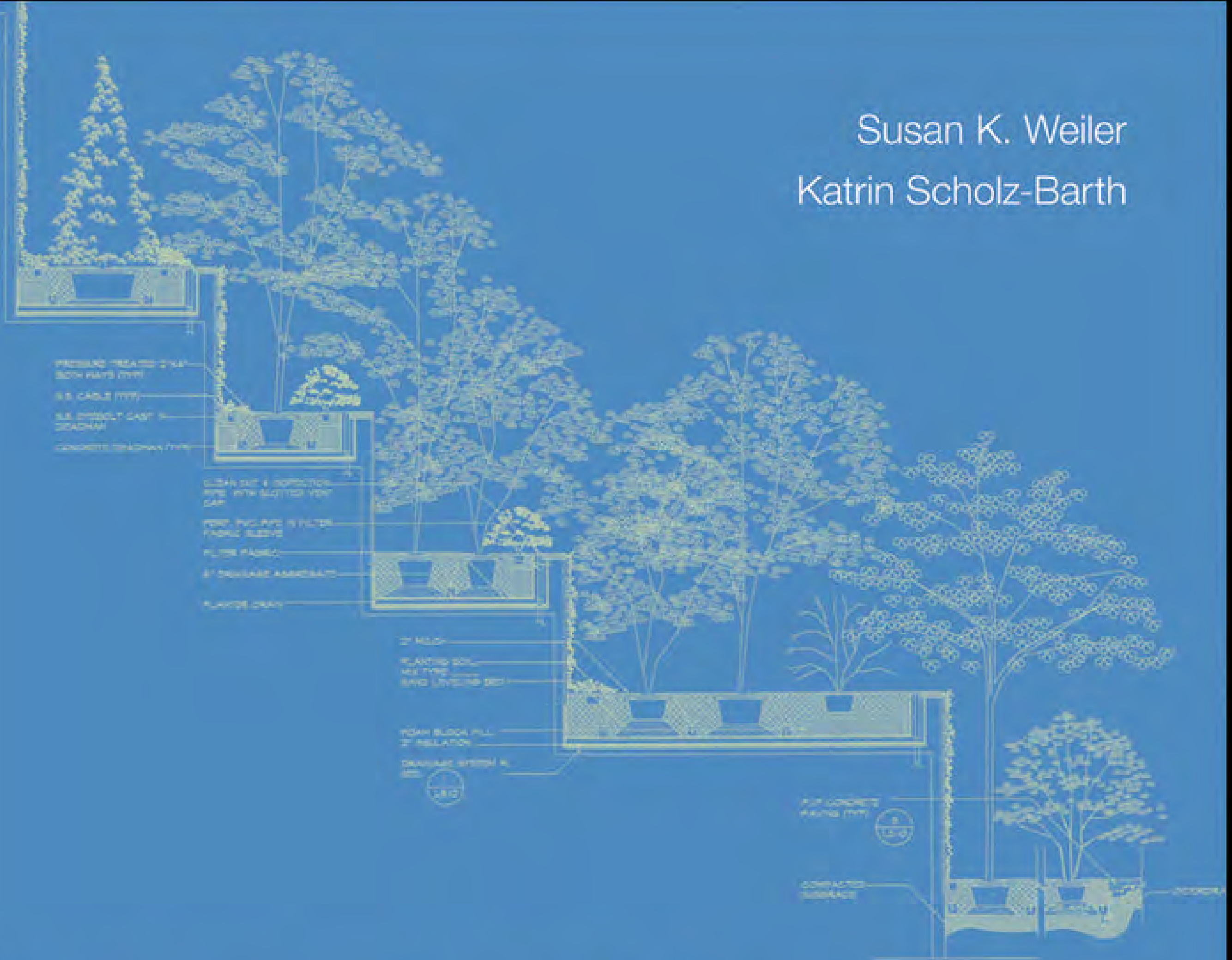
Susan K. Weiler
Katrin Scholz-Barth



Green Roof Systems

A Guide to the Planning, Design, and Construction of Landscapes over Structure

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Susan K. Weiler

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Contents

Chapter 1

Replenishing Our Diminishing Resources:
Integrating Landscape and Architecture 1

Chapter 2

Beyond the Property Line: Ecological, Economic,
Spatial, and Social Benefits of Green Roof Systems 18

Chapter 3

Envisioning Green Roof Systems: From City Scale to Project Scale 40

Chapter 4

Green Roof Systems at the Project Scale:
Site and Architectural Considerations 63

Chapter 5

Considerations in Developing Structural Systems for Green Roof Systems 88

Chapter 6

Component Parts: Inert and Dynamic 120

Chapter 7

Putting the Parts Together: The Design and Documentation Process 175

Chapter 8

The Bidding and Construction Process 203

Chapter 9

Minimizing, Managing, and Insuring Risk 269

Chapter 10

Maintenance Requirements and Performance Evaluation 282

Index 308

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Katrin Scholz Barth

Chapter 1

Replenishing Our Diminishing Resources: Integrating Landscape and Architecture

The world is a glorious bounty.

—Ian L. McHarg, *Design with Nature*

The technology and materials for vegetating roofs and creating usable open spaces over structure have been known for centuries. Since 4000 BC, practitioners of building and agriculture have utilized the knowledge and materials of their time to construct sacred places such as ziggurats, simple vegetated roofs, and remarkable gardens over elevated surfaces.

The *building green* movement is not new, nor is the practice of using natural resources responsibly to sustain life and encourage the regeneration of natural resources.

In the last five years, the term *green roof* has taken on ecological and social significance beyond its seemingly simplistic description. As commonly understood, the term has become an epithet for the reduction of pollution and urban heat islands, for large-scale mitigation of stormwater runoff, and for maximum utilization of urban land.

Justifiably, the concept of the green roof as a way to add pervious surface and usable open space without taking up additional land is easy to understand and should be equally easy to implement. Consequently, many clients, municipalities, architects, landscape architects, and planners have come to consider them as an integral element of sustainable building practice.

More recently, many European municipalities have mandated the incorporation of green roof systems as standard building practice. Even without legislative mandate, landscape architects and architects have, with the personal will and mandate of their clients, successfully built numerous green roofs as stormwater management systems and as comfortable, accessible, open spaces over structure. This has happened without fanfare, perhaps because many of these spaces have been imperceptibly integrated with the architecture and surrounding urban fabric, and perhaps because much of what sustains green roof functionality is invisible to the user.

Most roofs as we know them, however, are not invisible, and as cities grow so do the number and sizes of rooftops. So too does the amount of land used for roads, parking lots, and pavement. At issue is the fact that conventional rooftops and paved surfaces are impermeable, which in turn affects the quality of our water and air. The use of more and

FIGURE 1-1 Gardens at the United Nations, viewed from the East River, illustrate extensive portions built over the FDR Drive.

more land for building affects the way we live. As our cities grow we need to be thoughtful about how we use our limited natural assets.

One of many strategies for replenishing our diminishing resources and integrating landscape and architecture is the green roof, and its wide-scale utilization is the focus of this book.

FIGURE 1-2 Outside Geneva, Switzerland, where vast meadows grow over the roof of a reservoir, a rich palette of plants provide a diversity of habitats for insects and small animals, as well as nesting places for birds.

FIGURE 1-3 Even a small individual effort can help ameliorate the negative impacts of unplanned development and urban growth in the Netherlands. (Photo: Joyce Lee)

This book aims to provide a comprehensive, systems-based approach to understanding, designing, and constructing green roof systems in an urban environment. The following chapters will:

- Broaden the reader's understanding of the deleterious effects that conventional roofs can have on the environment

FIGURE 1-4 West Ferry Circus, a lush garden of canopy trees, shrubs, lawns, and walkways, is one of the numerous interconnected open spaces at Canary Wharf in London. This part of the project was built over a highway, service roads, mechanical equipment rooms, and major utilities. Other open spaces were built over three to five stories of parking, a shopping center, and a tube stop.

- Challenge conventional thinking about the design and development of our built environment and foster innovative solutions that change the perception, appearance, and use of roofs for the benefit of our natural and cultural environment
- Identify the environmental, social, and economic benefits of turning the underexplored surfaces of roofs into multifunctional systems for stormwater management and the creation of usable landscapes over structure
- Provide detailed insight into their design, construction, and maintenance

Defining and Redefining the Roof: Traditional Roofs and Green Roof Systems

In traditional building terms, the roof is considered the lid or top of a habitable structure that keeps the unwanted weather elements outside and helps maintain the most comfortable conditions and temperatures for human habitation inside. For as long as there have been humans seeking shelter beyond a cave or a tree canopy, some type of protective weatherproofing material was overhead to provide protection from the sun, wind, rain, and snow. This has evolved from natural materials such as leaves, thatch, and sod to more durable materials such as slate, wood shingles, asphalt shingles, EPDM (ethylene propylene diene monomer) membranes—and contemporary green roof systems.

In traditional building terms, roofs can be sloped or flat. (Flat roofs actually have a slight slope to them even though to the naked eye they appear flat.) Regardless of its overall configuration and architectural type, a sloped roof sheds rainwater, snow, and ice more quickly than a flat roof, and it is generally more suited for the application of smaller overlapping units for weather protection such as slate, wood, or asphalt shingles, clay tiles, thatch, or sheet metal. Sloped roofs, for some, have greater aesthetic appeal, which may be attributed to a more interesting architecture, size, scale, and the richness of traditional building materials used for weatherproofing.

Flat roofs are more practical for covering long spans of horizontal surfaces, but they can also be used to cover smaller structures. Because of the simpler surface configuration, weather protection for flat roofs can be accomplished more economically through using large pieces of protective membrane.

Both sloped and flat roofs become extraordinarily hot in direct sun exposure, especially in summer. The variation in temperature of the roof surface, even in moderate climates, can cover more than 70 degrees from morning till afternoon. The heat gain is more severe on flat roofs because the entire roof is exposed to the sun at all times. Even so, it is generally easier to build, inhabit, and maintain green roof systems that are constructed on flat or slightly sloped roof decks (the surface supporting the roof) than on ones with slopes because on flat roofs the loosely laid soil and vegetation layer is not subject to gravity and shear forces that pull on them. The primary advantages of constructing green roof systems on low-sloped roof decks are their applicability as stormwater retention systems, their reduction of heat gain, and their ability to be developed for usable open spaces in urban areas without taking up more land.

The technologies of each age add to our ability to live more efficiently and productively. Just as city builders of 4000 BC used the technology of their age to build beautiful rooftop gardens and other needed places, contemporary practitioners of design and building use the knowledge and materials of this time to construct our needed places.

We just need to think more carefully about how we can build our needed places *and* replenish our diminishing resources. This requires thinking about roofs in a different way. The roof, usually a leftover space, sitting unused and absorbing heat, can be transformed into a floor—a platform for activity—while providing insulation for the living spaces below.

Designing with Nature

In the first pages of *Design with Nature*, a seminal treatise on the importance of understanding and integrating natural, economic, and social systems, Ian McHarg points out that "the world is a glorious bounty" from which we benefit and for which we must serve as guardians.

Land and the natural resources it yields have enormous value, but more often they are commodities that have a price; all can be owned, bought, and sold. Land as real estate has its price, water has its price, and energy has its price.

Assigning a Value to Open Space

It is more challenging to assign a dollar value to land as open space. Whether it is under public or private ownership, open space with its intricate, interconnected elements of earth, animals, plants, water, and air provides the armature for the way we live. Well-cared-for open space is itself a valuable commodity and must be envisioned as such. It plays a pivotal role in improving water and air quality. It positively influences real estate values, and it can help to diminish energy consumption in the surrounding area. Yet we seem to take it for granted, and the responsibility for its stewardship is not always taken at individual,

FIGURE 1-5 Bryant Park provides enormous value as an urban open space and has significantly increased peripheral property values. The central lawn panel is built over the stacks of the New York Public Library.

municipal, federal, or global levels. Globally, the amount of open space continues to shrink and our natural resources continue to be diminished in extent and quality. Ozone depletion, air and water pollution, and acid rain have caused local and, cumulatively, global environmental problems. Deforestation and desertification, ground water depletion, and degradation of other natural resources have led to a loss of habitat and biodiversity.

As we develop land for building, we eat up at an alarming rate valuable open space that could be used for our own recreation or for providing connected corridors of habitat and a balanced diversity of vegetation and wildlife. More importantly, we are not carefully planning for the preservation of land we need for growing food or for the replenishment of clean water and air.

Unplanned development resulting from continued population growth may be seen as a root cause of consumption of land for building. This is not exclusively a problem in the developing world; North America has its very own disturbing track record. As an example, between 1973 and 1992 alone, metropolitan Atlanta, Georgia, grew at the expense of 380,000 acres of trees. This amounted to an average destruction of 55 acres every day for nineteen consecutive years. This rapid rate of urbanization in Atlanta prompted NASA to study the impact of development on the overall urban environment, focusing primarily on the regional climate and air quality. The study tied the development of the urban heat island phenomenon and elevated smog levels to the replacement of forests and agricultural land with dark surfaces of the built environment.[1] In our own country, which has some of the best agricultural soils in the world, farmland is being replaced at a rate of nearly 6,000 acres per day by housing, industry, and the services required to support them.

Cumulative Environmental Impacts of Urban Sprawl

When undisturbed forests, meadows, and prairies are replaced with buildings, along with asphalt and concrete roads and parking lots, the built surfaces become impervious to rainwater. Such a widespread trend has spiraling, deleterious consequences beyond removal of the plants and soils that act as natural sponges. Water and air quality is compromised directly and immediately by impervious surfaces. Water can no longer infiltrate the ground and is washed into streams and rivers when it rains, carrying with it nonpoint-source pollutants, nutrients such as phosphorus and nitrogen, and sediments deposited on the impervious surfaces. Dark, hard surfaces absorb solar radiation and store heat, making roofs and roads hot during the day; the stored radiant heat dissipates into the air at night, ultimately warming our globe. On a more recognizable level, regional climate changes can also be attributed to these significant changes in land cover and land use.

For example, Chesapeake Bay was once the most environmentally, socially, and economically diverse estuary in North America. In the last quarter century, unplanned development around the Washington, D.C., area has had deleterious effects on the health of the aquatic ecosystem, and in turn on the sociology and economy of the bay area. The leading cause of this has been the transformation of adjacent and regional open space to impervious surfaces, which has increased the amount of urban stormwater runoff into the bay. Sediment, nitrogen, and phosphorus input has degraded the water quality and with it

USA TODAY Snapshots®

Farmland shrinks

Total acreage of farms in USA (in millions of acres)

2000 945

2006 932

Oil closes above $100 a barrel for first time

Prices at gas pump could surge to $3.75

By James R. Healey
USA TODAY

Oil closed above $100 a barrel Tuesday for the first time in history — a surprise price surge that leaves experts and motorists wondering if there's no limit.

The closing price of $100.01 a barrel, combined with gasoline prices that already had begun rising before the oil spike, could push the U.S. average for gasoline to $3.75 a gallon by Memorial Day — more than 50 cents higher than the record $3.227 set on May 24.

"You can make a much more legitimate case now for $3.50 to $3.75 a gallon as the spring peak," says Tom Kloza, veteran analyst at the Oil Price Information Service, a consultant. "But $4? No."

The about-face for prices is "unexpected, based on what appears to be falling consumption by consumers," says Geoff Sundstrom, spokesman for AAA.

Forecasts of petroleum demand this year have been lowered by the U.S. Energy Department and the International Energy Agency. "It shows we're still at the mercy of those who choose to supply our market, or not," he says.

"Wow. We were talking 12 days ago about going down into the $70s. Now we're talking about $105, $110," says Peter Beutel, president of Cameron Hanover, an energy risk management consultant.

Prices were in the high-$90 range most of the day, then zoomed as high as $100.10 after reports, later denied, that a Nigerian emancipation leader was shot and killed by Nigerian authorities. Unrest in oil-rich Nigeria can lead to shortages that drive prices up.

Also behind oil's record:

► A Monday explosion at Alon USA Energy's refinery in Big Spring, Texas, will keep the facility closed longer than expected. Alon's goal is to resume partial operations in about two months. Although it's not a huge refinery, the U.S. petroleum supply network is tight enough that it doesn't take much to create worries about supply shortages.

► Venezuelan President Hugo Chávez had threatened to cut oil to the USA over a dispute with ExxonMobil, although he said Sunday that he doesn't plan to do so. Exxon won a court judgment freezing $12 billion in Venezuelan assets in return for oil facilities Chávez nationalized.

► Representatives of the Organization of Petroleum Exporting Countries have suggested the cartel won't vote to increase production when OPEC meets in two weeks.

► Oil is priced worldwide in dollars. A weak dollar means it takes more to buy the same amount of oil.

The government's weekly survey showed the U.S. average for regular gas at $3.042 a gallon, up 8.2 cents in a week.

Familiar territory

The U.S. average gasoline price has bounced back above $3

$3.00 $2.50 $2.00 0

$3.109

Tues.: $3.042

1/7/08 2/19/08

Crossword, Sudoku 5D
Editorial/Opinion 11, 13A
Lotteries 13C
Marketplace Today 5D
Market scoreboard 4B
State-by-state 9A

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FIGURE 1-6 This graphic from the front page of *USA Today* shows that 13 million acres of farmland were lost in the United States between 2000 and 2006. This information is juxtaposed with an article about oil costing more than $100 a barrel for the first time.

the bay's crab and oyster habitat. This means that the livelihood of fishermen and crab and oyster farmers along with their local history and traditions are at risk of disappearing—all as a direct result of increased pollution and diminished water quality stemming from development and urban runoff.

Vast and intact open spaces such as forests and prairie grasslands provide ecosystem services, the combined actions of the species in an ecosystem that perform services of value to society and that support the processes and functions on which human culture depends. Until recently, these were taken for granted and were not perceived as having value. Few people consider that our grocery stores are stocked with fruit because of the pollination services insects provide. In the nineteenth century, wetlands were viewed as disease-causing areas from which yellow fever and malaria emanated, and they were eliminated from the urban environment wherever possible. Now we marvel at wetlands' water-storage capacity and their role in preventing flooding as well as their critical role as sources of rich biodiversity. Freshwater wetlands hold more than 40 percent of the world's species and 12 percent of all animal species. In the nineteenth century, elaborate infrastructure for supplying fresh water and removing stormwater and sanitary wastes were built in our urban areas to eliminate disease and improve the health of residents. They were indeed marvels that demonstrated humankind's technology and ingenuity. Nature was revered for her beauty but not for her ecosystem services. Recently that view has changed. Today, New Jersey estimates the value of those services at between $8.9 billion and $19.8 billion per year.[2] Green roof systems can be a part of ameliorating the consequences of urbanization—the decline or destruction of these ecosystem services, specifically water systems.

The depletion of our natural resources and the degradation of our ecological, social, and economic environments, if taken in toto, are serious enough to make you want to stay in bed with the covers pulled tightly over your head. But there are ways of breaking the spiral. Despite these alarming trends, many individuals and communities are beginning to recognize the diminution of our natural resources and are doing much to minimize and even reverse it.

It is unlikely that our populations and in turn our cities will stop growing. We can, however, be more cognizant of the adverse environmental impact of unbridled, unplanned development sprawling well beyond urban centers. In turn, the risks of concentrating the built environment can be mitigated by making our cities livable and vibrant as well as socially, economically, and environmentally sustainable. One way is to superimpose green spaces onto surfaces that would otherwise be impervious to natural and climatic occurrences. This book seeks to explore the positive impacts on our environment that can be derived from the singular and cumulative application of green roof systems and to consider issues involved in their design, construction, and maintenance.

Roof as Floor

The term "green roof" today is often used as an umbrella term for a number of sustainable systems built over a structural decking that serves as a roof to that specific portion of the structure. As a "roof garden," "eco-roof," "extensive green roof," or "intensive green roof," the system acts and is perceived as a roof or lid. As a "roof garden," "open space over structure," or "intensive green roof," the system may serve as either a "roof" or a grade-level "floor."

This ambiguity and confusion of terminology is exacerbated by current jargon derived from European usage of "extensive" and "intensive," two words used within the fabrication, supply, and design industries. These terms, which may seem counterintuitive to English speakers, describe the depth of growing medium and level of effort required to maintain the green roof.

- *Extensive* is loosely used to describe a system that typically has a very shallow depth of soil or growing medium and is primarily used for its environmental benefits such as stormwater management and insulating properties. It is seldom irrigated; it is expected to require minimum maintenance; and it is not usually intended to be accessed directly for use as a garden or open space, though paved walkways and seating areas accommodate use as open space as well.
- *Intensive* is loosely applied to those systems that have a greater depth of soil or growing medium, which allows for a greater diversity in size and type of vegetation. This diversity usually implies a need for supplemental irrigation and, overall, a more intensive level of maintenance.

A disadvantage to using "extensive" and "intensive" as blanket terms is that neither clearly reflects the system's expected purpose or use nor adequately conveys design or maintenance requirements. Furthermore, a terminology-driven, rather than use-driven, approach to the design and construction of green roofs can lead to additional confusion and inaccuracy in design, documentation, and client expectations.

Ironically, in the design and construction of green roof systems, which comprise both living green roofs and landscapes over structure, the roof has to be thought of as a floor, above which a green roof system is built. If the definition of a roof is expanded to be a covering for any built structure at any elevation—such as a parking structure, academic or assembly facility, or any commercial or residential structure—and thought of as being programmed and designed for supporting a thin layer of vegetation to mitigate stormwater loss and heat gain or as usable, comfortable open space, the possibilities for beneficial uses of an otherwise vapid space become positively multiplied.

Coming to Terms with a Green Roof

While the generic term "green roof" already may have become too much a part of the green movement jargon for a clearer or new use of terms to take hold, describing specific applications of different types of green roofs is necessary.

Thus, for clarity, throughout this book, terms are defined as follows:

- *Green roof system* is used as an overarching description of a more environmentally, culturally, and economically sustainable use of a roof at any elevation.
- *Living green roof* is used to describe a thin-profile system where the growing medium is less than 8 inches deep and where the primary use is to effectively satisfy stormwater management requirements in lieu of conventional stormwater engineering methods.
- *Landscape over structure* describes a system where the growing medium is deeper than 8 inches; based upon programmatic requirements, it may be designed to accommodate its use as accessible open space. The combined depth of component parts may exceed several feet, and related systems required to support the uses often are more complex.

Living green roof and *landscape over structure* are not competing or contradictory strategies. Rather, large-scale ecological and social benefits can be recognized in the

FIGURE 1-7a–b Living green roofs can merge landscape and architecture by expanding beyond the conventional notion of roof. (Photo: Kai-Hennik Barth)

FIGURE 1-8 This is one of many gardens at the J. Paul Getty Center. All of them are over various structures used as garages, shipping and receiving facilities, storage areas, mechanical rooms, and portions of the scholars' libraries and studies.

appropriate application of either, as well as their combined use to reduce stormwater runoff, bind dust and pollutant particulates, reduce energy consumption, increase biodiversity, improve the visual quality of conventional roofs, and provide valuable, beautiful, comfortable, usable open space. The selection of the most suitable application should be defined by varied use and design goals.

Application of Living Green Roofs

Living green roofs offer ecological, aesthetic, and economic advantages. From an ecological standpoint, a major benefit of a living green roof is that it slows and detains stormwater runoff by providing a pervious, vegetated surface, thus preserving water resources and eliminating the need for monetarily and environmentally costly stormwater management systems. The growing medium and vegetation cover also help to shade the roof surface, preventing solar heat gain or loss and thereby lowering consumption of energy to heat and cool the building below. The transpiration of the vegetation provides an evaporative cooling effect that can lower the air temperature locally to below ambient temperatures, helping to reduce the urban heat island effect locally with global implications.

From an aesthetic standpoint, a primary application of a living green roof is to provide a visually interesting vegetation layer of diverse texture and seasonal color, in contrast to a rock ballast or dark surface.

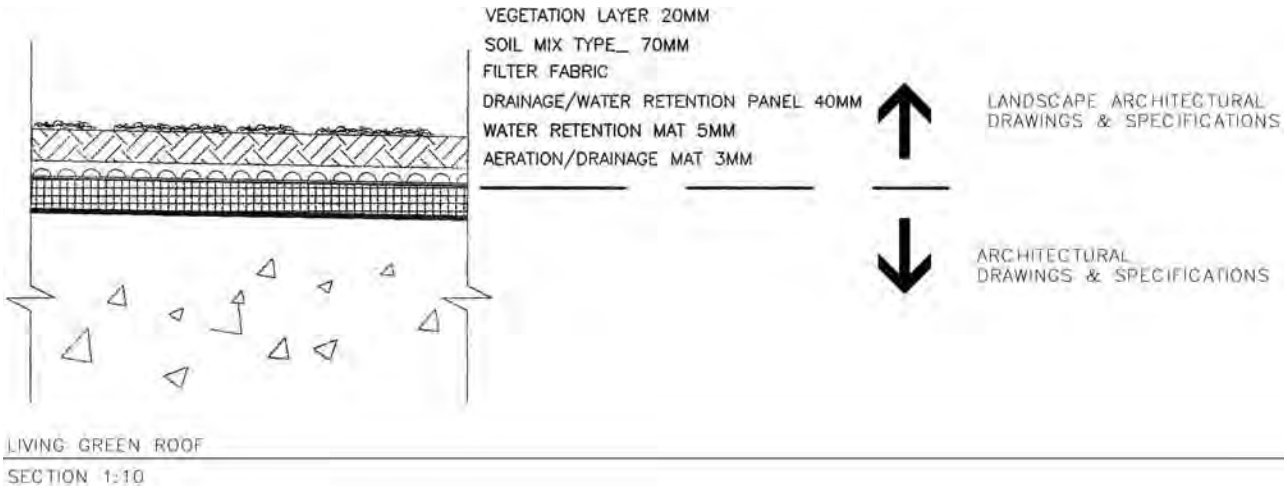

FIGURE 1-9 Detail section for a living green roof.

Economically, living green roofs may satisfy local governments' stormwater management requirements, which will reduce the cost of conventional methods of conveying stormwater from roof drains to ultimate outfall. This reduces not only owner construction costs but also the enormous costs to municipalities for infrastructure and operations associated with stormwater management. That is why today many municipalities offer

FIGURE 1-10 Although a number of species of the genus *Sedum* may be utilized, a balanced matrix of genera should be included in the plant palette of a living green roof.

incentives such as tax credits and larger allowable floor area ratios in exchange for implementation of living green roof systems.

The depth of growing medium required for a living green roof is typically 3 to 6 inches but may be as thin as 1 inch. Since the primary purpose of a living green roof is to detain stormwater runoff, irrigation typically is not employed. The lack of consistent supplemental watering, shallow soil depth, and exposure to intense and desiccating sunlight and wind require vegetation capable of surviving these harsh, dry conditions. Low-growing, horizontally spreading, water-storing plants, which occur naturally in alpine environments, have proved to be the hardiest and most suitable for these conditions. Generically this type of plant is known as a succulent: a plant that can store water in its leaves and stems for extended periods of drought conditions. Most often, but not exclusively, plants are selected from the hundreds of species in the genus *Sedum*, many of which are succulents. The dominance of their use in the overall plant selection of living green roofs has led to the occasional use of the misnomer "sedum roofs." Like most successful planting plans, the selection of plants for living green roofs should include a matrix of plant genera and species that provide adequate horticultural diversity and are suitable to the artificially created roof environment desired.

The maintenance required for such plant mixes is limited and might include initial hand-watering during installation and the establishment period as well as occasional weeding, fertilizing, and spot repair.

The relatively thin profile of the components of a living green roof generally weighs 12 to 15 pounds per square foot. Although each application of a living green roof usually will have specific design requirements determined through a structural analysis, structural upgrading of standard roof decking is usually not required because the weight of the living green roof profile is about the same as the weight of the stone ballast applied to protect and preserve the waterproofing membrane of a conventional roofing system. A living green roof, therefore, can be employed in place of stone ballast when, structurally, limited or no additional weight can be added to the deck. Also, because generally there is little or

FIGURE 1-11a Utilization of roofs for stormwater management systems at a manufacturing plant. (Photo: re-natur, 24601 Ruhwinkel, Germany)

FIGURE 1-11b This living green roof is over a parking structure that is part of a shopping center in the central business district of Nürtingen, Germany. The living green roof is primarily used for stormwater management, but it also adds a visual amenity for the residents and office workers in the adjacent building. Additionally, it offers limited access for shoppers, residents, and workers wishing to walk through the living green roof garden. (Photo: re-natur, 24601 Ruhwinkel, Germany)

FIGURE 1-12a Long views across living green roofs maintain the visual integrity of the rural landscape and provide part of the stormwater management system for this Swiss poultry farm.

FIGURE 1-12b A traditional vegetated roof insulates the coop at a Swiss poultry farm while also helping to integrate the roof into the surrounding rural landscape.

no additional cost to provide increased structural support for new buildings, it can also be a cost-effective way to provide greater visual amenity and environmental quality. (Chapter 5 addresses structural considerations for both living green roofs and landscapes over structure.)

Although living green roofs are not intended or designed to be physically accessible for use as an open space amenity, they can be combined with areas of the roof that are designed for active use. Clear demarcation of restricted use should be incorporated into the overall design.

Application of Landscapes over Structure

Depending on the amount of vegetation, most of the same ecological and environmental benefits may be derived from the construction of landscapes over structure as from living green roofs. The greater the density and coverage of the vegetation, the greater is the capacity of a landscape over structure to intercept, absorb, and slow stormwater runoff. Likewise, landscapes over structure offer the collateral benefits of more vegetation on the earth's surface.

Depending on planned use and the ultimate physical expression of the design, landscapes over structure, like any built landscape, can take many forms and have the potential for a wide range of ecological, aesthetic, and social benefits.

With a growing medium typically deeper than 8 inches, landscapes over structure can support a greater diversity in size and type of vegetation. Greater size and diversity of plants usually requires a deeper soil profile, supplemental irrigation, and a more complex infrastructure to support and sustain plant growth in an artificial environment.

In a landscape over structure, the structural system required to sustain the additional weight of growing medium, vegetation, site elements, and potential live loads is significantly

FIGURE 1-13 Vila Olimpica, in Barcelona, merges architecture and landscape, blending the adjacent buildings and their spaces below with lush exterior spaces of varied use. Landscapes were built over a hotel, shops, and a multistory garage.

more substantial and complex in terms of design, size, and cost than that required to support a living green roof. And invariably, the need to coordinate the various professional disciplines throughout the process of design, documentation, and construction has cost implications that must be balanced against the benefits of the end use. (This is addressed more fully in Chapters 3 and 5.)

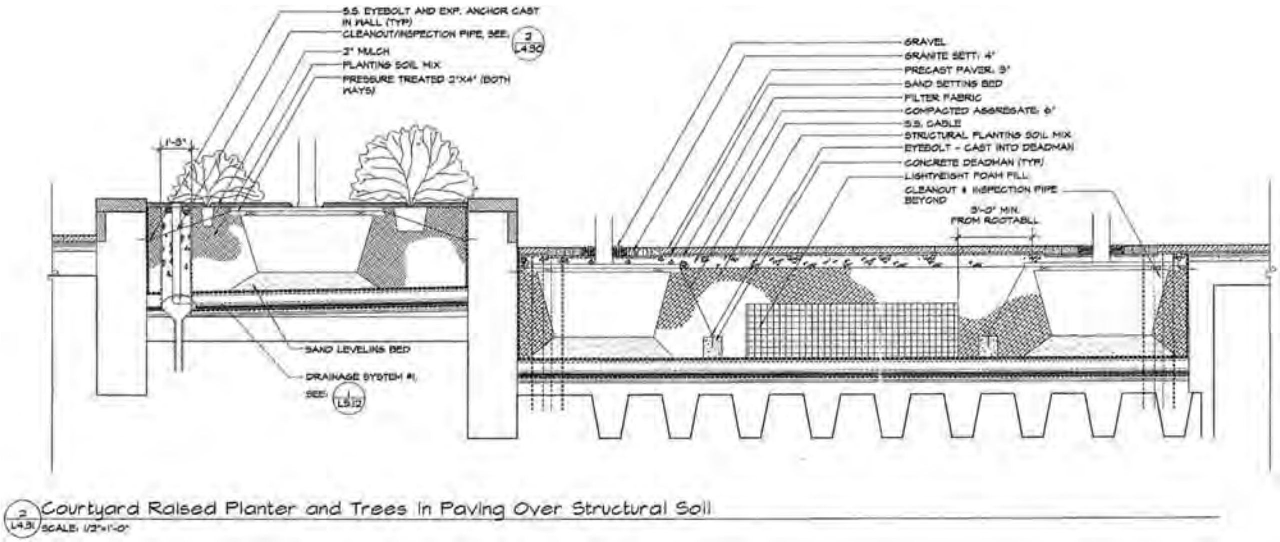

FIGURE 1-14 Detail section for a landscape over structure.

Maintaining Healthy Cities

It is clear that living green roofs and landscapes over structure are not a panacea for ameliorating the negative environmental impacts resulting from increased development or the loss of open space. They cannot and will not replace our forests and prairies, will not remediate the degradation of all stream corridors, and will not stop global warming by themselves.

However, living green roofs and landscapes over structure can act as buffers to mitigate the impacts of unbridled and unplanned urban growth and development. Reducing building roofs generates less stormwater runoff, reduces the heat gain that affects our indoor and outdoor environments, and mitigates the continued degradation of air and water quality. Programming for, building, and maintaining well-designed and constructed landscapes over otherwise unutilized roof decks provides additional usable, comfortable open space.

If municipalities provide incentives such as allowing developers to increase the floor area ratio, or lowering or even forgiving taxes, living green roofs become cost-effective immediately. The immediate cost-effectiveness of landscapes over structure is more difficult to derive if the benefits are measured only as cost savings. However, for either type of green roof system to become as commonplace in North America as they are in many parts of Europe, both need to be conceived as common elements of city planning and urban design.

Doing so also requires a departure from conventional approaches to design and construction, as well as collaboration and coordination among numerous disciplines of

FIGURE 1-15 Numerous gardens, courtyards, and seating areas for serendipitous encounters at the J. Paul Getty Center provide many places for comfort and respite.

FIGURE 1-16a–b Numerous individual installations of living green roofs in central Stuttgart and individual installations in the community of Hegeweisse, Germany, make a cumulative positive impact visually and environmentally.

design professionals. Architects, landscape architects, and structural engineers will need to determine the infrastructural needs to support the building and site program. Civil engineers will need to calculate water retention capacities of differing growing media at various depths on a site-specific basis. Mechanical engineers will be required to quantify the mass of the growing media and vegetation at various moisture levels and incorporate variant insulating values into the sizing of heating, cooling, and air-conditioning systems. Contractors and construction trades must depart from traditional practices of cost estimating,

FIGURE 1-17a–b Children explore their environment through the plants of a living green roof and the fountains of a landscape over structure.

project sequencing, and selection and installation of construction materials. And clients must be courageous in their programming, clear in their expectations, committed, and able to finance the project through completion, occupation, and continued maintenance.

The examples used throughout this book are typically derived from urban contexts because cities have the greatest potential for impacting our natural environments, both positively and negatively. The topics and methods are equally applicable to rural, suburban, and residential-scale situations; however, it should be kept in mind that every project is unique in its program, design, and construction requirements.

Summary

Regardless of the location and extent of a living green roof or landscape over structure, the benefits of a single installation are great. When the planning and design process considers effects beyond the limits of a project's property line, the potential positive, cumulative impact of individual initiatives upon our natural, cultural, and social environment is enormous.

Endnotes

1. Dale A. Quattrochi and Jeffrey C. Luvall, "High Spatial Resolution Airborne Multispectral Thermal Infrared Data to Support Analysis and Modeling Tasks in EOS IDS Project ATLANTA," available at http://www.ghcc.msfc.nasa.gov/atlanta.

2. New Jersey Department of Environmental Protection, "Valuing New Jersey's Natural Capital," April 2007.

Chapter 2

Beyond the Property Line: Ecological, Economic, Spatial, and Social Benefits of Green Roof Systems

A well-known scientist . . . once gave a public lecture on astronomy. He described how the earth orbits around the sun and how the sun, in turn, orbits around the center of a vast collection of stars called our galaxy. At the end of the lecture, a little old lady at the back of the room got up and said: "What you have told us is rubbish. The world is really a flat plate supported on the back of a giant tortoise." The scientist gave a superior smile before replying, "What is the tortoise standing on?" "You're very clever, young man, very clever," said the old lady. "But it's turtles all the way down!"

—Stephen Hawking, *A Brief History of Time*

Our world is interconnected. Only recently, however, have we developed an awareness of global interconnectedness and how changes in one part of the system affect changes in every other. The emergence of climate change as a critical global issue highlights these interconnections. What was possible to ignore when the population of the earth was a few hundred million people is impossible to ignore when the population is 6.6 billion presently and is expected to be almost 8 billion by 2025.

The decision to incorporate a green roof system into a project may seem quite separated from the global implications of climate change. Yet the platitude "Think globally, act locally" is apt. Green roof systems can provide valuable usable open space and help to ameliorate deleterious impacts on our urban environment by reducing stormwater runoff, lowering ambient temperatures, and reducing energy consumption. While an individual action may seem minuscule on a global scale, the cumulative effect of positive actions can have a large impact.

This chapter considers our air and water systems and their interconnectedness, particularly in our urban environments. The phrase "beyond the property line" refers to the fact that every project must be considered as part of a watershed and an airshed and thus as part of a regional system and ultimately a global one. Green roof systems can have positive effects on our air and water locally, and by extension their cumulative impact can be global. These positive impacts can be seen in the measurable improvement in air and water quality.

In order to understand the impacts—both positive and negative—of urbanization on our environment, it is helpful to have a basic understanding of applicable concepts and terminology used in the engineering and design fields. While some of these terms and concepts are becoming commonplace, sometimes they are used interchangeably or are improperly applied, thus limiting the discussion of the benefits of green roof systems to a surface treatment of the issue. An overview of the basic concepts of stormwater management has been included to provide a basis of informed language in the discussion of appropriate application of green roof systems.

From Green to Gray: The Effects of Urbanization

William Cronon, in *Uncommon Ground*, describes the core myth of Judeo-Christian tradition as "nature as Eden" and the resulting "Edenic narratives" of the loss of an original pristine nature through some human culpable act that results in environmental degradation and moral jeopardy. Thomas Jefferson celebrated the virtues of the agrarian way of life, viewing urban areas with distrust as sores on the body politic. Today, though, the majority of the world's people do not live in pristine nature or in a pristine agrarian society. While cities, in the support and sustenance of their society, can effectively concentrate the

FIGURE 2-1 Stormwater runoff severely impacts national waterways such as the Chesapeake Bay.

use of our natural and economic resources, they more often disrupt the natural systems of their environment through the patterns of unplanned urbanization. Many people rue the spiritual and metaphorical losses of both urban and rural environments.

The majority of the American population lives in the large megalopolises of the twentieth century, spanning the range from dense central cities to semirural exurbs. Sprawl consumes land, often former agricultural land or second-growth woodlands, disrupting or completely destroying ecosystem services. Similarly, modern agricultural practices, while sustaining the larger society, have led to serious environmental problems, including a loss of topsoil that is undermining our food security and nutrient-laden runoff that threatens the economic and ecological health and welfare of some of our most precious waterways and largest watersheds.

The Delaware River, the largest undammed river in the United States, supplies drinking water to approximately 14 million people. It has experienced decreased water quality and increased and more severe flooding in the last 20 years as its watershed becomes increasingly urbanized. No one needs to be reminded of the devastation and loss of life wreaked upon New Orleans by Hurricane Katrina in 2005. The disruption of the natural hydrological system by diversions, levee building, and draining of wetlands, originally built to protect New Orleans, increased the damage. Even prior to this nationally devastating hurricane, floods accounted for over 40 percent of all natural disasters, and the Federal Emergency Management Agency carried $524 billion in total coverage for flood insurance.

Urbanization and development bring profound changes to the preexisting hydrological system. The aforementioned examples are only some of the largest and most tragic. Communities undergoing urbanization rarely express emotion over the loss of ecosystem services or the predevelopment condition of the hydrological system. Instead, they usually express these in more wistful and metaphorical terms about the loss of what was. Old approaches such as green roof systems are being rediscovered and implemented to

North Carolina State University

A study conducted at North Carolina State University confirms the positive stormwater control performance of a living green roof. Monitoring data published from this study also are consistent with the findings of earlier research at both Pennsylvania State University and Michigan State University. Over an 18-month period, the 750-square-foot, 3-inch-deep green roof at Wayne Community College in Goldsboro, North Carolina, retained an average of 63 percent of the total rain and reduced the total runoff by 87 percent. The greater runoff reduction takes into account the peak flow rate reduction and is based on the distribution of rain events over a certain period of time, whether rain occurred after a profound dry period or on consecutive days. In a second project for which there were only three months' worth of runoff data available (July to September 2004), a 4-inch-deep, 1,400-square-foot living green roof retained an average 55 percent of the rainfall and reduced runoff by 57 percent. In this study, not only was the performance of the green roof measured in absolute terms of runoff rates and runoff volumes, but the resulting runoff coefficient was computed. For a 1.5-inch storm event, the volumetric rational runoff coefficient for the 3-inch-deep living green roof was 0.53, which is comparable to meadows and pastures. Even during a major 3.1-inch storm event, the green roof achieved some volume and flow reduction and runoff delay, with a runoff coefficient of 0.87, compared to 0.95 for conventional roofs. This indicates that even during a large rainfall event and full saturation of the growing medium the living green roof outperformed conventional roofs and provided 9 percent additional storage capacity.[1]

address and ameliorate these problems. While no one technology such as living green roof systems will entirely solve the problem, each becomes a part of a portfolio of management practices that together will have a cumulative positive effect.

Stormwater and the Hydrological Cycle

Stormwater replenishes our groundwater, lakes, rivers, and streams. It provides water to the root zones of the plants in undisturbed natural environment, for agricultural crops, and for plants used for shade or pleasure in our urban environments. To understand how green roof systems help sustain a healthy hydrological cycle, which in turn sustains the global climate, it is helpful to have a basic understanding of the current issues associated with stormwater. They include surface characteristics determined by vegetation and soils, storm characteristics including duration and intensity, and the management of stormwater as it runs off from our urban environments.

The natural hydrological cycle is simply the constant exchange of water between the atmosphere and the ground in the form of precipitation and evapotranspiration (the combination of evaporation and transpiration from plants). When precipitation in the form of rain or snow falls, it finds its way downhill if not intercepted. Foliage intercepts and disperses the energy of raindrops, protecting the ground surface by lessening the raindrop's erosive force. Healthy, vegetated soils slow precipitation down, further allowing water to soak in or infiltrate. In essence, vegetation and the soils supporting them act as large sieves or sponges. Unintercepted precipitation is called *stormwater runoff.*

Runoff can be categorized as either surface runoff or subsurface runoff. *Surface runoff* is water that moves on the ground by gravity until it finds an outlet to a pond, stream, river, lake, or ocean. *Subsurface runoff* is stormwater that infiltrates the soil moving through it both horizontally and vertically. The way stormwater moves and the rate at which it moves, as either surface or subsurface runoff, depends on the characteristics of the surface on which the precipitation falls and on the duration and intensity of the storm.

The goal of stormwater management practices is to minimize and effectively control surface runoff and maximize infiltration and subsurface runoff. Control of surface runoff is necessary because of the erosive power of water and the damage it causes. The Grand Canyon was formed by the erosive power of water; so are the deep gullies seen in urbanized areas. Maximum infiltration is desired so that water is available in the soil for plant growth and aquifer recharge.

Some cities lose as much water to stormwater runoff as would supply 3.6 million people with their average annual household needs. Table 2–1 below summarizes annual water loss for the top eighteen land-consuming U.S. metropolitan areas.

Surface Characteristics

Surfaces are referred to as either impervious (impermeable) or pervious (permeable). *Impervious* surfaces are surfaces that water cannot penetrate, such as paving or roofs. When precipitation hits an impervious surface such as a roof or pavement, runoff is immediate and follows the gravitational pull downhill. *Pervious* surfaces are those that water

TABLE 2-1: Groundwater Infiltration Loss[2]

Metropolitan Area	*Water Loss (billion gallons/year)*
Atlanta, Georgia	56.9–132.8
Boston, Massachusetts	43.9–102.5
Philadelphia, Pennsylvania	25.3–59
Washington, D.C.	23.8–55.6
Nashville, Tennessee	17.3–40.5
Charlotte, North Carolina	13.5–31.5
Pittsburgh, Pennsylvania	13.5–31.5
Houston, Texas	12.8–29.8
Greensville, South Carolina	12.7–29.5
Seattle, Washington	10.5–24.6
Chicago, Illinois	10.2–23.7
Raleigh-Durham/Chapel Hill, North Carolina	9.4–21.9
Orlando, Florida	9.2–21.5
Minneapolis/St. Paul, Minnesota	9.0–21.1
Detroit, Michigan	7.8–18.2
Tampa, Florida	7.3–17
Greensboro, North Carolina	6.7–15.7
Dallas, Texas	6.2–14.4

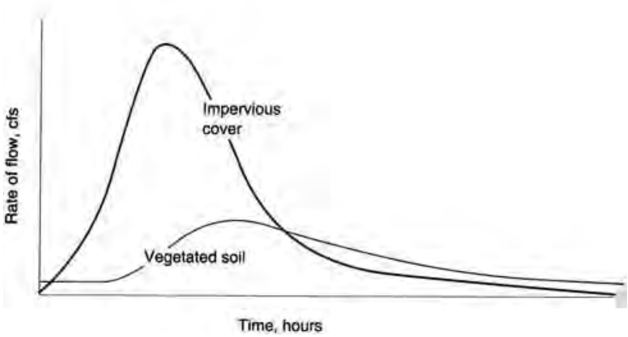

FIGURE 2-2 Vegetation and soil intercept stormwater before it can run off. The greater the permeability of the vegetative cover and soils, the longer it takes stormwater to become runoff and the more slowly it will move.

can penetrate. When precipitation hits a pervious surface such as soil, permeable paving, or a green roof system, the stormwater infiltrates this surface until it is saturated. After saturation, water follows the gravitational pull finding the shortest route downhill.

The amount of stormwater vegetation and soils can intercept and hold depends upon the type and extent of the vegetation, the topography of the ground plane, and the composition of the soil beneath it. The denser the mass of vegetation, the flatter the slope, and the more permeable the soil, the greater the system's ability to disperse and intercept stormwater before it hits the ground plane and to hold or detain it once it does hit. In a well-stratified forest consisting of different layers—canopy, subcanopy, shrub, and ground cover—some water is intercepted by each layer. This interception both reduces the impact of the raindrop and the amount of runoff. Topography is also a major factor. On steeper slopes, more water runs off faster than on flatter slopes. Likewise, sandy soils absorb more water than dense, clay soils. A well-stratified, mixed-species forest on a flat slope with sandy loam soils can detain or hold more precipitation than a coniferous forest on a steep rocky slope. A prairie with a diverse matrix of thickly matted grasses and perennials on a shallow slope slows down the movement of surface runoff more than a flat lawn. A mature lawn with uncompacted soils underlying it, even

FIGURE 2-3 This living green roof has a 6-inch soil profile and is covered with a matrix of grasses. (Photo: Kai-Henrick Barth)

National Research Council of Canada

In Toronto, Karen Liu, of the National Research Council of Canada, and John Minor, with the City of Toronto Public Works Department, divided a 5,000-square-foot roof into equal areas and installed one 3-inch-deep living green roof and one 4-inch-deep living green roof. The difference in the system profile buildup was not only the 1-inch difference in soil depth but also the use of different drainage materials. The drainage material for the 3-inch living green roof consisted of 1-inch-thick expanded polystyrene boards with drainage channels that did not provide any additional water storage capacity. In contrast, the 4-inch-deep green roof was installed with a 1-inch-thick composite semi-rigid polymeric drainage board with filter fabric attached. The little "cups" added about 0.11 gal/SF (or 1 gallon per 9 square feet) of water-holding capacity.

Runoff volume and flow rates were monitored and showed notable results. The living green roofs were effective in reducing the total runoff volume by an average annual 57 percent. The peak flow rates were also reduced by 25 to 60 percent, with peak performance for both volume and flow rate reductions occurring in summer. An equally important data point is the observed lag time of runoff after a 0.74-inch rain event. After the storage capacity of the living green roofs was exceeded, the peak runoff rate occurred 20 to 40 minutes after the rain had ended.[3] The lag time indicates the retention capacity of the roof and quantifies the storage capacity for stormwater quantity control.

