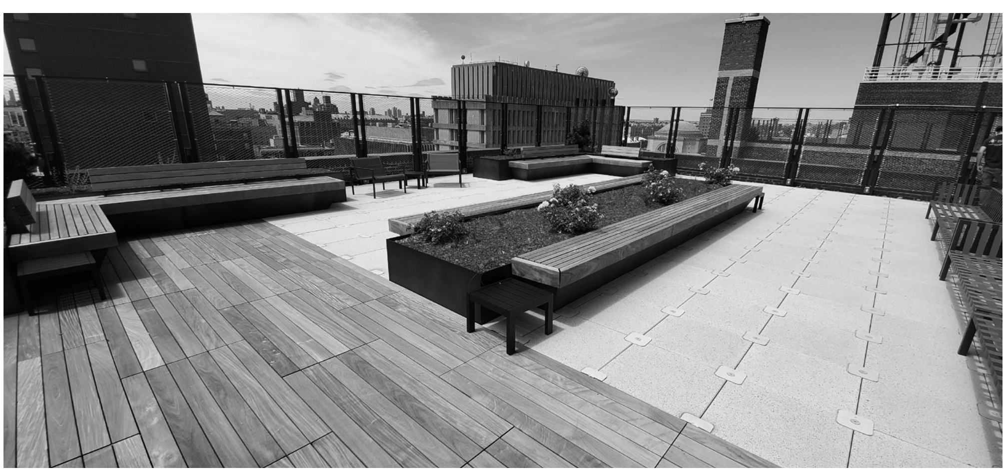
Too often, the design of paving systems for occupied terraces and/or roofs is overlooked by design professionals. Specification of concrete pavers of "typical" size and thickness predominates, often with little attention to the design significance of individual roof characteristics. Building roofs may have similarities, but the design parameters for each roof paving system are unique. Building height and location must be considered, because these factors have a direct impact on wind speeds and overall roof wind uplift pressures. Furthermore, parapet heights at roofs affect the overall wind uplift requirements and therefore also influence the selection of a suitable paving system.

Wind Uplift

When it comes to designing the roof paving system, wind uplift is the primary engineering challenge. The New York City Building Code references the Single-Ply Roofing Industry (SPRI) *RP-4 Wind Design Standard For Ballasted Single Ply Roofing Systems,* which guides design professionals in selecting an appropriate paving system based on wind speed, building location, height, exposure, and parapet height. However, this standard is limited to a maximum building height of 150 feet. For taller structures, the building code relies on the expertise of design professionals for the design and engineering of the paving system, which must be approved by the authority having jurisdiction.

Cushioned synthetic turf surfacing and climbing equipment converts this urban church rooftop into a playground oasis.

There are two methods for determining roof wind uplift for a specific building: ***wind tunnel testing*** or ***calculations*** based on the American Society of Civil Engineers' *ASCE 7 Minimum Design Loads and Associated Criteria for Buildings and Other Structures.* Wind tunnel testing involves constructing a scale model of the existing or proposed building and the surrounding structures on a turntable. The turntable is placed inside a wind tunnel that simulates the characteristics of natural wind, and the turntable allows the scale model to be rotated through a range of wind directions. The test building is equipped with sensors that measure wind pressures on the building, including facade and roof uplift pressures. The wind tunnel test provides more accurate design information than can be calculated based on ASCE 7. Not always, but often, wind tunnel testing yields reduced design pressures in comparison to calculated values, which in turn prevents over-design of building systems. Since wind tunnel testing generally results in cost savings for the design of building systems, the expense for the testing can be a good investment.



At this university residence hall roof terrace, lock-down concrete pavers and interlocking wood tiles secure against wind uplift, while providing an inviting blend of textures and hues.

For existing buildings, and when only the roof wind uplift pressures are required, the expense for the wind tunnel testing is generally not justifiable, and calculating wind uplift pressures based on ASCE 7 is a better alternative. ASCE 7 calculations take into account the general footprint of the building (in rectangular form), as well as the height and location of the structure. Since the formula is designed to encompass a simplified structure and does not precisely model surrounding buildings and geographic features, nor the exact geometry of the building, the wind uplift pressures are generally overdesigned. Still, if only the roof or roof finishes are being replaced, calculating wind uplift using ASCE 7 is generally the more cost-efficient option.

For high wind uplift pressures, several design solutions for the roof paving system are available. Options may include an interlocking system, where all the pavers on the roof are tied together and restrained at the edge. Considering that wind uplift pressures are generally highest at the perimeter and corners of the roof, the architect or engineer may design a system that straps the paving systems at those locations together and provides an edge restraint, generally anchored to the parapet wall.

Energy Code Compliance

Another aspect to consider when converting an existing roof to an occupied terrace is the likely potential for an increase in insulation. Energy codes are becoming more stringent, and, as new code iterations are released, greater insulating values of the roof assembly are required. Unless the building is designated as a landmark structure, adhering to the new energy code requirements is a must. Even if the building is not required to comply with the current energy code, it is good practice to follow new code requirements where practicable and contribute to energy conservation and sustainability. An increase in insulation generally raises the finished roof height and therefore can impact the height of door thresholds, roof guardrails, and flashings.

The building code also specifies solar reflectance index (SRI) minimum requirements for roof coverings to reduce the ***urban heat island effect,*** whereby building materials, especially dark-colored roofs, absorb and retain heat, causing cities to heat up significantly compared to the surrounding countryside. Therefore, in addition to meeting wind uplift requirements, the roof coverings/overburden system must meet SRI minimums that are generally related to roof slopes.

Primarily, a roof is designed to keep the building watertight. With the climate crisis reaching a state of urgency, energy conservation and ecological impact have become central design considerations, as well. When a roof is to be used as a gathering space, it sustains the additional burden of providing the appropriate safety features to occupants, while satisfying engineering requirements of transferring the additional load to the building structure.

Leak Detection and Repair

While roof pavers do provide extra protection for the waterproofing membrane and tend to extend its service life, they can contribute to more complicated ongoing maintenance.

If, over the lifespan of the roofing membrane, a leak occurs, the pavers, insulation, drainage mat, and other components would all need to be removed to locate the leak, confirm the damage, and repair the membrane. While damage to the membrane is much less likely in an inverted system, this is important to keep in mind.

There are products available to alleviate the process of chasing down a leak. Electronic leak detection systems, such as vector mapping, introduce a low voltage to the dampened roof membrane to pinpoint the location of a leak. However, for accurate results, exposure of the waterproofing membrane by temporarily removing the overburden assembly is recommended. Electronic leak detection also can be used immediately after repairs are performed to confirm that the leak was completely resolved. ■

If a leak does occur in a paver roof assembly, it can be hard to detect, espeically if water remains below the surface. Sometimes, it is only noticable after damaging spaces below.

Architectural Considerations

Once design considerations for weather protection, energy performance, safety, and structural capacity have been realized, the building owner and project team can turn their attention to matters of aesthetics and durability. Selecting a paving system demands consideration of maintenance requirements, longevity, and intended use, as well as integration with vegetative assemblies and site amenities such as furnishings, playscapes, and entertainment features.

Paver Material Options

After the engineering component of converting unoccupied roofs to occupied terraces is achieved, the ***overburden system,*** which is the most visible aspect of the conversion, must be designed. Overburden, in the form of paver systems, comes in many materials, each with distinct properties, benefits, and installation methods. Available in various sizes and geometries, the wide range of pavers on the market allows for unique designs.

Concrete. The most common paver material is concrete. Typically around two inches thick, concrete pavers come in a variety of shapes and sizes. Depending on the building height and wind uplift constraints, pavers can be loose-laid, integrated into an interlocking system, installed on a pedestal assembly, or some combination of methods. Concrete pavers are durable, relatively inexpensive, and widely available, making them ubiquitous in the market. Periodically, exposure and wear may cause pavers to crack, so planning for isolated paver replacement should be considered as part of long-term maintenance.