Water retention was calculated by subtracting the measured runoff from the total recorded rainfall amount. In this study the living green roofs were seeded, not planted, and exhibited sparse (only 5 percent) vegetation cover throughout the monitoring period. There was no water consumption by plants through either uptake or evapotranspiration and thus no added runoff reduction benefits from plants or foliage. The runoff reduction benefits were achieved solely by the soil profile.

if moderately sloped, is more effective at detaining and holding stormwater than a moderately sloped or even flat asphalt parking lot surface.

Soils

Once unintercepted precipitation hits the ground, the rate at which it either infiltrates into the soil or becomes stormwater runoff is again dependent upon the type of soil and the slope of the ground plane.

Soils are composed of particles. Sands and gravels consist of rather large particles or grains, with relatively large spaces between them. Clay, on the other hand, is composed of very small particles called colloids that have an electrical charge on their surface. Colloids have minute spaces between them. Water does not easily pass through clay because of both the small interstitial spaces and the electrical charge that binds it weakly to the clay colloid. Clay soils are much more difficult to wet, but once wet, they hold much more water for longer periods than the more porous sands and gravels.

In dry soils, the space between particles is filled with air. When water hits the soil, it displaces the air that exists between soil particles. During rainfalls of small volume and intensity, water may not displace all the air and the soil is moist only at the surface. During rainfall of great duration and intensity, the soil is thoroughly wetted and, like a soaked sponge, is filled to capacity. In such instances, all the pores in the soil are filled with water to many times the volume of their dry capacity. Some water passes through the soil, which is also acting like a sieve, and infiltrates through cracks and joints of weathered bedrock just below the soil profile until it reaches an impervious layer below which it cannot infiltrate. Water collects above this impervious layer saturating the soil pores. The top of this saturated zone is called the water table. Factors influencing the depth to the water table include the type of rock underlying the soil, the slope, the season, and the depth of the impervious layer. In areas of porous soils such as sands and gravels, derived primarily from sedimentary rocks such as sandstone and limestone, the water flows downward though fissures and cracks as well as through actual pores in the bedrock until it comes to deep underground reservoirs called aquifers. In soils consisting more of clays, derived from certain types of igneous and metamorphic rock, water is not able to flow through the bedrock and the impervious layer is quite close to the surface. In the latter case the soil may quickly be filled to capacity with water, resulting in large amounts of water running off into small watercourses that in turn empty into streams and rivers.

Storm Characteristics: Intensity, Duration, Design Storm, Frequency, and Time of Concentration

While there are site characteristics that influence the measurable interception and flow of stormwater, there are also rainfall characteristics that may be considered in terms of the measurable intensity, duration, and frequency of a storm.

Storm intensity is the amount of rainfall for a given unit of time and is generally measured in inches per hour.

Storm duration is the length of time between the onset of precipitation and its end.

A *design storm* is the magnitude and temporal distribution of precipitation from a storm event measured in probability of occurrence and duration (a 25-year, 24-hour storm, for example); the concept is used in the design and evaluation of stormwater management systems.[4] It is not uncommon to hear about a 100-year storm on the weather report. Such a storm is predicted to happen once in 100 years and thus has a 1 percent chance of happening in any given year. Most stormwater codes specify that stormwater infrastructure must be designed to handle a specific design storm, such as a 5-year storm, a storm that has a 20 percent chance of happening in any given year. The selection of the design storm is based on jurisdictional regulations, the environmental context of the project area, funds available to build the system, and the ultimate consequences of system overflow.[5]

Storm frequency is a statistical measurement of the probability that a given design storm will occur once in a given year. It is defined by the number of years during which the design storm or a storm exceeding it statistically may be expected to occur once. This has conventionally been based on observation and long-term probability. A 10-year storm means that a storm of this type has a probability of happening once in 10 years.

A *rainfall intensity curve* provides a graphic representation of statistically expected rainfall over a given time period.

Time of concentration is defined as the time it takes for surface runoff to flow from the hydraulically most remote part of the drainage area to the area being designed for stormwater management. This will take into consideration the slope and surface cover characteristics of the site.

Anyone who has experienced a summer thunderstorm in the eastern United States or a storm coming off the Pacific in San Francisco has experienced a high-intensity storm,

TABLE 2-2: 100-Year and 5-Year Storm Frequencies

City	*100-year 1-hour duration storm event rain intensity (in inches)*	*100-year 24-hour duration storm event rain intensity (in inches)*	*5-year 1-hour duration storm event rain intensity (in inches)*
Washington, D.C.	3.2	8.26	1.88
New York, New York	3.0	7.3	1.8
Boston, Massachusetts	2.5	6.5	1.5
Atlanta, Georgia	3.7	8.0	2.2
Miami, Florida	4.7	14.0	3.2
Wichita, Kansas	3.7	7.6	2.2
Chicago, Illinois	3.0	7.19	1.8
Minneapolis, Minnesota	3.1	6.0	1.8
Phoenix, Arizona	2.5	3.44	1.04
Las Vegas, Nevada	1.4	2.38	0.69
Los Angeles, California	2.1	78.0	28.79
San Francisco, California	1.5	45.0	29.88
Portland, Oregon	1.2	47.0	NA
Seattle, Washington	1.4	40.0	NA

Sources: International Plumbing Code 2003; G. M. Bonnin, D. Todd, B. Lin, et al., *Precipitation-Frequency Atlas of the United States*, NOAA Atlas 14, Volume 1, Version 3 (Silver Spring, MD: NOAA, National Weather Service, 2003); "Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years," NOAA Technical Paper 40 (1961); "Five to 60-Minutes Precipitation Frequency for Eastern and Central United States," Technical Memorandum NWS Hydro 35, NOAA (1977).

with torrents of water falling in a very short time with a correspondingly large amount of runoff. It is not uncommon to have a 2-hour storm that dumps 2 inches of rain per hour, for a total of 4 inches. On the other hand, gentle spring rains, in which smaller amounts of rain fall for a longer period of time, nourish the soil and new seedlings and result in much less runoff; 4 inches might fall over an 8-hour period, for a rate of 0.5 inches of rain per hour.

Because the effects of both urbanization and suburbanization have been viewed locally rather than globally, the incremental impact of discharging stormwater runoff has conventionally been viewed on a project-by-project or drainage-area-by-drainage-area basis. However, the way in which stormwater acts and how it should be managed has long been based on the observation and record keeping of the predictability of storms and their intensity, and how site characteristics, permeable and impermeable surface types, and topography can affect the flow rate and flow patterns of stormwater. For lack of a more comprehensive, if not global, way of thinking or evaluating stormwater runoff, the current means of measuring stormwater surface runoff (in cubic feet per second) has been known as the "rational method." The rational method is the one most often used in stormwater codes in the United States.

FIGURE 2-4 In a torrential downpour, great volumes of stormwater on paved, impermeable surfaces rush to sewers, rather than recharging our water systems.

Calculating Stormwater Runoff

It is important to understand, at least conceptually, how to calculate *peak runoff rate*—the volume of stormwater runoff per unit of time (cubic feet per second) that must be managed. Many times the landscape architect or engineer will be asked by how much the green roof system reduces peak runoff rate. Much of conventional stormwater measurement is based on the theory that the peak rate of the area being considered is equal to the intensity of rainfall multiplied by a coefficient representing the characteristics of the drainage area and by the size of the drainage area. A peak flow rate of, say, 1 acre-inch per hour can be directly converted to cubic feet per second. This measurement is then adjusted for the characteristics of the developed area, such as vegetative cover, paved surface, size of the developed area, and topographic features. The rational method utilizes an understanding of the following:

- Defined drainage area (regardless of property lines)
- Type of surfaces (permeable or impermeable) the stormwater hits
- Gravitational aspects (slope) of the site's topography
- Soil composition
- Storm characteristics

TABLE 2-3: Runoff Coefficient

Ground Cover or Land Use	*Runoff Coefficient (C)*
Forests	0.05–0.25
Lawns	0.10–0.35
Cultivated land	0.08–0.41
Meadow	0.10–0.50
Parks, cemeteries	0.10–0.30
Unimproved areas	0.10–0.30
Pasture	0.12–0.62
Pasture with moderate grazing	0.10–0.30
Bare earth	0.20–0.90
Steep grassed area (2:1 slope)	0.50–0.70
Residential areas	0.30–0.75
Flat residential areas, 30% impervious	0.30–0.50
Flat residential areas, 70% impervious	0.50–0.80
Business areas	0.50–0.95
Flat commercial/industrial area, 90% impervious	0.50–0.90
Asphalt or concrete streets	0.70–0.95
Brick streets	0.70–0.85
Roofs	0.75–0.95

To compute the peak runoff rate (in cubic feet per second) with the rational method, this formula is used:

$$Q = CIA$$

where

Q = Peak runoff rate (in cubic feet per second)
C = Runoff coefficient, a dimensionless coefficient between 1 and 0, where 0 is completely pervious and allows no runoff and 1 is completely impervious. As an example:

Woodland (flat, slope between 0 and 5 percent, sandy loam soil texture)	0.10
Asphalt or concrete pavement	0.75–0.95
Rooftop	0.80–0.95

I = Rainfall intensity in inches per hour (iph) for the design storm frequency and for the time of concentration of the drainage area
A = Area of the drainage area (in acres)

What is immediately apparent by looking at C, the runoff coefficient, is that when the other variables are held equal, peak flows are less when the surfaces consist of natural soils that allow infiltration.

Watersheds Are Independent of Property Lines

A watershed or drainage basin is the basic unit of regional stormwater management. It is the area drained by a river or stream and all of its tributaries. The watershed of the Mississippi and Missouri Rivers covers 1,245,000 square miles and drains the entire midsection of the United States, 41 percent of the area of the contiguous 48 states. Generally watersheds or catchment areas in stormwater management refer to the area that one creek or stream drains. We cannot forget, however, that a parcel of land in western Pennsylvania may drain to a creek that in turn drains to the Ohio River and ultimately into the Gulf of Mexico through the Mississippi River. Both the cumulative effects of development and the cumulative impact of incremental implementation of green roof systems that detain stormwater in Pittsburgh may ultimately have an impact on what happens in New Orleans.

In the process of urbanization, areas of forest, agricultural, and grassland soils that once permitted water hitting their surfaces to infiltrate are paved with concrete or asphalt, or become lawn, an often nearly impervious surface when underlying soils are compacted by heavy equipment during the construction process. What were originally pervious surfaces become impervious ones. When water hits a hard, impervious surface, it has no place to go but straight downhill as quickly as possible. Engineers have designed and built complex and beautiful infrastructures to collect stormwater and transport it to streams and rivers, where it is discharged. This, however, raises several important issues relating to stormwater: the cumulative effect of creating ever more impervious surfaces and removal

FIGURE 2-5 In addition to carrying surface pollutants from vehicles, stormwater runoff carries vast amounts of sediment to our sewers and eventually our waterways.

of stormwater quickly from sites, the resulting water quality and its effect on our streams and rivers, and the role of green roof systems in mitigating the effects of increased impervious surfaces.

The cumulative effects of urbanization require thinking about stormwater management at several scales simultaneously: the project scale, the watershed scale, and the global scale. This thinking becomes more complex when considering human-imposed political and property boundaries on the systems. Most watersheds cover multiple properties and more than one municipality, each one with its own rules and regulations concerning stormwater management; since water runs downhill, downstream municipalities always are at the mercy of those upstream. Cities at the mouths of rivers experience the cumulative effects of all actions upstream of them. Sediment resulting from erosion of a site upstream is deposited downstream in another locale. At the project scale, when a forest is cleared or a farm developed for human habitation, the effects are felt downstream. With less permeable surfaces, peak flow (Q from the rational method) increases—that is, more stormwater runs off per unit of time than previously. Peak flow becomes the critical variable in considering stormwater runoff and the positive impacts of green roof systems.

Water Quantity: Bigger and Bigger Pipes—10 Pounds of Water in a 1-Pound Bag

As development occurs, traditional engineering practices dictate that the runoff be collected or concentrated. In cities and densely developed areas, water will most effectively flow as quickly as possible to designated low points, where it is collected via inlets and catch basins into a network of storm sewer conduits, usually buried underground, and finally discharged into some water body. In less developed areas, water is collected in shallow surface swales, small rivulets that empty into creeks. A key consideration here is the time of concentration. Under the predevelopment conditions of a forested or agricultural soil, precipitation is absorbed and runoff is discharged only after all the pores in the soil have exchanged water for air. Under development conditions, the runoff is immediate. As soon as it hits an impervious surface, its journey downhill to its final destination begins. The problem is that when water falls on impervious surfaces, peak flow increases and the time of concentration shortens, meaning that more stormwater is concentrating faster at any given point downstream. The peak flow also has a higher velocity because water flows faster over smooth, impervious surfaces such as asphalt and concrete. The increased peak flow, shortened time of concentration, and higher velocity result in an overburdening of the existing storm sewer infrastructure as well as water with an increased potential to cause serious erosion damage.

Stormwater that falls on a building roof is generally collected by roof drains that are then discharged either directly onto the site or into a piped stormwater system. When stormwater is discharged onto the site, it is collected or concentrated in swales, the small drainage channels leading onto the remaining altered ground, which has often been made steeper for drainage purposes. Often the same is true for paved areas such as roads, parking areas, and walkways. Because there is a maximum slope for a parking area that is often less steep than the existing slope, the remaining areas are graded more steeply. Stormwater is collected in swales that flow over the regraded steeper slopes, resulting in runoff of a higher velocity.

To mitigate these effects, most municipalities require new developments to hold water on the site in order to reduce its flow to predevelopment rates. To accomplish this, water is collected in detention basins, large collection areas that hold water like a reservoir behind a dam. Water is then released into swales and drainage channels at the same rate that occurred naturally before development. Through this system, the peak flow is reduced and the time of concentration is increased and some, but by no means all, of the most deleterious impacts of stormwater runoff are mitigated. The plants and soil of a green roof system turn an impervious surface, the roof, into a pervious one that detains water, thus reducing peak flow and extending the time of concentration to delay runoff.

As a watershed becomes increasingly urbanized, ecosystem services are disrupted and destroyed, the water regime or local hydrological cycle is inextricably changed, and a vicious cycle ensues. Even relatively low levels of impervious cover in a watershed (as low as 8 percent of the total land area) pose great challenges in maintaining stream quality.[6] These streams are referred to as *impacted streams*, where greater peak runoff rates impact the shape of the stream channel, water quality, water temperature, and the health of the aquatic wildlife depending on it. Even with detention basins, streams receive increased volumes of water at high flow rates from many different areas. Stream channel erosion increases throughout the watershed, and its stream courses become less able to conduct the flow that they were able to handle before development. Greater peak flows increase the erosive power of the runoff, resulting in the deep gullies and eroded banks that are seen along all streams in urban areas. This, in turn, exposes tree roots, further decreasing channel stability. Consequently, sedimentation occurs downstream, resulting in further changes and loss of habitat. Loss of trees and consequent fragmentation, the breaking up of parcels or habitats into smaller, often isolated, units of the riparian tree canopy result in inadequate shade to maintain a stable water temperature, which, in turn, degrades aquatic insect and fish habitat. Streams in areas where impervious surface cover exceeds 25 percent of the total area in a watershed are referred to as *nonsupportive streams* and "essentially become a conduit for conveying stormwater flows, and can no longer support a diverse stream community."[7] In many areas, because groundwater recharge of streams is reduced, urban streams experience frequent and highly fluctuating runoff and are unable to maintain a stable base flow or dry-weather flow. The streambed may dry up completely and streams become periodic or intermittent. Fish passage during summer or dry-weather periods is no longer possible. In other areas,

FIGURE 2-6 Combined sewer outfall. Debris carried by runoff from streets and other impervious surfaces are discharged into urban streams.

because of less infiltration, there is a decrease in groundwater, exacerbating drought conditions for plants and greatly increasing fire risk in some fire-prone areas. Aquifers are not recharged, putting drinking water supplies at risk in areas that depend on wells for their local water supply. In those areas where water does reside, soils become saturated closer to the surface, decreasing the soil's bearing capacity and potentially resulting in earth slides. In these same areas, saturated soils force air out of the soil, inhibiting gas exchange in the root zone and leading to soils that are toxic to plant growth. Add to this runoff containing petrochemicals from fertilizers in agricultural areas and vehicles in urban areas as well as salt and sand from snow removal, and we have one big vicious cycle.

When we examine this vicious cycle from not just a local perspective but a global one, we begin to understand the scale of damage that current development practices inflict on the global environment.

In 1972 the United States Congress passed the Clean Water Act with the goal of striving for a zero discharge of pollution to protect U.S. waterways and drinking water sources and to control water pollution. The National Pollutant Discharge Elimination System (NPDES), a federal monitoring program that provides the means for monitoring compliance with the Clean Water Act, was established. In an effort to limit and control pollution from identifiable contributors, an NPDES permitting system was established for industrial users, manufacturers, and agricultural feedlots with direct discharge, often through a single pipe outlet (so-called point-source pollution).

In recognizing nutrient washout from agricultural fields and the impacts of impervious surfaces on streams and waterways, collectively referred to as nonpoint sources, the Clean Water Act was amended in 1987 with Section 319, the Nonpoint Source Control Program. It was called nonpoint because pollution did not originate from an identifiable contributor. Rather, it was the cumulative pollution load from many sources that posed an increased threat to human health and the environment. Section 319 contains three mandates for communities:

- Identify nonpoint sources of pollution
- Develop a management program and action plan to deal with it
- Provide funding for projects and measures that will reduce urban runoff

Somewhat ironically, the combination of all urban nonpoint-source pollutions originating within city limits from roofs, streets, and pavements discharged through storm sewer systems into urban streams is considered a point source. Cities therefore fall under the point-source regulation, which requires a National Pollution Discharge Elimination permit. Nutrient loads stemming from urban runoff cause most cities to violate their NPDES permits and the Clean Water Act. Cities, under court order, are obligated to create long-term plans to reduce and eliminate permit violations under increasingly strict regulations. The United States Environmental Protection Agency (EPA) is in the process of publishing regional nutrient total maximum daily load (TMDL) criteria, which specify discharge limits for every community across the United States. The net effect of the TMDL process is that discharge standards will be even more stringent than before. This means that, by federal mandate, surface water will require a greater amount of treatment for quality, quantity, and temperature before it can be released to rivers and streams.

The Special Problems of Cities and Decentralized Stormwater Management Practices

Urban sewer infrastructure was developed to handle runoff from large areas of impervious cover. It was designed, however, with limits to the size of the drainage area it could accommodate and consequently to the amount of runoff it could handle. In many cases, those limits are being exceeded. Also, highly developed areas and cities pose special problems. In newer cities the stormwater and sanitary sewers are separated. Stormwater sewers discharge directly into rivers and streams, while sanitary sewers are routed to a sewage treatment plant where the effluent is cleansed before being released into watercourses. In older cities, especially those in which the infrastructure was built in the nineteenth century, the storm and sanitary sewers are combined into one system that normally discharges treated effluent through a sewage treatment plant. During heavy rains the system quickly becomes overloaded and the capacity of the system is exceeded, resulting in combined sewer overflows (CSOs). To prevent flooding and sewer backup, the mixture of sewage and stormwater runoff is diverted to discharge points along surface water and receiving streams. The discharge of untreated sewage and stormwater can pose a hazard to water quality and human health. There are more than 700 CSOs that empty into New York Harbor; there are 450 in New York City alone, which discharge more than 40 billion gallons of untreated waste (20 percent of which is raw sewage) into the city's waterways about half of the time it rains.[8]

FIGURE 2-7 Living green roofs can be effective on a residential scale and provide visual continuity to the neighborhood setting. (Photo: Kai-Henrik Barth)

Best management practices (BMPs) for urban stormwater management have changed radically in the last decade, primarily addressing the most frequently occuring rain events of 1 inch or less. Whereas traditional stormwater management moved water offsite into underground infrastructure as quickly as possible, more recent BMPs use a decentralized or distributed system where rainwater is kept on site, reused, and recycled wherever possible. The goal of the decentralized system is to reduce peak flow rates and increase infiltration, thereby decreasing the total volume of stormwater to be conveyed so that existing sewer capacities need not be upgraded, saving both capital and operating costs. To accomplish this goal, many strategies are being employed. Some parking lots and recreation facilities are constructed so that large cisterns or infiltration basins are built beneath the surface not only to contain water falling on their surfaces but in some cases to take water from the street to provide for both detention and infiltration. Rain barrels and rain gardens are also encouraged, to prevent water from entering the infrastructure on a residential scale.

Decentralized stormwater management practices provide tremendous potential for the incorporation of green roof systems as BMPs because green roof systems address the first inch of rainfall—the most frequently occuring rain event. While conventional impervious roofs generate instant runoff, green roof systems intercept and detain stormwater, helping to reduce peak flows and lengthen the time of concentration, thereby decreasing the volume of stormwater conveyed immediately after rainfall. In the Washington, D.C., and Maryland area, decentralized systems that include green roof systems have been shown to effectively capture, treat, and reduce an average of 85 to 91 percent of the annual rainfall by addressing 1-inch rainfall events.[9] Municipalities have started to adopt this approach, referred to as the "90 percent rule."

During rainfalls of more than 1 inch, living green roofs capture and treat the first inch. In such larger rain events, however, the treatment is not as effective as it is with rainfalls

FIGURE 2-8 Retrofit living green roof. Designed for stormwater retention, amenity, and education, this living green roof can be seen from 6 floors and 4 glass-enclosed elevators. The Maryland Department for the Environment is a main tenant.

that have a total intensity of 1 inch or less. Stormwater treatment efficiency is a function of the *residence time*, or the time water is in contact with microbes, fungi, and bacteria attached to roots while percolating through the soil medium. During larger storms water moves faster through the soil medium and reduces residence time as well as microbial treatment activities, which, in turn, reduces the treatment efficiency.

The green roof system's water storage capacity or retention time is a function of the soil medium, depth, and porosity; existing soil moisture content; and roof slope. During rainstorms, water replaces air in the void spaces of the soil medium and is thus retained and detained.

A flat living green roof provides maximum water storage capacity when its soil medium is dry. Dry soil medium conditions are more likely to occur in summer, but runoff studies have found that water storage capacity is near 100 percent at any time of the year if a storm is preceded by at least five dry days. In contrast, retention capacity is expectedly lower when the soil medium is partially moist or wet, corresponding to seasonal conditions. The wet season coincides with spring and fall for many North American areas except the Pacific Coast, where the rainy season is from November through early April.

On average, a 2.5-inch-deep living green roof with a sedum and grass layer constructed on a flat surface retains about 67 percent of water on an average annual basis. A 4-inch-deep living green roof covered with grasses and herbaceous vegetation retains about 71 percent.[10] Putting this rainwater retention capacity in perspective with rainfall intensities and total rain amounts is most compelling. A major 2-inch rainstorm dumps approximately 1.25 gallons of water per square foot. A 2.5-inch-deep living green roof with an approximate 30 to 35 percent porosity retains about 0.5 gallons of rainwater per square foot, or 40 percent of the total rain amount. Most storms throughout the year generate less than 2 inches of rainfall, which means that green roof systems can absorb and retain an average of 75 percent of the annual rain and reduce stormwater runoff to sewer systems cost effectively.

Landscapes over structure have a deeper soil layer and likely provide a greater water retention capacity than thin-profile living green roofs. The overall design determines the

FIGURE 2-9 This multicolored living green roof is on a pitched roof of a chicken coop of this environmentally responsible poultry farm. (Photo: re-natur, 24601 Ruhwinkel, Germany)

final retention capacity, depending on the combination of planted versus paved areas and whether rainwater is utilized to directly drain water into the soil layer for uptake and transpiration by more mature plants. Although the deeper soil profile provides greater storage volume for stormwater retention, regular irrigation keeps soils moist and potentially reduces the overall stormwater retention capacity.

The roof slope is a variable that influences the green roof system's water retention capacity and storage volume. Flat roofs, or more specifically low-sloped roofs (slope of 1 percent or less), have the greatest retention capacity but must include a drainage layer to allow excess water to drain toward the roof drains. An increasing roof slope forces the water out of the soil medium's void spaces by gravity. Water drains away more quickly than on flat roofs and hence reduces the retention capacity of the roof.

The pervious nature of the living green roof soil and vegetation cover with a water retention capacity comparable to meadows is the single most persuasive argument for incorporating green roof systems as important elements into civic infrastructure for stormwater management, especially in densely populated urban areas. The living green roof simulates the water retention capacity of an area prior to development, helping to break the vicious cycle of urban stormwater management previously described.

Water Quality

Water quality is also of importance when discussing runoff. The health of watersheds and aquatic ecosystems, not to mention human ecosystems, is at great risk from the increase in stormwater volumes and associated pollution loads. Excess fertilizers from agricultural

FIGURE 2-10 Combined sewer systems discharge untreated sewage into urban waterways.

fields and lawns, primarily nitrogen and phosphorus in the form of phosphates, as well as urban runoff are the major causes of eutrophication, nutrient overenrichment that degrades water quality. Algae blooms consume and deplete dissolved oxygen in the water that fish need to breathe, leading to fish kills and oxygen-starved waters that cannot support a diverse and healthy fish population.

The concentrated pollutants in urban stormwater runoff come from fossil fuel combustion, a by-product of transportation, energy generation, and industrial and manufacturing processes. These emit pollutants, primarily mostly nitrogen oxides, sulfur dioxides, and particulate matter, into the air. Airborne pollutants settle on impervious surfaces, are mobilized by urban stormwater runoff, and washed into nearby streams and rivers with every rain.

Because the origin of nonpoint-source pollution is difficult to identify, it is also difficult to control and monitor. It contributes pollution loads with varying concentrations of different pollutants. In response, municipalities and stormwater permitting authorities traditionally require stormwater quality control for the first half inch of rain only. Frequently referred to as the first flush, the first half inch of rain is of greatest concern to municipalities because it creates instant peak flows, which carry the most concentrated pollutants.

TABLE 2-4: Surface Albedo Value

Material	*Surface Albedo Value*
Highly reflective roof	0.60–0.70
White paint	0.50–0.90
Grass	0.25–0.30
Brick/stone	0.20–0.40
Colored paint	0.15–0.35
Trees	0.15–0.18
Red/brown tile	0.10–0.35
Concrete	0.10–0.35
Corrugated roof	0.10–0.16
Tar and gravel	0.08–0.18
Asphalt	0.05–0.20

Air Quality

Urbanization and its subsequent increase in impervious surface cover affect air quality in many significant and intrinsically connected ways. Increased ambient air temperatures in urban areas lead to a subsequent increase in energy consumption to offset the increase; this stimulates greater energy generation, which in turn leads to an increase in air emissions and more air pollution. Air emissions together with elevated surface temperatures react to form smog and compromise air quality. Sprawling development further adversely impacts air quality because of

National Research Council of Canada

A field study by the National Research Council of Canada over a 2-year period has shown that living green roofs are indeed very effective in reducing heat transfer through the roof, reducing the average daily energy demand by 75 percent in the test facility (400-square-foot roof).[11]

The study found that the daily maximum membrane temperature underneath the green roof was significantly lower than the daily maximum membrane temperature of the bituminous reference roof with light gray gravel. During the 660-day monitoring period the temperature of the green roof exceeded 86 degrees Fahrenheit (30 degrees Celsius) only on 18 days, or 3 percent of the time. In contrast, the ambient air temperature exceeded 86 degrees Fahrenheit (30 degrees Celsius) on 63 days, or 10 percent of the time. The temperature of the reference roof was significantly higher throughout the monitoring period. Temperatures climbed above 122 degrees Fahrenheit (50 degrees Celsius) on more than 219 days, or 33 percent of the time.[12]

TABLE 2-5: Roof Temperature

Temperature Greater Than:	*Reference Roof*		*Green Roof*		*Ambient*	
	No. of Days	% of Days	No. of Days	% of Days	No. of Days	% of Days
86°F (30°C)	342	52	18	3	63	10
104°F (40°C)	291	44	0	0	0	0
122°F (50°C)	219	33	0	0	0	0
140°F (60°C)	89	13	0	0	0	0
158°F (70°C)	2	0.3	0	0	0	0

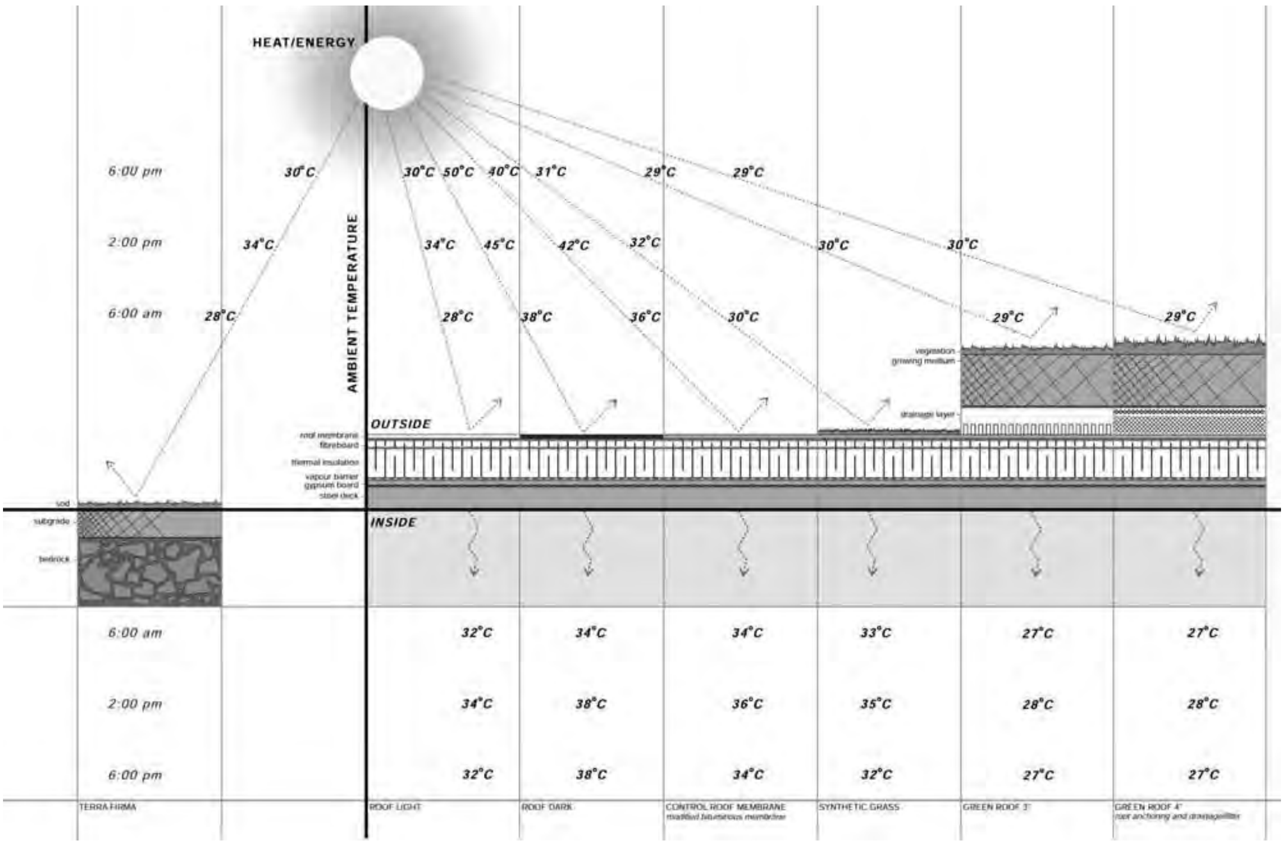

FIGURE 2-11 Ambient air temperature on a black tar surface roof and on Chicago's City Hall, covered with multiple green roof systems.

Many publications and programs resulted from concern over urban heat island effect, including EPA's Urban Heat Island Pilot Program (UHIPP), the Heat Island Reduction Initiative (HIRI), the EPA study *Cooling Our Communities: A Guidebook on Tree Planting and Light Colored Surfacing,* and its second edition.[13] These studies document the impacts of urban heat islands and associated poor air quality. As a result, the cities of Chicago, Sacramento, Salt Lake City, Baton Rouge, and Los Angeles, under UHIPP, have undertaken a number of initiatives that aim at the reduction of urban air temperatures through the use of reflective materials to prevent heat gain and absorption. The updated study Reducing Urban Heat Islands: Compendium of Strategies (2008) includes a chapter on green roofs as a viable mitigation strategy.

development and imperviousness further away from metropolitan areas and also because of a corresponding increase in vehicle miles traveled to connect to cities, triggering emissions of more nitrogen oxide and carbon monoxide.

The *urban heat island effect* refers to the increase in ambient air and surface temperatures in urban areas. A steady trend over the past 50 years shows that air temperatures in urban areas have risen by 2 degrees Fahrenheit (1.1 degrees Celsius) per decade and can be as much as 7 to 11 degrees Fahrenheit (4 to 6 degrees Celsius) higher compared to surrounding undeveloped and rural areas. Dark-colored impervious surfaces such as roofs and roads absorb solar radiation, store it, and radiate the heat back into the atmosphere (see Table 2.4). This not only affects the local microclimate but also has significant consequences on a regional and global basis. Air conditioners cool interior air but exhaust hot air to the exterior, causing local temperatures to rise. Ironically, this in turn makes cooling loads greater, increasing energy use.

TABLE 2–6: Roof Heat Flow

	Reference Roof	*Green Roof*	*Reduction*
Heat gain	5900 BTU/ft^2		
	(19.3 kWh/m^2)	270 BTU/ft^2	
	(0.9 kWh/m^2)		95%
Heat loss	13500 BTU/ft^2		
	(44.1 kWh/m^2)	10100 BTU/ft^2	
	(32.8 kWh/m^2)		26%
Total heat flow	19400 BTU/ft^2		
	(63.4 kWh/m^2)	271 BTU/ft^2	
	(33.7kWh/m^2)		47%

Communities recognize that this pattern of change in urban microclimates poses environmental and economic challenges. Similar to stormwater management and control, many cities have enacted local policies and regulations to reduce air pollution, including temperature and air emissions, to control respiratory illnesses and to improve community economic health.

Summary

We can no longer ignore the fact that our world is interconnected. Natural systems have no property lines, and changes to one natural system will have a cumulative impact on the delicate global balance. Although an individual action of implementing a green roof system may seem minuscule, the cumulative effects of many individual acts can have a remarkable positive impact upon our cities.

> *There are only a few gems for every hundred new technologies, and green roofs seem to be the most promising method for stormwater control. They reduce peak runoff rates and the temperature of water compared to runoff*

FIGURE 2-12 Chicago's City Hall green roof in contrast to adjacent black tar roof on other half of building.

FIGURE 2-13 The importance of the effects of water storage capacity can be taught at an early age. Extrapolated from this playful experiment is an understanding of managing our valuable stormwater effectively rather than dumping it into sewers. (Photo: re-natur, 24601 Ruhwinkel, Germany)

from conventional roofs. This is very important considering the adverse impacts of thermal shock on aquatic life. But we are seeing the greatest benefits of green roofs in the potential for controlling nutrients. The EPA is just beginning to roll out regional nutrient criteria, and states will have to adopt their own water quality standards for nutrients over the next three years. Interest in green roofs is only going to grow.

—John Cox, Department of Public Works, Stormwater Services, Durham, North Carolina

Endnotes

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Chapter 3

Envisioning Green Roof Systems: From City Scale to Project Scale

The city, as one finds it in history, is the point of maximum concentration for the power and culture of a community. It is the place where the diffused rays of many separate beams of life fall into focus, with gains in both social effectiveness and significance. The city is the form and symbol of an integrated social relationship: it is the seat of the temple, the market, the hall of justice, the academy of learning. Here in the city the goods of a civilization are multiplied and manifold; here is where human experience is transformed into viable signs, symbols, patterns of conduct, systems of order. Here is where the issues of civilization are focused; here, too, ritual passes on occasion into the active drama of a fully differentiated and self-conscious society.

—Louis Mumford, *The Culture of Cities,* 1938

Successful cities have long, interesting, and changing lives. The responsibility for future success rests upon a city's current inhabitants. Unplanned urban development has left many places vulnerable to a wide array of problematic consequences even beyond urban boundaries. Now more than ever, societies across the globe are taking notice of its warming and the ecological circumstances that contribute to and result from it. Fortunately, many people have become interested in ameliorating the negative impacts of urban development in favor of making cities great places to live while preserving our natural resources of land, water, and air.

Green roof systems can be a part of the solution. Until recently, the inclusion of green roofs in large projects was viewed as providing an amenity only, generally a rooftop garden. But with increased energy costs, stricter stormwater management regulations, and a renewed emphasis on linked open space systems, their inclusion is increasingly perceived as a viable strategy for reducing energy costs and meeting more stringent governmental regulations. They are also being designed in ways that make their environmental and fiscal value highly visible in the public arena.

Beyond everyday personal efforts of conservation of resources, positive ideas for the utilization of green roof systems—singly or as part of impactful, planned incremental applications—are being generated on many fronts.

- Citizens and policy makers at all governing levels are concerned with the effects of climate change and other damage to our environment.

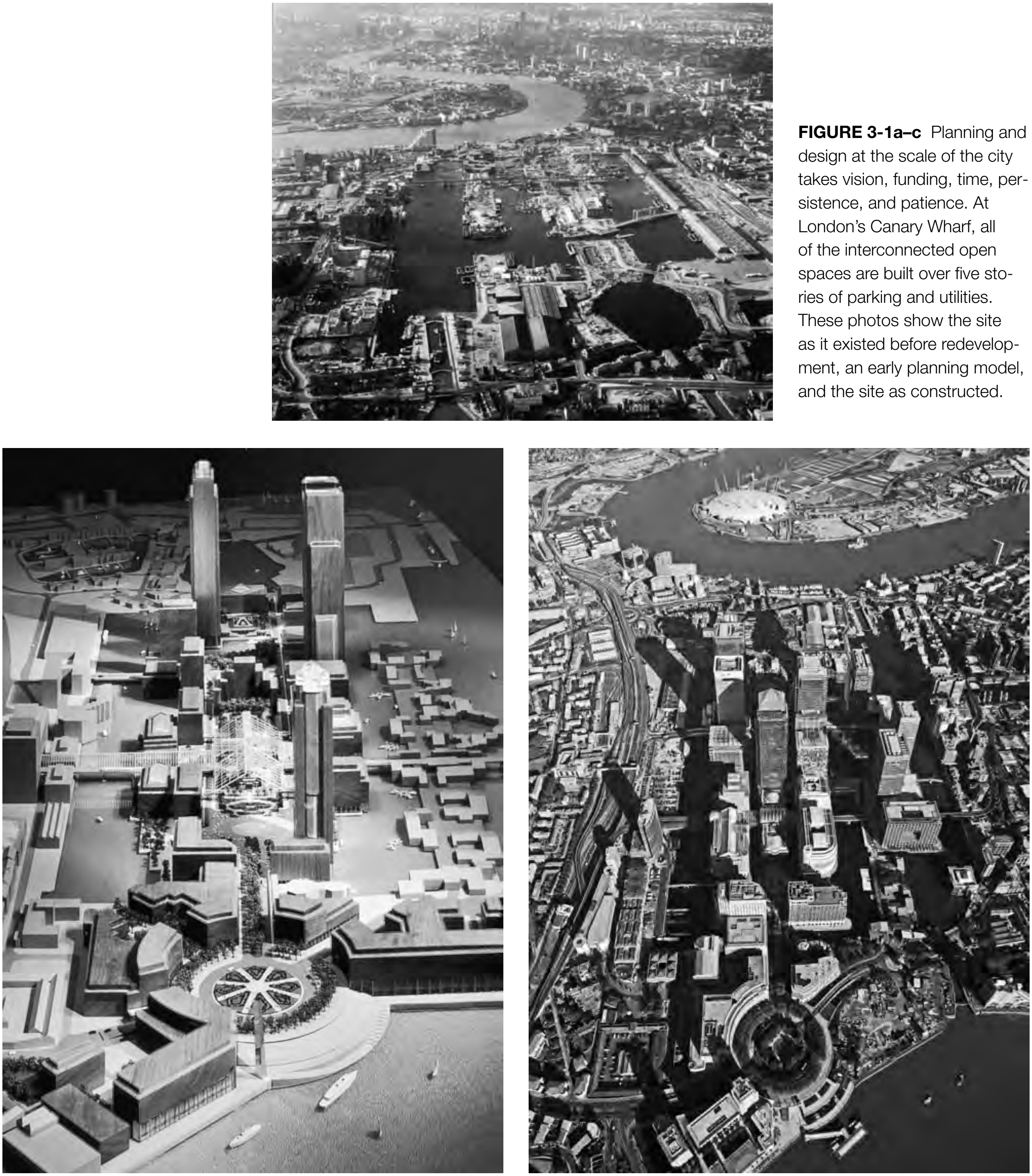


FIGURE 3-1a–c Planning and design at the scale of the city takes vision, funding, time, persistence, and patience. At London's Canary Wharf, all of the interconnected open spaces are built over five stories of parking and utilities. These photos show the site as it existed before redevelopment, an early planning model, and the site as constructed.

FIGURE 3-2a Millennium Park in Chicago is a superb example of municipal leadership in envisioning, funding, and building extensive public open spaces over parking facilities and other occupied spaces. Previously the Illinois Central rail yards bifurcated a significant portion of the heart of the city.

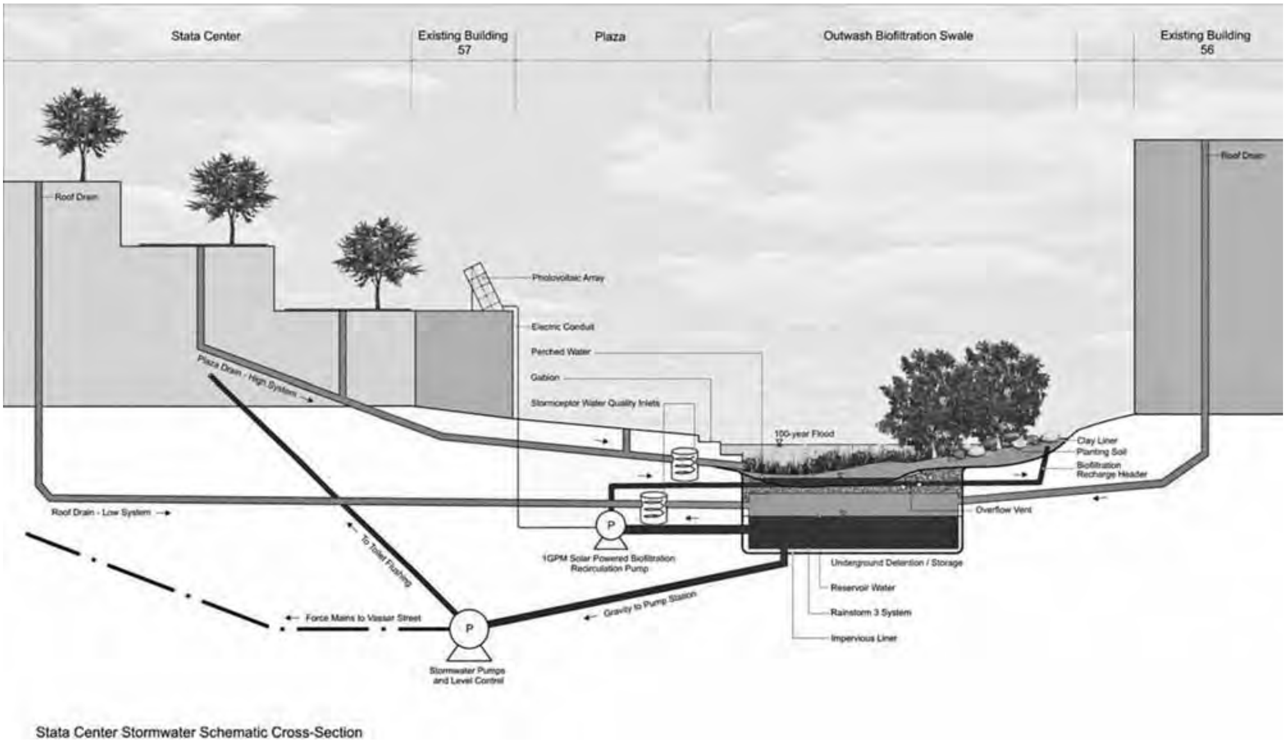


FIGURE 3-2b The Ray and Marie Stata Center utilized this innovative stormwater management system that functions as both garden and machine. The basin, plants, soils, and aggregates filter stormwater, it is stored in the below-grade cistern, and then it is recycled by solar-powered pumps for grey water uses.

- Municipal officials are looking for ways to encourage healthy, active cities and reduce the costs of civic infrastructure and energy consumption.
- Owners are looking for ways to reduce energy and other operating costs while providing the necessary facilities and programs.
- Planners and designers wish to implement best practices and find new ways to create livable and sustainable environments while ameliorating the undesirable aspects of building and living.

Even though the concept of green roof systems is ancient, in the last decade new technologies have become available that make their design and construction more feasible in a modern context.

Good planning, design, and implementation of green roof systems on a citywide scale require collaborative efforts and mutual respect among the team members. Each member has his or her role to play, related to specific expertise, interests, points of view, responsibilities, and goals. All should be willing to take risks and trust that these will yield great rewards.

This chapter addresses the importance of collaboration and the role of municipalities, citizens, owners, financial institutions, and the various design disciplines in recognizing and realizing opportunities. An overview of the initial large-scale planning phases as well as subsequent design phases of a project (programming, concept design, and schematic design) is also included in order to provide a basic understanding of project structure and requirements for early decisions and coordination to complete a project successfully.

Seattle Urban Design Guidelines

Seattle is actively promoting the use of green roof systems through several different programs. For example, green roof systems have been accepted and endorsed by all city agencies as a strategy to obtain the impervious surface reduction credit in the LEED certification system.

One of the more innovative programs is Seattle Green Factor, which requires 30 percent vegetated cover for new development in Seattle's neighborhood and commercial districts. The program strives to ameliorate some of the negative environmental impacts of increased development through the creation of a high-quality urban landscape and the environmental benefits that accrue from it. Most importantly, it recognizes that the urban landscape is not just an aesthetic amenity but is integral to the functioning of the city. The program encourages the use of multilayered vegetation in creating a more comfortable, livable, and environmentally friendly city. The benefits that accrue include:

- Reduced runoff through use of permeable paving and green roof systems
- Increased evapotranspiration due to increase in vegetated surface area
- Increased tree canopy
- Absorption of carbon and release of oxygen
- Reduced urban dust and cleaner air
- Reduced noise pollution

- Increased habitat for birds, bees, and other beneficial insects
- Increased property values
- Cooler, better-insulated buildings with longer roof membrane life
- Increased life of building cladding through use of green walls
- Increased desire to live and work in the city

The program contains a menu of different strategies, each assigned a factor score that developers use in meeting the landscape requirements. The highest factor scores go to living green roofs and vertical green walls, open water features, and low plantings in deep soils. Extra points are gained by ensuring that the landscape is visible to the public and by the use of drought-resistant plants. Seattle is exploring programs from other cities such as Portland and Chicago that encourage the use of green roof systems.

Saarbrücken: Subsidies for Stormwater Runoff Reduction

Programs in Europe, where sparse open space requires the careful and multifaceted use of land, also provide great examples of how local governments can subsidize and advocate low-impact development measures for reusing rainwater, eliminating and mitigating impervious surfaces, and enhancing natural drainage. The European programs are geared primarily toward individual homeowners and especially assist in an often self-motivated effort to conserve water and to practice environmental stewardship at home. The city of Saarbrücken, Germany, for instance, provides homeowners grants ranging from $2,700 to $5,400. The grant amount depends on the proposed project's total stormwater runoff reduction (thus reducing the municipality's infrastructure cost) and differentiates between various technologies. For instance, for collecting rainwater in a cistern or barrel for reuse either by toilet flushing or watering plants, the grant pays about $0.75 per square foot of roof area from which water is collected. "De-sealing" a driveway—removing impervious surface cover and replacing it with pervious materials to enhance natural infiltration—is valued higher and pays $1.50 per square foot. In recognition of the wide-ranging benefits of living green roofs, grants for their installation—new or retrofit—pay $3 per square foot of vegetated roof area.

Collaborators and Their Role: Initiating and Realizing the Vision

Municipal Leaders, Legislators, Regulators

The role of municipal leaders, legislators, and regulators is to provide civil services and clear legislation to encourage appropriate development at all scales while protecting natural and economic resources, upholding codes that protect health and safety, and enforcing community standards.