Porcelain. Porcelain tiles are an increasingly popular choice for finished roofs due to their aesthetic appeal and long-term performance. Manufactured in a slimmer profile than concrete at around ¾" thick, porcelain pavers are lighter, and therefore easier to transport and install. However, because of their light weight, porcelain pavers have more limitations in terms of the assembly and are best used in a pedestal or tray system. Porcelain is also completely nonporous, and therefore

For non-accessible roofs, pavers create a clean look *(right)* and improve safety over ballasted systems *(left)*.

will not stain, will not require any sealing, and will not fade over time. While the porcelain itself is extremely durable, the installation method, which involves setting the pavers in an adhesive around the perimeter of each tray, is subject to ongoing maintenance. The tiles can potentially debond from the trays and will require resetting to ensure a safe and secure finish surface.

Wood. Wood tiles offer a warm and modern finished roof. Typically constructed of ipe, a popular wood for decking, the tiles are durable and aesthetically pleasing. The wood can be finished in a variety of ways, including smooth surfacing or grooved surfacing, and either sealed to preserve the natural brown color or left untreated to weather, resulting in a gray hue. Wood tiles are best used in an interlocked pedestal system or secured to a subframing system to meet wind uplift requirements. Because of the nature of the material, the tiles will respond to the environment as does any wood deck, with the potential for splintering, splitting, warping, and separation over time. Even so, ipe is far more resistant to humidity and temperature fluctuations than most hardwoods. Another consideration is that unlike manufactured materials, wood naturally varies in color and will not provide as uniform an appearance as concrete or porcelain.

Playscape surfacing. In dense urban areas, available space for parks and playgrounds is limited. What some schools and nurseries are turning to is the opportunity to provide a play space on an available rooftop or terrace. To meet American Society for Testing and Materials (ASTM) impact standards for playground surfacing, interlocking rubber pavers or synthetic turf/grass with protective underpadding are utilized in tandem with play structures to protect against falls. Rubber pavers are best in a loose-laid system, due to the impact considerations of the live load in these circumstances. Synthetic grass, while not a paver system, can be installed in long rolls as a finish surface, either fastened or loose-laid atop the roofing assembly. Rubber infill material installed below the grass provides a comfortable and impact-resistant surface. The turf can also achieve an aesthetic function, similar to a green roof.

Green Elements

Greens roofs have become popular and more mainstream recently due to a more environmentally conscious public, as well as financial incentives and, in some cities like New York, government mandates (as part of the 2019 NYC Climate Mobilization Act). Green roofs provide for better stormwater management, improved air quality, and a reduction in the urban heat island effect, not to mention a popular amenity for building occupants.

Paver-on-Pedestal System Installation

Elevated paving units protect waterproofing and insulation with a level walking surface.

However, green roofs have some stigma in the construction and building management industry, mainly related to the perceived intensive upkeep, the tendency of plantings to wither and die off, and the initial startup costs. With a clear-eyed view of the available options and a diligent – although not necessarily laborious or expensive – routine maintenance program, an appropriately designed and correctly installed vegetative roof need not be as costly or as demanding as it might seem.

Intensive green roofs are the larger and more expensive green roof option, with a typical planting depth of greater than 8 inches. These roofs can support large plants in a wide variety of species, and they allow for highly designed and complex landscaping. While attractive, intensive roof plantings do often demand irrigation, weed control, pruning, fertilizer, and other regular upkeep to maintain their appearance, and such long-term maintenance should be considered before electing to include an intensive green roof area as part of an outdoor amenity space.

Extensive green roofs, on the other hand, have growing media that is less than 8 inches deep, are relatively lightweight, and have little need for maintenance and watering. These systems can only support small, low-growing plant species, such as succulents and sedum. Upkeep for extensive green roofs is minimal, but it's not zero; the misconception that these assemblies are "set it and forget it" is largely responsible for the unsightly brown patches of desiccated plants that have given vegetative roofs some bad press.

Modular plant trays are extensive green roof systems that offer an easier installation process. The trays allow the options of either pre-grown media, arriving on site with already planted species, or planted-in-place, where empty trays are installed on site before being filled with growing media and plants. The self-contained media also eliminates the need for root barriers and filter fabric, which are essential in traditional green roof systems.