Utility Fee Structures

Some cities have started to review their utility fee structures in an effort to charge for actual usage of water and wastewater systems. Currently, most American cities impose a flat rate that is evenly distributed between all property owners in a jurisdiction to cover utility infrastructure, infrastructure improvements, and maintenance expenses. Numerous European cities have implemented a more targeted fee structure that ultimately collects stormwater fees based on the actual impervious surface area of each property. Cambridge, Massachusetts, is one American city that has already implemented this for institutions. For many cities this may require a fundamental reevaluation of the tax laws to correct competing incentives that may have contributed to the misappropriation of our natural resources. Municipal services, including the cost of sewer infrastructure, are financed through tax dollars, and the calculation can be simple: decentralized stormwater management and rainwater collection ultimately benefit the community and its budget. If rainwater is kept on site, reused, and recycled, there is less runoff: peak flow rates drop and the total volume of stormwater to be conveyed is reduced. Existing sewer capacities may not need upgrades and expansion, saving additional construction and maintenance costs.

Revised utility fee structures for rain or stormwater runoff might be considered more equitable when fees are collected in proportion to the amount of runoff and financial impact upon the sewer system. While everyone relies on a functioning sewer system with appropriate capacities, those properties generating the most runoff should pay proportionally higher rates for accommodating the greater amount of runoff. A fair rain or stormwater runoff fee or tax could quickly turn the economics in favor of green roof systems. To a commercial developer, green roof systems could swiftly become an attractive alternative on economic grounds alone. Even for those who are not environmentally motivated, the initial cost of living green roofs could be much less than the cost of a cumulative annual tax.

Expedited Review and Approval

Perhaps one of the simplest—and, to an owner, most meaningful—gestures of collaboration a municipal, state, or federal jurisdiction can offer are indirect incentives via expedited review processes for those who advocate and are willing to incorporate green roof systems or other measures of low-impact development. For owners, shorter review time means known cash flow and predictable project costs.

Owners

Currently, advocating any green initiative can be challenging when there is no incentive. When the argument is based solely on altruism, convincing cost-conscious clients to increase their budgets for the inclusion of green roof systems can be a Herculean task and does not create a vibrant market. In the United States especially, fiscal conservatism, public image, fear of litigation, and, often, a reticence to embrace relatively unproven technologies frequently have greater weight in the decision-making process than all of the combined economic, social, and environmental benefits that green roof systems can provide.

The two most commonly cited barriers to the implementation of living green roofs and landscapes over structures on a large scale are cost and aggravation. Winning over conventional and financially conservative developers and their investors to the idea of increasing their green roof portfolios remains a great challenge. Even as many product manufacturers and their investors are poised to profit from their share in the next big "building green" market, only very recently have green roof systems started to be seen as offering a good return on investment. In the long run, the developer can expect economic gain due to enhanced building efficiency; the short-term yields are increased energy efficiency, lower operating costs, a better environment, goodwill, and good press.

The construction costs for including green roof systems either in new construction or in retrofit situations can, at first evaluation, seem indefensibly high. For example, the construction cost of a conventional flat roof with a waterproofing membrane, protection board, and ballast can range from $7 to $15 a square foot. The construction cost of a living green roof or landscape over structure can range anywhere from $15 to $70 per square foot. The premium for the living green roof is accounted for by factors such as risk coverage based on fear of the unknown, lack of construction knowledge, and perceived higher maintenance costs.

Take, for example, the construction costs of parking. Surface parking lots are relatively low-investment, high-return projects. Constructing a surface parking lot can cost as little as $250 per space, depending on the subsurface conditions and design profile. There are hundreds of thousands of acres of surface lots situated throughout cities and suburbs. Unfortunately, the societal and environmental short-term and long-term costs of these types of facilities are great: impermeable asphalt surfaces that can be as hot as 180 degrees, loss of a recharged water table because the stormwater runs off into local watercourses, higher municipal infrastructure costs to facilitate the runoff, loss of native soils and open space, and decreased water quality (often in larger rivers that are water sources for cities downstream).

The cost of an above-grade parking space in a garage structure can be 100 times more ($25,000), depending on the number of spaces created by the size of the garage footprint and number of levels. When long-term environmental and societal costs are taken into consideration, however, traditional garages have many of the same issues as surface parking lots. By contrast, construction costs per space for a "greener" garage with a vibrant landscape atop is only twice the cost ($50,000) of an above-grade space—and it includes the sophisticated civil engineering systems for stormwater management and mechanical, electrical, and plumbing systems for ventilation, lighting, fire suppression, and a structural system that supports trees, fountains, paving, and the live loads of human habitation. For some owners, these more expensive structures can be justified only in areas where space is at a premium and land values are high.

Green roof systems are currently in the early-adoption phase of the market. While their use is not yet widespread, it is becoming more attractive. As decision makers recognize the added value, both perceived and real, of green roof systems, the market will respond with technology that is more cost-effective and of better quality. The resulting

FIGURE 3-3a The client group and design team review a model of the aerial hedge, trellis, and paving proposed for an entrance plaza constructed over occupied space.

FIGURE 3-3b This perspective of the Comcast Center Plaza, Philadelphia, helped the client group to understand the design concept and requirements.

greater economic value will become a driving force for the appropriate application of green roof systems. When more green roof systems are installed and effectively maintained, proving their cost-effectiveness, it will become easier to decide in favor of them.

Financial Institutions and Insurance Companies

Financial institutions and insurance companies are also important partners in the collaborative process. The primary role of financial and insurance institutions is to provide financial resources to owners within acceptable risk and return parameters. They are therefore reluctant to accept projects employing unproven technologies unless there is a compelling and cost-effective reason.

To a lender, for example, profit from income generated from an expensive underground parking space may be long in coming. To an insurer, the risk of potential leaks or unlikely structural failure may seem beyond their risk tolerance and comfort zone for insuring, even with a high premium. The true benefits of a green roof system on such structures are often not accounted for. Also not accounted for by financial and insurance institutions are elements found in contemporary green construction that actually reduce project risk, such as better construction materials, techniques that can increase structural integrity, and high-quality overstructure building materials.

Until a new system of evaluation is implemented that accounts for the true costs of development, including costs that are now borne by society in general, lenders may view green roof systems as luxury items that raise the risk of a project. However, when the costs resulting from such things as increased ambient heat from dark roof surfaces and overloading of combined sewers are accounted for, green roof systems become cost-effective investments. As municipalities implement the aforementioned fees for actual usage, systems that allot such costs proportionately, green roof systems become more attractive investments for financing entities.

By having a greater understanding of the basic ecological function and technical applications of living green roofs and landscapes over structure, investors and insurers can be better informed as they engage in the decision-making process. They can fulfill their missions and responsibilities by including these types of projects in their portfolios.

Planners, Designers, Builders

Perhaps the greatest responsibility for promoting and effecting collaboration lies with those who have access to the widest and most comprehensive view: planners, designers, and builders. Whether at the large scale of comprehensive planning and urban design or at the scale of an individual project, planners and designers need to be cognizant of the potential of green roof systems.

It is therefore incumbent upon the design team to acquire accurate technical and mechanical data from successful installations; develop a thorough understanding of the unique requirements of the project; have the professional expertise to document the design; and partner with an equally knowledgeable and experienced contractor during installation. Moreover, many times ultimate persuasion is achieved not solely through technical expertise but rather in combination with the ability to inspire a sense of stewardship in the owner, boards of directors, trustees, and investors. These groups want to understand the environmental and social relevance of green roof systems to their mission, philosophy, or curriculum as it relates to the return on the investment for which they are equally responsible.

Owners require a design team that can effectively evaluate available options for technical, environmental, social, and economic soundness; recommend the best design solutions; and provide guidance during the construction phase. There are many farsighted owners who are disappointed that their design team has failed to introduce them to new technologies or building practices that ultimately could have improved a project's overall quality and, in turn, property value. Owners expect professionals in the design and building industry to be knowledgeable about new, currently available technologies.

These clients need to know:

- Whether new technologies for the incorporation of green roof systems are feasible and appropriate for a specific project
- What the incentives are for inclusion of these systems
- How individual or collective design and construction initiatives can contribute to more efficient, less costly acquisition of permits or satisfaction of other municipal requirements
- The ways in which green roof systems simultaneously address multiple environmental issues

They also need to know the following:

- What are the true costs, and when are they incurred?
- What are the true benefits, and when are they realized?

Planning and Design Process

Green roof system projects evolve in the same way that most conventional projects do; however, in their conception, planning, and design, they obviously require a number of specialized considerations. This chapter identifies opportunities within conventional practice for incorporation of green roof systems into the planning and design phases. The discussion anticipates constraints and complications that might deter their

FIGURE 3-4 An urban design study for Brooklyn Atlantic Yards, prepared by a landscape architect, indicates both the site context and its relationship to regional transportation and open space systems.

FIGURE 3-5 Aerial photograph of existing site within its neighborhood context.

incorporation into projects that could benefit from them, and identifies the early phases of a project during which particular attention to detail must be paid in order to realize a successful project.

Comprehensive Planning and Urban Design

Comprehensive planning occurs at the citywide or even regional scale. Most municipalities are required to have a comprehensive plan that specifies zoning, use, transportation systems, and the types of buildings that are permitted, along with their associated

Combined Context + Site Plan

FIGURE 3-6 Proposed large-scale planning and development projects are studied in the context of the larger urban site.

requirements. A comprehensive plan establishes overall goals for development and specifies ways in which these goals can be met. If properly elucidated, many of these goals and ways to achieve them are specifically germane to various applications of green roof systems, such as open space use and stormwater management. More recent comprehensive plans will identify opportunities for linking green roofs' contribution in terms of open space systems and stormwater reduction to overall amelioration of the impacts of climate change.

Because the inclusion of green roof systems can often help fulfill a number of design and regulatory requirements, they should be considered in the earliest phases of planning and design. In some municipalities, the use of living green roofs and landscapes over structure is rewarded with tax benefits or the granting of greater floor area ratios.

Master Planning

Master planning follows the requirements and guidelines established in the comprehensive planning phase. Occasionally, municipalities will undertake a master plan when they have a specific interest such as the development of a town square. More commonly, the owner or developer of a parcel will convene the master planning phase. Master plans are typically undertaken for larger projects in which several parcels or a very large parcel with

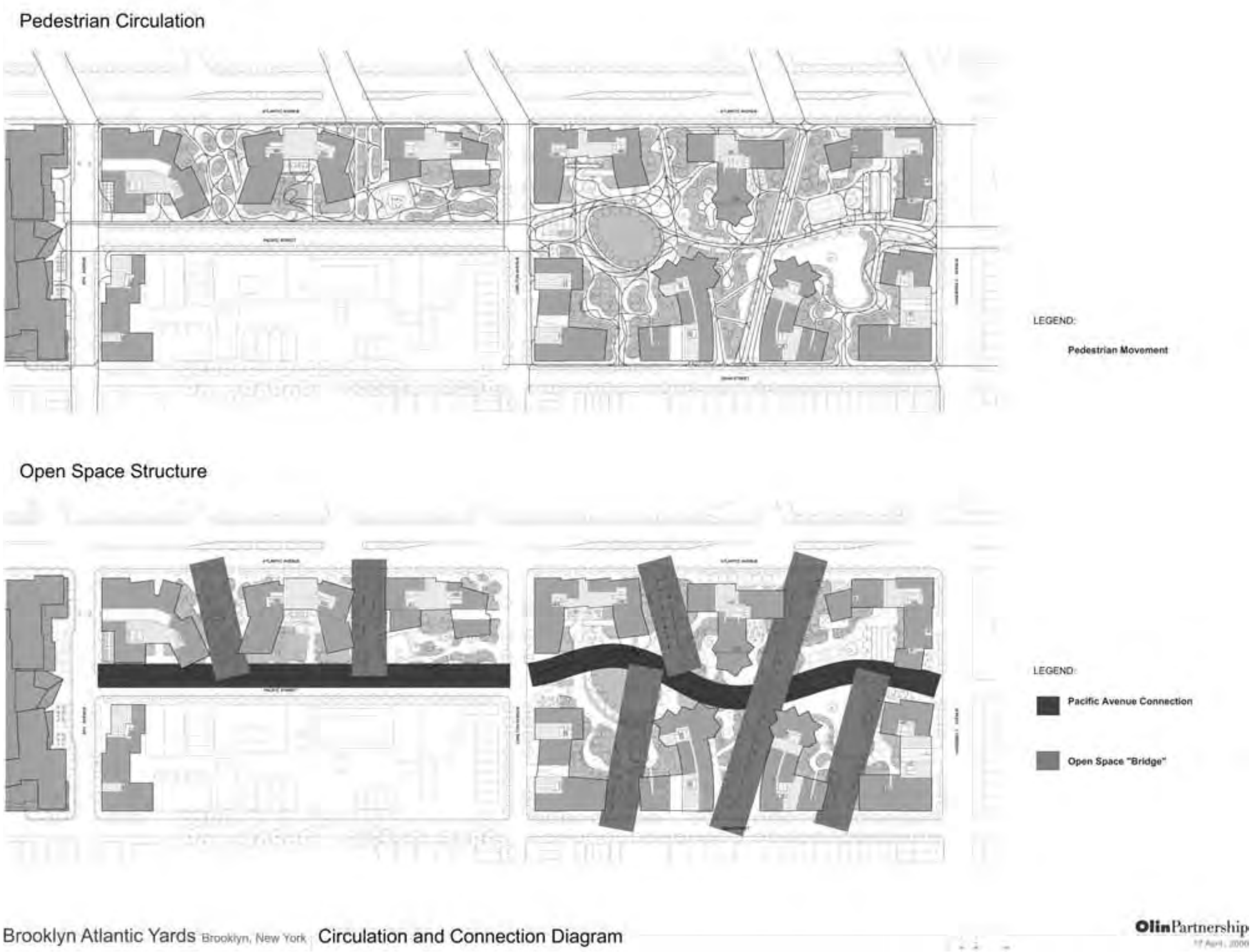


FIGURE 3-7 Circulation and connection diagrams show potential for merging the landscape and the architecture to form cohesive pedestrian and open space systems.

multiple components (buildings, roads, open spaces) is associated with the overall area of development. The project may involve an undisturbed site or one containing existing buildings or civic structures.

Master planning is undertaken for a variety of project types, including mixed-use developments, educational and corporate campuses, and institutions such as museums. The master plan determines the major organizational relationships of building massing, circulation, and open spaces, as well as overarching goals and recommendations for the best long-term development of an area. The master planning process also determines order-of-magnitude costs and establishes strategies for implementation and phasing.

The master planning process can be led by any of the design professionals, including urban designers, planners, architects, or landscape architects. Usually an entire planning and design team includes professionals from these disciplines plus a transportation planner, engineers (structural, civil, mechanical, electrical, and plumbing), construction management, and cost estimators.

The master plan identifies building locations, massing, heights, floor area ratios, circulation elements (i.e., roads), surface parking and above- and below-grade parking structures, pedestrian paths, and landscape features such as woods, meadows, lawns, streams, and ponds as well as highly visible or significant civic open spaces. With a master plan, opportunities and constraints not previously visible are discussed. For example, the roofs of underground parking structures become opportunities for linking open space systems and reducing stormwater runoff. Thoughtful planning and design can either conceal that they are indeed roofs or clearly and elegantly demonstrate the benefit of their use.

In the master planning phase, green roof systems are examined for initial feasibility and their requirements are established. It is imperative that structural requirements for green roof systems, particularly landscapes over structure, be identified.

It is in this phase that individual project elements and their preliminary cost estimates are established. The design professionals leading the master planning must have a working knowledge of the types of structural systems appropriate for constructing landscapes over structure. It is also particularly important to understand the geotechnical constraints of the site and the structural and utility implications of loading requirements on the finished surface.

Feasibility, Programming, and Pre-concept Design

Once the master plan has been established, individual projects designated in the master plan are developed and tested. An individual project usually begins with a feasibility study that tests the likelihood of success and whether the project's financial, aesthetic, environmental, construction and logistical goals determined in the master planning phase can be met. Since the economic feasibility of a project is often the limiting factor in building green roof systems, the costs and economic benefits must be evaluated.

Programming and pre-concept design are often undertaken concurrently in order to establish an overall design and construction approach and to further identify opportunities and constraints that will be encountered throughout the project. Pre-concept design often consists of analyses of both the environmental impacts of a project and the site conditions.

On larger, more complex projects, especially ones that include landscapes over structure, it is essential by this time to have a full complement of design consultants on the project team. At a minimum, the design team usually consists of an architect and landscape architect or a specialized living green roof designer as well as civil, mechanical, electrical, plumbing, and structural engineers. The design team must ensure that any special structural requirements are taken into account in the feasibility study since they may have a significant impact on cost. The owner's team includes the owner's representative, the construction manager, and usually legal counsel. On some projects a larger group is assembled, including an economic development consultant and a marketing consultant. On certain large public sector projects, an advisory board may be required by law.

The following products are generally required in the feasibility and pre-concept phases:

- Environmental impact analysis
- Other analyses or reports required by local, state, or federal entities
- Initial site analysis (wind, solar, vegetation, views, circulation)
- Geological investigation and report (soils, depth to bedrock, etc.)

Programming is a continuous process and happens at every phase as the project is refined and developed. It is considered a separate but integral part of feasibility studies and pre-concept design and normally runs concurrently with those. The primary purpose of programming is to establish exact project needs and required design elements. These in turn identify project determinants such as uses and sizes as well as the finished form of the project and the infrastructure to support its sustained success. At this stage of the planning and design process, the basic program is set.

Programmatic requirements for green roof systems can differ greatly, ranging from an ecologically beneficial living green roof to a municipality's desire to integrate a comprehensive series of linked open spaces of high public visibility and civic use. In the case of a living green roof, programming will help to determine the types and extent of materials needed to detain the anticipated volume of stormwater. Each project (or individual component in a series of linked open spaces built over structure) will have its own programmatic requirements.

Among the primary programming requirements of building green roof systems is an initial understanding of whether the landscape is accessible or inaccessible to human use.

An investigation into programmatic requirements should be guided by the following questions:

- Does the owner intend to use the space only as a visual amenity in support of stormwater management and other ecological benefits?
- Does the owner intend to create usable open space?
- Who will use the space and how will it be accessed?
- What are the climatic opportunities and constraints of building a landscape over structure?
- What are the owner's plans for maintenance, including repairs of waterproofing, paving, soils, and fountain mechanicals?
- What are the benefits and costs of the maintenance involved?
- What are the accessibility requirements for maintenance and replacement?
- In the case of civic spaces (e.g., lawns, gardens, athletic facilities, ice rinks, art, fountains, public restrooms, parking), will the city or municipal agencies be willing to assist in the initial and long-term programming of the space?

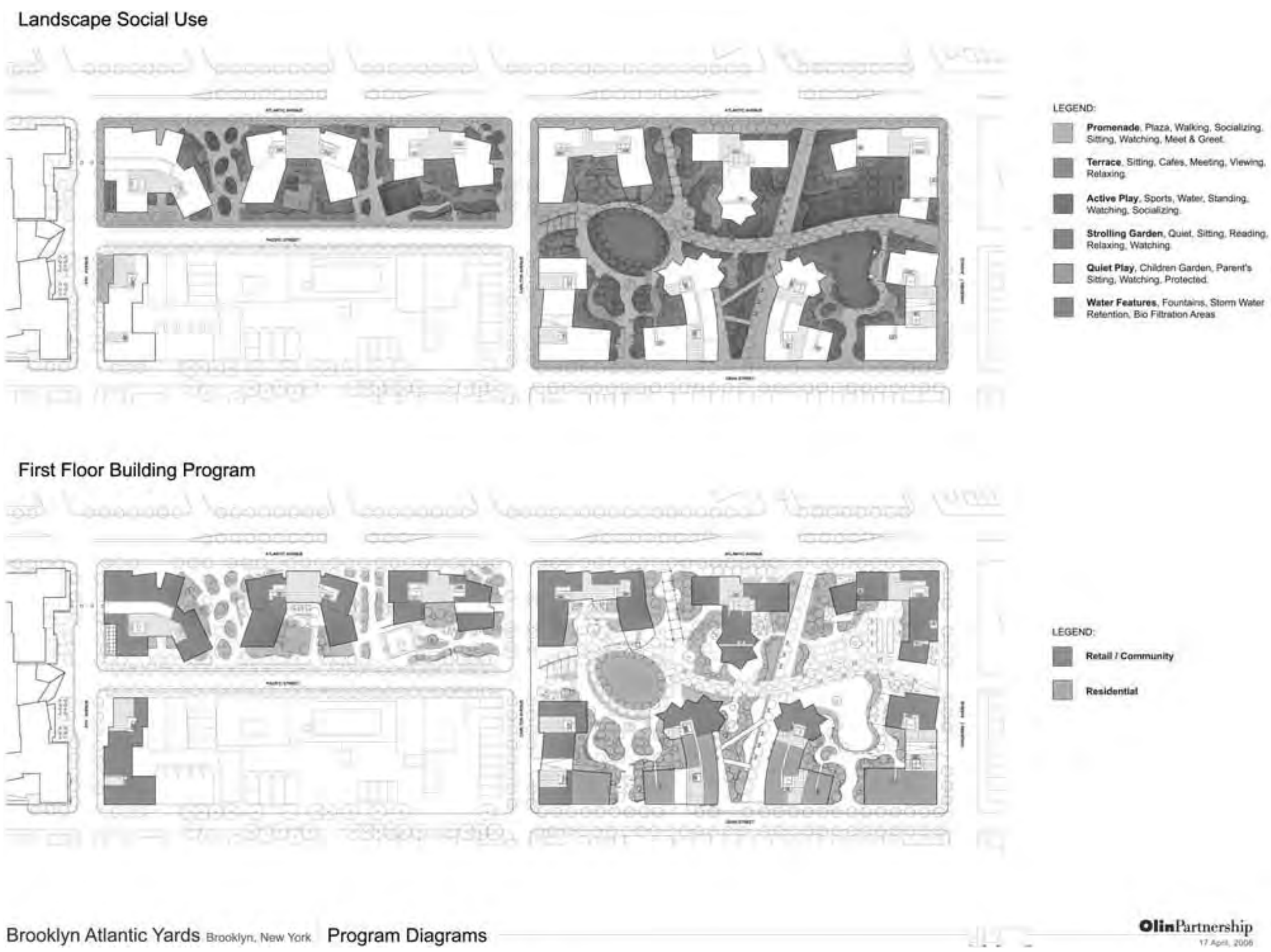


FIGURE 3-8 Building and landscape social-use diagrams showing the relationship of potential first-floor interior and exterior uses as developed from project programming requirements.

Concept Design

The primary objective of this phase is to arrive at a clearly defined, feasible concept and present it in a form that allows the owner to fully understand the scope of the project and approve it. The concept is usually conveyed in drawings as well as text. Secondary objectives include clarification of the program, exploration of alternative design solutions, and ultimate determination of the feasibility of the project.

While this varies with every project, typically work in this concept design phase includes:

- Initial application of programming requirements
- Initial indication of overall size and configuration of building and associated open space

FIGURE 3-9 Proposed illustrative site plan showing building footprints, streets, open spaces, and relationship to adjacent sites.

Products of this phase should include:

- Illustrative site plan, site sections, building plan, and building sections that show the integrated development of the following:
  - Conceptual details: site and building sections, roof sections
  - Conceptual details indicating the specific interface between the top of the slab and grade and site finishes
  - Initial consideration of materials
  - Structural analysis (initial considerations and alternative construction methods)
  - Column spacing, size, slab depths, soil weights, loading requirements, etc.
  - Mechanical, electrical, and plumbing analysis: venting requirements, power requirements, etc.

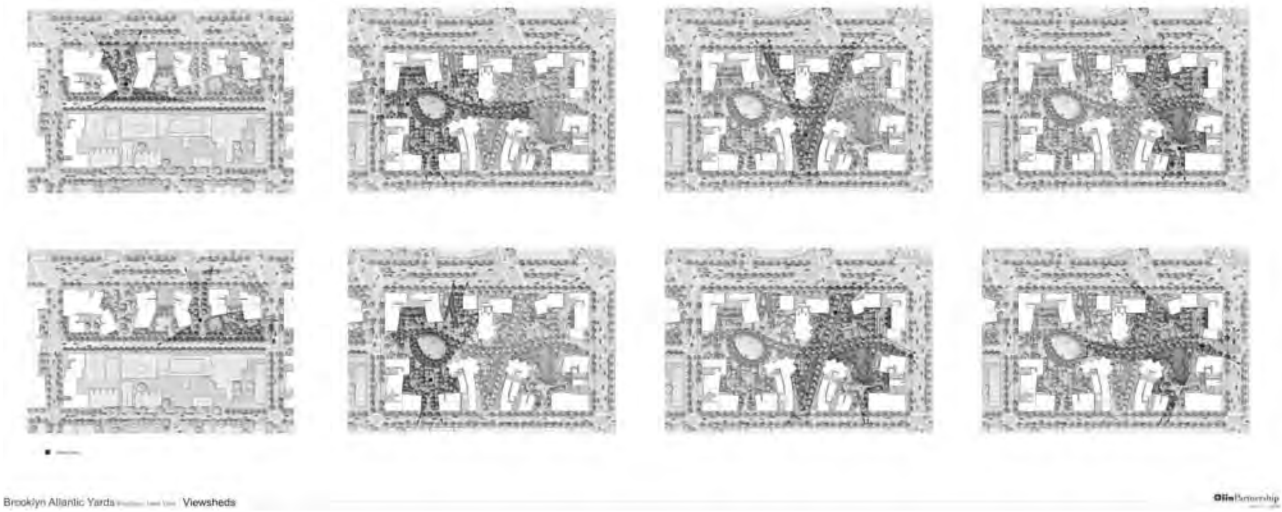
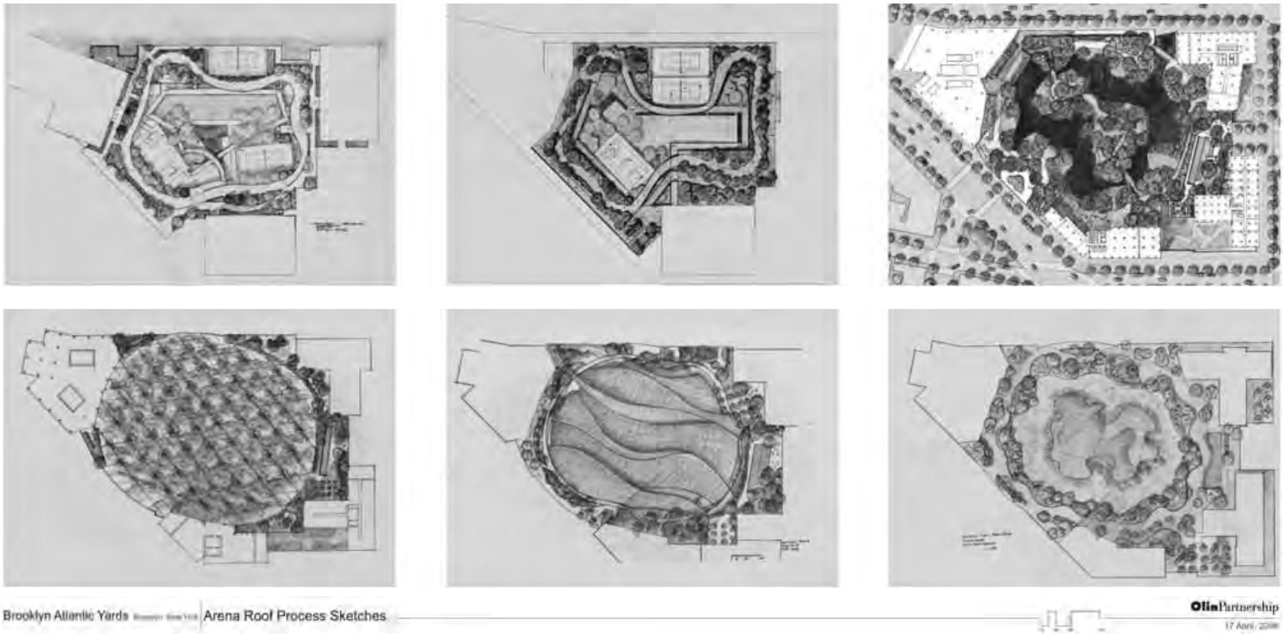


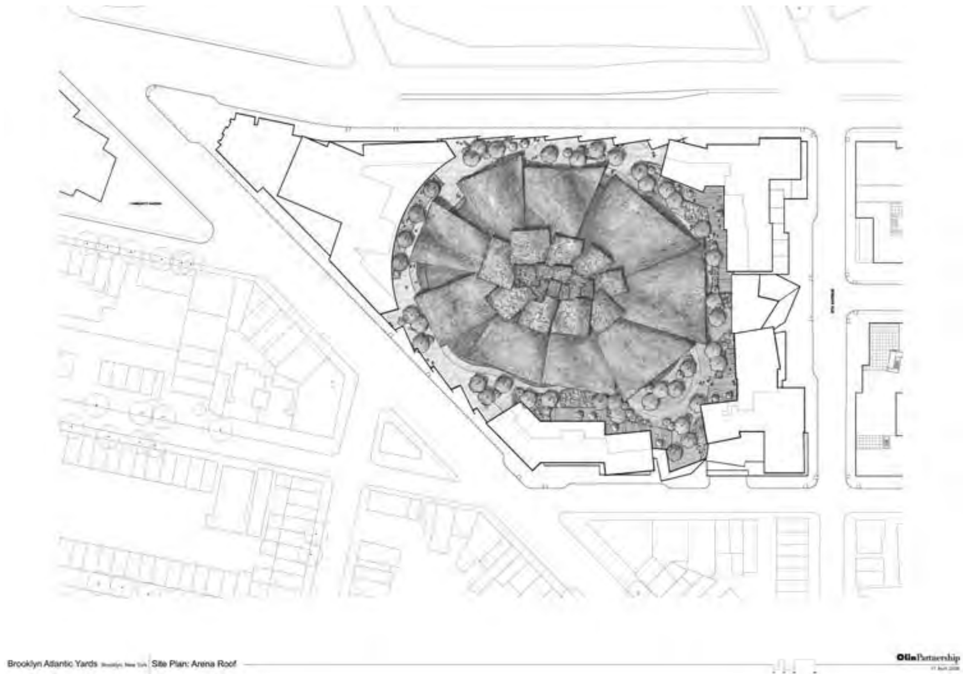
FIGURE 3-10 Viewshed diagrams. Specific viewsheds to be preserved are also identified.

FIGURE 3-11 Merging landscape and architecture by incorporating parks, gardens, living green roofs, walkways, and stormwater retention systems constructed over complex utility, transportation, and structural systems is central to the concept and development of the buildings and public open spaces.

FIGURE 3-12 Site section illustrating the interrelationship of buildings, landscape, and subsurface parking and transportation.

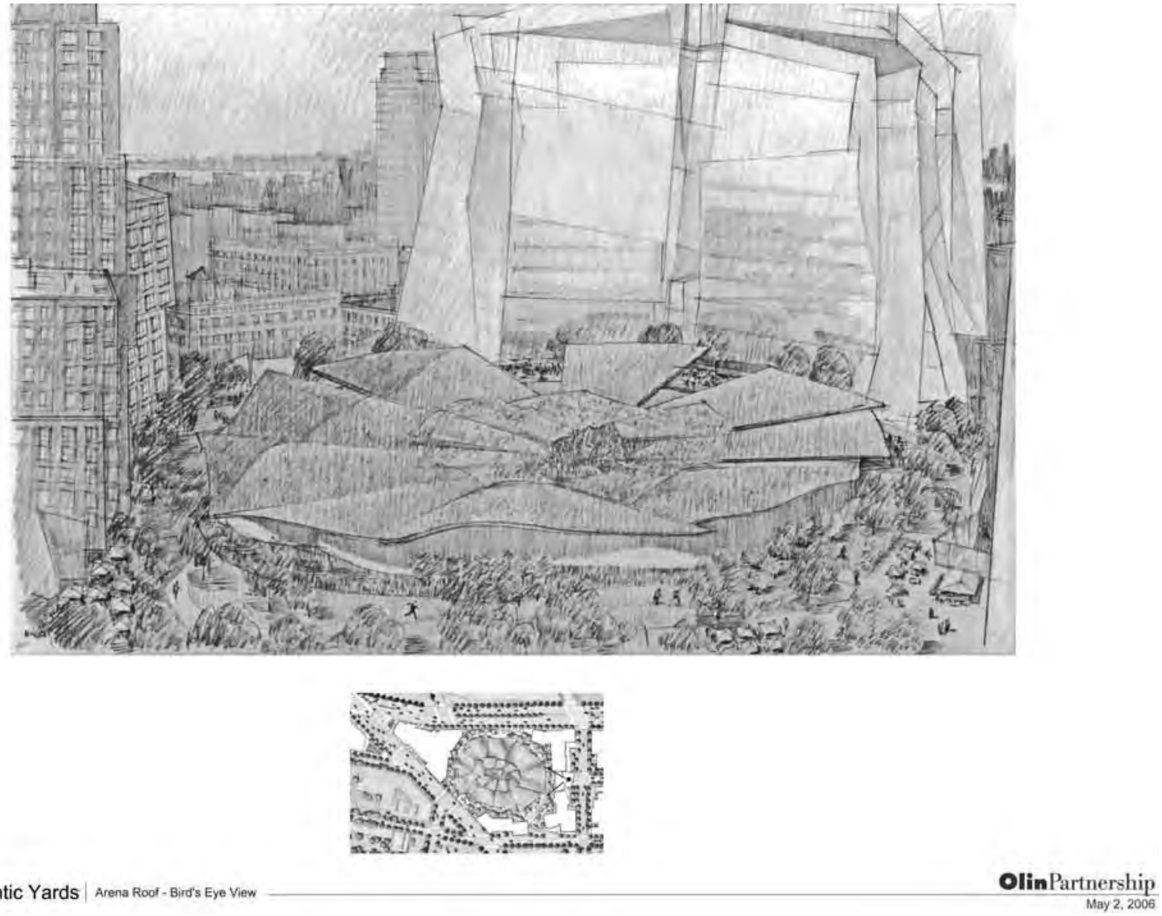


(a)



(b)

FIGURE 3-13a–c Process sketches (a) illustrate design alternatives for an arena roof. The plan and perspective (b) are of the preferred alternative for the arena roof, developed in the concept phase of the project. The roof of the arena, set within an urban park constructed over below-grade parking, is covered with a living green roof (c).



(c)

FIGURE 3-13a–c *(Continued)*

- Civil engineering analysis
- Stormwater management requirements
- Legal requirements: land ownership, easements (especially utility and communication), zoning, permitting, codes

■ Economic impact analysis, including:

- Order-of-magnitude cost estimate for probable construction costs. Typically cost estimates are organized by construction industry standards (CSI) divisions (such as earthworks, concrete, electrical, etc.). Estimates should be completed in successive phases of work. As the project detail emerges, the construction costs can be more effectively evaluated.
- Cost-benefit analysis. Typically this weighs total financial costs against the financial gain. Both the costs and the gains are measured against some time frame or rate of return. Analyses for green roof systems done in dollar terms alone are not sufficient to show the benefits of green roof systems, though

social and environmental gains are more difficult to assess. True sustainability occurs when all costs are balanced or outweighed by all benefits.

- LEED sustainability analysis
- Sustainable Sites Initiative analysis
- Life cycle cost analysis
- Community impact analysis, which identifies stakeholders, potential positive and negative impacts upon them, and issues that may arise

FIGURE 3-14 A community workshop allowed citizens to help determine the size and location of public open spaces.

Schematic Design

During schematic design, the design concept is advanced and developed with more detail and the design direction determined. Programming requirements are incorporated, resulting in a determination of general organizational principles and size of project elements (e.g., building orientation, footprint, and height; roadways and parking; general grading requirements; walls, stairs, and fountains; paved versus planted areas). An initial range of suitable materials is considered. Details begin to emerge that show the relationship of site and building materials to each other and their method of construction.

For green roof systems, it is essential in the schematic design phase to have correct survey information in order to coordinate the finished grade of surface elements as well as confirm subsurface conditions (especially stormwater outlets).

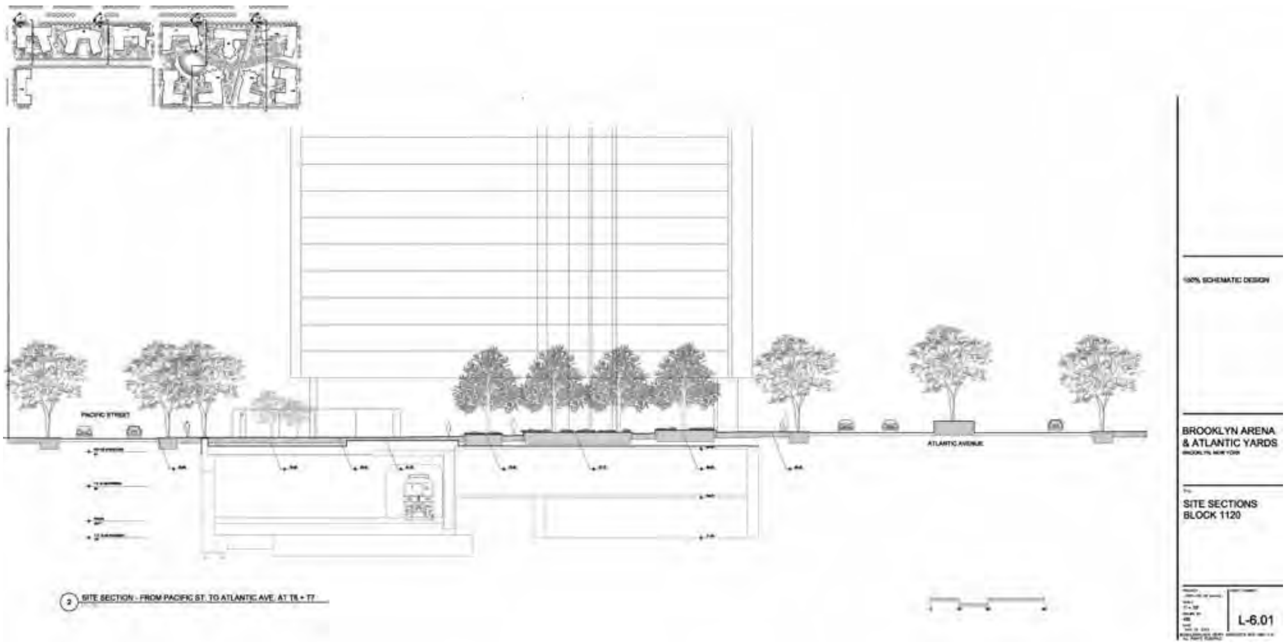


FIGURE 3-15 Schematic phase section, showing relationships of street widths, required planting depths for canopy trees, finished grades, tops of structural slabs, and below-grade transportation and parking requirements.

The products are very similar to those described for concept design. Each discipline on the job—architecture, landscape architecture, and structural, mechanical, electrical, plumbing, and civil engineering—has a set of schematic design drawings at this phase. The drawings are closely coordinated to eliminate any conflicts between the disciplines. The cost estimate is further refined at this phase. Outline specifications are generally required at this phase.

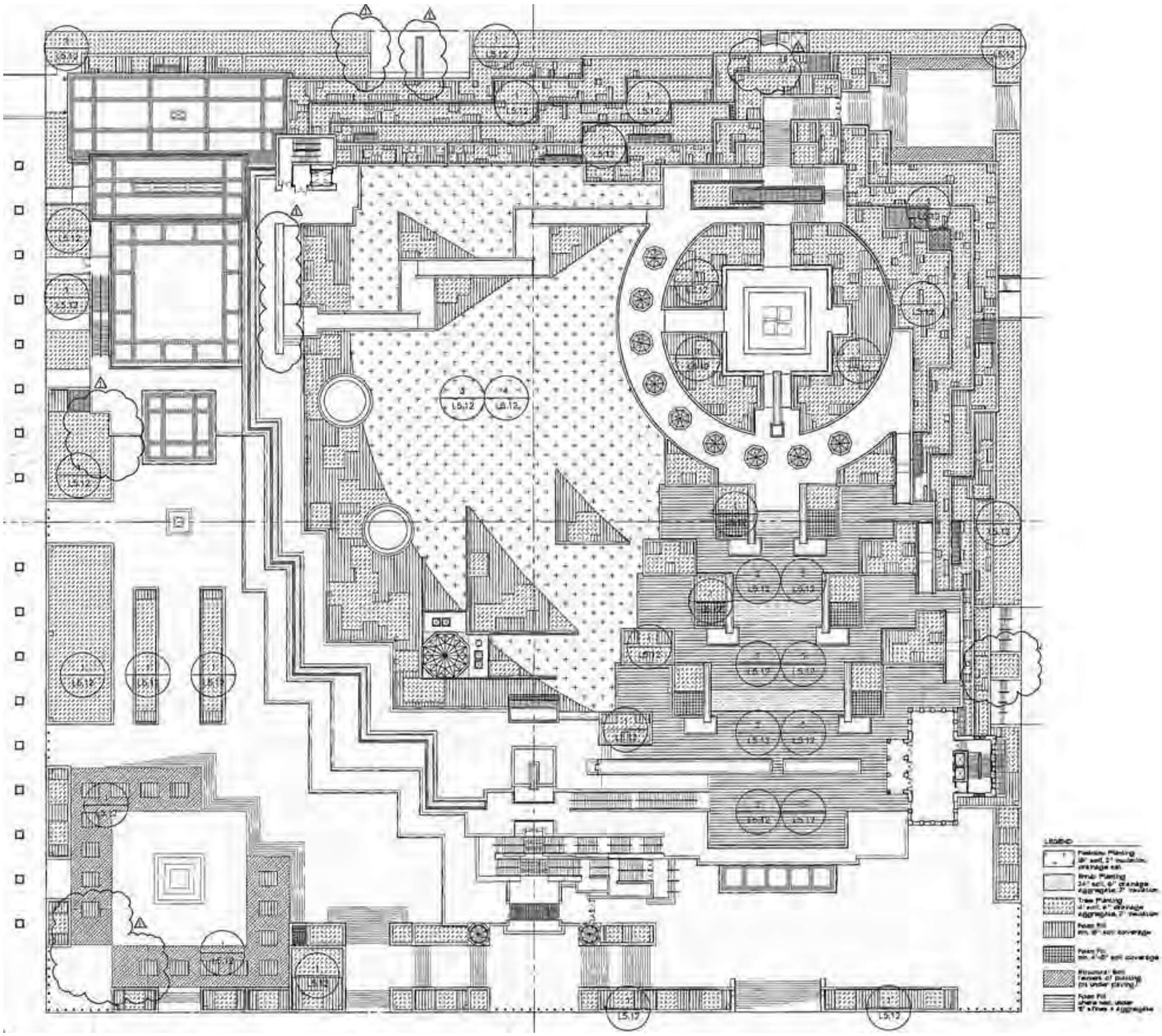


FIGURE 3-16 Early collaboration of the design team allows the structural engineers and landscape architects to provide each other with key design requirements. This schematic design study indicates types, depths, and locations for soils, lightweight fill, and paving.

FIGURE 3-17 This diagram was generated by the structural engineer in developing requirements for the structural system.

Design Development and Construction Documentation

Design development and construction documentation are the "meat and potatoes" for design consultants and contractors. In these phases, the overriding vision and ideas become specific information about how to actually build a project.

Design development is the phase of the project when all of the issues left unresolved at the end of schematic design must be worked out at a scale that minimizes major modifications during the preparation of construction documents. This is the period in which refinement and coordination come into play.

The primary objective of the design development phase is to define and describe all important aspects of the project that fix and define the dimension and materials of the project. Since this phase may also determine the guaranteed maximum price (GMP) of the entire project, it is absolutely essential that all the infrastructural elements and components associated with green roof systems are identified and coordinated. If the cost estimators, because of omissions or lack of clarity, miss them, the potential for the green roof to be excluded from the project is greatly increased.

Construction documents are all of the written and graphic documents prepared or assembled by the required disciplines (architect, engineer, landscape architect, etc.) for communicating the design and administering the construction contract. These typically include the drawings, specifications, bidding requirements, and project manual. The contract documents enable concepts to be translated into reality. These two later phases are more fully addressed in Chapters 7 and 8.

Summary

No one society can take credit for the evolution of our great cities; likewise, no one industry or agency is entirely at fault for eroded, degraded, and depleted natural environments or for the built environments that may have been the cause. No one industry or agency should bear the responsibility and economic burden for their necessary repair and restoration. The greater the collaboration within and between industries and agencies, the greater the opportunity to enhance life on multiple levels and reduce the level of environmental, social, and financial risks we all must endure. All should be willing to take calculated risks and trust that these will yield great rewards.

Chapter 4

Green Roof Systems at the Project Scale: Site and Architectural Considerations

Planning for the incorporation of green roof systems at the scale of the city allows for the greatest cumulative positive impact of individual applications of green roof systems. The actual realization of that impact begins at the project level. The project level may be a single living green roof or landscape over structure, or a comprehensive system of linked green roofs within a multibuilding project.

At a project level, green roof systems can be incorporated into the specific programming needs of urban life—living, working, shopping, recreation. They can also be incorporated into the way we get to or move around cities, through pedestrian circulation, public transit, vehicular circulation, and parking systems. It is also possible to utilize green roofs to link open spaces physically and visually while positively affecting microclimates. Perhaps one of the most important but least considered uses of green roof systems at a project level is to merge architecture and landscape to provide a greater level of aesthetic and environmental sustainability to urban environments.

To achieve this, of course, takes the will and ability on an owner's part to bear the potentially higher short-term costs to achieve long-term economic, environmental, and social benefits. It also takes the ability and willingness on the part of designers and builders to collaborate in the integration of their work. At the project scale, the collaborative process required to plan at the scale of a city evolves to the very specific coordination of building systems.

Beyond willingness and ability, project-scale collaboration requires an integration of expertise in order to:

- Understand the implications of coordinated decision making among the owner, design disciplines, and contractors from inception through project completion
- Make the appropriate decisions needed early in the design process
- Understand the potential and implications of trade-offs

The primary focus of this chapter is the enormous potential of green roof systems at the project scale to integrate architecture and landscape, and to realize the many benefits they bring into the urban environment. The secondary focus is to provide a basic understanding of the early decisions that may need to be made to successfully implement the design and construction of green roof systems.

Merging Landscape and Architecture

A significant aspect of the use of green roof systems is their ability to merge architecture and landscape more effectively. Their individual and cumulative application on a large scale in urban environments can offer more than environmental benefits. Physical and psychological health benefits can also be derived from the continuity of open space achievable through use of green roof systems.

With their utilization the seamless integration of landscape and architecture is accomplished through a comprehensive design and construction process that strives to:

- Link open spaces with physical and visual continuity
- Enhance urban microclimates by mitigating the impacts associated with urban development
- Enhance the integration of transit and parking by minimizing physical conflict and maximizing visual continuity
- Enhance the day-to-day urban events of people living, shopping, or seeking recreation and revitalization in the city

FIGURE 4-1 The lobbies of this conference facility were designed to afford the greatest views to the landscape beyond, which includes the landscape over structure and the greater mountain landscape beyond.

Linking Open Spaces with Physical and Visual Continuity

Green roof systems are particularly beneficial in the urban environment for their ability to help link the spaces between buildings.

From a comprehensive urban planning and design aspect, the intentional connection of open spaces becomes very important. The way individual project scale spaces are linked, how people move from one space to another, and how types of spaces are perceived all need to be considered. The effective linkage of interior space to exterior space can be strongly influenced by how humans perceive the differences and commonalities between being inside and being outside. The significance of living green roofs and landscapes over structure in influencing human perception is that even from an interior perspective, the positive visual or psychological experience of exterior spaces can be extended and heightened by their use. As the merging of landscape and architecture becomes increasingly effective, the mind is less and less prone to disturbance due to visual discontinuity. This is particularly true with respect to large-scale landscapes—urban, rural, or agricultural.

The physical and psychological health benefits to inhabitants of buildings having views and linkages to the exterior are now known to be profound. This is particularly pertinent to hospitals, recovery sites, and healing gardens, where views to the outside allow people to heal and recover more quickly. Likewise, workers having pleasant views to the outside have been found to have fewer sick days and stress-related absences from work.

Desirable visual access to the outside should be a design goal when possible; in some places it is a design regulation. In some municipalities in Germany, for example, there are mandatory requirements providing that every office worker have a direct view to the outside from a sitting position. In lieu of vapid conventional rooftops green roof systems are an effective way to provide this visual amenity, particularly when part of usable open space.

FIGURE 4-2a–b At this vineyard in Tuscany, a portion of the utility yard and the entire roof of the service building were covered with a gentle, inviting lawn framed by a stone parapet wall and hedges. From below it is clear how to navigate the service yard; from above, the visitors' view of the agricultural Tuscan landscape is uninterrupted.

FIGURE 4-3 This use of a living green roof, although not accessible to human use, keeps the view of the natural landscape intact. (Photo: © Zinco)

At the J. Paul Getty Center in Los Angeles, for example, the interior galleries are linked by numerous exterior spaces. The architecture is merged with the terrain of the landscape in stepped terraces, gardens, courtyards, fountains, and a cactus promontory built over structural decks with occupied space below. The composition of the buildings frames the views of the larger landscape—ocean, mountains, and city—and the landscape of the buildings provides a rhythm of color, light, shade, and fragrance that complements the architecture and provides respite for workers, visitors, and local residents.

FIGURE 4-4 The city of Stuttgart has had some of the most effective municipal green roof requirements and incentives in Germany since the 1970s; now living green roofs are common in the urban landscape. (Photo: © Zinco)

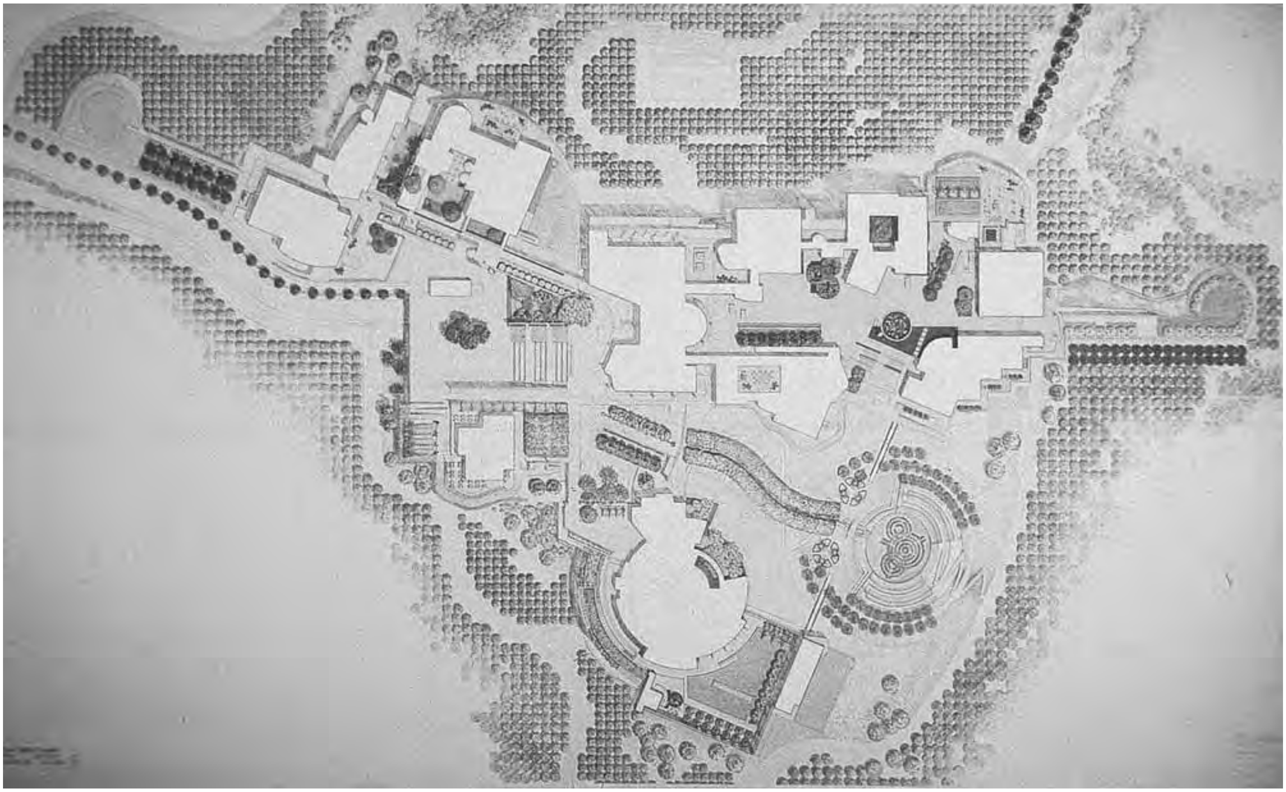


FIGURE 4-5a–b The J. Paul Getty Center comprises six separate institutions on 110 hilltop acres. More than 800 staff members are engaged in scholarly research, conservation, and management of its extensive collections. Many of the stepped terraces, gardens, and water features lie over structures, with the space below occupied by research and conservation operations.

Enhancing Urban Microclimates

Living green roofs and landscapes over structures can be quite effective in their ability to help ameliorate the negative impacts of microclimates created in urban environments.

Canary Wharf, as an example, is a revitalized 75-acre portion of London's Docklands that once served the trade to the Canary Islands. Intended by its developers to become a new financial center, it required the technological infrastructure to support modern world-wide trading and banking practices. It also required an open space infrastructure to attract, support, and maintain key tenants. The resulting 12.5 million square feet of office space, facilities, roads, and parks are built entirely over roadways, utility infrastructure, transit hubs, and multiple stories of underground parking adjacent to the Thames.

Extensive wind tunnel studies helped determine the most advantageous locations and configurations of buildings, streets, and open spaces. Large-caliper trees were viewed as essential for both immediate aesthetic impact and to ameliorate the microclimate. For these semimature trees to survive and thrive immediately over a structural concrete deck, there needed to be tremendous coordination among all design disciplines to provide an invisible artificial growing environment and long-term support system, along with an enormous commitment by the owner to the costs of installation and maintenance.

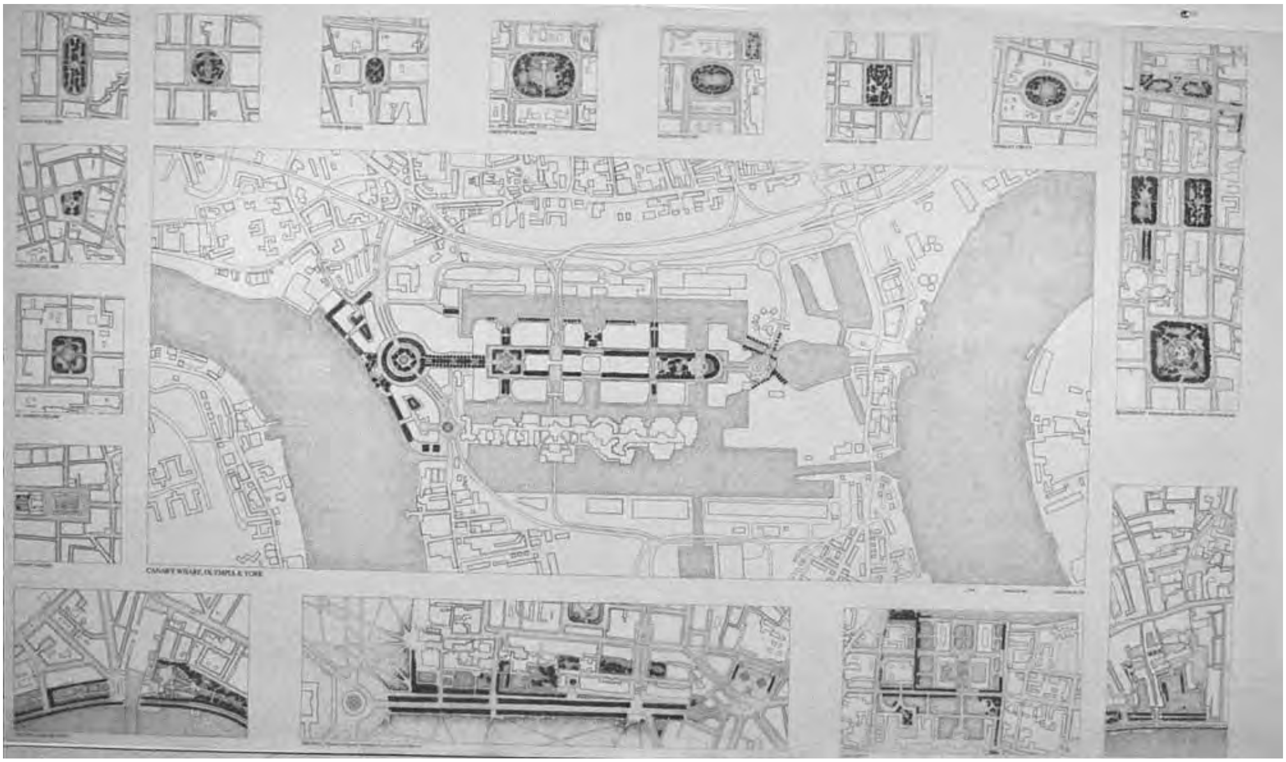


FIGURE 4-6 Plan of Canary Wharf with comparative open spaces in London shown.

FIGURE 4-7 Installation of very-large-caliper trees in below-grade planters. The radial pattern reflects road circulation, building and open space configuration at finished grade.

FIGURE 4-8 Completed open space.

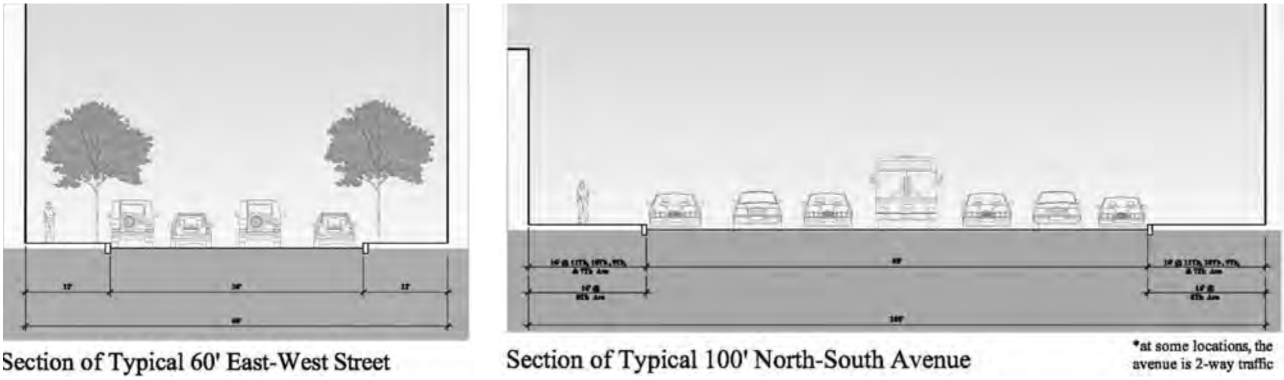


FIGURE 4-9a-b Sections of typical 60-foot-wide east-west streets (a) and typical 100-foot-wide north-south avenues (b) show the relationship between street width and the height of adjacent buildings. The proximity to the Hudson River and resultant wind and air movement on the open space corridor can create a very unpleasant microclimate for pedestrians.

Hudson Yards is a designated redevelopment area in New York City stretching from the Hudson River to Seventh Avenue and 42nd Street to 26th Street. It encompasses current and vestigial structures of industry and transportation, including rail lines, hulking remnants of harbor piers, Penn Station, and the Port Authority Bus Terminal. This visionary planning study is an excellent example of how a series of individual projects can link open spaces, enhance urban microclimates, integrate transit, and positively add to life in the city.

The existing microclimate is affected by its topography of significant high and low points (contributing to unique landscape slopes and views west toward the Hudson River and back to midtown), the existing width and orientation of streets, the presence of street trees, and the height and orientation of buildings.

The program for Hudson Yards' redevelopment included requirements for 1 million square feet of mixed-use buildings, a new football arena, and significant public open space.

A major part of the design concept was developed from a thorough understanding of the effects of the existing microclimate and proposed innovative ways of combining buildings, pedestrian connections, living bridges, living green roofs, and public open spaces of various configurations and sizes built over structure to not only mitigate and ameliorate potential negative impacts of wind and air movement but also enhance the overall urban environment.

Particular emphasis was placed on creating not only physical and visual links but "ecological links" as well:

- *Resources*: water, educating inhabitants about the microclimate
- *Health*: pollution absorption, particulate filter, oxygen production
- *Nature:* views, connection to river, interaction with nature, urban refuge
- *Wildlife*: wildlife corridors, bird habitat, beneficial insects

FIGURE 4-10 Living bridge.

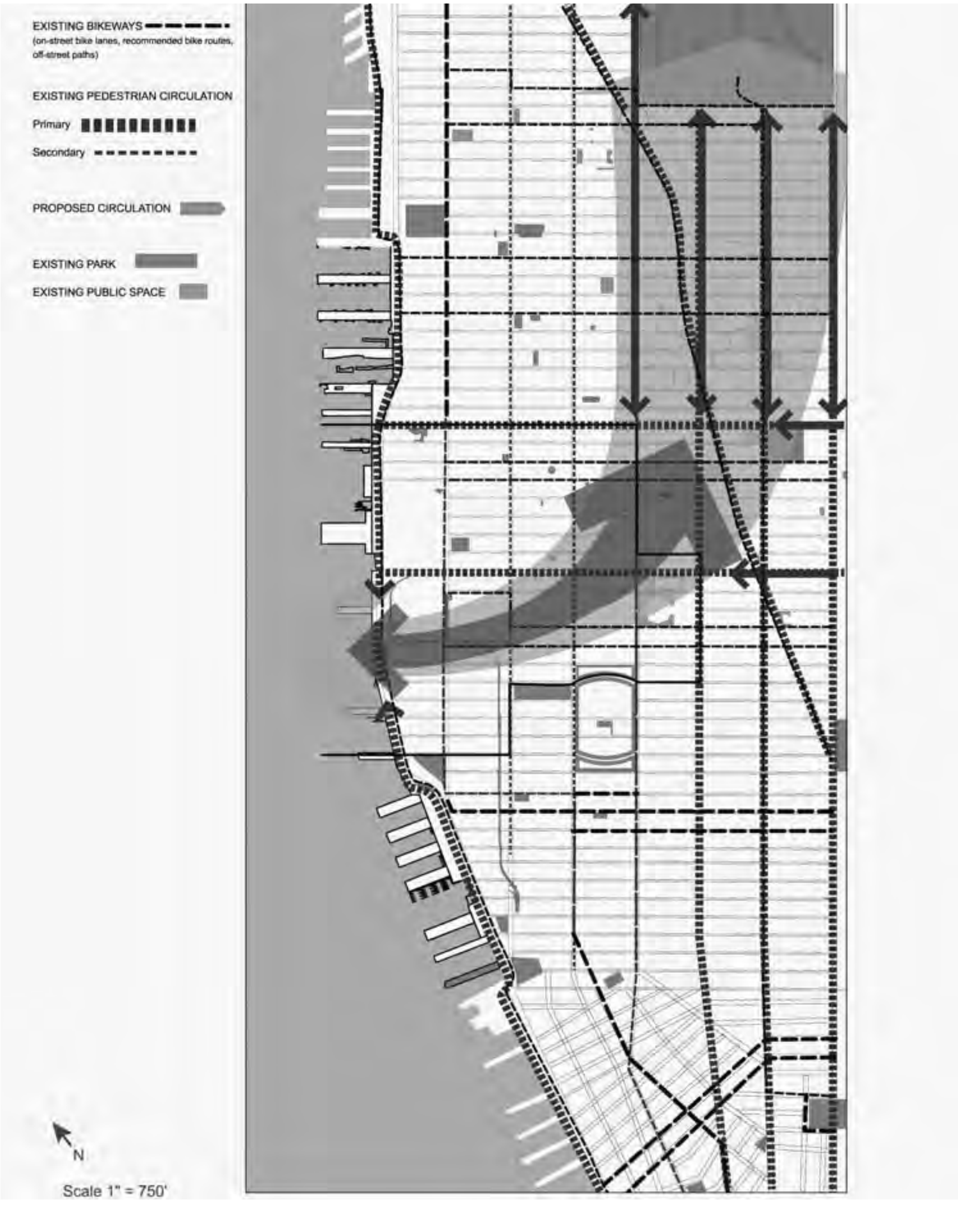


FIGURE 4-11 Links: pedestrian and open space.

FIGURE 4-12 Proposed green links and institutions.

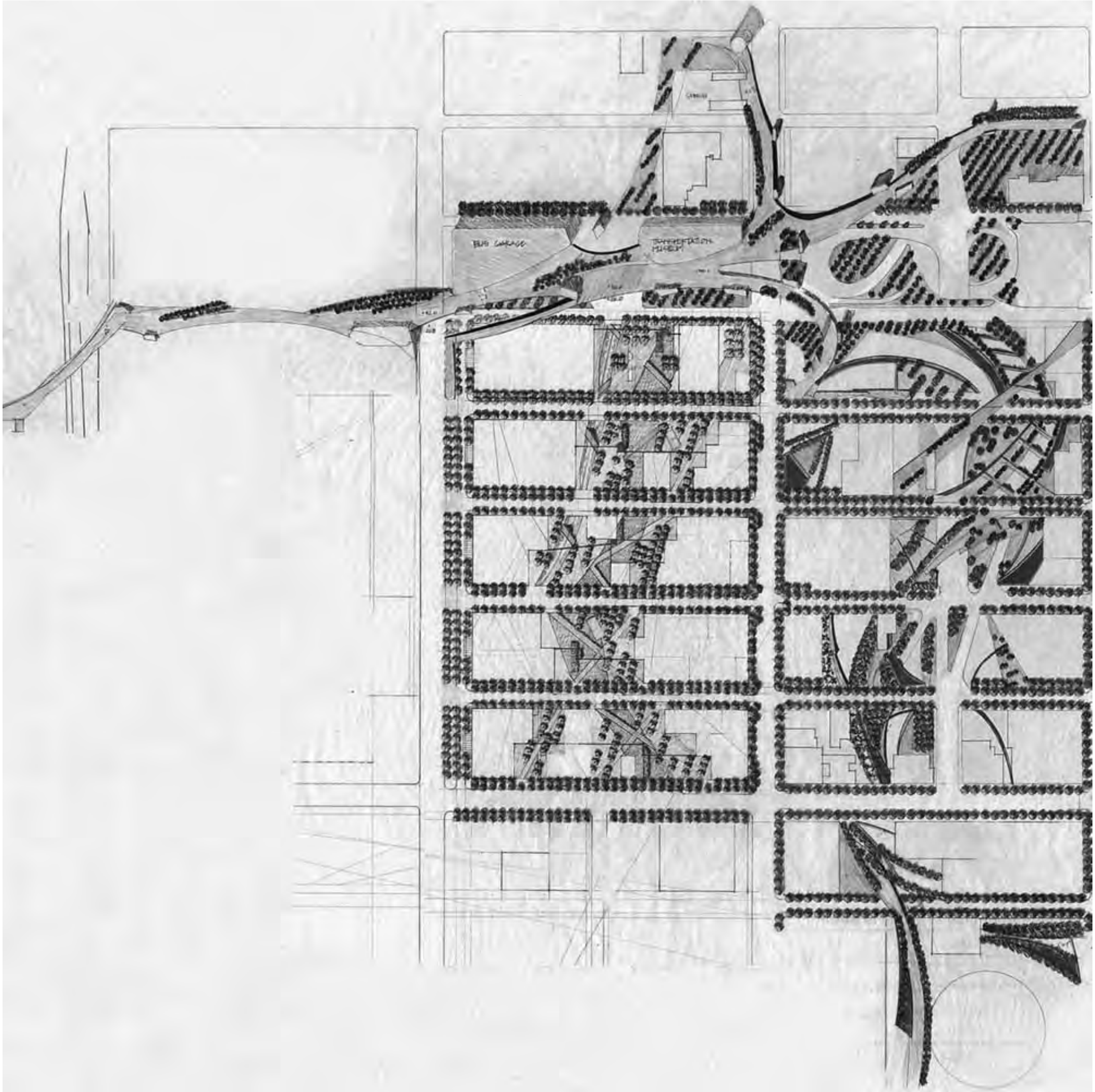


FIGURE 4-13 Concept drawing showing open space and pedestrian linkages.

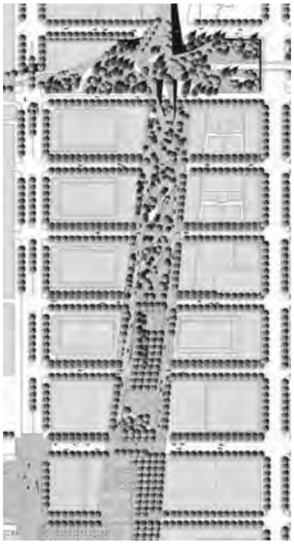


FIGURE 4-14a Plan of mid-block boulevard at Hudson Yards.

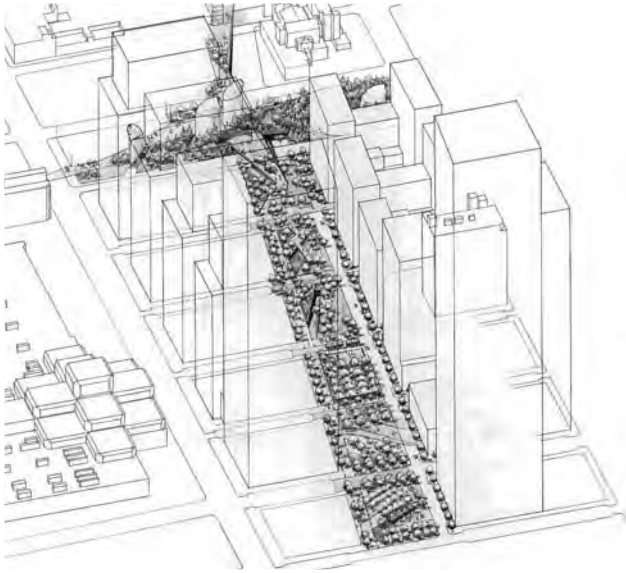


FIGURE 4-14b Axonometric projection of midblock boulevard at Hudson Yards.

FIGURE 4-15a Plan of mid-block park at Hudson Yards.

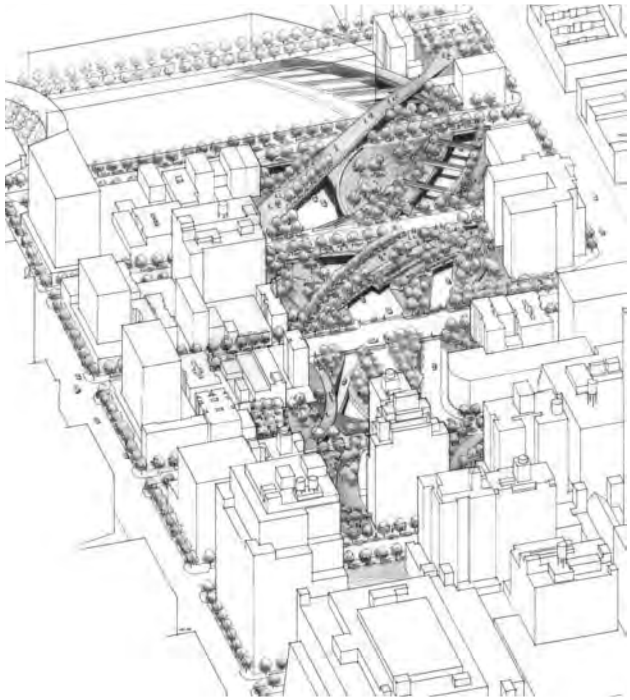


FIGURE 4-15b Axonometric projection of midblock park at Hudson Yards.

FIGURE 4-16 Existing conditions of buildings and an underutilized plaza in Cleveland.

Green roof systems can also be quite effective in their ability to help ameliorate the negative impacts of microclimates—created by the buildings with which they are integrated.

All individual projects should be evaluated for any negative impacts they may be imposing on the immediate microclimate, such as excessive solar exposure, shade, or wind. Project design should also be evaluated and leveraged for the ability to create a more pleasant interior and exterior environment.

FIGURE 4-17 Diagrams of potential configurations of earth mounds.

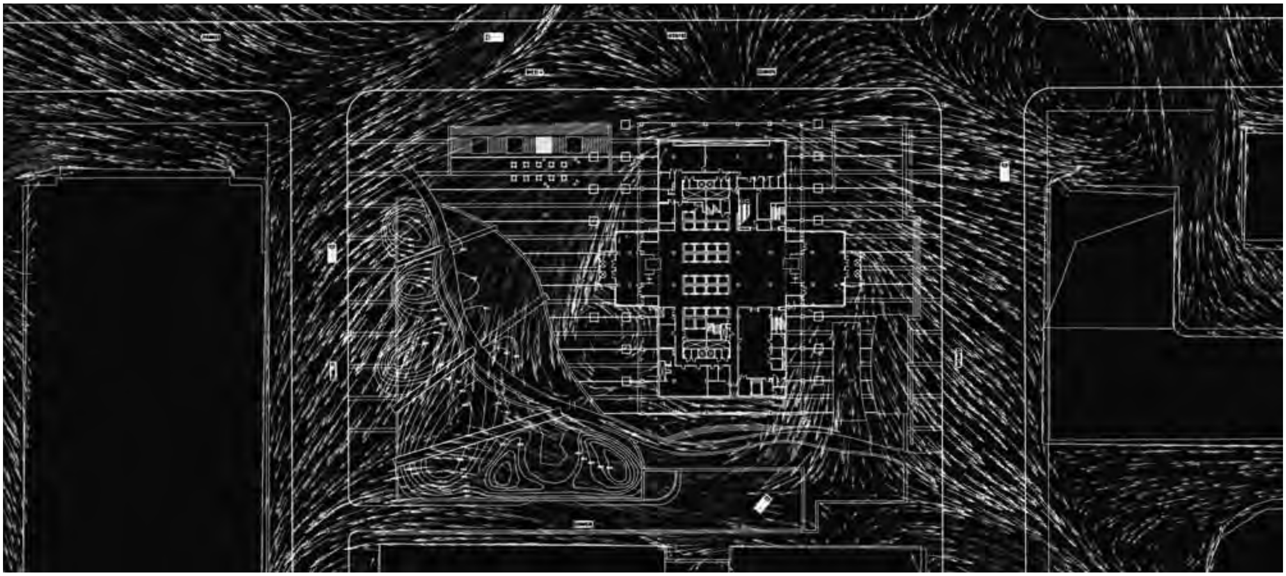


FIGURE 4-18 Combined diagram of the effect of wind on different configurations of earth mounds and vegetation massing in relationship to the buildings.

FIGURE 4-19 Illustrative plan of proposed planting and earth mounding.

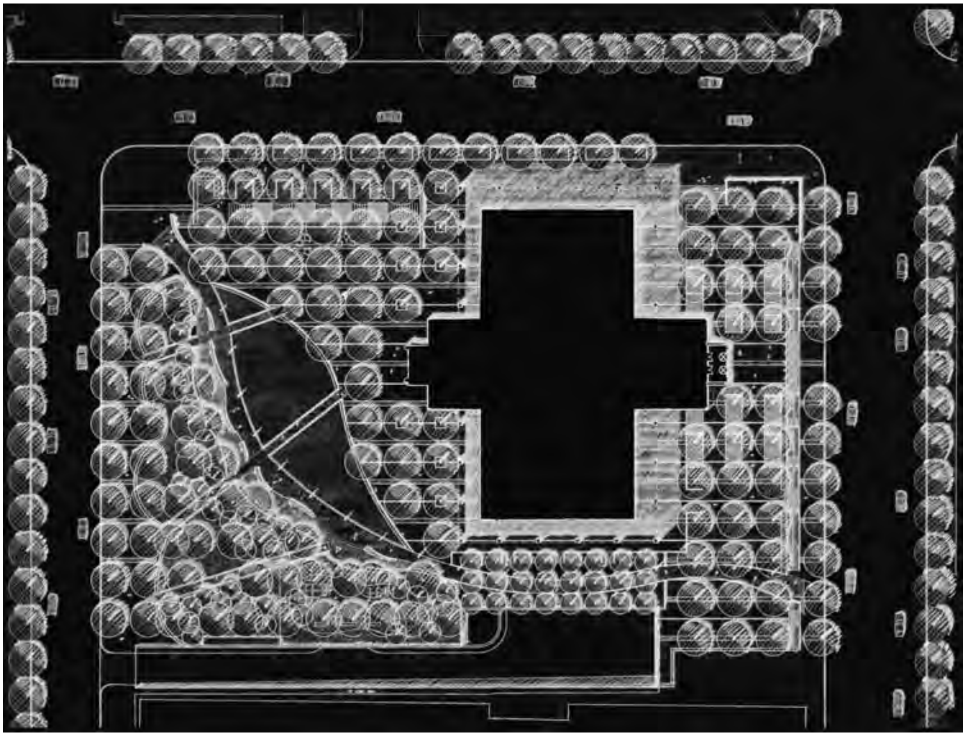


FIGURE 4-20 Construction photo: note wall and tree locations.

As an example, in downtown Cleveland a redesign for an existing building and adjacent plaza was intended to allow new uses in an ensemble of federal buildings that had become inefficient in their current configuration and capacity. The exterior plaza, over a parking deck, was seldom used largely because of harsh winds off nearby Lake Erie, exacerbated by the configuration and orientation of the buildings.

Early in the design process, the architects, landscape architects, and structural engineers collaborated to assess the structural capacity of the garage deck and the potential

FIGURE 4-21 Perspective of proposed design illustrating location of trees and sculptured earth mounds that help to buffer winds off Lake Erie.

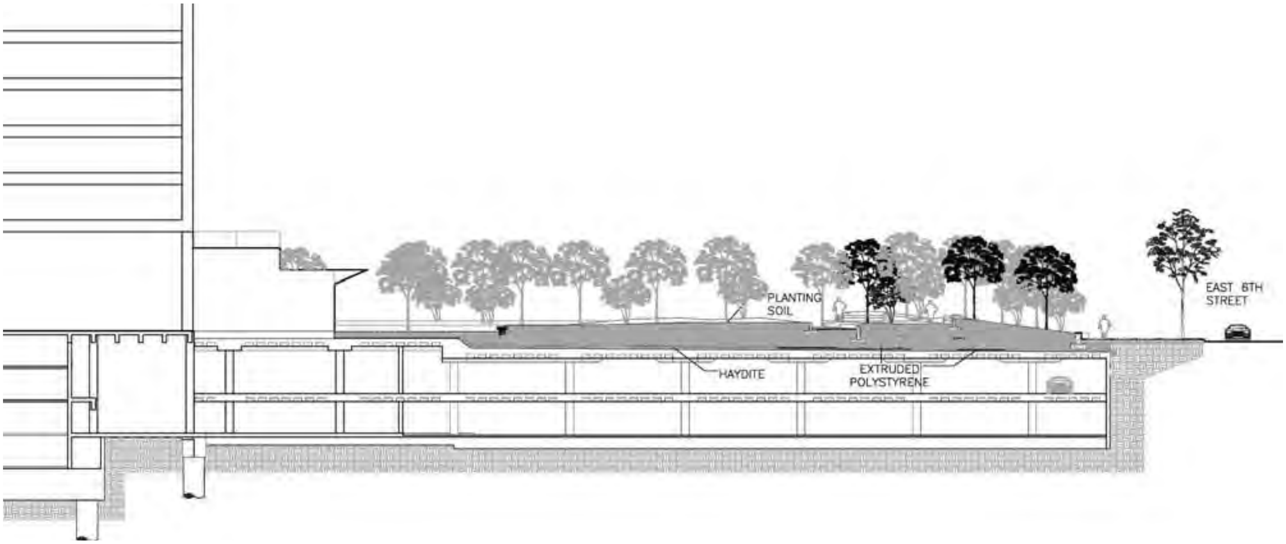


FIGURE 4-22 Detail of paving and planting in a fill section over structural deck during design development.

issues in retrofitting the deck to support the load required by soil and trees. Wind tunnel and wind modeling studies were utilized to determine the configuration of mounded earth and groves of vegetation that would most effectively mitigate the harsh wind.

The early development of the design required an understanding of components and systems in coordination with the architects and structural engineers. This provided the basis for allowable weight limits for the soil and trees, the resultant location and depth of lightweight fills, and location of large-caliper trees in relationship to the structural column grid.

Once these conditions and limitations were understood, the details and specifications for this landscape over the parking garage deck were developed. Waterproofing membrane and protection for both existing and new membranes, type and location of lightweight fills, drainage profiles, large-caliper tree planting, soil mixes, irrigation, paving, retaining walls, site lighting, and numerous other utility systems all needed to be coordinated.

Enhancing the Integration of Transit and Parking

Green roof systems can also provide a more aesthetically pleasing and environmentally effective means of integrating transit modes into the urban landscape.

Mass transit, particularly in cities, is clearly desirable. Trains, subways, trolleys, and even buses get more people to more places more efficiently. They take up less public space than automobiles and generally have fewer negative environmental impacts. Unfortunately, in the United States mass transit systems are not widely used regionally, and

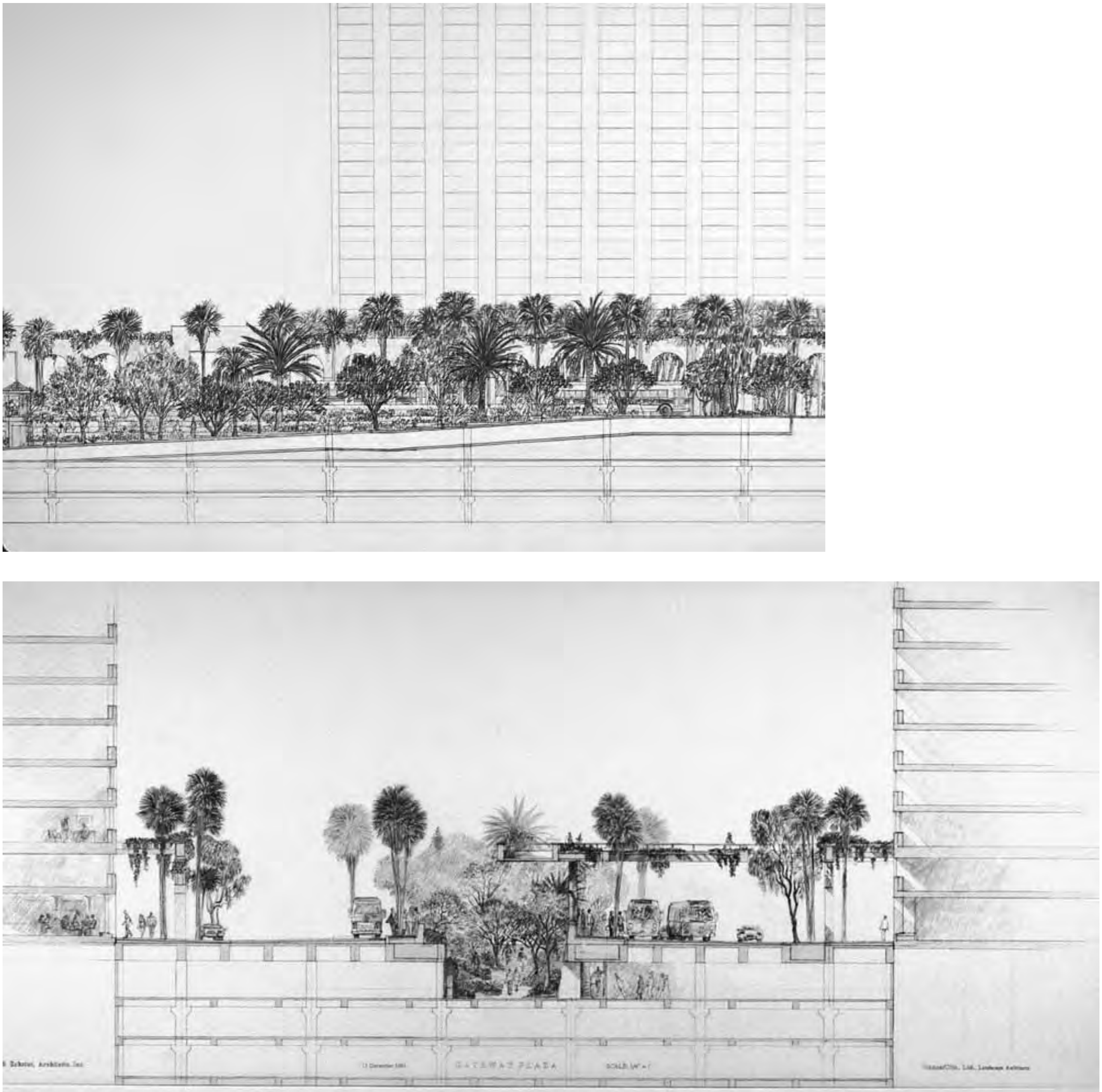


FIGURE 4-23a–c Gateway Center, Patsouras Plaza, Los Angeles. This intermodal transportation hub is one of the largest in the country and links the historic Union Station and Amtrak rails with a surface bus plaza, the subway, light rail, and a 3,000 car park-and-ride facility. Selling public transportation in Los Angeles required clear and accessible pedestrian circulation as well as commercial amenities. Early design studies show how the structural design was coordinated with the open space. An arroyo (dry riverbed) formed an accessible pedestrian connection to the concourse level from the bus plaza.

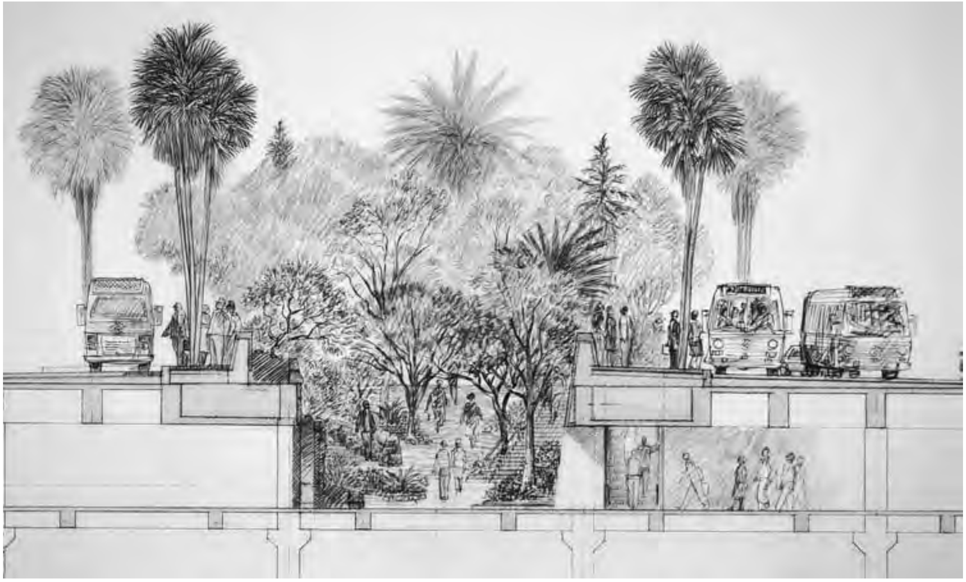


FIGURE 4-23a–c *(continued)*

sometimes not even locally. They are poorly subsidized and underutilized, which often makes them more expensive and less convenient than driving—which results in bigger roads, a more dangerous pedestrian environment, and more parking lots.

While cars and parking lots can compromise the safety of the pedestrian environment, automobiles are a reality of city life. In the city, land is a finite and valuable commodity, whether owned publicly or privately. Driving a car through a city may still be free (except in London), but parking is not.

Structured and underground parking is costly but needs to be considered in the contexts of time, the value of land, and the negative environmental impacts of surface parking. With shrinking land resources, particularly in urban environments, and a growing number of automobiles, parking is an important consideration and offers great potential for the utilization of landscapes over structure. The integration of green roof systems as part of the design and planning process can help ameliorate the negative impacts of transit and parking in urban environments as well as provide additional usable open space.

Integrating green roof systems into existing transit systems can be quite complicated and costly. Private development usually can provide only a portion of the construction costs. Also, because transit systems are often owned by municipalities or giant national rail lines, many issues of right-of-way and ownership of air rights might be involved. Long-term planning, funding, vision, and public patience are usually required to see successful completion of such a project.

New construction, while having many of the same ownership and cost issues, obviously has much more latitude in determining the program and design requirements. Early planning and coordination may be less complicated but are still required.

While not a new innovation, building a highly desirable or usable landscape over parking structures also allows for the introduction of new ways of looking at parking in the city.

For new urban design projects, the introduction of underground parking is usually limited by cost or environmental conditions. For older cities, extraordinary historic preservation considerations may be involved. In many European cities, plazas that have been in existence for hundreds of years have been allowed to remain plazas unfettered by automobiles; however, many of them have been completely dismantled, had parking installed below, and then restored as the great urban plazas that they once were, but now serving double duty. The Champs-Élysées, for example, has been completely revitalized, with vehicular and pedestrian circulation reconfigured to eliminate conflicts and with parking completely underground.

Surface, Structured, and Underground Parking

Surface parking, although relatively inexpensive (currently about $250 per space), is not very efficient from an urban design perspective. Structured parking (above-grade parking on multiple levels) may be more efficient but is much more expensive (currently about $25,000 to 35,000 per space depending on subsurface conditions, ventilation system, and the finished treatment of the top deck). The top deck can be used for parking, for a living green roof, or for a more developed, usable landscape. Most expensive is underground parking, the costs of which are difficult to predict and depend upon subsurface conditions and use above the structural decking.

Often an owner is willing to pay for the cost of parking, as it may be required by zoning ordinance or needed to make the project feasible, useful, meaningful, and attractive to tenants.

FIGURE 4-24 Working in collaboration with a glass artist, the project team integrated the ventilation shaft and equipment from the parking structure into the fountain design as part of a sitewide arts program.

Structured Parking

Structured parking needs to have ventilation. Typically, the requirement for venting structured parking is a certain percentage of open wall or surface area as related to the entire perimeter of the garage. Every municipality will have different code requirements for this.

If structured parking has great expanses of open wall area for ventilation, it tends to be unsightly, and will need either some type of screening or planted buffer to make it more aesthetically appealing. If the structure is mechanically vented—meaning there are no openings on the sides—then it will need a sprinkler system for fire suppression as well as mechanical and electrical air circulation. These mechanical systems can potentially result in quite unsightly venting units that protrude from the top of the structure. However, sometimes this is the only option. In this case it is important to consider the location and architectural expression of vents, elevators, or other required extrusions from the structure below.

Often structured parking is required to have ground-floor retail as a wraparound. This means either that the bay system has to be of a shallower depth to accommodate the store depth and height or that it has to be placed over the top of the retail units, thus requiring two levels of access to the parking floors. If a green roof system is incorporated, the structural system needs to be coordinated with the structural requirements of the green roof.

Underground Parking

It is much easier to plan underground parking in a new development than it is to retrofit an existing structure. The advantage of underground parking is that it can be built into the open space infrastructure for the project.

In the development of Mission Bay in San Francisco, for example, the design guidelines mandated the physical connection of specific areas that were considered part of the open space armature. While this included major streets and public open spaces, in some cases the guidelines addressed requirements for both semipublic and private open spaces.

For cost and geotechnical reasons it was not possible to sink all of the parking below ground. This meant that where parking was a combination of half floors (8-foot-height clear), a total height of nearly two and a half floors might emerge above finished grade. This "podium," instead of being finished with a conventional waterproofed and ballasted roof surface, was developed as a series of rooftop parterre gardens. (This type of design is sometimes referred to as a podium-level garden.) Both the garage floor and roof deck elevations needed to be coordinated with the various floor and half-floor elevations of the buildings. Additionally, the structural requirements of these podium gardens could potentially add another 2 or 3 feet of depth for soil and planting from the top of the slab of the garage roof. The height requirements of half floors and the structural requirements for soil loads all needed to be coordinated with both interior and exterior finished floor elevations.

The inclusion of green roof systems with underground parking has a number of tradeoffs, including geotechnical considerations, water table considerations, and stormwater considerations. The biggest consideration, however, is cost: every foot of excavation, foot of retaining wall, foot of poured concrete, and additional column costs money. The cost often may be justified by need or by municipal requirements, but it is expensive and often resisted.

Adjacent street circulation as well as garage ingress and egress need to be considered along with interior circulation patterns and drive widths. The slab depth will be dependent not only on bay layout and column spacing but also on the loading requirements of the deck. Loads may include saturated soil, trees and other vegetation, fountains, paving, and live loads.

Other considerations that need to be coordinated with living green roofs and landscapes over the structural deck include required floor-to-floor heights, slope of the deck, drainage requirements and design, utilities, mechanical ventilation, stairwells, and elevators.

Early Planning and Design Considerations for Green Roof Systems

As illustrated throughout this book, there are many examples of green roof systems that enhance the day-to-day experiences of people living, shopping, or seeking recreation and revitalization in the city. In terms of how the green roof system interfaces with those experiences, many of the issues explored in this chapter are similar to those encountered with standard buildings and landscapes. However, the artificial environment of a green roof system is less forgiving than standard buildings and landscapes when the various stages of the process have not been well executed.

While most design professionals, owners, contractors, and product suppliers understand that some horticultural infrastructure is required to sustain plant life in a green roof system, the complexity of the integration of architecture and landscape in the design and construction of living green roofs and landscapes over structure may not be fully appreciated. Green roof systems require a higher level of coordinated design, documentation, and construction than currently utilized in standard projects. Furthermore, because much of what sustains green roof systems is below the finished surface, problems may not become apparent for some time.

Beyond the considerations, early decisions, and trade-offs discussed above in relation to parking structures, there are also some additional considerations that must be taken into account early in the design process. Probably the most important is establishing finished floor elevations in relation to the top of the structural deck or slab.

Establishing Finish Floor Elevations and Tops of Slabs

One early decision that needs complete coordination is the establishment of finish floor elevations in relationship to the top of the structural slab and the exterior elements. This is very important, as it will have a direct impact upon the long-term viability of planting and the ability to construct suitable paving systems and other site elements. It will also affect the ability to use and maintain the project in the manner intended. Often, to have accessible ingress and egress from a finish floor elevation, the tolerance may be a half inch or less. If the top of a structural slab is set too high, it will be very difficult to attain the proper relationship between the interior floor and the exterior finish grade elevation. For example, in paving, if the top of the slab is set too high, the paver thickness, setting bed, insulation,

FIGURE 4-25a–b Exchange Square at Bishopsgate is built above the tracks and rail yards of Liverpool Station in London. The placement of the commercial buildings in relationship to the station and city streets helped to form the open space of this multilevel public plaza. A ramped walk and a curving sandstone wall form the primary pedestrian connection from Bishopsgate Road to a lower-level plaza. The change of elevations accommodates a stepped fountain and amphitheater with a stage and broad lawn for performances for the lunchtime, evening, and weekend crowds. Extensive coordination of all the transit, building, structural, utility, and landscape systems was required from the earliest planning sessions through construction.

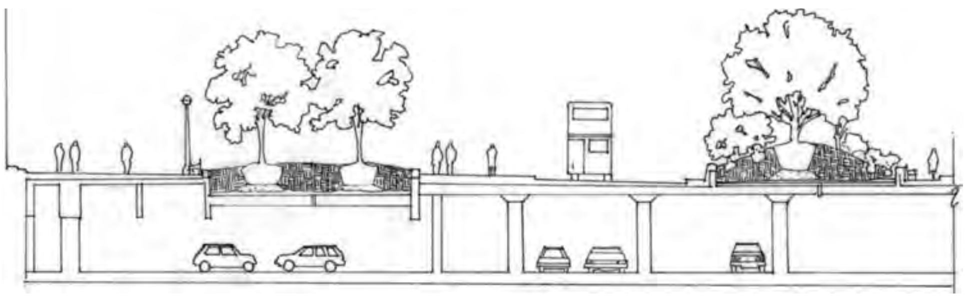


FIGURE 4-26 Early concept detail for Hackney Gate, showing minimum depth of soil mix or growing medium required for a large-caliper tree. (Dimensions are shown in mm.)

and subdrainage components can be compromised. Positive flow of drainage away from the interior finish floor elevation can also be inhibited.

As another example, for living green roofs there may be additional requirements to establish and accommodate a freeboard (additional capacity between the finish floor elevation and the top of finished grade for storing unexpected amounts of stormwater) for controlling high-intensity storms.

While every project will gain more specificity with each subsequent design phase, there are several key issues that should be considered very early in the project, since they can have enormous programming, aesthetic, and cost implications.