One benefit of the modular system is its seamless integration with any of the paver assemblies discussed above. The modular trays can be installed using the same pedestal system as the roofing pavers, allowing concrete, porcelain, or wood tiles to be installed directly adjacent to the plant media. Using two systems in tandem eliminates the concern for foot traffic and allows a fully accessible amenity space where tenants can enjoy the value of a green roof without compromising the durability of the growing media.

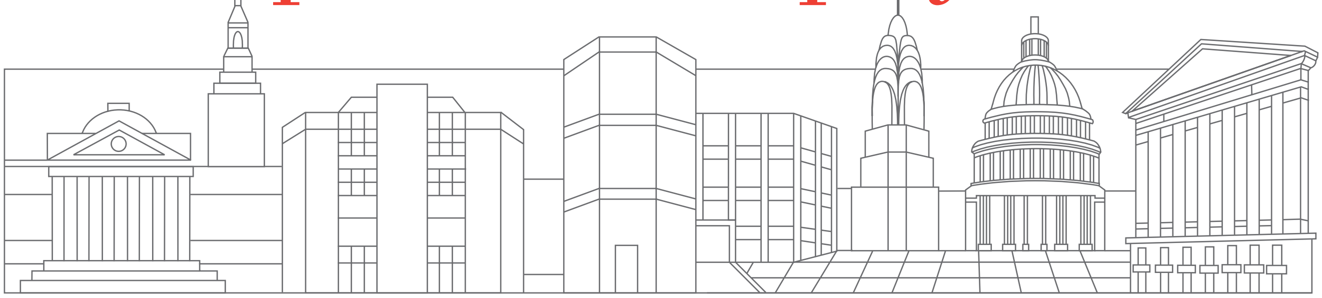
Due to the sensitive nature of the plantings, as well as structural considerations, green roofs typically cannot support the foot traffic of public access and therefore are generally restricted spaces. Modular systems address this issue by building in walkway pavers alongside plant trays, but traditional extensive and intensive roof assemblies must also incorporate dedicated pedestrian spaces and provide clear boundaries to prevent people from compromising the roof assembly by venturing into planted areas.

Furniture

Any of the paver materials used in conjunction with a pedestal system have a secondary benefit for occupiable outdoor space: the provision of a level and resilient surface upon which to place outdoor seating, tables, lighting, and other fixtures. Pedestal systems allow for a sloped roof to facilitate water drainage underneath the pavers, while maintaining a level finished surface. In a traditional roof assembly that does not have a paving system, either the slope of the deck itself or the slope of tapered insulation causes the finished roof level to

(continued on page 8)

representative projects



Roof Paver Systems

Designing a roof paver assembly that is durable, code-compliant, energy-efficient, and aesthetically appealing demands more than a one-size-fits-all approach. What's right for a university dormitory in Manhattan is not necessarily best for a Washington DC office building, and retrofitting a Belle Epoque townhouse for a roof amenity space is completely different from creating a pedestrian plaza over an eighties parking garage.

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4 Columbus Circle Office Building
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Roof Paver System Investigation

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Hotel Marcel (Pirelli Tire Building), New Haven, Connecticut, *Building Enclosure and Roof System Consultation for Adaptive Reuse.*

222 W80, New York, New York, *Building Envelope and Roof Amenity Space Consultation.*

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Green elements, like these living walls and planters, are visually striking while serving to improve air quality and stormwater management.

be uneven, creating complications with the installation of fixtures and finishes. For pedestrians, a sloped surface can be a fall hazard, and it can make navigating the roof difficult or impossible for those with impaired mobility.

A further benefit of paving systems is that they create a barrier between the rooftop furniture and the roof membrane, which, when left exposed, can be vulnerable to scratches and tears that can compromise the integrity of the waterproofing.

Small Space, Big Benefits

Even a modestly sized roof terrace can yield dividends when converted to an inviting tenant space. With demand for outdoor recreational areas growing, urban building owners would do well to maximize available space by converting untapped rooftops into building amenities. Add to that the growing impetus toward responsible design that minimizes climate impact, and the benefits of combining public open-air spaces with vegetated assemblies is clear. With appropriate consideration of structural capacity, occupant safety, roof maintenance and lifespan, accessibility, and aesthetics, an ordinary roof area can become an attractive and desirable asset. ■

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