In order to determine finish floor elevations and tops of structural slabs, early design coordination between the landscape architect, architect, structural engineer, and civil engineer need to address the following issues:

- Program and expected use of finished exterior surface
- Surface material and profile of components
- Structural requirements
- Surface grading and drainage requirements
- Subsurface drainage requirements
- Minimum slope requirements, cross pitch, integral pour or topping slab, drain locations
- Waterproofing requirements

Other early considerations might include requirements for:

- Height limitations for the bottom of structural elements (beams, girders, columns, slabs, etc.), such as floor-to-floor height requirements
- Mechanical, electrical, or plumbing plenum or conduit locations
- Vent size, direction of flow, noise level, location, and surface expression

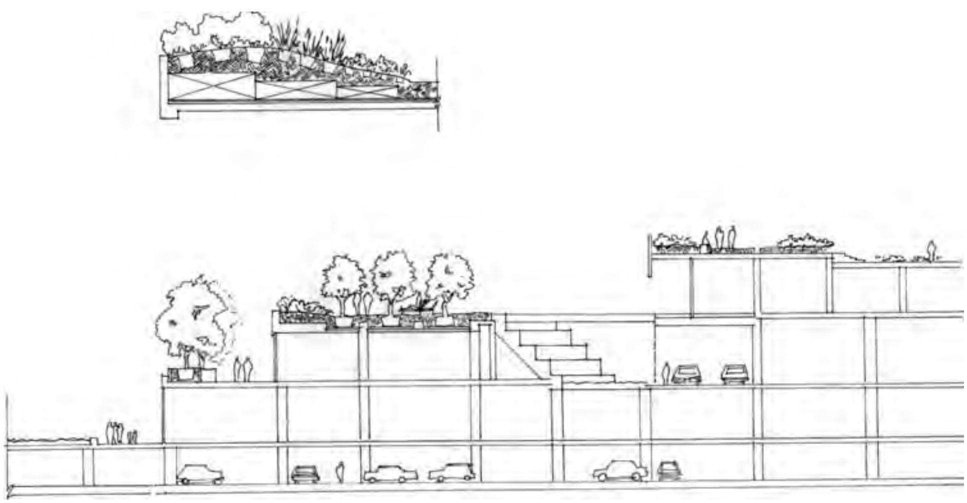


FIGURE 4-27 Early concept section for Vila Olympica, Barcelona, showing relationship between parking structure below and planting requirements.

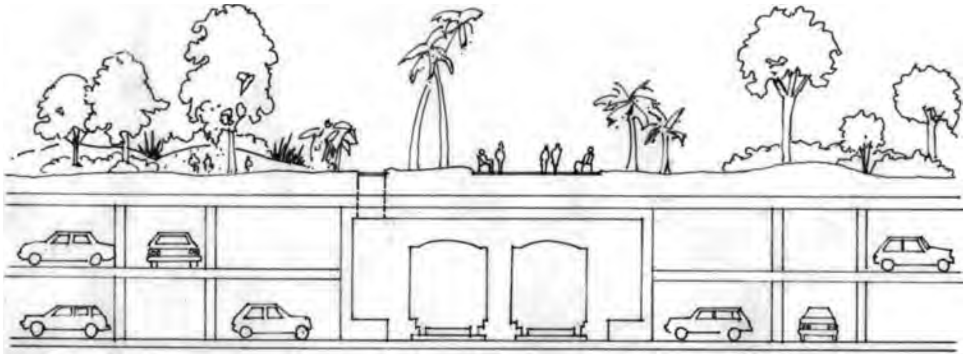


FIGURE 4-28 Early concept section for Bishopsgate showing continuous planting pit in relationship to rail platform below.

If it is determined that planting is a part of the program, key issues to be addressed should include:

- Whether the planting is a living green roof or a more complex landscape intended as accessible open space.
- Plan limits of each type of planting
- Horticultural requirements
- Expected planting profiles (low-growing drought-resistant plants, ground covers, shrubs, trees, etc.)
- Soil mix or growing medium type, depth, and weight
- Maximum depth and weight of root balls or box sizes
- Irrigation requirements
- Drainage system type and depth required for component parts such as drainage aggregates, panels, or mats
- Insulation requirements

Early consideration for coordination of other site elements might include requirements for:

- Site walls or stairs
- Fountains
- Other special site features

Some additional considerations in determining top of slab are geotechnical conditions such as depth to bedrock and type of soil, water table and ability to discharge stormwater, and zoning height restrictions.

Collaboration and Potential Trade-offs

Effective and productive collaboration with other design disciplines necessitates the ability to clearly explain one's own project requirements and how they fulfill the programmatic elements that have been determined by the client. More important, it demands the ability to understand the requirements of other design disciplines. This may require learning to read and comprehend another discipline's drawings and terminology, as well as establishing an appropriate and clear vocabulary for one's own specific discipline that is also reflected in the drawings and specification.

Because building systems are so integral to the design and construction of living green roofs and landscapes over structure, there will always be complications and unforeseen conditions in coordinating and constructing the work of all the disciplines. The building program will dictate the structural design; the structural design can impact the depth of allowable planting or weight of soil. To function most efficiently, the ventilation or emergency generating system will need to be expressed at the surface, often dead center in the main garden feature or fountain, as a very large and utilitarian piece of machinery that needs additional free air space. The building footprint may not match its exact location on the site survey; the structural deck may be poured too high in the field to get the paving section installed correctly.

Looking for opportunities for each discipline to achieve as much of the required program as possible with the desired design and to accept reasonable trade-offs when required will greatly benefit the work of all and the finished project.

Summary

The potential for the incorporation of a green roof system is enormous. There are many existing examples of living green roofs and landscapes over structure enhancing the everyday lives of those who live, work, or play in our cities. Some of the most successful green roof systems are not even perceived as such, because the architecture and landscape have been seamlessly merged.

Each green roof project will have its own specific programmatic, design, and maintenance requirements. Their successful implementation often requires consideration and integration of numerous building and site elements, early design decisions, and many trade-offs throughout their design and construction.

Achieving the aesthetic, environmental, and social sustainability benefits green roof systems can bring to our urban environment requires an owner who is willing to bear the potentially higher short-term costs to achieve longer-term gains, as well as designers and builders who are willing to be collaborative in the integration of their work.

Chapter 5

Considerations in Developing Structural Systems for Green Roof Systems

The planning, design, and documentation considerations of determining the appropriate structural system to support green roof systems require early and continuous coordination and collaboration among numerous design disciplines, the owner, and contractors.

Understanding the structural considerations of living green roofs and landscapes over structure requires some basic knowledge of structural systems and structural components. It also requires the ability to interpret structural drawings.

It is the intent of this chapter to offer a preliminary discussion of structural engineering as it affects green roof systems, to help allied design disciplines ask the right questions, and to help provide an understanding of the scope and expertise of each of the disciplines. Likewise, this chapter seeks to provide structural engineers with a basic understanding of areas where coordination and collaboration are essential—particularly early in the design process.

Most often the first concern centers on soil weight. The depth of growing medium required for a living green roof is typically 2 to 6 inches. Consequently, the overall thin profile of a living green roof generally weighs 14 to 42 pounds per square foot (psf). For new construction, structural upgrading of standard decking and roof framing usually is not required because the added weight of the profile is about the same as that of the stone or pavers applied as ballast to protect and preserve the waterproofing membrane of a conventional roofing system. Even in those situations where ballast is not required, only minor structural upgrades to the roof deck and framing may be required (i.e., a heavier guage metal roof deck may be required, and steel roof beams may get slightly heavier to support the green roof system loads). A living green roof, therefore, can be employed with no structural impacts to the roof deck or framing when the green roof is used in lieu of ballast and with minor structural impacts when ballast would not be required. While currently the cost of the materials and installation of a living green roof may be more than that of ballast, generally there is little or no additional cost to provide increased structural support. A thin profile living green roof then becomes a very cost-effective way to provide greater visual amenity and environmental quality. In retrofit situations it is essential, of course, to evaluate existing buildings on a case-by-case basis to ensure the existing structure has the capacity for a living green roof.

In contrast, landscapes over structure typically involve the support of considerably heavier loads than a conventional floor or roof structure with office-building-type loading. They often require a more complex infrastructure to support and sustain the growth of larger and more diverse vegetation.

Many considerations affect the selection of the structural system employed when designing green roof systems:

- Project programmatic and design requirements
- Geotechnical considerations such as depth to bedrock or hydrostatic conditions
- Soil bearing capacity
- Material selection and availability
- Weight of materials such as:
  - Soil
  - Vegetation
  - Water
  - Paving
  - Components of other site features such as fountains, walls, or stairs
- Costs

Programmatic requirements coupled with the type of landscape that is ultimately planned atop the structure are perhaps the most significant considerations that drive the selection of the structural system.

In new construction it is easier and more cost-effective to coordinate the design of the structural system to support the architectural and landscape architectural elements of the project. In retrofitted projects or in projects where the structural, architectural, and landscape architectural design are not coordinated early enough, the structural system employed or required can limit the flexibility of the program and design of what goes on top of the structure.

Early Planning and Design Considerations

The structural system required to support the additional weight of landscape over structure—soil mixes, growing media, vegetation, site elements (such as paving, walls, stairs, fountains, etc.), and potential live loads—is usually significantly more substantial in size and cost than that necessary to support a living green roof. The complexity involved in coordinating the various professional disciplines throughout design, documentation, and construction invariably has cost implications, which must be weighed against the benefits of the end use. Clearly it is preferable to begin coordination and dialogue among the varying disciplines and the owner at the beginning of the project.

As discussed in Chapter 4, a number of early design decisions need to be made, including coordination of finish floor elevations in relationship to the top of slab elevation and configuration.

For projects with significant planting, even if the structure has been designed to allow for the weight of large-caliper trees and saturated soil, the allowable depth for the soil or root balls of any significant size can be severely impacted if the various elevations have not been properly coordinated.

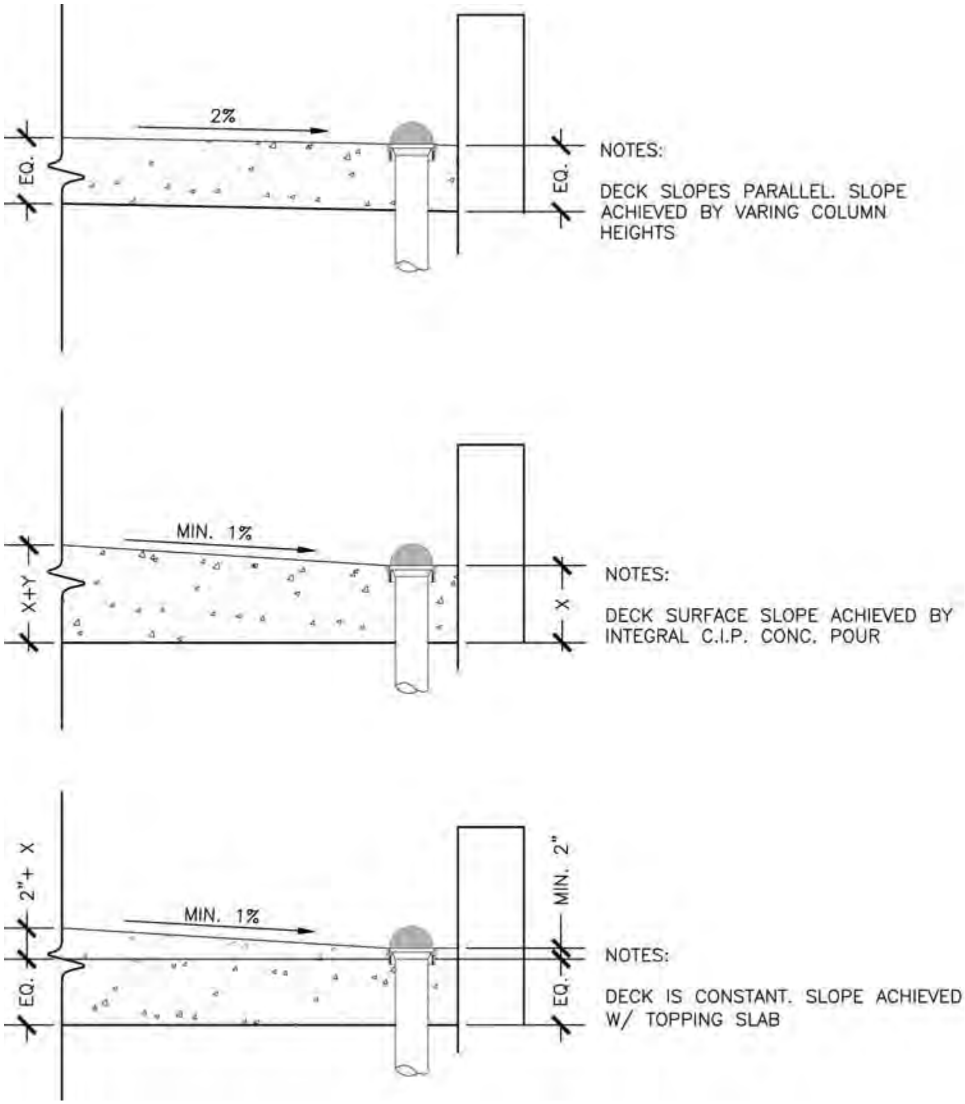


FIGURE 5-1a Proper drainage of structural decking may be achieved in a number of ways. Usually, the most economical and easiest way is to achieve parallel slope through varying the heights of columns. The deck drains may be pitched at 2 percent slope to one side.

FIGURE 5-1b The slope of the structural deck to achieve appropriate drainage may also be achieved by means of an integral pour; however, the weight of the thicker slab must be accommodated, along with the resulting thinner planting or paving profile at the thicker portion of the slab. To lessen the thickness over the length of the slab, a high point can be established, pitching excess water to more than one drain.

FIGURE 5-1c Sometimes a topping slab of lighter-weight concrete is used over a level structural deck to achieve appropriate drainage. This is sometimes used when crickets need to be employed to direct excess water to several drains and it would be difficult or costly to achieve this in an integral pour, or where there are weight or depth restrictions.

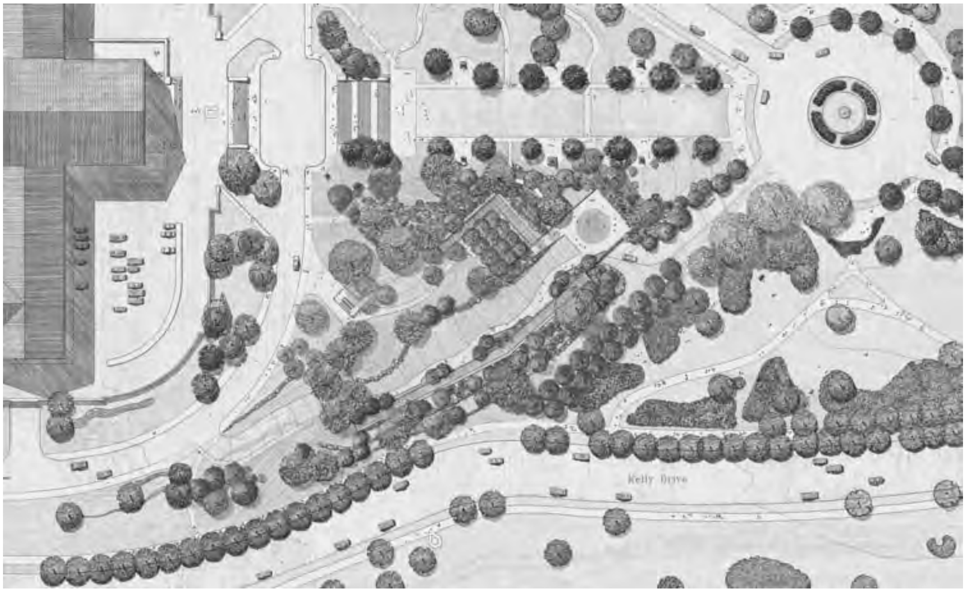


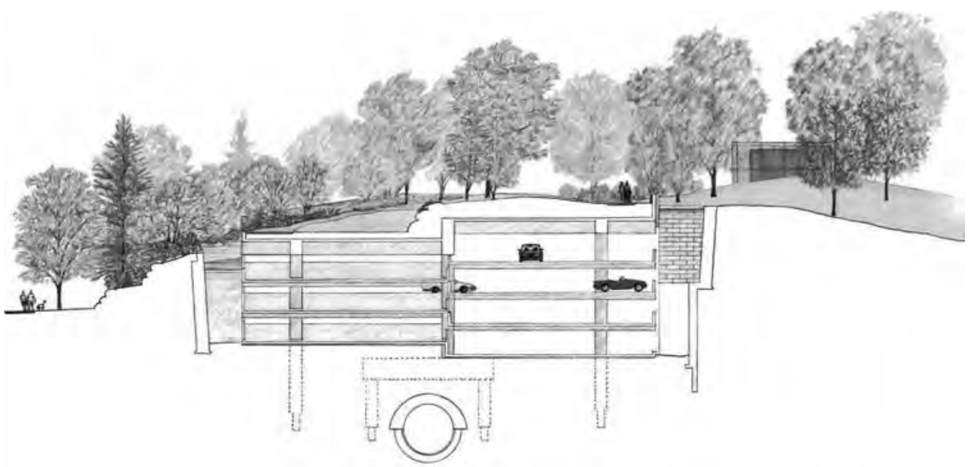
FIGURE 5-2 Illustrative site plan for a sculpture garden over a 400-car parking structure for the Philadelphia Museum of Art.

Basic Structural Principles and Considerations in Design, Documentation, and Building of a Landscape over Structure

While the remaining chapters discuss some specific considerations of structural systems as they relate to green roof systems, the following diagrams and details illustrate an overall approach to the design and documentation of a sculpture garden integrated with a parking structure.

FIGURE 5-3

FIGURE 5-4 Illustrative elevation and section showing early conceptualization of relationships between vehicular and garden circulation, finished grade, and floor-to-floor heights for parking levels and the garden. Natural ventilation eliminates the need for mechanical venting equipment on the garden level. The stepped planters screen areas—open for natural ventilation—that would allow the parking deck and cars to be visible.



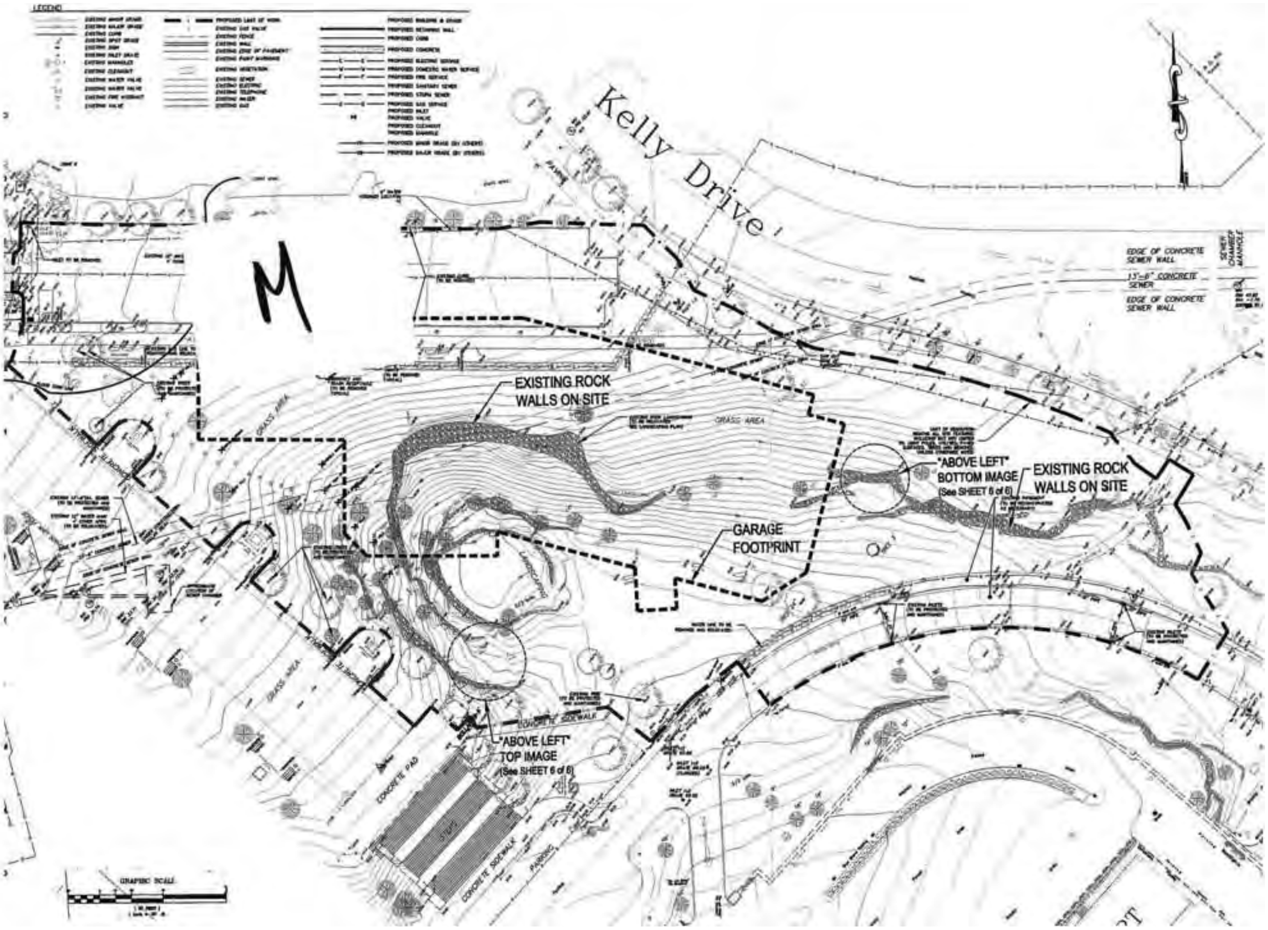


FIGURE 5-5 Existing site conditions with building footprint.

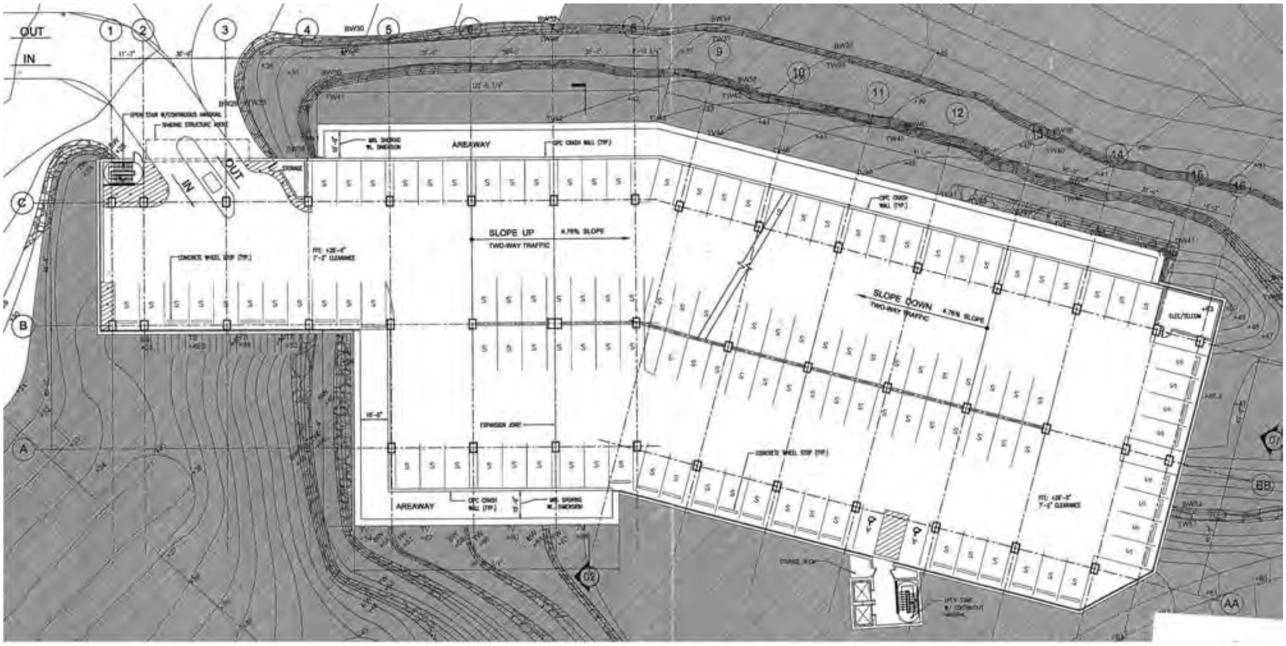


FIGURE 5-6 Plan of structural grid for the ground floor. Note the column spacing.

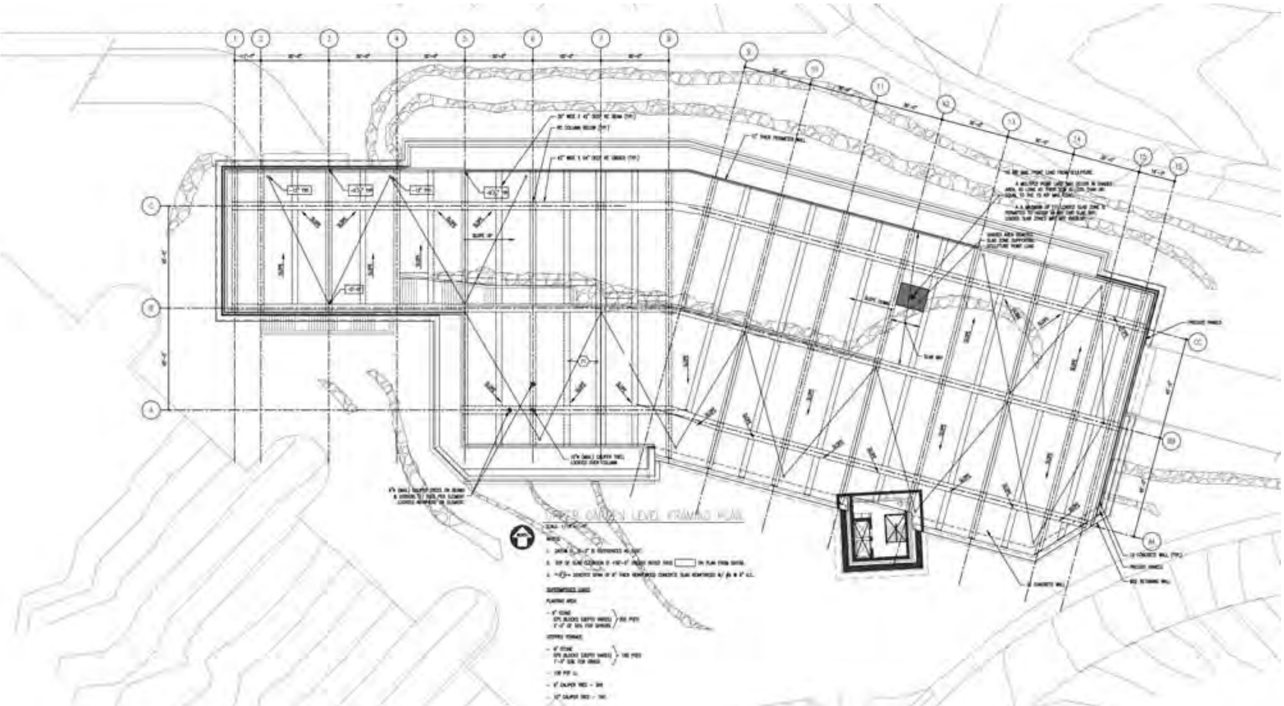


FIGURE 5-7 Terrace framing plan.

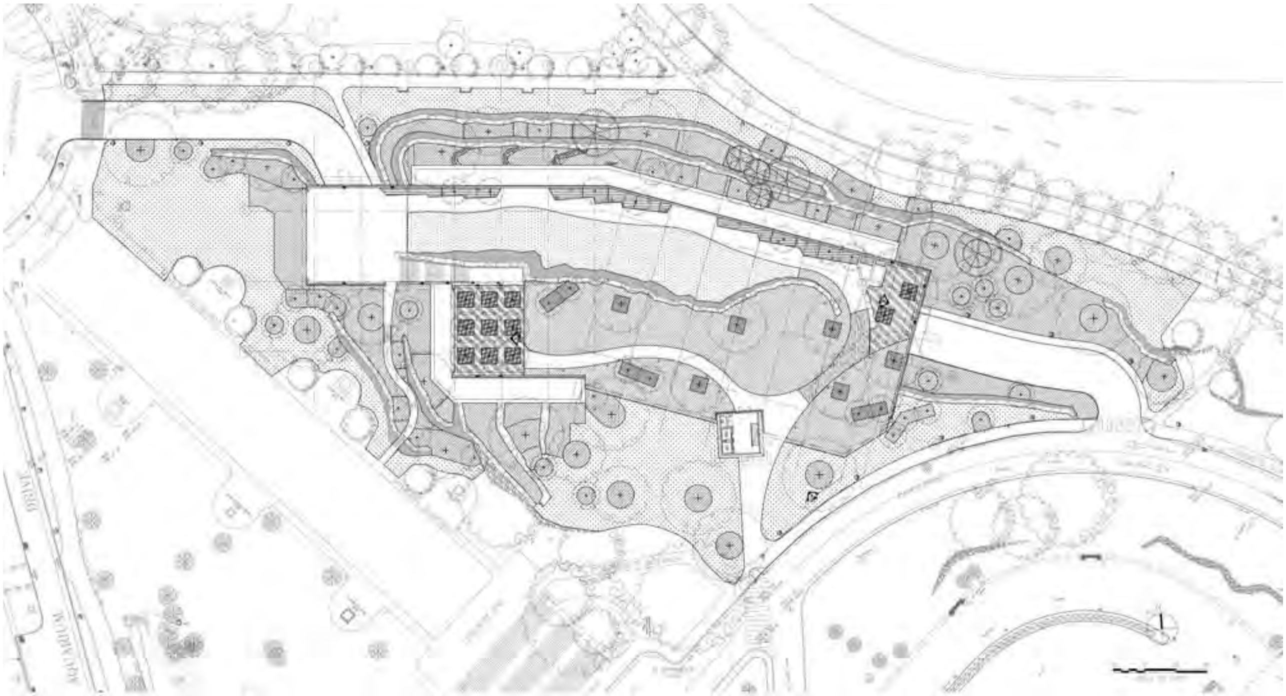


FIGURE 5-8a Development of the fill conditions plan required close coordination and collaboration with the geotechnical and structural engineers to establish design loads and locations for trees and sculpture.

FIGURE 5-8b The fill conditions plan was integrated with the design and detailing of the planting systems.

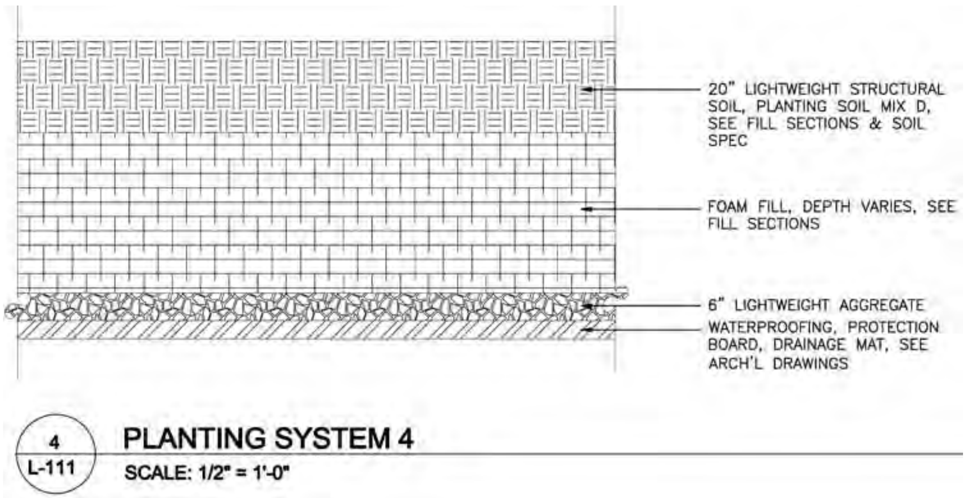


FIGURE 5-9 This detail for a planting system shows fill conditions for a deep section of structural soil used for trees in paving.

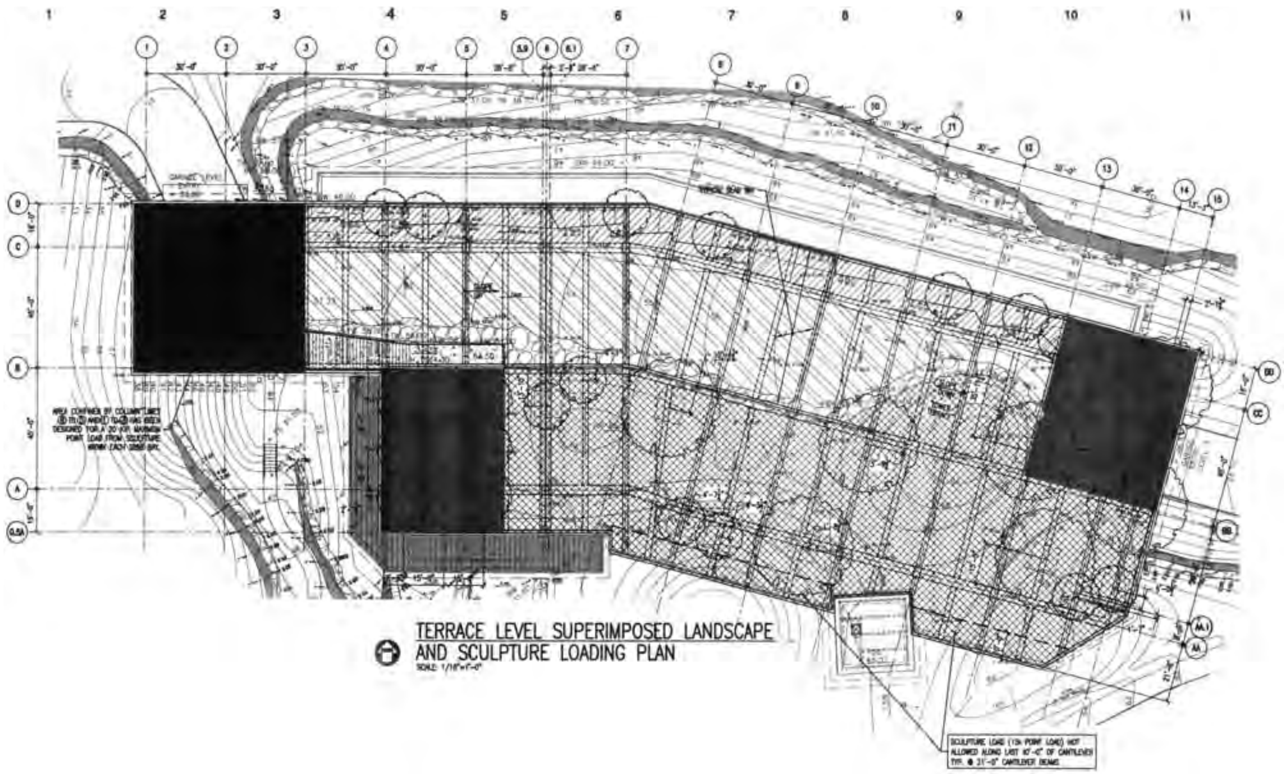


FIGURE 5-10a Terrace-level structural plan with the landscape and sculpture loading plan superimposed.

FIGURE 5-10b Nine different loading conditions needed to be assessed in determining the structural system.

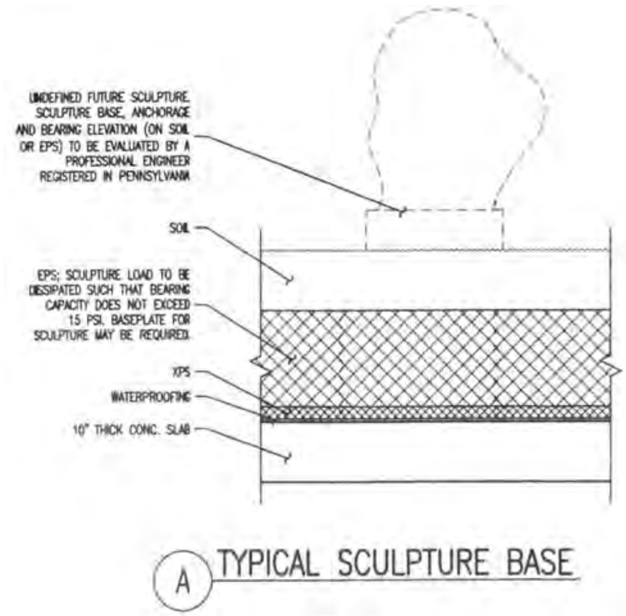


FIGURE 5-10c The structural system needed to accommodate flexibility for sculpture locations.

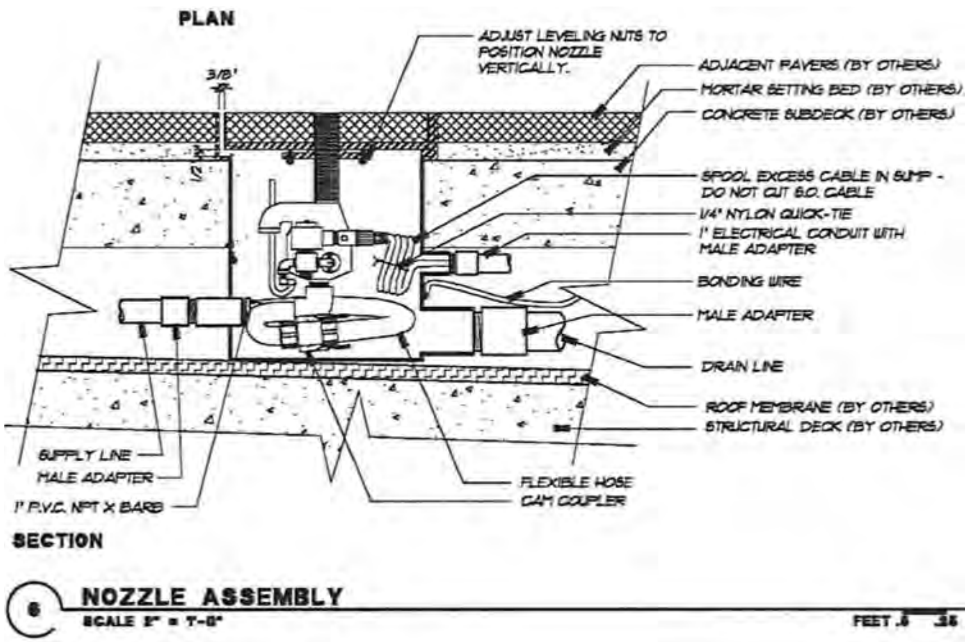


FIGURE 5-11 The limited depth between the top of the structural deck and the finished grade required shallow nozzle assemblies for fountain jets.

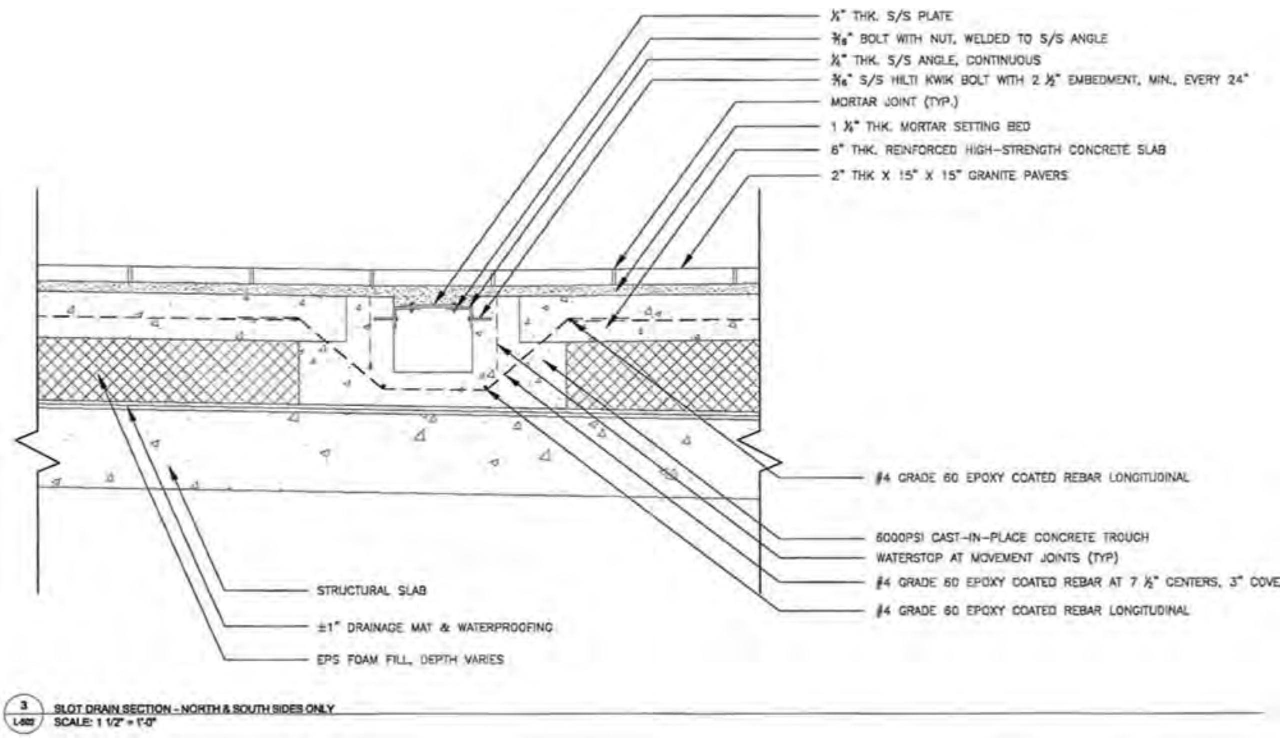


FIGURE 5-12 Detail for paving system integrated with fountain.

Defining Key Structural Considerations: Loads and Basic Structural Principles

To help anticipate constraints, opportunities, and associated project costs, early analysis of proposed loads and testing of proposed structural systems should be part of a coordinated design team effort.

In the conceptual and schematic design phases, the landscape architect should be working with the architect and structural engineer to determine the requirements of the landscape architectural program as it relates to the requirements of the architectural program. From this, the structural engineer will begin to develop loading diagrams and structural systems to support the landscape and building programs.

Basic Structural Properties and Components to Be Considered

STRUCTURAL SYSTEM SELECTION

Supporting a landscape over structure requires the structural support of considerably heavier loads than a conventional floor or roof structure. The heavy landscape loads applied to the structure (these are superimposed dead loads, see below) result in heavy (and often times deep) structure self-weight (also a dead load). Regarding loads, following are some commonly used terms and their definitions.

DEAD LOAD: The self-weight of structure and weight of a non-transient superimposed loads such as soil, trees, and concrete topping slabs.

LIVE LOAD: The load associated with the intended use or occupancy; the building occupants. As an example, from the American Society of Civil Engineers, ASCE 7–05, "Minimum Design Loads for Buildings and Other Structures," the following loads are established for minimum uniformly distributed live loads and minimum concentrated live loads:

TABLE 5-1: Load by Use

Occupancy or Use	*Uniform psf*	*Concentrated lbs*
Assembly areas and theaters		
Lobbies	100	
Stage floors	150	
Office buildings		
Lobbies	100	2,000
Offices	50	2,000
Gymnasium	100	
Sidewalks, driveways, and yards subject to trucking	250	8,000

TRANSIENT LOAD: A moving load, rolling load, or otherwise short-term or temporary load. Wind and seismic loads are considered transient loads.

GROUND SNOW LOAD: Ground snow accumulation data are compiled by the National Weather Service for regions throughout the United States. Local jurisdictions also keep records and prescribe design minimum snow loads (weight). Snow load is a function of the specific gravity of the snow and the depth of expected snowfall in the region.

ROOF SNOW LOAD: Roof snow loading is the ground snow load adjusted for roof slope and wind exposure resulting in a lesser load than on the ground. Windblown snow creates drift accumulation in roof valleys, at roof discontinuities or steps, and against parapets. Drift loads can be many times greater than the ground snow load.

DENSITY: Mass divided by volume, expressed most commonly in pounds per cubic foot or kilograms per cubic meter. Normal-weight concrete weighs 150 pounds per cubic foot; lightweight concrete weighs about 110 pounds per cubic foot.

SPECIFIC GRAVITY: The density of a material divided by the density of water (62.4 pounds per cubic foot). Soil weighing 120 pounds per cubic foot has a specific gravity of 120 ÷ 62.4 = 1.92.

POUNDS PER CUBIC FOOT (PCF) VS. POUNDS PER SQUARE FOOT (PSF): Given a material density in pounds per cubic foot, it is most useful to convert this into a uniform load in pounds per square foot to discuss structural loading and to determine supporting structural member sizes. This is done simply by multiplying the density (pcf) by the depth of the material. For example: 4 feet of soil in a planter weights 480 psf (120 × 4 feet). For comparison, 12 feet of snow in Valdez, Alaska, with a specific gravity of .2 on a school roof weighs 150 psf. This is the actual code-prescribed design roof snow load in Valdez. Twelve feet of snow is only about 30 percent of the weight of 4 feet of soil in a planter. Rooftop plantings are heavy!

POUNDS PER LINEAL FOOT: A line load, such as the weight of a building wall supported by a continuous footing.

LATERAL FORCE: Any force (usually wind or seismic) that tends to cause a buiding to move laterally. Lateral forces are resisted by floor and roof diaphrams that transfer lateral forces to the building's lateral force resisting system (i.e., shear walls, braced frames, or moment frames).

DIAPHRAGM: A horizontal or sloped structural element, usually a floor or roof deck, that is used to transfer lateral forces (i.e. wind and seismic) to the building's lateral force resisting system.

SHEAR WALL: A wall designed to resist lateral forces parallel to the plane of the wall.

COLUMN: A structural member that primarily takes axial loads (loads that are parallel to the long axis of the member).

BEAM: A structural member that primarily takes bending loads (loads that are perpendicular to the long axis of the member).

GIRDER: A larger beam that supports multiple beams.

DECK: An exterior floor supported on at least two opposing sides by an adjacent structure, or by posts, piers, or other independent supports.

BUILDING CODE: A national document that includes building design requirements. National codes are often amended by individual states to include specific requirements. Previously, various codes were adopted by individual states, including the Uniform Build Code, Standard Building Code, National Building Code, and the California Building Code. The current codes used by most states are International Building Codes (IBC).

Other commonly used reference documents are:

ASTM: American Society for Testing and Measurements
ACI: American Concrete Institute
AISC: American Institute of Steel Construction

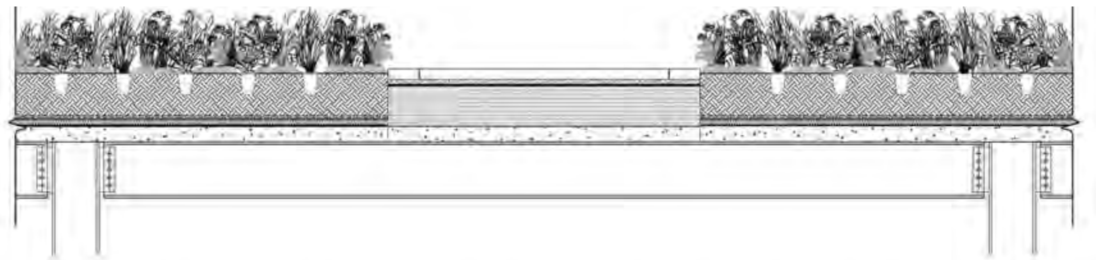


FIGURE 5-13 Section illustrating schematic design for planting and paving over the proposed structural system.

Determining Design Load

Using typical plans and sections, the structural engineer will begin developing loading diagrams that will start to define early structural requirements and potential structural systems that might be appropriate.

From schematic level plans and sections provided from the landscape architect, the structural engineer will know this project area will have a 10-foot-wide band of brick paving over a 2-inch setting bed, approximately 14 inches of lightweight insulating fill, drainage matting, and the waterproofing membrane system. On either side of the paving is a 10-foot strip of shrub planting in 18 inches of soil over 2 inches of insulation and the waterproofing membrane system, but with a different drainage system. The structural engineer has superimposed an initial structural grid with a 30-foot by 30-foot column spacing. Beams spaced at 10-foot on-center frame into girders that span 30-feet from column to column. However, the size and depth of the beam under the paving and planting (beam A) will need to be different than where there is no paving or planting (beam B).

Material Weight for Components

Soil	120 pcf
Pavers	145 pcf
Sand	120 pcf
Insulation	.5 psf per inch of thickness
Drainage mat	4 psf
Definitions:	
Pcf	pounds per cubic foot (same as density)
Psf	pounds per square foot
Plf	pounds per lineal foot
Kif	kips per foot
1 kip	1,000 pounds

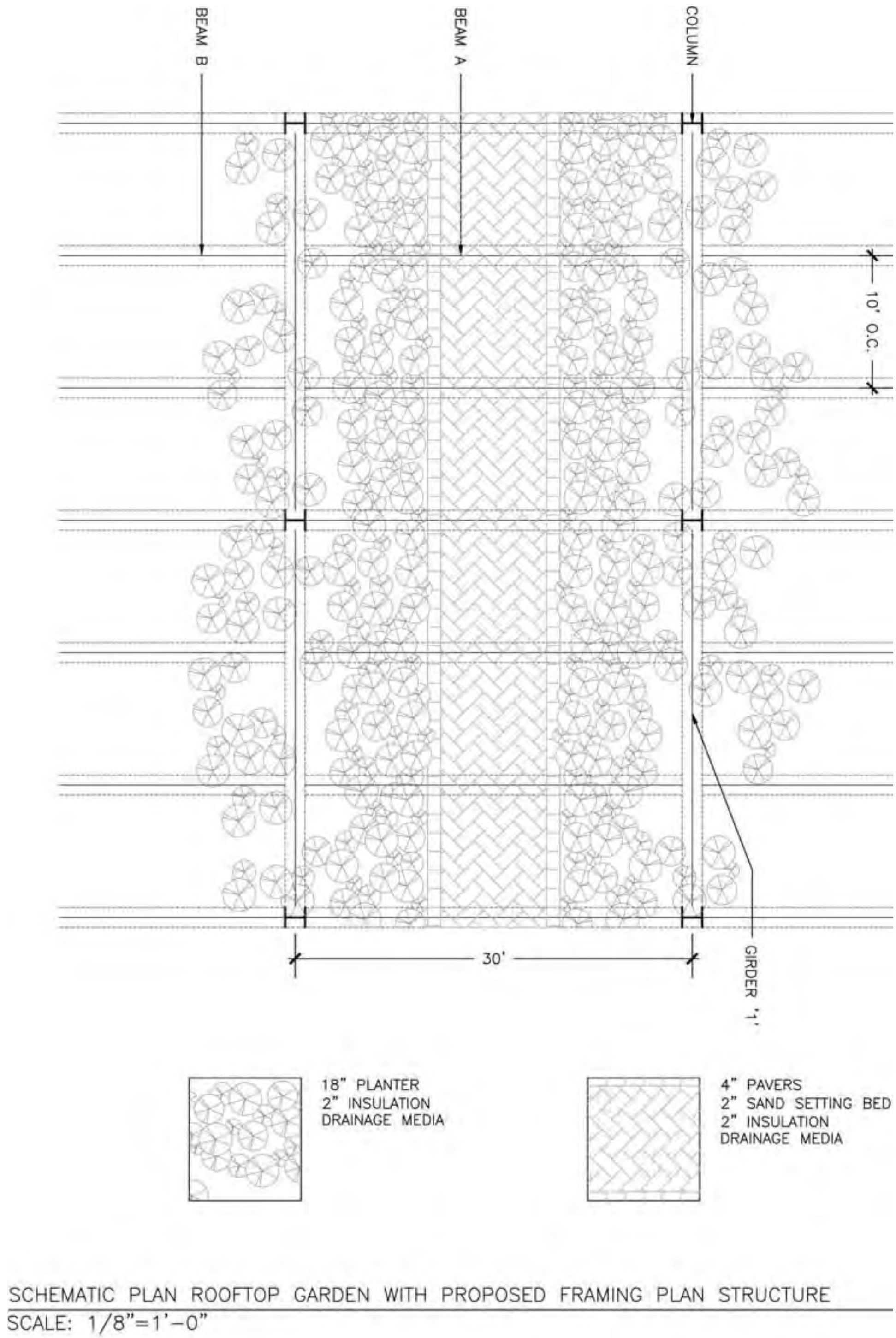


FIGURE 5-14 Plan illustrating structural engineer's proposed structural grid superimposed over the landscape architect's materials plan.

Therefore:

18 inches of soil @ 120 pcf = 1.5 ft × 120 pcf = 180 psf

4 inches of pavers @ 145 pcf = 0.33 ft × 145 pcf = 48 psf

2 inches of sand @ 120 pcf = 0.17 ft × 120 pcf = 20 psf

The loading calculation and diagrams for sizing the beams are shown in Figures 5-15 and 5-16.

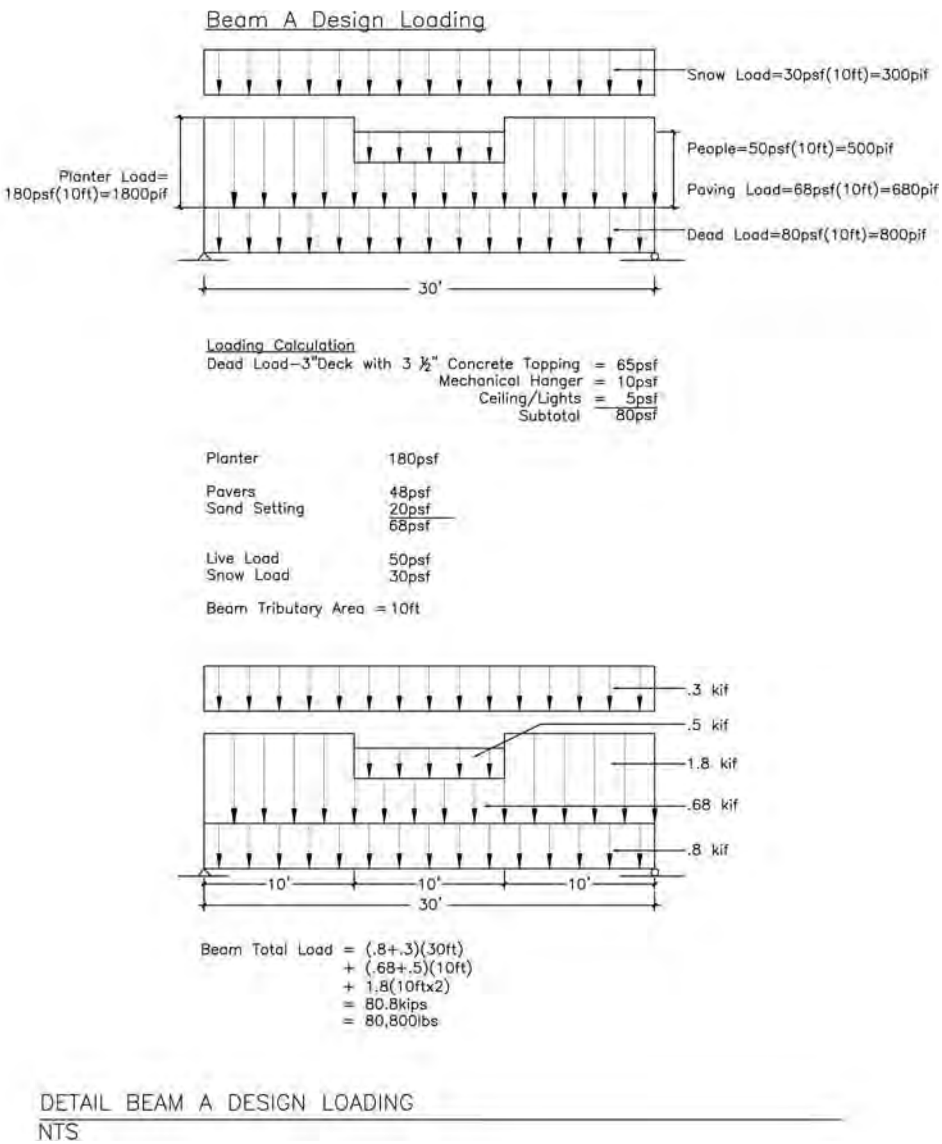


FIGURE 5-15 Structural engineer's loading diagram for sizing beam A and beam B.

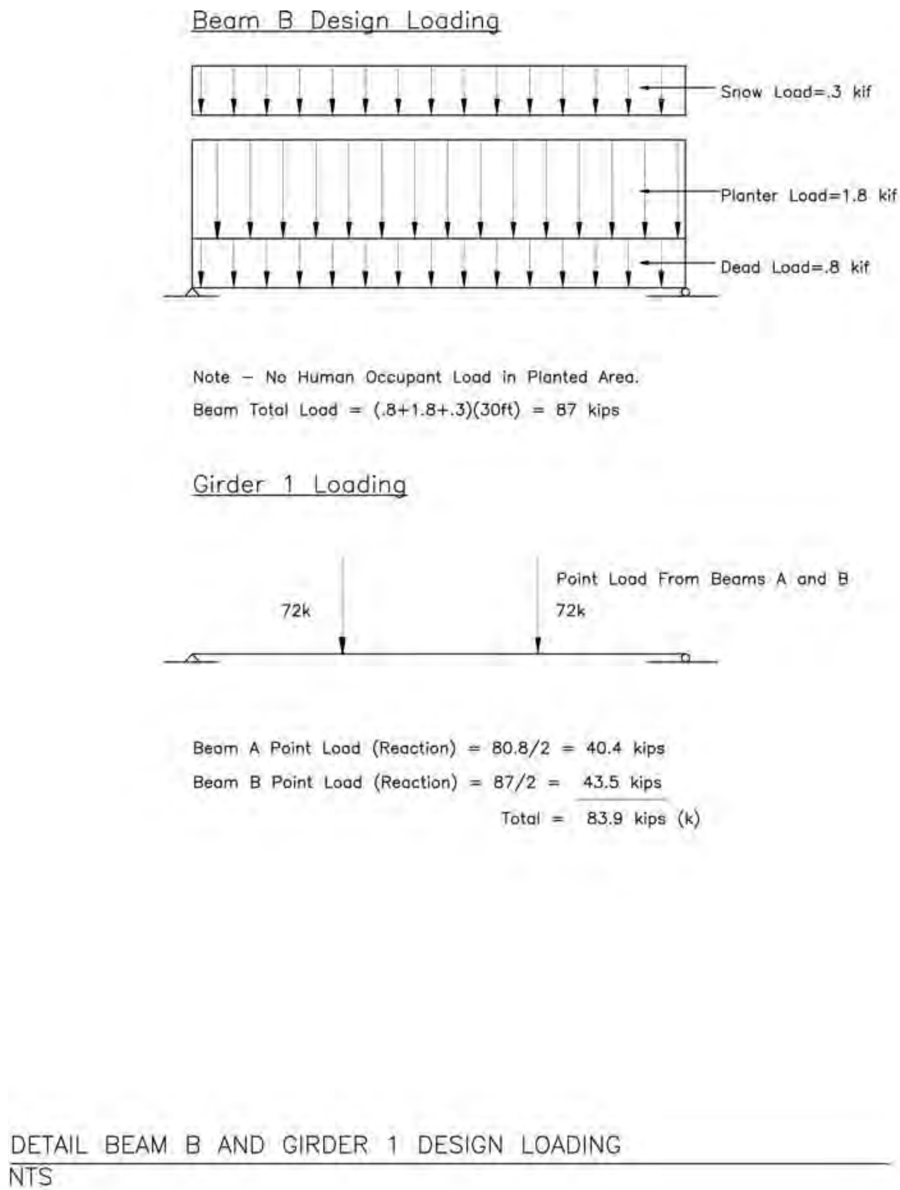


FIGURE 5-16 Structural engineer's diagram for girder 1 design loading.

From this loading information, the structural engineer can perform a preliminary design to establish the depths of beams and girders supporting the landscaped areas. With depths of beams and girders established, the preliminary details can be developed. Figure 5-17 shows the structural engineer's resulting schematic detail for a condition where the paving meets an exterior door. Figure 5-18 shows the structural engineer's resulting schematic detail through the girder in the shrub planting area.

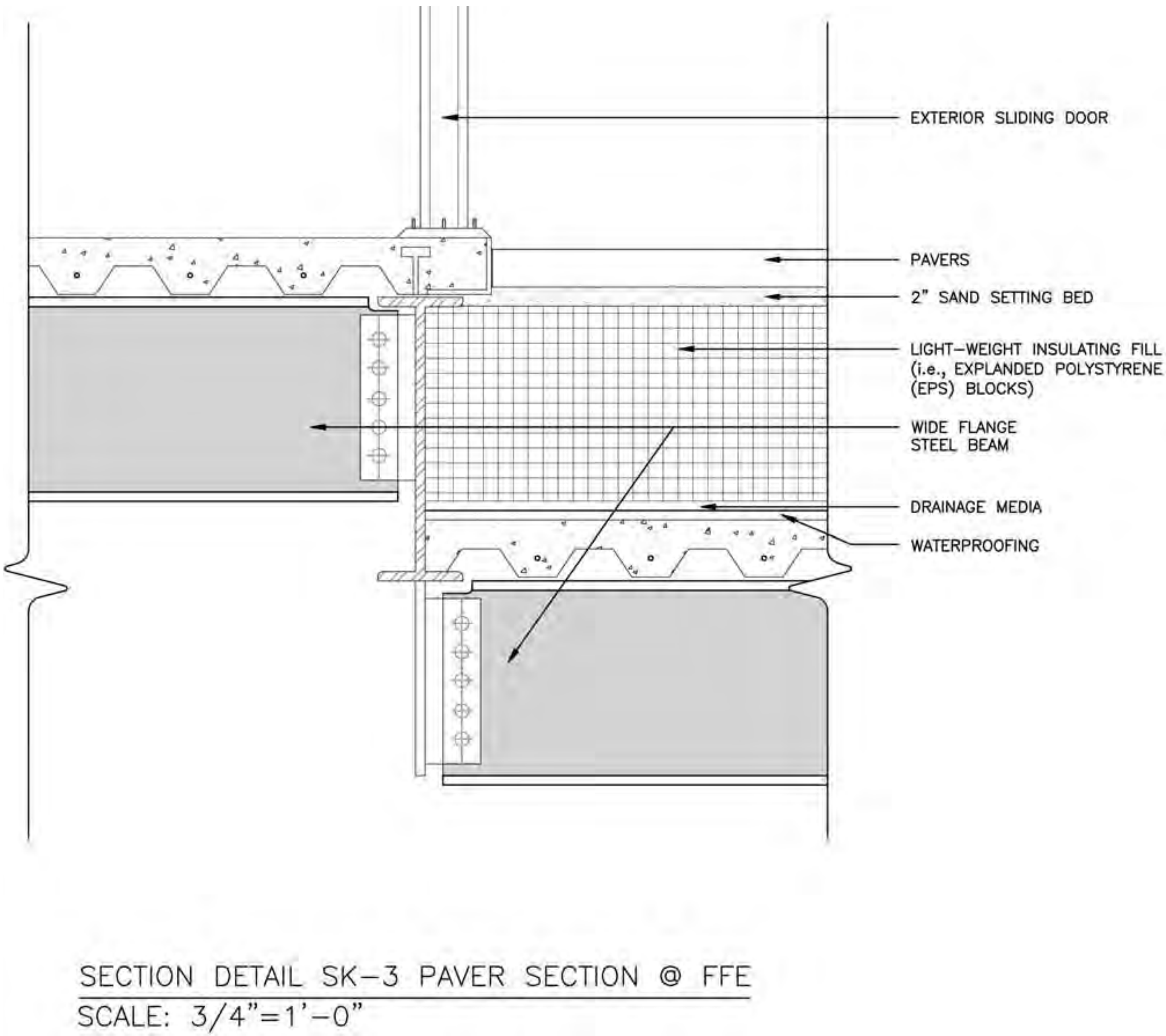


FIGURE 5-17

These details show that the load imposed on the structure due to a particular landscape can be significant. The planting system alone can turn what would be a lightly loaded roof into a heavily loaded floor, or in some instances a roof level responsible for supporting the equivalent of two or three floors' worth of load.

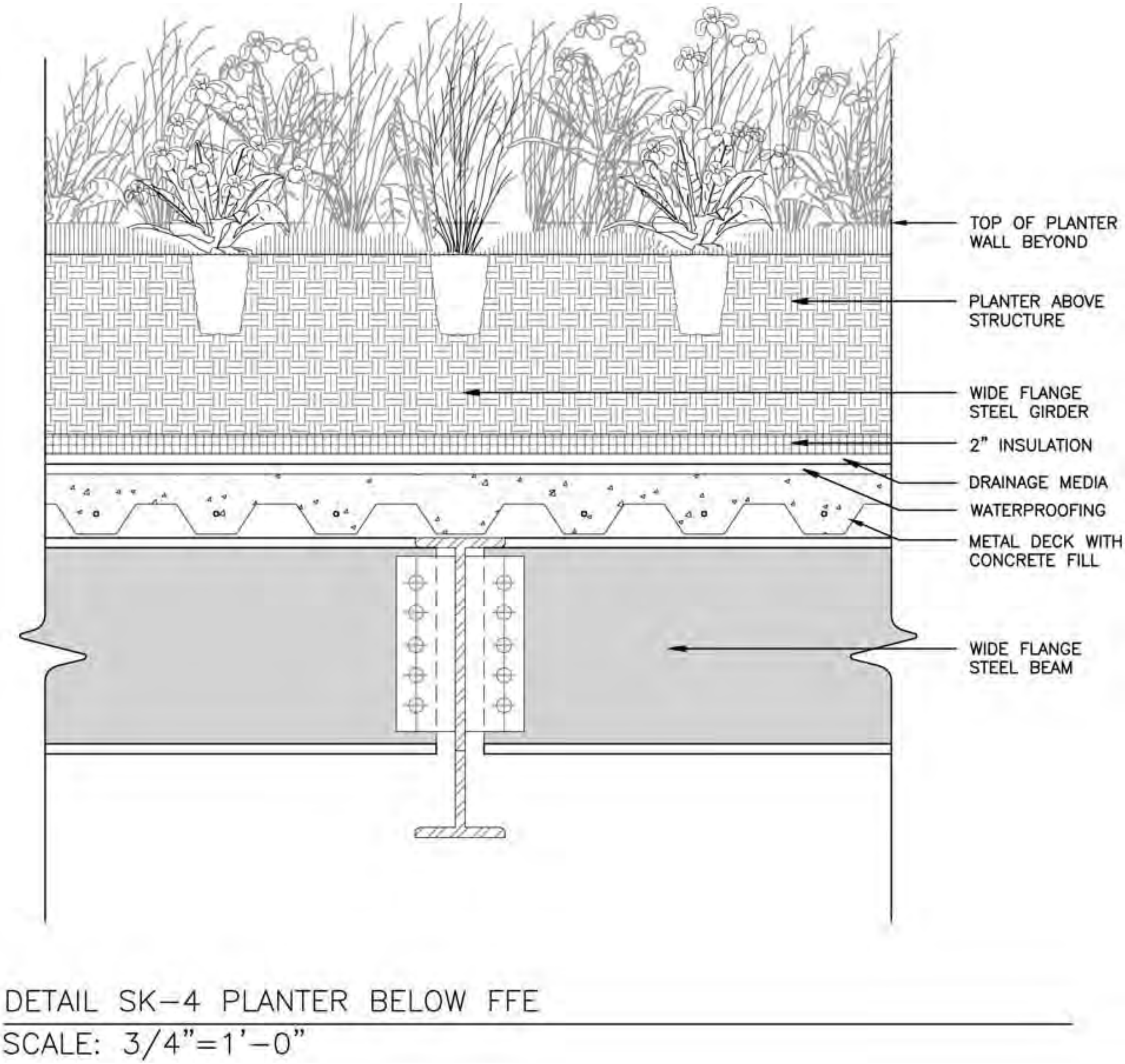


FIGURE 5-18

Load and Relative Cost

Greater loads typically translate into greater cost. This series of sketch illustrations was rendered by the structural engineer during a meeting early in the master planning phase of a multiuse development. The design team and owner were determining the most cost-effective way to organize parking on the site with the least amount of detrimental environmental impact.

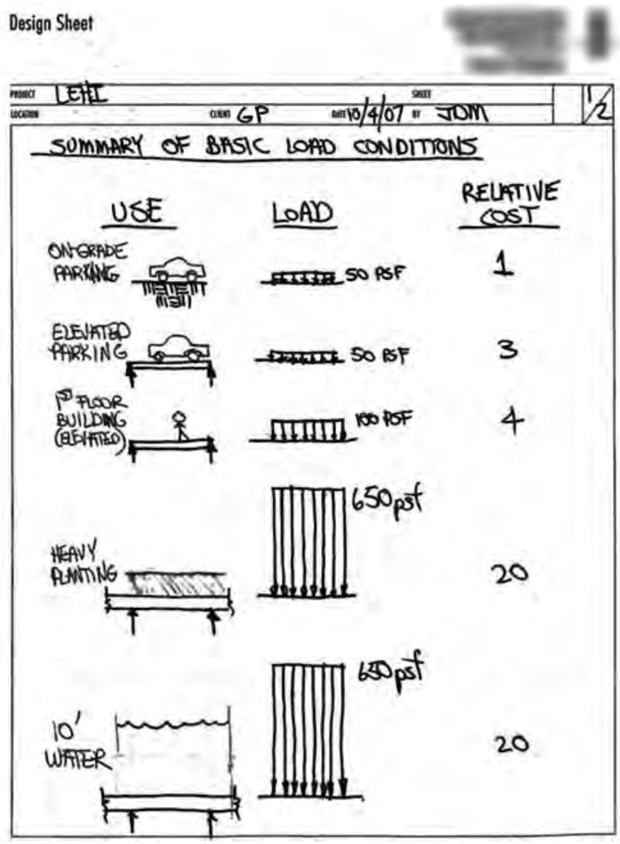


FIGURE 5-19a

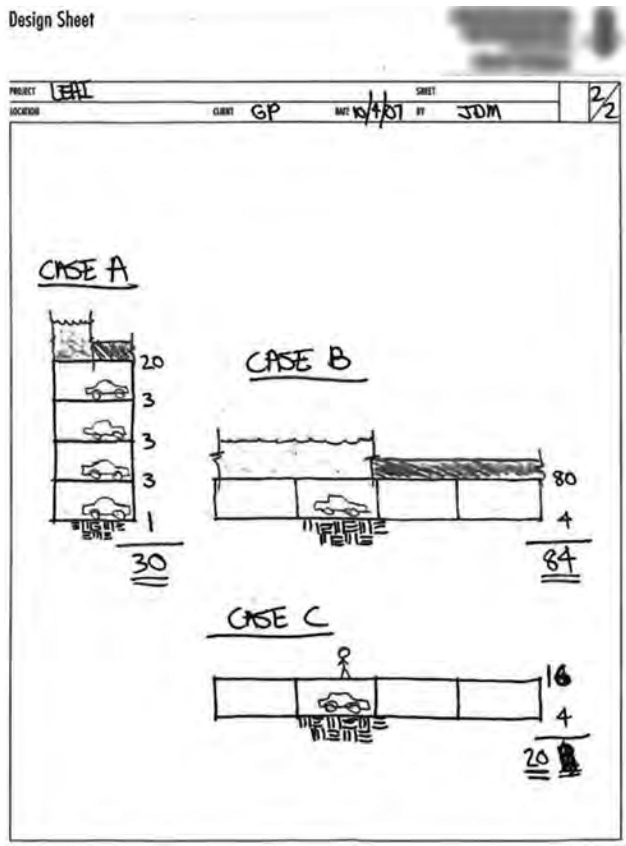


FIGURE 5-19b

Soil Densities and Loads

Soil densities and loads vary depending on the type of soil (or other growing medium), its level of compaction, and its moisture content.

Soil density is measured in pounds per cubic foot (pcf). Soil loads are expressed in pounds per square foot (psf) and are calculated by taking the soil density multiplied by the soil depth. For example, saturated soil with a typical compaction level has a density of approximately 120 pcf. If a 2-foot layer of soil is to be placed on top of a building structure to plant shrubs, the soil load is 120 pcf x 2' soil depth = 240 psf. Practicing structural engineers will typically discuss landscape loads (and most other loads) in terms of pounds per square foot, so understanding their vocabulary and how the soil loads are calculated will be useful in those types of discussions.

TABLE 5-2: Weights of Commonly Used Growing Media Components

Loamy soils (saturated)	100–120 pcf
Clayey soils (saturated)	105–125 pcf
Silty soils (saturated)	100–120 pcf
Humus	80–85 pcf
Mulch	90–95 pcf
Lightweight aggregates	45–55 pcf
Sand (saturated)	120–130pcf
Prefabricated lightweight soils (saturated)	6.5–8 psf per inch of depth

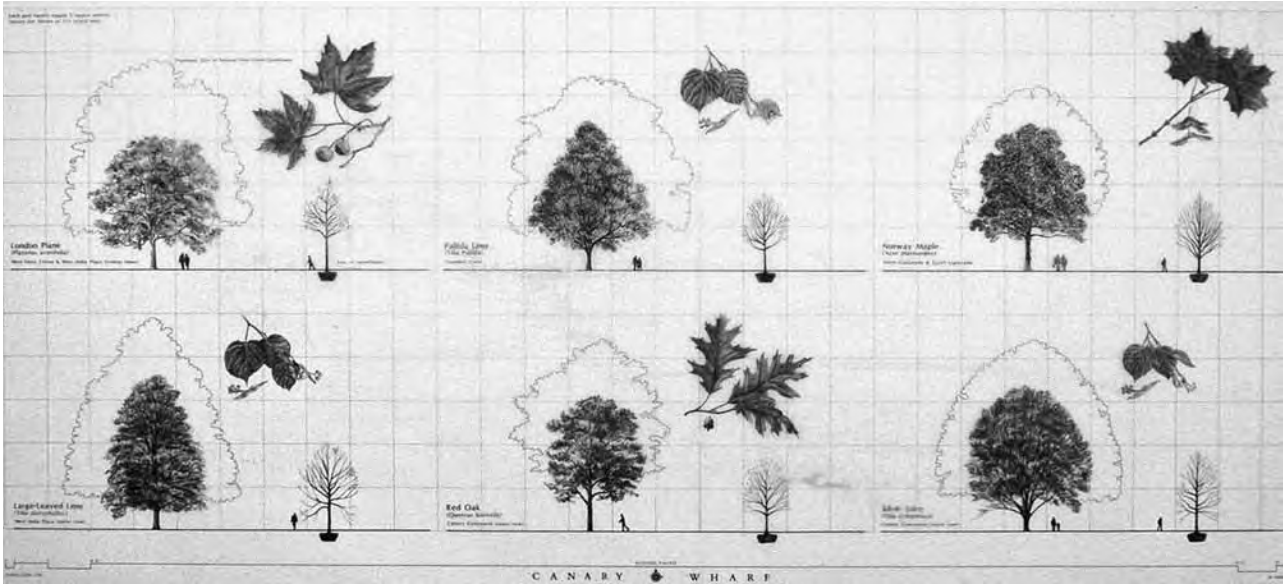


FIGURE 5-20a These drawings were used to help convey to the owner the proposed planting palette as well as the positive impacts of installing semimature trees. The larger-caliper trees were required to buffer harsh winds deflected from tall buildings and the Thames, as well as to provide a more immediate open space infrastructure.

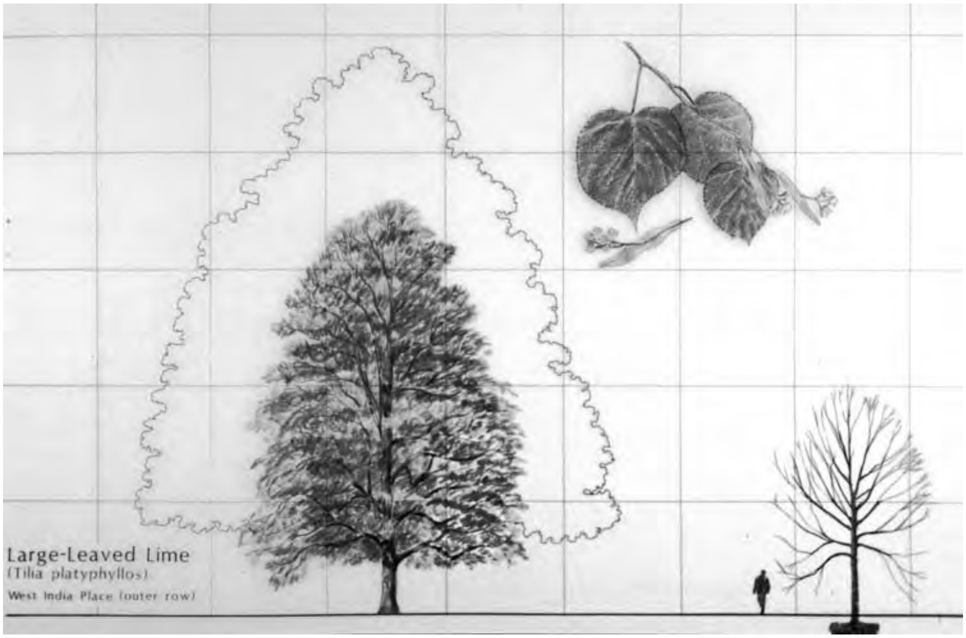


FIGURE 5-20b They were also used to study the size of trees at installation and expected growth in urban conditions over structure. The outermost profile indicates growth expected in terra firma conditions. The grid is 5 meters × 5 meters.

Vegetation Weights and Loads

As discussed earlier, the added weight of a living green roof is about the same as that of stone ballast applied to protect and preserve the waterproofing membrane of a conventional roofing system. The weight of the soil and vegetation of a living green roof is of less concern to the structural engineer than the more variable conditions of a landscape over structure. To the structural engineer, vegetation is broken into three main categories: lawns, short grasses, and ground covers; shrubs; and trees. These categories are distinguished according to the depth of soil required to promote growth and the weight of the vegetation itself. Typical minimum soil depths to promote growth are: 12-inch soil depth for grass areas, 24-inch soil depth for shrub areas, and deeper soil depths to accommodate medium- and large-caliper trees. For lawns and shrubs, the weight of the actual grass and shrubs is typically considered to be insignificant in comparison to the weight of the soil required for growth.

Therefore:

- A lawn area with 12 inches of soil weighs approximately 120 psf (120 pcf x 1' depth). No additional load is added for the weight of the grass itself. (It should be noted that while it is technically possible to grow grass with less than 12 inches of soil, it is highly problematic. Over time the cover soils on elevated sites, such as roofs, become desiccated so rapidly that they freeze and thaw at a faster rate and with more damaging effects than a deeper soil profile.)
- A shrub area with 24 inches of soil weighs approximately 240 psf (120 pcf x 2' depth). Again, no additional load is added for the weight of the shrubs themselves.
- Trees, which are a special load case for a number of reasons, are the only type of vegetation where the vegetation weight is considered significant, both at the time of installation and at full maturity. Therefore, structural requirements for trees are more complex and deserve further consideration.

Design Load for Trees in Landscapes over Structure

There are not many references available that provide guidance on calculating tree loads at installation or determining their weight through growth over time. For this reason, the following section addresses the main components to consider when calculating tree loads and provides an approach to calculate these loads.

The components that make up tree loads are:

- The weight of the tree itself (trunk and canopy) at the time of installation
- The root ball
- The soil around the root ball that fills up the balance of the tree pit (typically for landscape over structure, trees are planted in a defined area or "tree pits")
- The mature tree green weight (trunk and canopy) of the tree at full maturity.

Figures 5-21a and 5-21b show one kind of tree installation over a structural deck. In this figure, a waterproofing system is applied to the concrete roof slab structure. A

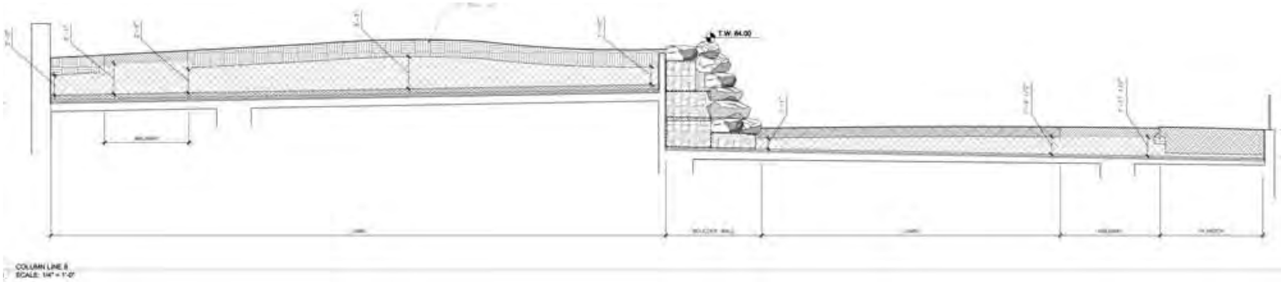


FIGURE 5-21a Section at column line B indicates a drainage system and a planting system are placed continuously over the structural slab. Tree planting pits have been located within the section profile.

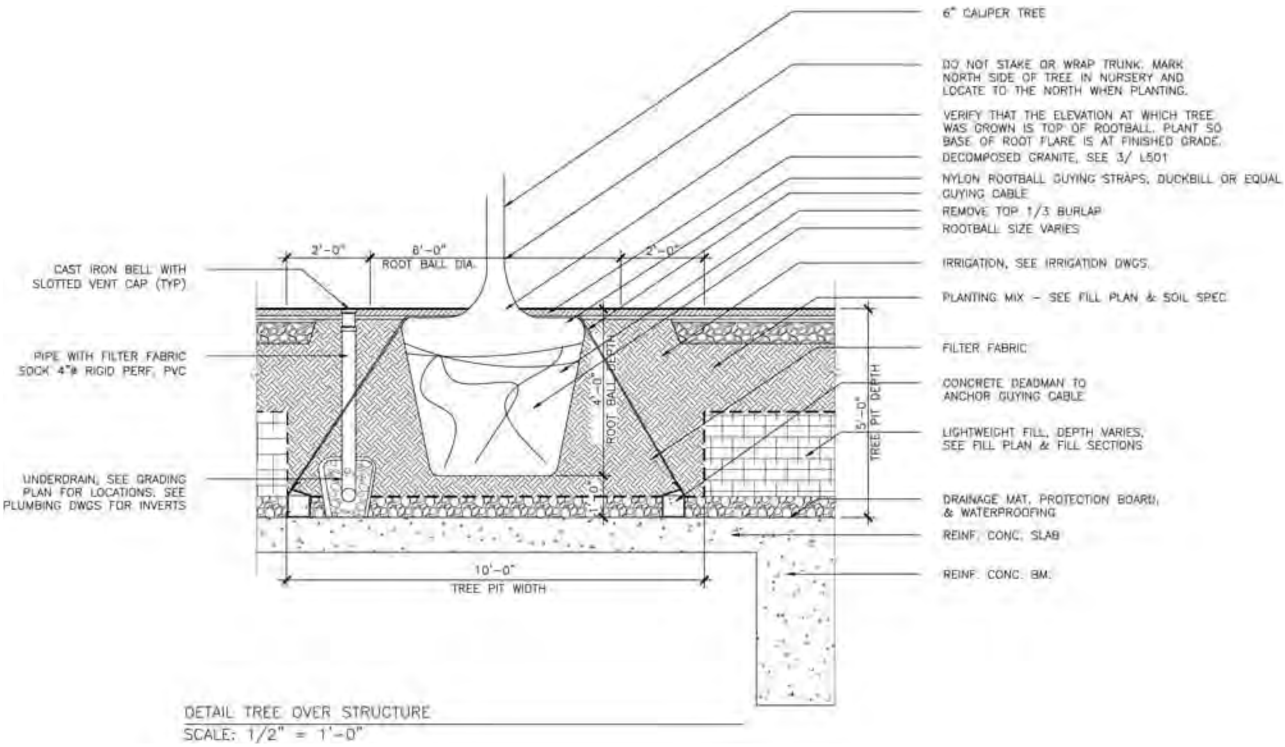


FIGURE 5-21b This detail shows the location of the tree within the section's profile. Note that the omission of the lightweight EPs fill creates the tree pit, which is filled with root ball and soil mix.

6-inch-thick drainage layer is placed over the entire roof structure, and a filter fabric is placed atop the stone drainage aggregate.

To reduce the total weight of the landscape material over the structure, expanded polystyrene (EPs) blocks can be placed over the entire structure, except at locations where trees are to be planted. Omission of the EPs creates the tree pits, where the root balls and surrounding soil may be backfilled with a soil mix. In all other areas, an 18-to-24-inch layer of soil mix is placed on top of the EPs blocks because, in this example, it is the minimum required soil mix depth to accommodate the lateral root network of the newly installed trees, to promote growth and to provide some stabilization of the root mass. (The tree may also require additional below-grade guying.)

This approach to landscape over structure is the result of an iterative design process in which the architect, landscape architect, and structural engineer evaluate a number of considerations, such as requirements for finish floor elevations and top of structural slab.

To calculate the design load for the tree, the structural engineer and landscape architect will need to determine the tree pit size (plan area and depth) so the soil weight in the tree pit (including the root ball) can be calculated. To determine the tree pit size, the structural engineer and landscape architect must estimate the root ball size (diameter and depth) of the tree being planted so that a tree pit of adequate size can be specified to promote tree growth through the life of the project. The structural engineer and landscape architect will also need to estimate the mature tree green weight (trunk and canopy) at full maturity, which is added to the tree pit soil weight to obtain the total tree design load. Although it is not as critical as the mature tree green weight, the tree's weight at installation is something of interest that the structural engineer and landscape architect know.

Weight at Installation

Within the nursery and design industries, there is a rule of thumb which puts forth that two-thirds of the weight of a tree at installation is generally considered to be in the soil of the root ball and the root mass, and one-third is the tree's green weight (trunk, branches, and leaves). Installed weights can be determined by delivery weight information provided by nurseries. As an example, following are some actual weights of trees delivered to a project site:

Approximate Delivery Weight of Trees

Diameter (Caliper)	*Approximate Weight (in lbs)*
3"	4,000
4"	6,000
6"	12,000
8"	16,000

However, there is another generally accepted rule of thumb that 1 inch of caliper translates to 100 pounds of tree green weight, or biomass above ground (trunk, branches, and leaves).

Considering the data in the table above, these two rules of thumb give very different results for the tree's green weight. For example, for the 6" tree in the table above, the green weight would equal one-third × 12,000 lbs = 4,000 lbs using the two-third–one-third rule of thumb. The same 6" tree's green weight would equal 600 lbs using the 100 lbs per inch caliper rule of thumb. These two numbers are significantly different.

In a study done by the USDA Forest Service that spanned 15 years, the green weights for various species of trees were weighed in the field and published in the study.[1] Upon reviewing the data in the study, we find that the 100 lb per inch caliper rule of thumb holds true for small caliper trees (8" caliper or less) at most heights and medium caliper trees (10" to 14" caliper) at heights less than 50 feet. For larger caliper trees at larger heights, the green weight can be as much as 200 or 300 lbs. per inch caliper.

From this, we can conclude that the 2/3–1/3 rule of thumb tends to overestimate the green weight and therefore, underestimate the weight of the root ball. The 100 lbs per inch caliper rule of thumb is more accurate, especially for smaller caliper trees (less than 8").

TABLE 5-3: American Standard for Nursery Stock Minimum Root Ball Sizes

Caliper	*Minimum Diameter of Root Ball*	*Minimum Depth of Root Ball*
3 inch	32 inches	20 inches
3½ inch	38 inches	23 inches
4 inch	42 inches	25 inches
4½ inch	48 inches	29 inches
5 inch	54 inches	32 inches
5½ inch	57 inches	34 inches
6 inch	60 inches	36 inches
7 inch	70 inches	36–42 inches
8 inch	80 inches	42–48 inches

Please note that sizes are shown only for shade trees and, for the purpose of this chapter, for trees of 3-inch caliper and larger.

Source: American Standard for Nursery Stock (ASNI Z60.1–2004). Within this edition there are also recommendations for minimum box sizes.

Size of Root Ball

In the design and construction of landscapes over structure, standards for the diameter and depth of root balls are important. The primary reason is horticultural viability, but these dimensions are also important in determining the depth of the planter area below finished grade required for the tree planting.

The American Standard for Nursery Stock (ASNS) recommends that trees' "root ball sizes should always be of a diameter and depth to encompass enough of the fibrous and feeding root system as necessary for the full recovery of the plant." The size of the root ball will depend upon a number of factors: type of tree and growth habit, growing medium, growing conditions, transplanting practices, and root mass. The root ball size is also related to the measurement of the trunk *caliper* (diameter).

- The caliper of a tree is generally measured at 6 inches above the beginning of the root flare. For trees of greater than 6-inch caliper, it is measured at 12 inches above the root flare.
- The recommended minimum depth of root balls less than 20 inches in diameter should not be less than 65 percent of the diameter of the root ball.
- The recommended minimum depth of root balls greater than 20 inches in diameter should not be less than 60 percent of the diameter of the root ball.

To estimate root ball diameter, a good rule of thumb is that the root ball diameter in feet equals the tree caliper in inches.[2] This rule of thumb results in root ball diameters that are slightly larger than minimums shown in Table 5-3 and this rule is recommended for early planning and sizing of tree pits.

To estimate the root ball depth, a good rule of thumb is that the root ball depth is 2/3 of the root ball diameter. This rule of thumb applies for trees with a caliper of 6" or less. For 6.5" to 10" caliper trees, the root ball depth remains constant at approximately 48" deep. For 11" to 15" caliper trees, the root ball depth remains constant at approximately 60".

Estimating Mature Tree Green Weights

Estimating mature tree green weights (trunk and canopy) is an important part of determining the total tree design load for landscape over structure. The mature tree green weight is added to the tree pit soil weight to determine the total tree design load.

A critical part of estimating mature tree green weight is estimating the caliper and height of a particular species at full maturity, given that it's growing in a landscape over structure environment (as opposed to its natural habitat). Estimating these things can be difficult. Incorporated into a design team's best estimate of how much a tree will grow in artificial conditions are experience, limited actual data, and an understanding of how much biomass a tree might gain over time in its natural environment. Trees may grow larger than predicted, and therefore determining the future caliper and height is at best an estimate founded on a landscape architect's professional knowledge and experience.

Once estimates are made of the tree caliper and height at full maturity, a mature tree green weight can be estimated using research results from the USDA Forest Service. As discussed in the "Weight at Installation" section of this chapter, the USDA Forest Service performed a study that spanned 15 years where the green weights for various species of trees were weighed in the field and published.* Table 5-4 presents green weight data for various species, tree calipers, and tree heights, which can be used by the landscape architect and structural engineer to estimate the mature tree green weight for the landscape over structure project. The caliper sizes selected from the study represent the midrange of the sample data and offer a reasonable expectation of caliper growth expected in trees growing over structure. See the sidebar discussion "Forest Sciences Research and Allometry" for more information on this study.

FOREST SCIENCES RESEARCH AND ALLOMETRY

Although not directed at the horticulture design industry, allometry is the study of the relative sizes of plant parts. It is usually based on relationships of a tree's diameter at breast height, total height, total biomass, leaf weight, and weight of the bole and branches. Often data is derived as both wet (green) weight and oven-dried weight by measuring distinct components soon after felling or by chopping them up and then weighing them.

The resulting data are generally used in forest studies to determine overall biomass, expected annual growth, board feet available for sale, air exchange, and effects of stress factors such as air pollutions or insects.

In a study done by the USDA Forest Service, the *living* or *green weight* (the weight of the entire tree above ground) was measured for eight tree species. The sample trees were selected within a 55 mile range of Houghton, Michigan, and represented an equal number of trees in each predetermined diameter (or caliper) class. After the individual tree was felled, various measurements of heights and weights were determined.*

The terms used in the study, and referenced here, were as follows:

- *Diameter breast height (dbh):* the diameter of the tree in inches outside the bark measured at a point 4.5 feet above the ground
- *Tree height:* the height of the tree in feet from the cut stump to the tip
- *Tree weight:* the green weight in pounds of the entire tree—wood, bark, limbs, and foliage above the cut stump

The data are in Table 5-4 extracted from the study to observe the relationship between caliper size, tree height, and green tree weight (biomass above ground) and are reasonable to use to estimate mature tree green weights for landscape over structure.

*Helmuth Steinhilb, Roger Arola, and Sharon Winsaurer, "Green Weight Tables for Eight Tree Species in Northern Michigan," USDA Forest Service General Technical Report NC-95, 1984.

TABLE 5-4 Tree Green Weights, Height and Caliper dbh in Natural Conditions

Tree Species and Height	*Green Weight, (lbs) 12" caliper dbh*	*Green Weight, (lbs) 16" caliper dbh*	*Green Weight, (lbs) 20" caliper dbh*	*Green Weight, (lbs) 24" caliper dbh*	*Green Weight, (lbs) 26" caliper dbh*
Trembling Aspen					
40' h	934	1,642	NA	NA	NA
50' h	1,161	2,046	3,184	NA	NA
60' h	1,389	2,451	3,816	NA	NA
90' h	2,071	3,664	5,712	NA	NA
Red Oak					
40' h	1,143	2,030	NA	NA	NA
50' h	1,428	2,537	3,963	NA	NA
60' h	1,713	3,034	4,755	NA	NA
80' h	2,284	4,058	6,339	NA	NA
Red Maple					
40' h	965	1,699	NA	NA	NA
50' h	1,201	2,119	2,677	NA	NA
60' h	1,437	2,539	3,739	NA	NA
80' h	1,909	3,379	5,268	NA	NA
Sugar Maple					
40' h	994	1,747	NA	NA	NA
50' h	1,236	2,177	3,386	NA	NA
60' h	1,478	2,607	4,058	NA	NA
90' h	2,990	3,997	6,074	8,735	10,247
White Spruce					
40' h	1,080	1,801	NA	NA	NA
50' h	1,312	2,214	NA	NA	NA
60' h	1,544	2,626	4,017	NA	NA
80' h	2,007	3,450	5,305	NA	NA
Balsam Fir					
40' h	1,064	1,835	NA	NA	NA
50' h	1,312	2,275	NA	NA	NA
60' h	1,560	2,761	4,202	NA	NA
80' h	2,055	3,596	5,578	NA	NA
Red Pine					
40' h	1,044	NA	NA	NA	NA
50' h	1,303	2,311	NA	NA	NA
60' h	1,563	2,772	NA	NA	NA
80' h	2,082	3,964	5,767	NA	NA
White Birch					
40' h	1,005	1,780	NA	NA	NA
50' h	1,254	2,223	3,469	NA	NA
60' h	1,503	2,666	4,161	NA	NA
80' h	2,002	3,552	5,545	NA	NA

(Because most of the fibrous roots are in the upper portions of the root ball, the diameter is more important to the re-establishment of the tree than the depth.)

Recommended root ball diameters and depths for early planning and tree pit sizing are summarized in Table 5-5 (see Table 5-5 footnotes 1 and 2 for more discussion on root ball diameters and depth).

Calculating Tree Load

A procedure for calculating the tree load on a structure is described below. The tree load is comprised of two parts: the weight of soil in the tree pit (including the root ball) and an estimate of the mature tree green weight. The steps below describe how to estimate the tree pit dimensions, which are needed to calculate the soil weight in the tree pit. They also describe how to estimate the mature tree green weight and establish the total tree load. Following this procedure is an example that refers to Figures 5-10a, b, and c. Table 5-5 summarizes this calculation procedure and calculates tree loads for 3" to 12" caliper trees.

1. *Estimate the root ball diameter.*
   Root ball diameter in feet = tree caliper in inches (see "Size of Root Ball" section on page 110 for full discussion).
2. *Estimate the root ball depth.*
   Refer to Table 5-5 for root ball depth as a function of tree caliper (see "Size of Root Ball" section for full discussion).
3. *Determine the tree pit width and depth.*
   The width of a square (in plan) tree pit is determined by the diameter of the root ball, plus some additional width of soil around the root ball to promote growth. Table 5-5 allows for 2 feet of additional soil around the root ball. The tree pit depth is determined by the root ball depth plus the depth of the component layers below it and above the structure. Layers over the structure may include waterproofing, drainage board, insulation, a stone layer, and a soil/sand leveling bed to place and set the root ball. Table 5-5 allows for 1 foot below the root ball to accommodate a 6" stone layer, a 3" to 4" sand leveling layer, and a couple of extra inches for waterproofing, drainage board, and insulation.
4. *Calculate the soil weight (including root ball) in the tree pit.*
   The soil weight (including the root ball) in the tree pit can be calculated by multiplying the soil density (Table 5-5 uses 120 pcf) by the tree pit plan area (width x width) by the tree pit depth.
5. *Estimate the mature tree green weight (trunk plus canopy).*
   Based on the tree species, its caliper at the time of installation, and the growth environment for the landscape over structure, a landscape architect can use his or her professional judgment to estimate how big (caliper and height) the tree could be at full maturity. With this information, Table 5-4 provides data of mature tree green weights as a function of species, caliper, and tree height, which can be used to estimate the mature tree green weight for a landscape over structure project. Table 5-5 uses 6,000 lbs for this value, which encompasses most species up to 20 inch caliper and 80 feet tall.

TABLE 5-5: Tree Design Load

Caliper (in)	*RB Diameter (in)*[1]	*RB Depth (in)*[2]	*Pit Width (ft)*[3]	*Pit Depth (ft)*[4]	*Tree Pit Soil Weight (kips)*[5]	*Mature Tree Weight (kips)*[6]	*Tree Design Load (kips)*[7]	*Tree Design Load (psf)*[7]
3.0	36	24	7.0	3.00	18	6	24	482
3.5	42	28	7.5	3.33	23	6	29	507
4.0	48	32	8.0	3.67	28	6	34	534
4.5	54	36	8.5	4.00	35	6	41	563
5.0	60	40	9.0	4.33	42	6	48	594
5.5	66	44	9.5	4.67	51	6	57	626
6.0	72	48	10.0	5.00	60	6	66	660
6.5	78	48	10.5	5.00	66	6	72	654
7.0	84	48	11.0	5.00	73	6	79	650
7.5	90	48	11.5	5.00	79	6	85	645
8	96	48	12.0	5.00	86	6	92	642
8.5	102	48	12.5	5.00	94	6	100	638
9	108	48	13.0	5.00	101	6	107	636
9.5	114	48	13.5	5.00	109	6	115	633
10	120	48	14.0	5.00	118	6	124	631
10.5	126	54	14.5	5.50	139	6	145	689
11	132	60	15.0	6.00	162	6	168	747
11.5	138	60	15.5	6.00	173	6	179	745
12	144	60	16.0	6.00	184	6	190	743

1. Root ball diameter: L. Halprin, *Cities* (Cambridge: MIT Press, 1972), states that a good rule of thumb is: root ball diameter in feet = tree caliper in inches. This rule-of-thumb will result in slightly larger root ball diameters than listed in ANSI Z60.1–2004 (Guidelines for Root Ball Diameters and Depths) which is okay for the purposes of pit size determination and load calculation.

2. Depth of root ball = ~2/3 diameter of root ball (ANSI Z60.1–2004) for trees with 6" caliper or less. Root ball depth stays constant at 48" for root balls with diameters between 78" and 120", and maxes out at 60" for root balls with diameters between 126" and 180" ("Part II—Estimator's Information; Surtees' Landscape Service Charts; Set No. 1—Ball Sizes—Weights") ANSI Z60.1–2004 also confirms this, as it states that for root balls with a diameter > 48", the depth will be scaled down from the 2/3 guideline.

3. For the purposes of this table, the tree pit width is 2 feet larger on each side than the root ball diameter. This dimension should be verified on each project by the landscape architect, and should be selected to enable installation and promote growth.

4. For the purposes of this table, the tree pit depth is 1 foot deeper than the root ball depth. This is to accommodate the waterproofing, drainage board, a 6" stone layer, and a 3" to 4" soil/sand leveling bed layer to place and set the root ball. If insulation is required, the pit depth may need to be deeper.

5. Tree pit soil weight = soil density (120 pcf used in this table) x tree pit plan area x tree pit depth.

6. Mature tree green weight are obtained from Table 5-4, after discussion with landscape architect who provides direction on estimated tree caliper and height at maturity for a given species growing over structure. For the purposes of illustration, this table uses a 6,000 lb, which corresponds to a 20"-caliper tree, 80' to 90' tall (see Table 5-4). This mature tree green weight is the weight of the trunk and canopy only, not the root ball.

7. Total tree design load = tree pit soil weight + mature tree green weight. Area load in psf is obtained by multiplying load in kips by 1000, and dividing by tree pit area in square feet.

6. *Calculate the total tree design load.*
The total tree design load is calculated by adding the tree pit soil weight to the mature tree green weight. The units for loads this large is usually kips (1 kip = 1,000 lbs). It is often convenient to discuss this load as a uniform area load (a downward pressure), which is calculated by dividing the total tree design load (in pounds) by the tree pit plan area. The units for this uniform area load are pounds per square foot (psf). Total tree design loads, in both kips and psf, are shown in Table 5-5.
7. *Calculate the tree pit soil weight.*
To do this, define the tree pit geometry (width, length, and depth). The width and length of the tree pit are determined by the diameter of the root ball, plus some additional width of soil around the root ball to promote growth. This is typically established by the landscape architect. In this example, 18 inches on each side of the root ball is required. Therefore, the tree pit width (and length) = root ball diameter + 1.5' + 1.5' = root ball diameter + 3'. The tree pit depth is determined by the root ball depth plus the depth of the sand setting bed layer. In this example, the tree pit depth = root ball depth + 6". The weight of soil in the tree pit is then equal to tree pit length x tree pit width x tree pit depth (soil density.
    In this step, the tree pit soil weight includes the root ball weight without "double dipping" on the root ball load. The final tree load will simply be the tree pit soil weight (this step) plus the mature tree weight (step 6). (The only purpose in calculating the root ball weight was to estimate the initial tree weight upon delivery.)
8. *Calculate the total tree load.*
As stated at the end of step 7 above, total tree load = tree pit soil weight (step 7) + mature tree weight (step 6). The unit of measurement for this load is kips, where 1 kip = 1,000 lbs. For example, a tree may have a total tree load of 30 kips, which is equivalent to 30,000 lbs.
9. *Convert the total tree load to psf.*
Alternatively, the total tree load is sometimes discussed in terms of pounds per square foot (psf). This is done by taking the total tree load (in pounds) and dividing by the area of the tree pit. For example, if the 30 kip tree discussed in step 8 above resided in a tree pit whose length and width were 8' each, the uniform load of the tree on the tree pit area would be 30,000 lbs ÷ 64 ft^2 (footprint of the 8' by 8' tree pit) = approximately 470 psf. Please be aware that this higher intensity of load applies only over the footprint area of the tree pit.

For the 6-inch-caliper shade tree shown in Figure 5-10c, calculate the total tree load in kips and in psf.

1. *Estimate the root ball diameter*.
Per the rule-of-thumb discussed in the procedure above, a 6" caliper tree has a 6' diameter root ball.
2. *Estimate the root ball depth.*
Per Table 5-5 on page 114, roof ball depth = 48" = 4'

3. *Determine the tree pit width and depth*.
   Through discussions with the landscape architect, it is decided that the tree pit width should be 2' larger on each side than the root ball diameter, and that the tree pit depth should be 1' deeper than the root ball to accommodate the stone layer and sand setting bed. Therefore . . .
   Tree Pit Width = 6' (root ball diameter) + 2' + 2' = 10'
   Tree Pit Depth = 4' (root ball depth) + 1' = 5'
4. *Calculate the soil weight (including root ball) in the tree pit.*
   Soil weight in tree pit = soil density x tree pit width x width x depth
   = 120 pcf x 10' x 10' x 5' = 60 kips
5. *Estimate the mature tree green weight (trunk plus canopy).*
   Through discussions between the landscape architect and the structural engineer, it is conservatively decided that this 6" caliper White Spruce would likely get no larger than 20" caliper and 80 ft. tall at full maturity. Referring to Table 5-4, we then estimate the mature tree green weight to be 6,000 lbs, or 6 kips.
6. *Calculate the total tree design load.*
   Total tree design load = soil weight (including root ball) in tree pit + mature tree green weight.
   = 60 kips + 6 kips = 66 kips
   Expressing this load as a uniform area load,
   66 kips/(tree pit plan area) = 66,000/(10' × 10') = 660 psf
   This matches the results shown in Table 5-5 on page 114.
   Comparing this high magnitude of load to other cases below,
   - 30 psf snow load on a roof structure without landscape
   - 180 psf of dead load on a roof structure with a grass landscape (6" stone layer + 1' of soil @ 120 pcf = 180 psf)
   - 300 psf of dead load on a roof structure with shrub landscape (6" stone layer + 2' of soil for shrub planting @ 120 pcf = 300 psf)

   one can see how the intensity of total tree loads over the tree pit areas can have a significant impact on the structure below.

Wind Load: Calculating Wind Load on Vegetation

From a structural viewpoint, wind load is typically negligible on grass and shrubs but should be considered on trees planted over structure, though even with trees it is often not a governing load case for the structural engineer. When the wind blows, the wind pressure (measured in pounds per square foot) acts against the tree's canopy and the surface of the trunk. A tree planted firmly in its tree pit, with its root network extending radially over some considerable distance, acts like a vertical cantilever (a flag pole) that is fixed at its base to resist these overturning forces. The real mechanism that provides the tree's stability is the stiff root network. This is why it is so important to promote and establish a continuous and dense root network for trees planted over structure, especially in the upper 12–18" of the planting system.

The vertical forces imposed on the structure due to the wind's overturning effects are in many cases minimal because the radial root network is so large. The broader the base of the radial root network, the smaller the overturning forces that are imposed on the structure below. From a structural engineering viewpoint, the vertical overturning forces on the structure due to wind loads are very small in comparison to the vertical dead and live loads acting on the structure; therefore the vertical overturning forces on the structure due to wind load do not significantly affect the structure's design.

The horizontal forces imposed on the structure due to the wind pressure on a tree's area (canopy and trunk) can be significant to the structure's lateral force resisting system design, depending on the building's size and the nature of the landscape. The height of the vegetation and the planting's density (in plan) will affect the significance of this additional wind force on the structure. For example, consider a six-story building with trees

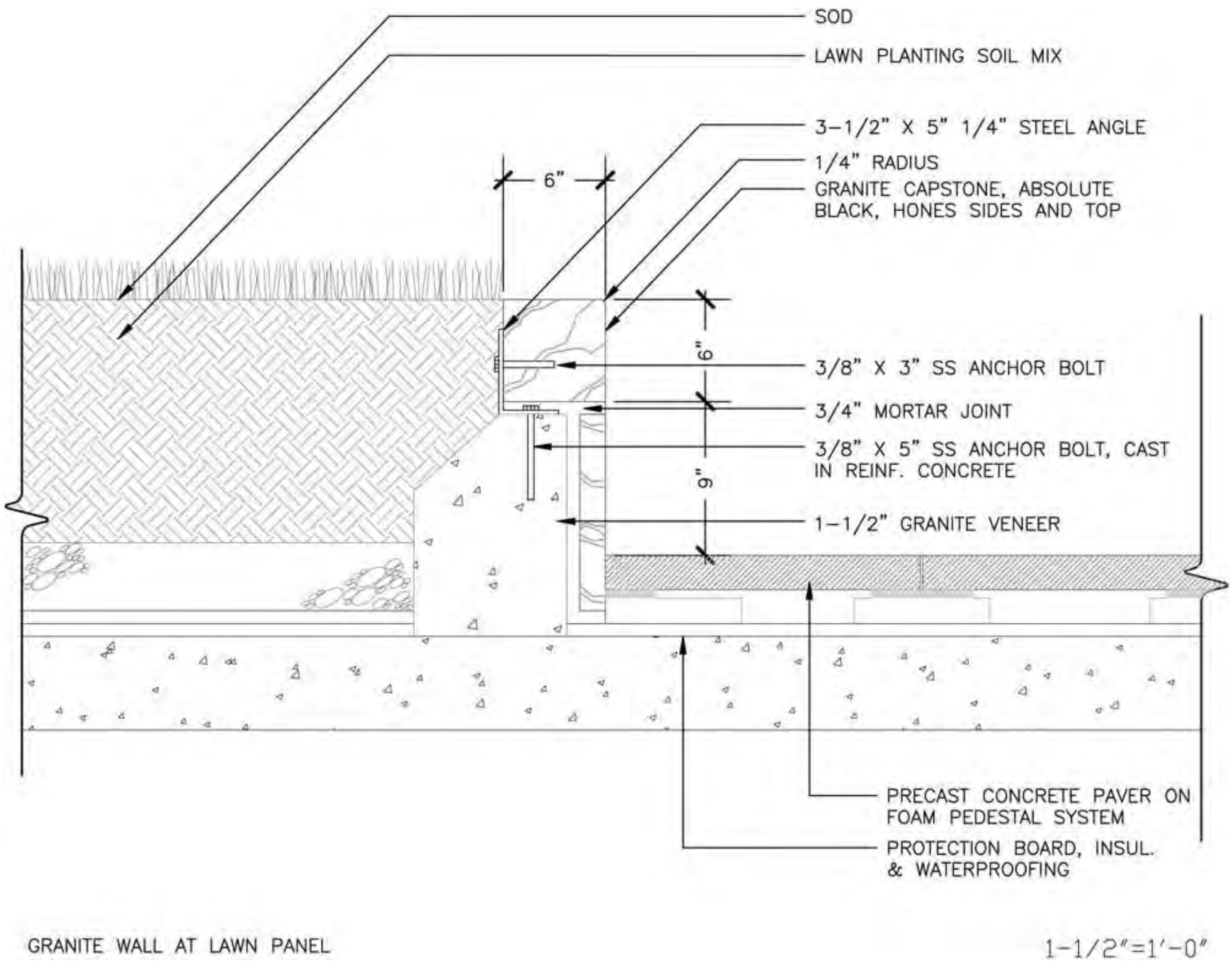


FIGURE 5-22 This detail shows the materials comprising the planter, wall, and paving systems. The weight of each material can be used to determine overall load.

planted sporadically on the structure's roof level. The wind force acting on the building is calculated by multiplying the wind pressure by the building's area in elevation. This will be a large horizontal wind force, as the area of a six-story building's elevation is large. The additional force of the wind acting against trees sporadically placed on the roof should be considered but may prove to be rather insignificant in comparison to the wind acting on the building itself. However, if a one-story building had a landscape over its structural slab, with densly planted trees, the wind load on those trees would be more significant to the building's structural design.

Other Material Weights and Loads

Table 5-6 provides weights for typical materials found in landscapes over structure, such as concrete, topping slabs, granite (stone), gravel, and stone fines.

Water: Basins and Fountains

The unit weight (or density) of water is approximately 62 pounds per cubic foot (pcf). This is about half that of well compacted, saturated soil (120 pcf). Most water features used in

TABLE 5-6: Weights of Commonly Used Materials

Lightweight Components	
Expanded aggregates (shale, slate, etc.)	45–55 pcf
Drainage Materials	
Gravel aggregates	120–135 pcf
Lightweight drainage aggregate	45–55 pcf
Drainage matting	4 psf
Drainage panels	0.75 pcf
Drainage Assemblies	
Mats, panels, filter fabrics, moisture retention matting	2–2.5 lbs/in/ft^2
Insulation	
Extruded polystyrene (xPs)	0.5 psf per 1" thickness
Expanded polystyrene (EPs)	5 pcf
Paving Materials	
Brick pavers (4" thick)	140–150 pcf
Stone (granite, sandstone, limestone, etc.)	150–160 pcf per 1" thickness
Precast concrete pavers	15 psf per 1" thickness
Water	62.4 pcf
Normal-weight concrete	150 pcf
Lightweight concrete	110 pcf

landscape over structure incorporate reinforced concrete to construct the basins, fountains, and other components that are required to contain the water. The unit weight (density) of reinforced concrete is approximately 150 pcf, which is about 2.5 times that of water. For example, a rooftop water feature that holds 2 feet of water will likely require a 6-to-8-inch thick reinforced concrete slab and walls to contain the water. The combined weight of the concrete and water is approximately 225 psf (150 pcf x 0.67' + 62 pcf x 2' = 225 psf). This load is similar in magnitude to planting shrubs over structure with 2 feet of soil (120 pcf x 2' soil depth = 240 psf), which is significant.

Material Loads of Other Site Elements

The weights of other site elements such as walls and stairs would be calculated in a similar way by understanding the component parts, their densities, and their geometry. Site walls, depending on thier thickness and height, can impose significant loads on the structure. Site stairs can also impose significant load to the structure below, due to both the stair's own self weight (dead load) and the code mandated live load for those stairs, which could be as high as 100 psf.

Summary

The load imposed on the structure due to landscape is significant and should be considered when determining loads and accompanying structural systems. All systems—architectural, landscape architectural, structural, mechanical, electrical, and plumbing—need to be thoroughly coordinated in order to ensure a successful project.

Endnotes

1. Helmuth Steinhilb, Roger Arola, and Sharon Winsaurer, "Green Weight Tables for Eight Tree Species in Northern Michigan," USDA Forest Service General Technical Report NC-95, 1984.
2. *Cities,* Lawrence Halprin, MIT Press, 1972.

Chapter 6

Component Parts: Inert and Dynamic

All planting and site work over structure requires careful design, documentation, and construction. Paramount to a project's success is the complete and seamless integration of the structural requirements and architectural expression of what lies below, with the final surface expression of the rooftop or finish grade.

Basic to building successful green roof systems is the structure to support it, waterproofing to protect what is below, protection board to protect the waterproofing, and drainage systems to release excess water beyond the system's retention capacity.

Roofs at any elevation are inherently stressful environments, particularly for planting, because they are subject to excessive heat, accelerated evapotranspiration, and desiccating and potentially damaging winds.

FIGURE 6-1 Living green roof plants offer a great diversity in color, texture, and height for both their foliage and blossoms.

FIGURE 6-2 This fountain at the J. Paul Getty Center, Los Angeles, is part of its extensive courtyards and gardens built over structure.

FIGURE 6-3 Site work for landscapes over structure require careful coordination in design and construction.

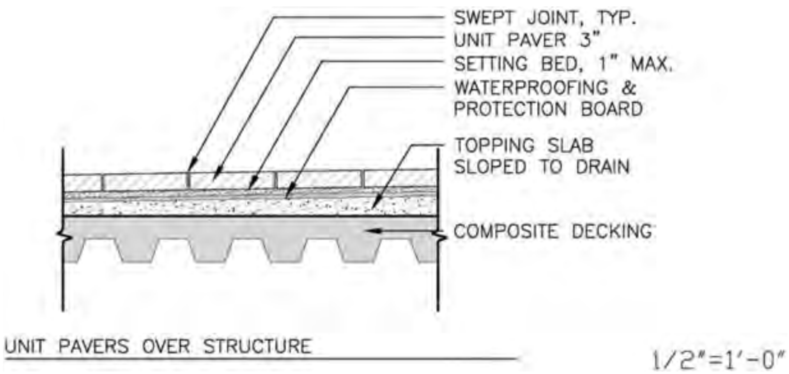


FIGURE 6-4 Composite steel and concrete structural deck with topping slab for positive drainage.

Planting requirements include insulation from thermal fluctuation, sources for water and aeration, the selection of plants that can survive and flourish in an artificial environment, and a growing medium of suitable depth in which the plants can gather nutrients and establish and maintain their root systems.

While from a horticultural viewpoint it may seem that green roof systems are basically composed of soil and plants over waterproofing, it is the thorough understanding of each component and the complexity of the interaction within this layered system that makes them work and thrive.

Likewise, from a conventional site work design and construction viewpoint, paving requires the appropriate slab support, setting, and drainage systems. Stairs and walls require the correct structural integrity and appropriate finishes, and site lighting, fountains, and other major site elements require coordinated mechanical, electrical, and plumbing infrastructure. However, to successfully implement green roof systems, the planning and design considerations, selection of component materials, and coordination required in documentation and construction demand early and continuous collaboration among numerous design disciplines, the owner, and contractors.

Understanding System Components

The basic components of green roof systems are waterproofing, soil, and plants. While this combination of components might not appear overly difficult to design and construct, the success of green roof systems lies in understanding the complexity of and interaction among these parts and the layering of additional supporting components. This is not to imply that green roof systems should be considered difficult to design and construct; rather, the clearer their purpose and the more successful their design and implementation, the more cost-effective and commonplace they will become.

Living green roofs and landscapes over structure should be considered as protective roofing systems, just like inverted roofing membrane assemblies (IRMAs) or gravel-ballasted roofs. The added layers over the waterproofing membrane—insulation and gravel for conventional roofs, or insulation, soil, and vegetation for green roof systems—protect the roofing membrane against direct ultraviolet exposure. The advantage of a green roof system over an inverted membrane or gravel-ballasted roof is that it is a living environment. These environments do require some very specific design of the different components to ensure the integrity of the waterproofing membrane, the extended roof service life, and the successful function of the living green roof or landscape over structure.

In the design and documentation of green roof systems, selecting and specifying the most appropriate components can become an overwhelming task because so little comprehensive information unique or site specific to these systems is readily available. Many of the systems that have been utilized previously came about through a combination of trial and error, experience, and invention. Additionally, like most projects that deal with the dynamic elements of climate and resultant landscapes, no two projects or project conditions are ever the same.

It is crucial to determine not just how the parts of the system combine to function as a whole but also how both the entire system and each component part must perform both initially and over the life of the project. The selection of components can be further complicated because sometimes the same component might be used for more than one function in a system, in different locations. An example of this is drainage matting, which is used under insulation to facilitate drainage across the top of the slab and may also be used just below the soil mix or growing medium as aeration matting.

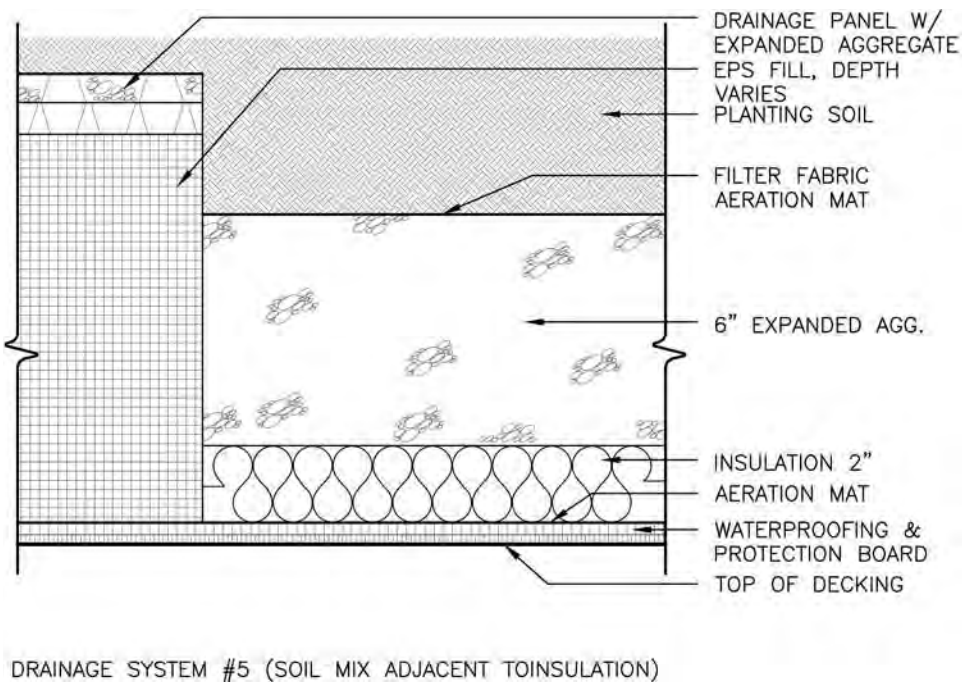


FIGURE 6-5 Drainage over expanded polystyrene (EPs) block used for lightweight fill.

To choose the most appropriate system of components, it is helpful to understand the technical properties that lead to proper sustained performance, whether a product is commercially available or needs to be custom-fabricated, whether or not there are measurable standards and requirements for that product, where it can be found, whether there are similar products of equal or better quality, and whether there are particular attributes that need to be specified for its successful installation and performance.

At a minimum, the following basic information should be determined for each of the components:

- **Function:** What does the component need to do?
- **Physical properties:** What is the component made of and what can that material do?
- **Physical limitations:** Are there any limiting qualities that can affect the component's performance within the system?
- **Relationship to other components:** Is the component compatible with adjacent components?

Component Properties, Function, and Performance

The most basic knowledge of a component should include the ability to provide a general description of its physical attributes, specific function, and system application.

For each component it is beneficial to assess:

- Performance criteria
  - What does it need to do?
  - Does it do what it needs to do?
  - How can the reliability of its performance be evaluated?
- Technical requirements
  - What are the quantifiable requirements?
- Resources for evaluating a product
  - Are there existing industry standards, testing and governing agency standards, or professional association requirements and recommendations?
- Materiality
  - From what is it made, and how does the material affect the component's performance?
  - Is it compatible with other system components?
- Existing products
  - Will an already existing product work in the given situation?
- Fabricators and suppliers
  - Who makes the product?
- Availability
  - Is it readily available?
- Custom fabrication
  - If it is not readily or commercially available, who can fabricate it?
- Evaluating new products and construction trends
  - Are there new or untested products available or should one be invented?

- Considerations in documenting and specifying components
  - Where is the component used? If it is used over an expansive area, are its physical dimensions, as fabricated, consistent with its application?
  - Are there physical or chemical reactions to other materials that may affect the component's performance?
  - Does the component need to be coordinated with other consultants' work?
- Considerations in installation of components
  - Are there particular requirements or logistical considerations for the component's installation or maintenance to ensure the best performance?
- Considerations in specifying components
  - What product data or physical samples are required to ensure that the product used meets the specification?
- Applicable standards
  - What standards are available to help in selecting the appropriate component?
  - What standards are clearly applicable and appropriate to include in the specifications for the component?
  - Does the component need to be confirmed by testing, and if so, how should the test results be interpreted?
  - Are there fabrication standards that need to be reviewed prior to or after fabrication?

Inert Components

The first portion of this chapter provides a basic explication of commonly used inert components in the designing and documenting green roof systems:

- Waterproofing membranes
- Root barriers
- Protection boards
- Insulation
- Insulation materials used as lightweight fill
- Drainage materials
- Aeration materials
- Moisture retention materials
- Filter fabrics
- Drains

Chapter 7 focuses on considerations when combining individual components into appropriate systems during the detailed design and construction of site elements such as planting, paving, walls, and stairs.

Dynamic Components

The latter portion of this chapter provides basic information required to understand the dynamic components of soil, soil mixes, or other growing media and plants. Irrigation as a system is also briefly addressed.

Product Data

Generally, product data:

- Indicate both the product's proprietary name and its generic name
- Provide information in a format that can easily be reviewed for compliance with ASTM or other industry standards
- Clearly identify the manufacturer
- Give a brief product description, including specific applications for which the product is suited as well as limitations and cautions
- Provide information on warranty
- Include physical or chemical properties and environmental data
- Offer a brief description of installation requirements or procedures and recommendations for preparations, protections, storage, or maintenance requirements
- Indicate availability, including how to contact a product representative and where technical assistance services may be found for additional information on suitability or alternative products
- Provide technical data listing applicable standards
- Refer to any ASTM or other industry governing or reference standards

Available Standards and How to Use Them

As with any other design and construction project, appropriate selection, documentation, and specification of a component is essential. In unconventional construction such as living green roofs and landscapes over structure, it is even more important because installations are less common and results over time are not readily available. The current proliferation of manufacturers' "complete green roof systems" makes it tempting to forgo thorough understanding and specification of component parts in favor of specifying a proprietary system. However, each living green roof or landscape over structure has its own unique requirements. It is more than prudent to know what is being specified.

Some standards and references are available that specifically address living green roofs and to some extent landscapes over structure.

FLL GUIDELINES

Guidelines for the Planning, Execution and Upkeep of Green-Roof Sites is produced by the Forschungsgesellschaft Landschahftsentwicklung Landschaftsbau (FLL; German Research Society of Landscape Development and Landscape Design). The most recent English translation of this German publication is based on the 2002 release. They provide very general, basic information on the design, installation, and horticultural parameters for green roof systems. Extensive technical reference data is provided for measuring and evaluating drainage and growing medium aggregate distribution and measuring water retention capacity. However, some of the standards for measurement and testing procedures, particularly for particle testing for growing media, differ from those commonly used in the United States, making it difficult to compare and evaluate test results.

AMERICAN SOCIETY FOR TESTING AND MATERIALS STANDARDS (ASTM)

The American Society for Testing and Materials (ASTM) Green Roof Task Group (E.06.71) continues to develop acceptable high-quality green roof design standards that allow for greater application of standards for a wider variety of green roof systems. Five standards are available:

ASTM E2396–05	Test Method for Saturated Water Permeability of Granular Drainage Media (Falling-Head Method) for Green Roof Systems
ASTM E2397–05	Practice for Determination of Dead Loads and Live Loads Associated with Green Roof Systems
ASTM E2398–05	Water Capture and Media Retention of Geocomposite Drain Layers for Green Roof Systems

ASTM E2399–05	Maximum Media Density of Dead Load Analysis of Green Roof Systems
ASTM E2400–06	Guide for Selection, Installation, and Maintenance of Plants for Green Roof Systems

While somewhat daunting to navigate and to reference, ASTM standards are also available for most individual components of green roof systems.

ASTM standards in general will:

- Provide a standard specification for a type of generic material
- Identify the scope of a particular standard, such as type, physical properties, dimensions, and performance criteria for application
- Identify if there are specific building codes addressing performance
- Reference other ASTM standards for measuring properties or specific terminology
- Establish terminology such as definitions and descriptions of terms
- Establish classification
- Identify requirements for shop drawings, certificates, samples, delivery requirements, etc.
- Establish standards for materials and manufacture, composition, process, or specific safety requirements
- Establish the physical requirements: dimensional requirements, workmanship qualification requirements, strengths, resistance values, and performance
- Establish standards for dimensional tolerance and permissible variations
- Establish requirements for workmanship, finish, and appearance
- Identify test methods for establishing properties and characteristics
- Identify criteria for inspection, rejection, and certification
- Establish standards for specific markings that may be required

Note that the ASTM standard may contain an appendix with nonmandatory information that may offer end-use considerations such as performance over time when exposed to certain environmental or use conditions.

MASTERSPEC

MasterSpec has released Section 02940, Vegetated Roof Assemblies. MasterSpec, a system of consistent specification format and information conforming to the Construction Standard Industry divisions and sections, is prepared and licensed for subscriber use through the American Institute of Architects (AIA).While its full-length version and evaluation provide helpful general comments, terminology, and additional references, use of this MasterSpec section is more applicable to living green roofs than to landscapes over structure. It also tends to be more applicable to specification of proprietary composite systems associated with proprietary waterproofing membrane systems. This may be appropriate if compatibility of systems of a single, specified supplier is required; however, like any other standard, it must be used in conjunction with a complete understanding of the green roof system being designed and documented. Each system of components must be coordinated with all of the design disciplines and specified in the appropriate sections.

Inert Components

Roof Slope

In traditional building terms, the roof is considered the lid or top of a habitable structure that keeps the unwanted weather elements outside and helps maintain the most comfortable conditions and temperatures for human habitation inside. Typically, roofs are thought of as a durable, finished surface for a single- or multiple-story building. They can be sloped or flat and are generally covered with some type of weatherproofing material to

FIGURE 6-6 Steeply sloped roof with a living green roof application. (Photo by re-natur, Germany)

provide protection from the sun, wind, rain, and snow. This finished surface material (such as stone ballast, slate, asphaltic shingles, thatch, green roof system, etc.) is placed over some type of supportive decking that has been treated with a waterproofing substance.

Regardless of its overall configuration and architectural type, a sloped roof sheds rainwater, snow, and ice more quickly than a flat roof and is generally more suited for the application of smaller overlapping units for weather protection such as slate, wood, or asphalt shingles; clay tiles; thatch; or sheet metal. Sloped roofs have greater aesthetic appeal for some, which may be attributed to a more interesting architecture, size, scale, and richness of traditional building materials used for weatherproofing.

Flat roofs are more practical for covering long spans of horizontal surfaces, but flat roofs can also be used to cover smaller structures. Because of the simpler surface configuration, the weather protection for flat roofs can be accomplished through larger units of protection membranes, often of pliable materials, such as molten tars and asphalts or elastomeric or plastic polymer-based sheets. Although in some cases flat roofs are more economical to construct and cover, the primary disadvantage is that the lack of slope, required to facilitate the drainage of stormwater, can lead to accumulation of water in low spots and accelerated deterioration of the entire roofing system.

FIGURE 6-7 A flat roof suitable for an installation of a living green roof. (Photo by Atlantis)

More accurately, the two types of roofs (which can be used in combination) are referred to as *sloped* and *low-slope roofs,* because a slight positive slope on an apparently flat roof accommodates drainage by gravity and prevents water and puddles on the waterproofing for prolonged periods of time.

In conventional construction, low-slope roofs are often covered with

FIGURE 6-8 Roof as floor: installation of waterproofing membrane over the roof deck of parking structure at Pershing Square, Los Angeles.

large expanses of waterproofing membranes and are then covered with stone, gravel, or slag ballast to prevent wind uplift and deterioration from UV exposure. For those looking onto such a roof from neighboring buildings, these can be desolate, unattractive places, with fans, vents, and HVAC systems.

Both sloped and low-slope roofs become extraordinarily hot in direct sun exposure, especially in summer. The variation in temperature, even in moderate climates, can exceed more than 70 degrees over the course of the day. (See Chapter 2 for further discussion on the impacts of heat generated from conventional flat roofs.)

The application of either a sloped or low-slope roof depends on the architecture, building type, historic preservation codes, geographic location, desired function, cost, and personal preference.

The application of a green roof system on a sloped or low-slope roof depends on intended purpose or use and practicality of application. For a living green roof, if the primary purpose is to maximize retention and reduction of stormwater runoff, low-slope roofs are well suited because the minimal slope facilitates the delay and detention of stormwater runoff. Sloped roofs, on the contrary, produce greater volumes of stormwater runoff at a faster rate, because of the forces of gravity pulling the stormwater off the roof deck.

If the primary purpose of the living green roof is aesthetics, reduction of heat gain, increase in biodiversity by attracting wildlife, or visual amenity, sloped roofs are as suitable for living green roof applications as

FIGURE 6-9 Pershing Square "floor" after installation of the site work and landscape planting.

FIGURE 6-10 Successful installation of a living green roof on a 15° sloped roof decking. (Photo by re-natur, Germany)

FIGURE 6-11 Failed soil installation on a sloped surface. Shear forces may not have been accounted for appropriately. (Photo © Jeffrey L. Bruce & Co.)

flat roofs. Of course, installation costs can increase with sloped roofs because barriers or baffles are required to break the shear forces that otherwise increase the possibility of the soil and vegetation layer sloughing off before the plants' root systems interlock sufficiently to form a continuous, stabilized vegetation layer.

For a landscape over structure, multiple configurations and slopes potentially can be accommodated by varying the depth between the top of the roof deck and the finish grade. Installation costs will likely increase with the additional fill required and complexity of construction.

At the scale of the city, low-slope roofs may provide the greatest potential for new or retrofitted application of green roof systems. Therefore, although there are many examples of appropriate application of green roof systems to sloped surfaces, the primary roof type discussed in this section is a low-slope roof and its associated structural deck.

The Deck or Structural Slab

In the design and construction of living green roofs and landscapes over structure, the roof has to be thought of as a floor that can support the required components, and above which a green roof system is built.

The surface upon which a roof is constructed (spanning the beams or joists) is the deck. The deck can comprise a number of structural materials and systems, such as plywood sheathing, metal or concrete, or Tectum in older buildings. Generally, the most suitable finished deck (structural slab) for landscapes over structure is reinforced concrete because of its load-bearing capacity for the added weight of the landscape above. The deck may be a poured reinforced concrete slab or a metal deck that is filled with concrete. However, for living green roofs in new or retrofit applications other decking systems and surfaces may be appropriate because they add less weight. The roofing or deck surface may guide the selection of the most appropriate waterproofing system.

Different waterproofing materials will also impact suitability for a green roof system. For instance, slate, tile, and metal roofs do not lend themselves to a living green roof installation, whereas single-ply or built-up roofs can accommodate them. Metal roofs, in particular, contract and expand with temperature flux, which stresses the membrane under the living green roof. Metal also conducts heat well, transferring temperature changes directly to plants and growing media unless separated by insulation.

Both living green roofs and landscapes over structure are considered protective roofing systems, as are inverted roofing membrane assemblies or stone-ballasted roofs. The added layers over the waterproofing, whether insulation, gravel, paving, or a growing medium and vegetation, protect the roofing membrane against direct UV exposure and potential mechanical damage or wind uplift. The vegetation layer, as a living environment, adds the benefits of energy efficiency, stormwater reduction, and biodiversity in addition to the protection of the membrane. From a construction point of view, there may not be that much difference in the complexity of installing an IRMA or gravel ballast roof and a living green roof. However, the dynamic environments of both living green roofs and landscapes over structure do require a very specific understanding of function, design, and detailing of the different components to ensure the integrity of the entire system and an extended roof service life.

Decks constructed with low or even no slope require high-quality materials and

FIGURE 6-12 Achieving slope of a structural deck.

FIGURE 6-13 Installation of reinforcing for a topping slab over structural deck. (Photo © Jeffrey L. Bruce & Co.)

workmanship to prevent the accumulation of water. Proper construction techniques for adequate deck or slab drainage must be considered and implemented to allow excess water to drain sufficiently by gravity and to avoid deterioration of inert components, such as waterproofing, insulation, and concrete. Adequate drainage via gravity is a primary defense in protecting the roof deck against long-term water collection, progressive collapse, and ultimate failure of the entire system.

Optimal water retention in planted areas makes water available for plants to grow and reduces potable water demand for irrigation. If water is drained away too quickly, plants can't use it. However, excess water in this dynamic system must be drained to avoid anaerobic conditions in soils or growing media. The lack of oxygen in soils can cause them to become "sour" and even toxic to plants, resulting in poor growth or even plant death.

For both conventional roof deck and green roof systems to drain excess water, the minimum slope, or gradient, of the deck should be 1 percent. For poured-in-place concrete decks, the minimum gradient should be 2 percent to account for concrete creep (sag) over time.

Attaining adequate positive slope may be accomplished in a number of ways. If the required floor-to-floor height can accommodate it, the columns can be incrementally shortened to achieve the required deck slope. This allows the deck to slope consistently and maintain the same thickness. If the column heights cannot be adjusted to accommodate the slope, the top of the deck itself may be poured to slope from a given high point,

FIGURE 6-14 Pumping concrete for a topping slab. (Photo © Jeffrey L. Bruce & Co.)

causing the thickness of the slab to vary. (A more in-depth discussion of structural considerations in deck and slab construction is in Chapter 5.)

A topping slab may also be utilized, wherein an additional layer of concrete, sometimes reinforced, is applied to the top of the cast-in-place concrete deck and is sloped in the direction of the predetermined locations of deck drains. Both the topping slab and increased thickness of the slab can increase the complexity of construction, and the additional weight will be of concern to the structural engineer. The loss of depth to finish grade will be of concern to the landscape architect.

Depending on the location of the waterproofing membrane and insulation, however, a topping slab may act as a “working slab” or “waste slab” that protects the waterproofing membrane or other components from damage during construction.

For living green roofs, where the growing medium and overall depth of all the system components does not typically exceed 4 to 6 inches, the slope of the deck may be adjusted by tapering the insulation of an IRMA.

Waterproofing

The primary purpose of waterproofing is to keep unwanted moisture (from rain, snow, hail, and condensation) out of the structure below. Worry about roof leakage is the most frequently cited reason for a client’s hesitancy in including a green roof system. Will the waterproofing membrane hold up to the components placed over it or the activities for which the green roof system has been programmed?

Waterproofing is the primary protective element of the slab and of the structure below. Additionally, because the waterproofing typically is below all the components of a green roof system, it can be difficult to access and repair. The selection, installation, and protection of the waterproofing membrane are paramount to the success and the longevity of any additional components or systems over the structure. The failure of a waterproofing membrane can lead to the failure of the entire living green roof or landscape over structure.

It is essential that the selection and specification of the waterproofing membrane be coordinated with the selection and specification of other components within a rooftop system. This will help ensure compatibility of components and the long-term performance of the entire system and will also help to comply with any requirements of the manufacturer’s or installer’s warranty.

Enormous technological advances in the fabrication, installation, and longevity of waterproofing membranes over the past 20 years as well as newly available leak-detection systems may lessen the hesitancy of a client seeking to utilize rooftops for more than overhead protection. However, it is important to include the client in selecting and specifying the entire system so that the interrelationship of components is understood, particularly for its intended use and subsequent maintenance requirements.

Types of Waterproofing

The following information on differing types of waterproofing membranes is included to provide a broad base of knowledge when discussing and determining the appropriate waterproofing membrane for green roof systems.

Industry and generic definitions of roofing types may vary, but three major roofing types for low-slope roofs are generally recognized:

- Built-up membrane
- Single-ply membrane (which includes hybrid or composite membrane types)
- Fluid-applied membrane

Within each of these general types, the material composition, fabrication method, or installation technique may vary. Table 6-1 highlights the attributes and applicable uses of each type as they pertain to use for green roof systems.

BUILT-UP ROOFING Built-up roofing systems are, as the name implies, roofing systems assembled in place by alternating layers of "felts" and some type of molten bitumen. The felts or plies traditionally have been fibrous material, such as fiberglass or polyester sheets, impregnated with asphalt. In early systems even paper or rags were used. The fiber sheets provide the reinforcement for the integrity of the system. The molten bitumen supplies the primary water resistance and most often is asphalt or coal tar.

Material Composition and Fabrication

Asphalt Asphaltic materials are petroleum derivatives and are the most commonly seen materials in routine waterproofing membrane installation. The hot asphaltic materials are softened in simple on-site "boilers" and applied when liquid. Asphalt is less dense than coal tar and weighs about 20 percent less. It also has a wider range of climate and slope suitability based on softening points. In its processing it can be produced in several different grades or types, each having varying softening points. The higher the softening point, the steeper the roof upon which it can be used.

Coal Tar Coal tar, derived from coal, is sometimes valued for its resistance to exposure to pollutants and ultraviolet rays. It is less soluble in water than asphalt and therefore more resistant to moisture and ponding. Coal tar is more suitable for nearly level or very-low-slope decks.

Installation Techniques Typically, the molten bitumen is hot-applied or "hot mopped." Sometimes it is applied via a flame. The bitumen can also be cold-applied (sprayed or brushed) as a mastic, hardening when the solvents evaporate. The main purpose of the molten bitumen, in whatever the material composition, is to fuse the felts and achieve the result of continuous waterproofing.

Built-up roofs usually consist of three- or four-ply installations and require some type of protection over the surface to protect the membrane from mechanical damage or deterioration from ultraviolet rays. Traditionally a ballast of stone aggregate has been used to prevent ultraviolet deterioration and cracking.

SINGLE-PLY Single-ply roofing systems have been employed since the late 1970s, and are based on the use of large thermosetting (sometimes referred to as elastomeric) or thermoplastic sheets adhered to the deck by any of numerous means. They are called single-ply because one layer of membrane provides the waterproofing.

TABLE 6-1: Waterproofing Membrane Systems

Type	*Material Composition*	*Fabrication Method*	*Installation Method*	*Consideration for Use as Waterproofing System*	*Consideration for Use in Green Roof Systems*
Built-up in situ of layers of felts and molten bitumen	Felts or plies: fiberglass, polyester sheets		Alternating layers of felts/plies	12–15-year life expectancy; needs ballast to prevent UV deterioration and cracking	• Living green roof is same weight as ballast. • Adds life expectancy. • Multiple entry points make it more susceptible to root penetration. • If organic, can serve as food for other organisms. • Requires separate root barrier for use underneath a green roof and separation sheet for material compatibility.
	Molten bitumen: asphalt (petroleum derivative), coal tar (coal derivative)		• Hot-mopped • Flamed • Cold-applied (sprayed or brushed)		• Organic product and can serve as food for other organisms. • Requires separate root barrier for use underneath a green roof and separation sheet for material compatibility.
Single-ply thermosetting	Neoprene, EPDM	Vulcanized or cured at factory, rolls 50–100’ wide	Joined at seams; adhered to deck with adhesives	• Easy to install. Adhered seams may delaminate and leaks may develop over time. • Limited membrane thickness (only up to 60 mil). • Exposed perimeter flashing is UV-resistant.	• EPDM considered most sustainable and is root-resistant, but limited membrane thickness can limit depth of living green roof. • Approved for airport roofs because of resistance to jet fuel emissions.

Type	*Material Composition*	*Fabrication Method*	*Installation Method*	*Consideration for Use as Waterproofing System*	*Consideration for Use in Green Roof Systems*
Thermoplastic, thermoplastic olefins	Plastic polymers (PVC, TPOs)	High heat; flexible sheets	Seams heat-welded with flame, hot air, or solvents to create a continuous sheet of waterproofing. Fully or partially adhered to roof deck or loose-laid.	Greater membrane thickness (up to 120 mil) for better protection. Exposed perimeter flashing is UV-resistant. Heat-welded seams reduce risk of leaks or root penetration. Poor recyclability.	Synthetic material resistant to root penetration. Approved for airport roofs because resistance to jet fuel emissions.
Thermoplastic with thermosetting characteristics	CPE, CSPE	High heat; sheets with curing agents	Sheets		
Thermoplastic modified with bitumen	SBS, APP		Sheets, often with reinforcing fibers or coatings	Resist high heat. Elasticity accommodates deck movement.	Requires separate root barrier for use underneath a green roof and separation sheet for material compatibility.
Fluid-applied	Asphalt emulsions, silicones		Sprayed or rolled	Complex shapes, vertical surfaces	Requires separate root barrier for use underneath a green roof and separation sheet for material compatibility.

Material Composition and Fabrication

Thermosetting Membranes Thermosetting or elastomeric membranes are made from synthetic materials such as neoprene or ethylene propylene diene monomer (EPDM or rubber). These membranes are fabricated and formed into rolls in a vulcanization or curing process that takes place at the factory. The rolls are usually 50 feet wide and 100 feet long and hence provide large sheets to cover large roof areas without the need for multiple seams. Thermosetting membranes do not soften with heat and are not pliable.

An EPDM membrane is considered by some to be the most sustainable waterproofing product when considering toxicity and its life cycle of manufacturing, recyclability, and disposal.

Thermoplastic Membranes Thermoplastic membranes are derived from plastic polymers such as polyvinyl chloride (PVC) or thermoplastic olefins (TPOs). Although they are also

FIGURE 6-15 Heat-welding seams of waterproofing membrane. (Photo: re-natur, 24601 Ruhwinkel, Germany)

processed at high temperatures as liquids or semisolids, they do not undergo a factory curing process. The resulting thermoplastic membranes are flexible and easy to handle. They are stable in temperature extremes: they do not become brittle in cold temperatures or too soft in warmer temperatures. They are pliable when heated and therefore can be heat-welded to create a continuous sheet of waterproofing.

There are many proprietary waterproofing membrane products, fabricated from specific blends of plastic polymers, that have replaced PVC as a preferred thermoplastic membrane.

Thermoplastic Membranes with Thermosetting Characteristics There are some membranes formed with compounds (CPE and CSPE) that are classified as thermosetting and are formulated as sheet materials with curing agents but which do not cure until several months after manufacturing. Thus they are manufactured as thermoplastic membranes but have characteristics of thermosetting membranes.

Modified Bitumen (Mod-Bit, Polymer-Modified Bitumens, Rubberized Asphalt) Another type of waterproofing membrane includes bitumens (rubberized asphalt, derived from asphalt) that have been modified by polymeric binders to enhance elastomeric (SBS) or thermoplastic (APP) properties. These are known as modified bitumen (frequently shortened to mod-bit or rubberized asphalt).

The binders used to modify the bitumen in both sheets and adhesives as well as the reinforcing fibers, granular surfaces, or other coatings produce a combined system with

FIGURE 6-16 Hot-mopping of rubberized asphalt membrane. (Photo © Jeffrey L. Bruce & Co.)

increased flexibility (SBS), resistance to UV rays, resistance to extreme temperatures (APP), resistance to fire, and resistance to material fatigue caused by any of the preceding conditions. As proprietary systems, these assemblies may utilize separate plies: a base ply as the actual membrane, intended to provide elasticity to accommodate deck movement (which is important for landscapes over structure but not so much for living green roofs), and a top ply, which may be a layer of reinforcing fibers impregnated with the modified bitumen.

Hybrid or Composite Membranes Modified bitumen membranes are sometimes installed in multiple plies and over built-up systems utilizing asphalt-impregnated rolls of felts. These composite systems provide the durability of a built-up membrane but do not require the deck to have the load-bearing capacity to sustain the heavy aggregate ballast needed to protect the membrane against wind uplift and deterioration from UV exposure on conventional roofs.

Installation Techniques Single-ply membranes are commonly manufactured in large rolls, which are rolled out on the roof and the seams joined in situ.

Thermosetting membranes are joined at the seams and are adhered to the deck with adhesives. Some products have pressure-sensitive tapes on the seams to facilitate installation; however, these glued seams may delaminate over time, posing a greater risk for leaks.

Thermoplastic membranes' seams are heat-welded by flame, hot air, or solvents to create a continuous sheet of waterproofing. The consolidated waterproofing membrane is then secured on the roof using mechanical fasteners or adhesion, depending on both the deck configuration and material characteristics of the membrane.

Fully adhered applications utilize sheets and adhesives to completely adhere the membrane to the deck. Sometimes the sheets have prefabricated adhesive strips, and sometimes hot- or cold-applied adhesives are used. A fully adhered roofing membrane means that, should a leak occur, water cannot travel underneath the membrane but usually surfaces inside the building at the location of the damaged membrane. Fully adhered systems are a preferred option for installing single-ply waterproofing and often are required by property insurers to lower the risk of wind uplift.

Partially adhered applications rely on adhesion at specific points by means of mechanical fasteners or battens attached by screws concealed and impeded from protrusion into the membrane by overlapping and sealed seam edges. For a green roof application or conventional roof, this means that water can travel underneath the waterproofing should a leak occur, which complicates the efforts to find and repair leaks in the waterproofing.

Loose-laid applications are installed by rolling out the sheets, seaming all joints, then attaching the entire membrane at the roof deck perimeter. To protect the waterproofing against wind uplift, ballast of gravel, pavers, or established vegetation is required to weigh the membrane down. The added material often also functions to protect the membrane against UV exposure and deterioration or damage by hail or falling debris. Loose-laid membranes are used to protect the membrane against shear force in applications where lateral movement is expected in the deck.

Green roof systems can function as ballast but as such need to meet a minimum critical weight so that during dry soil conditions the roofing membrane is sufficiently protected against wind uplift. (See Chapter 9 for more details regarding wind uplift requirements and considerations.)

FIGURE 6-17 Application of membrane reinforcement. (Photo © Jeffrey L. Bruce & Co.)

FLUID-APPLIED MEMBRANES Fluid-applied systems are most often used for complex shapes such as domes and shells as well as for vertical sides requiring waterproofing. Water-repellent compounds such as asphalt emulsions, silicones, and neoprene are typically applied with sprayers and rollers.

Selecting the Most Appropriate Waterproofing System for Green Roof System Applications

Although there are advantages and disadvantages for each, any of the above systems may be used in green roof applications if the waterproofing membrane is protected from above by insulation, protection board, or other components. A significant measure of exposure protection is inherent in covering the waterproofing membrane with plants, paving, or other site elements.

BUILT-UP MEMBRANES IN GREEN ROOF SYSTEM APPLICATIONS Built-up membranes typically have an average life expectancy of 15 to 20 years with traditional protection measures (ballasts, etc.), sometimes longer. Even though they may have a relatively long life span, built-up roofs are less commonly used in green roof systems because they are more labor-intensive to install and maintain.

While a living green roof or landscape over structure can serve the same function as stone ballast—protecting the membranes from ultraviolet deterioration and atmospheric pollution—built-up membranes are considered to be more susceptible to root penetration because of the multiple plies, which provide multiple entry points for root growth and thus air and moisture. Additionally, asphalt is an organic product and can serve as food for organisms. In green roof systems, an asphalt-based roofing system must be covered with a high-density polyethylene (HDPE) membrane, or root barrier, to prevent root penetration.

SINGLE-PLY MEMBRANES IN GREEN ROOF SYSTEM APPLICATIONS Single-ply membranes average a serviceability of 10 to 15 years. A major advantage in the use of single-ply systems is that they are faster to install and require less labor than built-up systems. Because of their characteristic flexibility, they are less susceptible to cracking and seam failure; combined with fewer seams, this lessens the potential for leaks. Both PVC and EPDM membranes have been considered easy to install and comparatively low-cost. The use of single-ply waterproofing for green roof applications varies widely, from small residential installations using 45- to 60-mil EPDM to complex roof decks using 80- to 120-mil PVC membrane over concrete, wooden, or even Tectum decks. There are also flannel-backed PVC membranes to help smooth out a rougher concrete surface without compromising the waterproofing integrity.

EPDM membranes provide a good system for living green roofs because the synthetic rubber is root-resistant, and an additional root barrier may not be necessary. For smaller green roof projects with a roof width less than 50 feet, EPDM is also an excellent choice because of ease of installation, a minimum of seams, and overall functionality and cost-effectiveness.

FLUID-APPLIED MEMBRANES IN GREEN ROOF SYSTEM APPLICATIONS As discussed above, fluid-applied membranes are most often used for complex shapes such as domes and shells as well as for vertical sides requiring waterproofing. Their application

A Comparison of Waterproofing Membrane Use in Europe and the United States

In Europe, where living green roofs are quite common, installers use 60- to 80-mil PVC single-ply roof systems for the most efficient, cost-effective construction. Reinforced PVC works well for waterproofing because it is heat-seamed, which reduces the risk of potential leaks, and it also provides protection against root penetration. While PVC is not a sustainable material due to its manufacturing process and poor recyclability, it performs multiple functions and thus eliminates the need for additional materials and associated costs.

Other suitable materials commonly used in Europe for waterproofing and root protection include rubber membrane (EPDM) or hypolan (CSPE). The disadvantage with EPDM is that seams need to be bonded with adhesives or tape, which might present a higher potential risk for leaks. Thermoplastic olefins (TPOs) are also specified for green roof system base waterproofing and are often considered more environmentally acceptable than PVC. However, TPOs have not been on the U.S. market as long as they have in Europe and thus have not been as well tested here. Additionally, U.S. manufacturers of TPOs often need to add bromides (fire retardants) to meet the more stringent U.S. fire codes. These bromides can interfere with the long-term performance of the membrane.

in green roof systems might be appropriate for the vertical surfaces of planter walls, stairs, or other site elements of landscapes over structure. Complex shapes such as domes or shells would most likely not accommodate living green roofs or landscapes over structure.

Considerations in Selecting a Waterproofing System

Because of the importance of this primary protection, waterproofing systems with multiple functions and greater longevity are preferred. Failure of the waterproofing system can lead not only to interior damage to the building but also to the erosion or corrosion of the reinforcement and slabs. Many green roof systems have outperformed conventional roofs because of the inherent protection of the waterproofing. However, the costs of replacing any waterproofing can be high, and that is even more true for living green roofs and landscapes over structure because of the inherent complexity. This often means that green roofs are not fully replaced as designed when problems occur. The waterproofing system is repaired without replacing the green roof system as originally designed, leaving only aesthetically unpleasing, unusable green roof ghosts.

The selection of the waterproofing system ultimately may rest with the architect; however, it should be with the consultation of the structural engineer, landscape architect, supplier, installer, and owner. The waterproofing system utilized for construction of living green roofs and landscapes over structure will be based on a number of considerations.

Size and complexity of the deck configuration: A deck surface that has numerous upturned beams, planter walls, wall or stair footing changes in elevation, water features, or penetrations may not lend itself to complete and adequate coverage by a single ply.

Assigned use below deck: The use below the deck may also have a major impact on the selection of the waterproofing system. A green roof system over an unheated parking structure may allow the use of a less conservative system than if over library stacks or a collection of priceless art.

Construction techniques: Green roof systems require installation and subsequent maintenance measures that may affect the selection of the waterproofing membrane. Avoid construction techniques that might allow:

- Excess moisture in the concrete deck, because it can cause vapor expansion leading to rupture and excess vapor below the deck
- Thermal expansion or movement, because it may cause cracking or tearing of the membrane
- Mechanical damage to the membrane during construction
- Mechanical damage to the membrane during subsequent installation of surface or subsurface elements (footings, irrigation, electrical conduit, new drains or new utility cores, plants with large root balls)
- Leakage at seams, drains, flashing, or penetrations for utilities

Program and maintenance: The programmed use of a landscape over structure (not to mention future uses not yet foreseen) may warrant a different waterproofing system than an inaccessible living green roof. Expected and probable maintenance, including inspection of both the waterproofing membrane and other components above it, may also affect the selection of the system.

Accessibility to the membrane: If the waterproofing membrane will be easily accessible for inspection and repair, the choice of waterproofing system may be different than in the case of a green roof that is difficult to access or for a complicated landscape comprised of walls, stairs, paving, fountains, and planting over the waterproofing membrane.

Ability to protect the membrane: If the membrane is protected from deterioration by ultraviolet rays and unintended construction or maintenance damage by protection boards, insulation, topping slabs, foam fill or soils, a less conservative system may also be employed. A redundant drain system and leak detection system may also offer greater levels of comfort in selecting and specifying the system.

Climate, availability of materials, and construction expertise: Local climatic conditions should be considered, as should the local availability of materials. Waterproofing is a relatively common construction activity; however, in constructing green roof systems, there can be uncommon construction requirements. Many proprietary waterproofing systems are installed by the manufacturer's approved and certified contractors, who are familiar with the product and experienced with specific construction methods. This helps ensure proper installation as well as protects the viability of the warranty. (See Chapter 9 for additional considerations of warranties and insurances.)

Cost: The cost of waterproofing systems may differ greatly, based on the system selected, additional belt-and-suspender details, bidding environment, and prevailing construction costs. Given the crucial nature of waterproofing and the cost to repair or replace it, generally this is one system that should not be value-engineered.

Leakage is rarely a problem in the body of the membrane. The most likely places for failure are roof perimeters, penetrations such as flashing at drains, between expansion joints, at connections to parapets, and anywhere else where there is noncontiguous coverage of the membrane. Additionally, consider the compatibility of membranes with other chemicals that may be used in the installation, such as deicing salts, fertilizers, and herbicides. Other potential hazards include insects, roots in search of moisture, or damage from tools and other maintenance activity that may be unforeseen at the time of selection of material.

The quality of workmanship, testing, and subsequent inspection and protection of the waterproofing membranes is absolutely essential to the success of a green roof system. Localized depressions can retain water that can lead to anaerobic conditions, particularly in living green roofs. Unevenness in seams allows for water penetration. All flashing around drains and other penetrations such as vents, skylights, upstand beams, draining sleeves, irrigation sleeves, and electrical conduits must be thoroughly checked—not only after installation but also after the work of every trade that may affect the protection of the waterproofing. Flood testing of all waterproofed systems should be undertaken prior to the installation of the next component of the system.

For large areas, particularly flat roofs, flood testing may require intermittent damming, which can also lead to membrane damage. The use of a leak detection system allows for easier field testing, requires only water sprayed on the membrane as opposed to flood testing, and monitors the system over longer periods of time.

All systems are only as good as their maintenance, which involves monitoring and quick repair of known leaks. Leaks within systems are often difficult to detect because the actual entry point of the water may not be where the leak becomes apparent inside the building. The water may be following the conduits or some other subsurface condi-

FIGURE 6-18 Flood testing of waterproofing membrane. (Photo © Jeffrey L. Bruce & Co.)

Conducting a Flood Test

Prior to the installation of a green roof system, a flood test must be conducted on all areas specified for planting. The test should be conducted either by means of electronic testing or by ponding water at a minimum of 2 inches for a period of 48 hours to verify the integrity of the waterproofing membrane installation. If leaks are detected, the waterproofing system must be repaired to the manufacturer's satisfaction before proceeding with the green roof system installation. The flood test must also be repeated after repairs have been approved by a manufacturer's representative, to ensure that the waterproofing system is watertight. The structural engineer must verify that the roof deck structure supports the dead load weight of the water necessary to conduct the flood test.

tion. Therefore the maintenance program should be considered prior to selection of the system.

Other considerations include protection from ultraviolet rays, atmospheric conditions, pollutants, excessive heat, and freezing and thawing. In some conditions where the planted areas are extensive and the soil mixes are deep, protection from animal damage such as rodents should also be considered. This is why it's usually important to have more than one protection layer over the waterproofing. These protection layers can include the insulation, a concrete topping slab, or, in nonplanted areas, pavers.

FIGURE 6-19 Waterproofing membrane damage.

Sources for Additional Reference

Architectural Graphic Standards

American Concrete Institute (ACI 525 1R) (protective barrier systems)

ASTM C–898 and C–981 (longevity and performance of roofing materials and systems are often evaluated in terms of tensile strength, elongation, tear resistance, weathering, permeability, and absorption)

National Roofing Contractors Association: Construction Standards

Using a Waterproofing Consultant

Often on a complicated project the primary consultant and owner may wish to employ experts in waterproofing technology and installation. The scope should include early consultation and coordination on the part of the other project design consultants such as the architect; structural, mechanical, electrical, and plumbing engineers; landscape architect; and living green roof consultant as well as the owner and construction manager.

During documentation, in addition to the detailing and specification of the waterproofing system, it is also essential to ensure the coordination of construction details and specifications, particularly in relationship to flashings, drains, and other deck or deck wall penetrations.

During construction it is crucial to have third-party oversight of surface preparation, membrane installation, testing, and protection of the waterproofing membrane. The oversight for protection during construction needs to extend to all trades throughout all phases of construction to ensure protection from accidental damage to the membrane from storage of materials, construction debris, exposure to incompatible solvents, or unintended deck or wall penetration from utilities, irrigation systems, below-grade tree guying, and shovels.

Root Barriers

Root barriers are intended to prevent damage to the waterproofing membrane from root penetration or perforation. This includes permanent resistance against root invasion by plant roots and plant rhizomes (subterranean offshoots), particularly at waterproofing membrane seams and along perimeters and wall connections, where waterproofing membranes are the most susceptible to failure and subsequent leaks.

Green roof systems differ from conventional IRMA systems in that a root barrier is needed to protect the waterproofing against aggressive roots in search of air, food, and water. All asphalt-based roofing materials (built-up systems, shingles, etc.) require a root barrier because plants can easily penetrate and break up the materials and use the organic asphalt products as food. In contrast, synthetic roof materials such as thermosetting EPDM and thermoplastic PVC and TPOs are root resistant and can double as a waterproofing membrane.

Most effective primary root barriers are simple polyethylene (plastic) sheets, applied directly over the waterproofing membrane. To ensure chemical compatibility of materials, a separation sheet might be needed. Additionally, some secondary root barriers may consist of polypropylene geotextile fabrics, impregnated with root inhibitors, applied over the drainage board to prevent roots from filling in void spaces of the drainage core. Sometimes the polyethylene sheeting used as part of drainage matting is expected to act as the root barrier, but this can reduce permeability and lead to drainage problems. Another choice is chemically inert, anti-rot, granular-surfaced modified asphalt sheets reinforced with spun-bonded polyester, installed as part of the waterproofing system. The chemical stability of impregnated fabrics should be evaluated to prevent potential pollution washout or damage to plants. Root barriers should contain no substances harmful to plant growth, such as copper or arsenic; however, manufacturers do not always provide precise information as to which inhibitors or biocides are being used in their products. Additionally, unnecessary human exposure to the actual root-inhibiting chemicals employed should be prevented.

Root barriers are typically manufactured in rolls and can either be loose-laid, affixed with adhesives, or incorporated as part of the waterproofing. The seams of the root barriers should be overlapped by a minimum of 12 inches.

The location of the root barrier is, depending on the kind used, typically directly over the waterproofing membrane, part of it, or over the protection board. A polyethylene root barrier should be placed under polystyrene insulations. Although the insulation is hydrophobic (meaning it can tolerate water exposure), water vapor from condensation can still be transmitted and the root barrier could form an unintended vapor barrier. This may lead to waterlogged insulation and soil-fouling processes.

Selection of the root barrier should be made in consultation with the landscape architect or living green roof consultant, architect, waterproofing manufacturer, installer, and independent waterproofing consultant. Ultimately, the selection is typically specified by the architect; but it is important that all the affected design disciplines understand the purpose, function, and composition of the root barrier specified.

For both the root barrier and the protection board, if polyethylene sheet is used, it is necessary to ensure that it is not affected adversely by solvents released from curing membranes. Fabricators can now supply nonbituminous or bitumen-resistant products, because bitumen is organic and can serve as a food source for bacteria. Microbial activity can lead to deterioration and ultimately easier penetration for roots.

The type of soil mix or growing medium and plants selected as well as water availability may affect the choice of root barrier. Plants with strong rhizomes such as bamboo and some deep-rooted grasses are very aggressive in root growth and should not be used unless additional and extreme precautions are taken to protect the waterproofing membrane. Well-fertilized growing media that lack sufficient water may lead to aggressive root growth in search of moisture, which can accelerate potential root penetration of the waterproofing membrane.

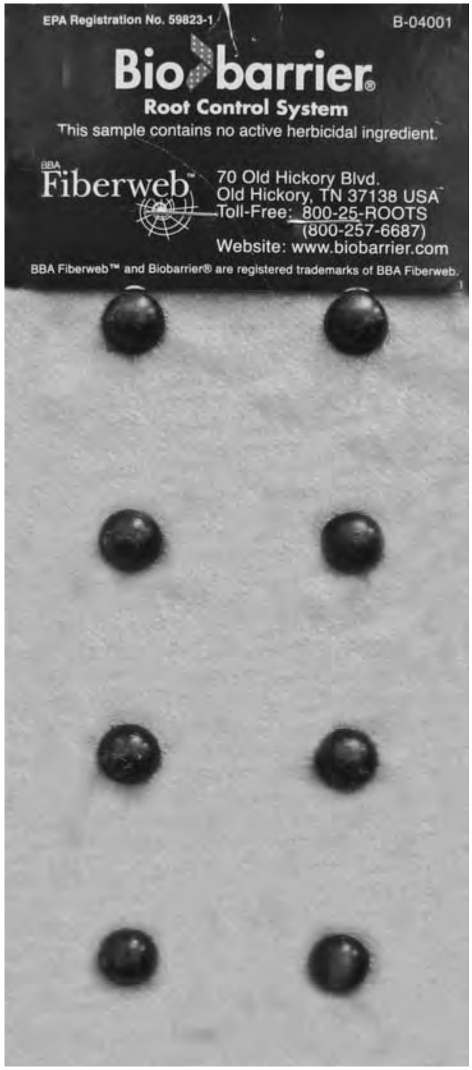


FIGURE 6-20 Root barrier.

Protection Board

Protection of the waterproofing membrane is extremely important for both horizontal and vertical surfaces in building landscapes over structures. Once it is installed, the waterproofing membrane is susceptible to damage from construction activity, equipment, and foot traffic. Immediate and permanent protection is required. Even after construction is complete, uncoordinated maintenance and repair operations of other building or landscape systems can cause unintended damage.

Protection board may be any material that protects the waterproofing membrane itself. Protection board should be durable and made from materials that do not deteriorate in water.

Semi-rigid sheets of cement board can be used, as can pressure-laminated fiberglass or mineral-reinforced asphaltic core that is part of the waterproofing system. Typically protection boards are 1/8 inch to 1/4 inch thick. They are used for both horizontal and vertical surfaces.

For deck surfaces, a temporary protection layer can be installed, such as felt, tar paper, or proprietary particle composite board, but this is not recommended. Often in the interest of cost savings, there is incentive to rely on the drainage layer (either geocomposite drainage board or a granular drainage fill) or the insulation board to act as the protection board. Although these materials do increase the protection of the waterproofing membrane in the final installation, they will do little during the heavy construction required to complete some installations—especially for landscapes over structure. Likewise, damage to the drainage boards, aggregate particle size of the granular drainage layer, or the insulation itself is possible, which in turn will limit their long-term performance and efficacy.

It is also necessary to monitor and inspect the seams of the protection board periodically during the construction process and immediately before installing the next component. Even on the best-run construction sites, a variety of tools and even foot traffic can dislodge panels, and fasteners can get caught under the seams.

Another method of providing a protection layer is to install a permanent concrete working slab. This may be a reinforced concrete slab of 3 inches or more to protect the membrane through extensive additional construction phases. A major disadvantage of utilizing a slab over the membrane is that it is very difficult to routinely inspect the waterproofing, find the source of a leak, or repair one.

Occasionally, the working slab is expected to provide the slope required for drainage. This is not recommended for several reasons. As it is a working slab, the site control and quality of finish to achieve and maintain the final top-of-slab elevations required for positive deck drainage may not be part of the contractors' scope in this construction phase. Proper slope and finish should be attained in either the original pour of the slab or in a secondary, permanent topping slab fully coordinated with both individual drain locations and comprehensive stormwater collection system. (See Chapter 5 for structural considerations.) The working slab is also subject to damage during the construction process, increasing the likelihood of ponding of water in depressions and migration of water in cracks. It is very difficult to repair cracks or depressions in the concrete or correct elevations when the landscape components are being installed—often many months later.

In some instances, it may be advisable to install a slip sheet between the membrane and working slab to prevent shrinkage cracking in the working slab resulting from stresses

FIGURE 6-21 Installation of protection board over multiple surfaces.

FIGURE 6-22 Placing drainage matting over deck for a living green roof. (Photo: Atlantis, Australia)

on the membrane. However, if any paving system is to be installed over this, it is very important not to use any material that can act as a slip sheet. This is also applicable to thin polystyrene boards used as protection boards.

Insulation

In the construction industry, thermal insulation is required by building codes because it provides a thermal break between the inside and outside of the building. Insulation helps to keep a building warmer in the winter by reducing the loss of interior heat or penetration of cold air through the exterior surfaces of the building. In warmer seasons or climates insulation helps keep the heat out and cool air in the building. The more stable and optimal the interior temperatures, the more comfortable it is for the building's inhabitants. Insulation also helps to reduce condensation that takes place on surfaces directly exposed to both hot and cold on opposite sides. Reduction of condensation and associated moisture in a building enhances human comfort and prolongs the life of materials. Most significantly, good insulation helps to reduce the energy demand to heat or cool buildings.

Greater concern over consumption of energy and associated economic, environmental, and cultural costs has led to more innovative, comprehensive, and integrated design solutions and more effective materials and methods of construction. In many cases, energy efficiencies have been regulated by code, induced by incentive, and rewarded by tax and energy cost savings. New products and proprietary systems as well as greater coordination between the design disciplines have made determining the type, thickness, and placement less difficult and more understandable.

Standards for allowable heat loss and energy efficiency are generally mandated by building codes and differ with regional and local climate conditions. Strict standards may be required by municipalities to increase building energy efficiencies. While achieving energy efficiency through multiple means is becoming a common and conscientious practice in design and construction, green roof systems can be a significant part of energy efficiency due to the amount of heat transfer that occurs through the roof or top of the slab. The overall energy savings depend on the roof-to-wall ratio. A low-rise building with a high roof-to-wall ratio benefits more from a green roof than a high-rise building that loses more energy through the building envelope and glazing.

Both types of green roof systems add mass over the structural decking, thus serving as insulation. However, it should be noted that living green roofs only *add* insulation and cannot *replace* it, because their insulating properties depend upon the depth and moisture content of the growing medium. One way to improve the energy performance of a building with a green roof system is to increase soil mass—the greater the soil depth, the more insulation value or thermal resistance.

Measurable Effectiveness of Insulation: R-Value

The most common insulation products used in the construction industry are fiberglass batts or blanket insulation, injected polyurethane foam, or polystyrene board products (sometimes called "blue board"). Insulation as a component can be evaluated for numerous performance attributes; however, insulation effectiveness is expressed in its R-value.

The R-value is a material's thermal resistance, meaning how well it resists the effects of thermal influences of heat or cold. The *R* stands for resistance to heat flow; the higher the value, the greater the insulation value. As a measurement, thermal resistance is generally expressed by comparing its ability to resist heat fluctuation at a given temperature and over a given period of time. Because its resistance can increase with its mass or thickness, it is also measured by using a constant unit of thickness. Therefore its measurement is usually expressed in units of hr/ft^2–°F/Btu-in or m—K/W. This means that at a given mean temperature and given time of exposure, each inch of thickness will provide a certain degree of thermal resistivity. For example, a 2-inch thickness of insulation board may have an R-value of 10, while a 4-inch thickness of the same insulation board will have an R-value of 20.

Different products can be measured against each other to determine the individual component product with the best insulating effect. Additionally, the insulating effect of multiple components can be measured cumulatively to determine the overall effectiveness of a system.

As an example of individual comparison of products, two different brands of insulation board of the same thickness may have significantly different R-values. Two different soil mixes, each 6 inches deep, may provide significantly different thermal resistance because of their composition and resultant water-holding capacity. Wetter soils have lower R-values than drier soils. Similarly, different plants form different root mats with varying ability to trap air, which can also affect the overall thermal resistance. If high R-value is the most important criterion in component selection, then products offering the highest cumulative R-value should be used in the system. Conversely, if the compressive strength of the insulation board is of greater consideration and soil mix conditions (depth, solar orientation, irrigation, etc.) are expected to vary significantly, other characteristics of each of the components would have to be assessed to evaluate the overall suitability of the products within a green roof system—including the system's effectiveness for insulation.

The required R-value is usually determined by the architect and MEP. However, there are a number of other considerations that must be considered in evaluating, selecting, and specifying the insulation, such as:

- Type of green roof system
- Type of insulation product
  - Extruded polystyrene (xPs), usually boards
  - Expanded polystyrene (EPs), usually block
- Material composition
- Compressive strength
- Water absorption rate
- Depth restrictions from top of slab
- Location of insulation in relationship to the waterproofing membrane
- Overall system of components specified

The polystyrene products generally referred to and used for insulation can be used for more than one purpose in green roof systems. As boards, they have a high R-value, are high in compressive strength, and are lightweight. In addition to their insulative value, they also provide supplemental protection to the waterproofing membrane. If tapered, they function similarly to a topping slab by providing adequate slope required for drainage. Nontapered boards can also facilitate drainage if they have drainage channels chamfered into the bottom of the board. As large, easily maneuverable lightweight blocks, they are often used as part of a fill section for deep profile landscapes over structure.

Polystyrene: Types, Material Composition, and Fabrication

The discussion of insulation as a component will be limited to polystyrene, since it is the most commonly used insulation. Polystyrene is a petroleum-based product.

Fabrication of polystyrene involves either the expansion or extrusion of polystyrene resin beads, or pellets, thus providing the two most common products: xPs (planar, extruded polystyrene boards) and EPs (block-molded expanded polystyrene).

Used directly on vertical or horizontal building surfaces as boards, this application of polystyrene is generally referred to as “insulation board” or simply “insulation.” When used in geotechnical applications, it is generically referred to as “geofoam” or “geoblock.” “Geoblock” is commonly used when referring to the use of large blocks of polystyrene to distinguish block from board.

Usually produced as rigid boards, xPs is formed in an extrusion process that involves additives, heat, and pressure. In green roof systems, boards are most commonly used for insulating the roof decks for living green roofs and deck slabs for landscapes over structure. As an extruded foam product, xPs provides a very dense, hydrophobic insulation. Although it may be custom-fabricated in larger sizes, as a board it is usually produced in 2-foot-by-8-foot or 4-foot-by-8-foot sizes and in thicknesses of 1 to 5 inches.

Typically, one person can handle these boards, which can be easily cut in the field to fit most horizontal and vertical surfaces as well as for drain fittings or utility conduits.

Also available are tapered xPs boards that can be used, in some instances, to provide the slope required for drainage without having to build up the structural deck with a topping slab. Both flat and tapered boards are available with chamfered grooves in the bottom, to further facilitate drainage. Styrofoam is a proprietary polystyrene product and is often used as an interchangeable term for xPs or board.

Blocks of EPs are made by exposing the polystyrene resin to steam, heat, and pressure and finally forming it into large blocks. This material is available in blocks 4 feet by 8 feet by 30 inches (or greater) and is often used as lightweight fill in construction where large areas of high-strength fill are required. The blocks can be shop-fabricated in compliance with shop drawings or easily field-cut. Although slightly cumbersome for one person to handle, the EPs blocks are lightweight and easy to install.

Both EPs and xPs are suitable alternatives to soil mixes where large quantities of fill are required. Both are lightweight, easy to handle, and can be field-cut. Shipping and installation costs are typically the same. The two materials have different characteristics—such as R-value, density, and compressive strength—that may make one more suitable as fill than the other. Both are hydrophobic, but xPs is cited as having a lower absorption rate than EPs. Absorption of moisture could decrease thermal effectiveness, but neither material’s rate of absorption significantly affects its compressive strength or deformation properties. Retained excess moisture or standing water due to an inadequate drainage system can add weight to the structure, increase the potential of condensation, and cre-

FIGURE 6-23 Installation of drainage board over xPs insulation board, protection board, and waterproofing membrane. (Photo © Jeffrey L. Bruce & Co.)

FIGURE 6-24 EPs blocks for lightweight fill over structural deck. (Photo © Jeffrey L. Bruce & Co.)

FIGURE 6-25 EPs blocks can be easily cut in field with a hot wire. (Photo © Jeffrey L. Bruce & Co.)

ate anaerobic soils conditions. The selection of either xPs or EPs, when used as structural fill, should be in full collaboration with a structural engineer.

In general, the cost of producing EPs is usually reported to be one-third that of producing xPs. Because polystyrene is a petroleum-based product, the cost to produce either can fluctuate with world oil costs, making both of them potentially a costly alternative.

Location of Insulation in Relationship to Waterproofing

In building and waterproofing systems, the most commonly used insulation material is xPs boards. Their placement in relationship to top of slab and waterproofing can vary.

When insulation is placed below the structural deck and waterproofing membrane, some condensation can occur, compromising interior finishes and potentially leading to the cracking of the structure and rupture of the membrane.

Above the deck, it can be placed above or below the waterproofing membrane. When insulation is placed below the waterproofing membrane, condensation can occur, although it will be minimal (and less than if insulation is placed below the structural deck). Condensation can increase thermal fluctuation; below the membrane, it can increase the potential for vapor blisters and membrane rupture. Any resultant moisture can travel under the insulation, making it more difficult to locate and repair any leak.

Generally, the preferred location for insulation is above the waterproofing membrane. This is often referred to as a protected or inverted roofing membrane assembly (IRMA). When the insulation is placed above the waterproofing membrane, there is less chance of

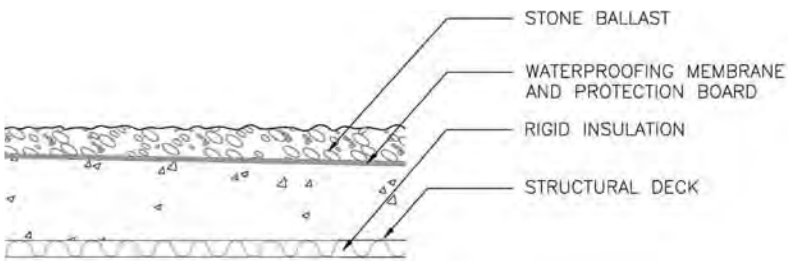


FIGURE 6-26a Insulation under the structural deck with conventional stone ballast.

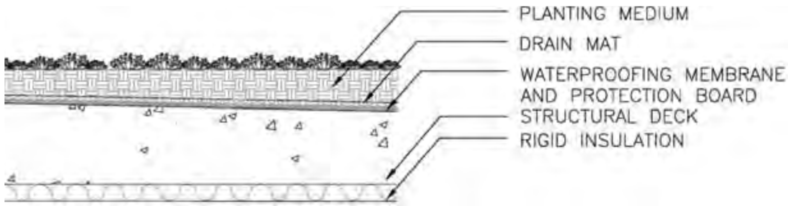


FIGURE 6-26b Insulation under the structural deck with living green roof.

condensation. Other advantages to this installation technique are easier coverage and extra protection for the membrane. The disadvantages (aside from wind uplift exposure during installation) are that the insulation in this location can impede drainage, and if it is subject to long periods of exposure to excess water, it can lose its thermal resistance.

Insulation for Protection of Vegetation Against Thermal Fluctuation

While the mechanical engineer and architect generally determine the type and depth of insulation required for optimal interior building conditions and compliance to codes, they may be less knowledgeable to what extent thermal fluctuation affects the vegetation of green roof systems. Particularly in winter, when the roots of the vegetation can freeze, thaw, and refreeze, the insulation underneath the vegetation layer does not only insulate the building but also helps to protect the plants' root systems. For living green roofs, without some insulation below the vegetation and a thin layer of growing medium, the plants can be adversely affected by temperature fluctuation during winter. Typically 2 to 3 inches of insulation material is sufficient to protect plants from permanent frost damage.

There is no constant R value for soil or growing media, because of the variable moisture content. Trapped air within the particles of aggregate provides the insulative value in winter, and evapotranspiration prevents heat gain in summer. (See Chapter 2 for more information on the hydrological cycle and the ameliorative impacts of green roof systems.) Determining the location and depth of insulation to ameliorate these impacts can be a challenge, but a few rules of thumb can guide the decision.

Insulation for Living Green Roofs

A living green roof essentially becomes the ballast of an IRMA. The living green roof does not replace the insulation; rather, it adds mass, and (depending on the soil moisture content) can vary in insulative value. Even in wet conditions a living green roof provides some

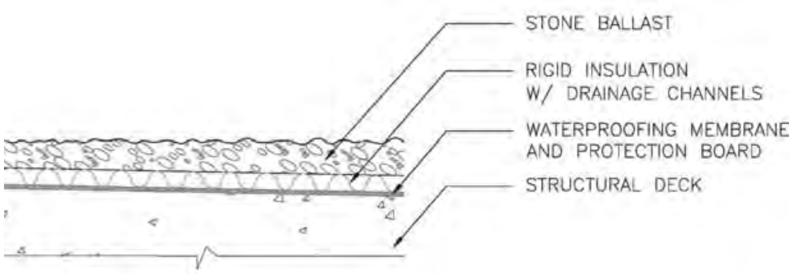


FIGURE 6-27a Inverted roofing membrane assembly (IRMA): insulation over the structural deck and waterproofing membrane with conventional stone ballast.

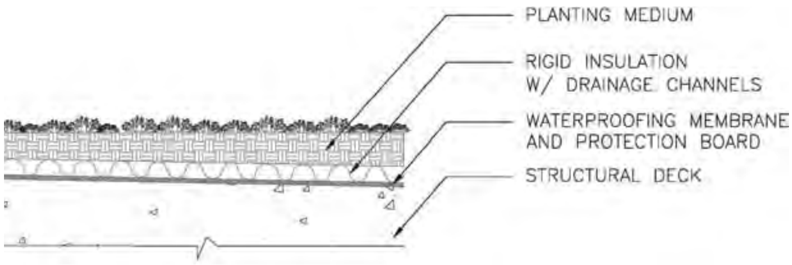


FIGURE 6-27b Insulation over the structural deck and waterproofing membrane with living green roof.

insulative value in that the vegetation layer and textures can slow down winds and hence reduce heat exchanges through the roof.

Insulation for Landscapes over Structure

Perhaps the most significant conditions to consider are those directly above the structural slab and directly below the structural slab. Since there are numerous applications of landscapes over structure, the resultant conditions and required component systems will vary. For example, if the landscape's vegetation is directly over a heated space, the thermal fluctuation will be greater because the temperature of the unheated space will be more consistent with the temperature of the exterior space. The heat emitted from a heated structure below heats up the soil, subjecting frozen roots to thawing and then refreezing.

In conditions where the heat fluctuation from below may not be a significant factor, both the depth of soil and the location of the planting above finished grade should be considered. Since the R-value is cumulative, the insulation over the waterproofing membrane, used mainly for building insulation, combined with the thermal mass of a deeper soil profile may be adequate to protect the vegetation from thermal fluctuation. However, for vegetation in planters above grade, sunlight striking the vertical surfaces of raised planters can cause significant thermal fluctuation. Not only can the freezing, thawing, and refreezing of plant roots be detrimental to the vegetation, but thermal fluctuation can also expand and potentially crack the rigid walls of planters. It is important, therefore, to insulate the sides of raised planters as well as the bottom. Because, similar to structural slab conditions, the sides of raised planters are usually waterproofed, the addition of insulation against the waterproofing membrane on vertical surfaces also provides an additional protective layer to the membrane.

Insulation Materials Commonly Used as Lightweight Fill over Structure

In landscapes over structure, a change in elevation of the top of the structural deck may reflect the architectural uses below or the additional depth of soil required to accommodate the size of the tree root ball. The depth and extent of fill required between finished grade and top of the structural deck can be significant.

Every additional unit of load can increase deck thickness and beam and column size, which can result in adding to building footprint and height, construction time, materials, and ultimately cost. Lightweight, easy to handle, and readily available, polystyrene products offer an attractive alternative to heavier growing media or complex structural decking configurations.

Recently, very lightweight, air-entrained concretes have been used as an alternative to xPs and EPs. These "flowable fills" need to be evaluated for their suitability for structural capacity, desired porosity, permeability, and installation requirements. As a "liquid" material, its use to achieve sloped surfaces is difficult. There are also new products that combine the use of polystyrene to achieve slope and flowable fill.

Currently, the most limiting factors to the consistent utilization of lightweight concretes are structural capacity, cost, and local expertise in installation.

Insulation in Relationship to Drainage Material

For living green roofs, insulation on top of the waterproofing membrane can be chamfered, creating drainage channels to facilitate the positive flow of excess water. For landscapes over structure, with varied depths of soil and varied conditions for site elements, tapered and chamfered insulation boards should not be relied upon as the primary drainage system.

Because they are hydrophobic, EPs and xPs insulations can be placed directly above the drainage layer and under growing media or pavers, but both need to have adequate compressive strength to avoid crushing and loss of insulating properties.

Insulation over a Drainage Course

Insulation, particularly if installed as a tongue-and-groove assembly, can create a drainage plane on which water can pond. To avoid this undesirable condition, the insulation needs to be pitched or tapered toward the roof drain to ensure adequate drainage of excess water. Drainage grooves (chamfers) on the bottom of insulation may sufficiently facilitate drainage. However, a thin drainage mat or panel underneath the insulation may help to prevent standing water and waterlogged insulation, especially on low-sloped or flat roof decks. In landscapes over structure, where soil mix depths or fill sections may be significant, it may be necessary to install a secondary aggregate drainage course separated with a filter fabric, depending on the materials above the insulation (soil mix or paving).

Additionally, it might be necessary to install a polyester scrim sheet or polyethylene drainage mat directly over the insulation blocks to keep aggregate fines from migrating; this will also provide an additional drainage/aeration layer.

Insulation and Drainage Under Paving

To facilitate subdrainage and alleviate the potential for extended exposure to water, a granular or permeable drainage layer may be placed below or above the insulation.

Differential icing can occur on paving when one area over a structural deck has insulation in the composite system and an adjacent area has little or no insulation. Increasing the depth of the granular base under the paving setting bed can lessen the potential for differential icing.

Potential for Puncture or Deformation

Used as fill sections, xPs or EPs can be subject to puncture or deformation due to differential loads. One of the ASTM standards for compressive strength in geofoam products is the percentage of overall deformation of the product under the maximum allowable compressive strength. Generally the structural engineer will help determine if materials (such as a concrete paving subbase or a soil mix) placed over the polystyrene fill provide adequate load transfer and distribution.

Drainage Materials

Adequate drainage is essential to maintain effective waterproofing, the structural system's integrity, the survival of the plants, and durability of site elements such as walls and paving. There must be a way (preferably with built-in redundancies) to collect, absorb, direct, and distribute water throughout the entire landscape system.

Living green roofs are intended to detain at a minimum the initial 0.5 to 1 inch of rainfall of the most frequently recurring storms in a given region. Water beyond the absorption and storage capacity of the living green roof system must be directed to drainage outlets and released. For landscapes over structure, excess water from rain or irrigation must be released by directing it through surface or subsurface drains to the stormwater system. As discussed previously, standing water in soil leads to the depletion of oxygen and the creation of anaerobic conditions as well as deterioration of inert components and potential system-wide failure.

The drainage layer can be a single medium or component or a combination of components to facilitate the positive flow of excess water. To filter and delay runoff, the drainage system should be continuous across the top of the waterproofing membrane. The thickness of the drainage layer and the materials used to accomplish adequate drainage may differ; like all other components and systems, drainage systems need to be evaluated for the most appropriate applications to specific conditions.

Adequate drainage increases the ability of air to flow through the soil or growing medium and lessens the potential for detrimental anaerobic conditions. Airflow helps to maintain a healthy soil environment, which includes beneficial soil bacteria and worms, by allowing more pore space for root growth and development. Air may be incorporated into the soil by combined use of materials that are usually associated with drainage components. Some mats facilitate both drainage and aeration.

Stone Drainage Aggregates

To provide consistent and reliable long-term drainage, readily available and commonly used drainage materials such as crushed stone, pea gravel, or small-diameter river rock must be double-washed and cleaned of fine particles so that they drain freely. The type of stone and particle size distribution may be similar to that used in conventional terra firma subdrainage systems. It should not be from a parent material that can be easily pulverized during quarrying, installation, or long-term use. Fines can clog the air spaces of the drainage aggregate or materials such as geotextile fabrics that are adjacent to the drainage layer.

The weight of a stone aggregate and its maximum water-holding capacity must be considered because the system can become quite heavy and the structural slab must be sized to accommodate it. The additional thickness of the slab can add cost and reduce the allowable planting depth.

Lightweight Drainage Aggregates

Lightweight aggregates, such as expanded or balled clay, expanded slate or shale, or other ceramic products, are an attractive alternative to drainage stone because they are much lighter. The consistency in particle size allows selection of grade or mix of grades for a

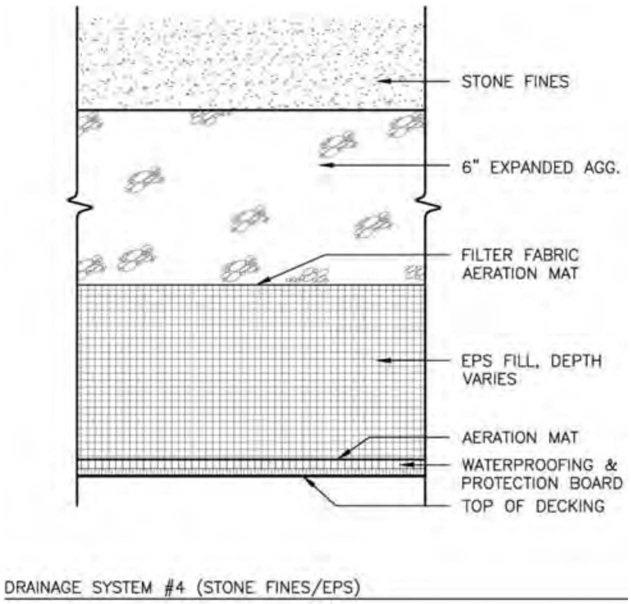


FIGURE 6-28 Drainage aggregate above insulation and under paving.

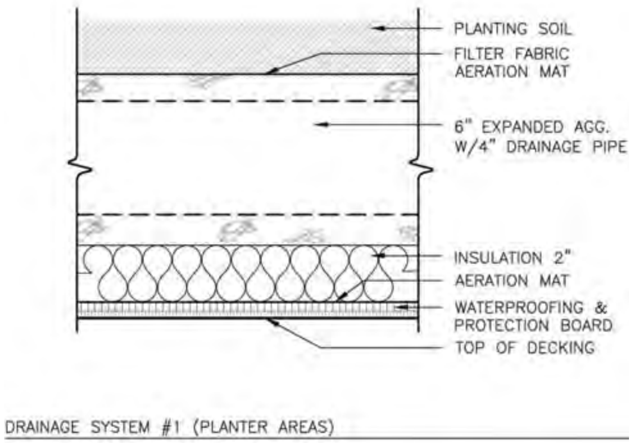


FIGURE 6-29 Drainage pipe in lightweight expanded drainage aggregate.

specific purpose such as allowable or required rate of compaction or rate of flow of water through the aggregate. Disadvantages are that they typically are much more costly than crushed stone or drainage mats or panels, and the composition, fabrication, and availability of the material can vary locally. The higher cost of the lightweight aggregate may need to be balanced against other factors such as the increased costs of the structure to support a heavier drainage stone or the implications of a thinner allowable planting or paving profile.

Both stone and lightweight drainage aggregates can be used to store water for recharge and later use, similar to a natural aquifer.

Lightweight aggregates are fabricated according to standard grades and are more consistent in composition and the distribution of particle size. The appropriate grade must be specified; ASTM currently broadly categorizes the grades as fine, medium, or large, and grade is determined by the size and distribution of particles within an allowable range.

Synthetic Drainage Components and Composite Drainage Products

A wide and sometimes confusing range of synthetic products are available as drainage components and composite systems for green roof construction. Drainage mats and panels are an attractive alternative to several inches of gravel drainage aggregate, especially where depth and load restrictions apply. They are lightweight, thin in profile, and generally easy to install, and they can also perform other component functions such as aeration or as a water reservoir.

For living green roofs, where the growing medium is typically shallow and where the overall weight should be comparable to traditional stone ballast, these thin, lightweight composite products may suffice and be completely appropriate and effective if they meet the minimum weight criteria to prevent wind uplift, but may not provide adequate water retention capacity.

For landscapes over structure, where the soil mix may exceed 18 inches and where large-caliper trees with deep and heavy root balls are installed, these mats and panels should not be automatically considered an adequate drainage system. Depending on use, required performance, depth and extent of the soil mix or growing medium, and the overall system of components, a more extensive drainage system with a thicker layer of drainage aggregate as well as drainage laterals and mains may be required. Additionally, these drainage mats and panels can be used in the overall system, augmenting the drainage or aeration system or serving as redundant “belt-and-suspenders” components in complex systems.

Composite products include looped polyamide filaments, high-impact polystyrene, or polyethylene molded or extruded into egg-carton-shaped panels with pegs, cups, cones, domes, or channels. Additionally, the core of a drainage mat or panel may be attached to or sandwiched between other materials that can function as filter fabrics, moisture retention mats, root barriers, or separation layers between other components. A number of products are available that combine the functions of drainage conduit, water retention or reservoir device, and conduction of airflow to the root zone.

Conventionally, this array of products is used for vertical drainage of foundation walls in order to direct excess water and relieve hydrostatic pressure. Many of these products have been adapted for horizontal drainage systems of both living green roofs and land-

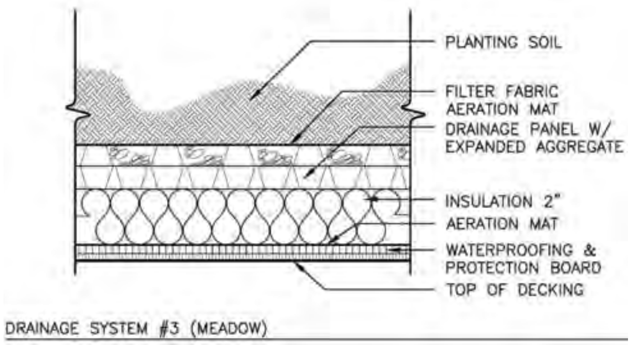


FIGURE 6-30 Drainage and aeration layer under planting soil.

FIGURE 6-31 Filter fabric/aeration mat.

scapes over structures. It is important to understand the performance requirements of a composite drainage product. It is also important to understand whether the product is meant to be used horizontally or vertically.

For clarity within this discussion, *drainage mat* is used to describe a composite drainage component that is flexible and typically has a core of crush-resistant filaments or fibers; a *drainage panel* is used to describe a composite drainage component that is more rigid and typically has a core of crush-resistant “cups” and or “cones” (also called “domes” or “pegs”).

(The use of *drainage board*, sometimes used interchangeably for either of the above, is avoided here, since it further confuses the function of the specific component.)

Following is a brief discussion of commonly available composite drainage components, their intended primary function, and additional application for green roof systems. The primary purpose of drainage mats or panels for green roof systems is to provide unobstructed pathways for excess water to flow toward the drains and gutters. Obviously, it is important to select the drainage component or composite product for its required performance. Additionally, all of these products need to be evaluated for properties such as compressive strength, moisture retention capacity, and compatibility with other components.

Drainage Mats

In a vertical or horizontal application a drainage mat facilitates the movement of excess water and provides for some additional airflow. It is not intended to retain excess water.

Used horizontally, it is most effective where a very thin profile is required, allowable loads and depths are limited, and drainage of excess water from horizontal surfaces is not of primary concern. One type of drainage mat is a webbed plastic mat fabricated in sheets of varying size, ranging in depth from 1/8 to 1 inch, and most commonly available with a geotextile or filter fabric attached. This type of drainage mat should not be used in areas under paving, as it can interfere with the interlocking qualities required in the setting bed. In some cases, depending on the materials, it can even act as a slip sheet, seriously impacting the stability of the pavement. Additionally, it does not have high compressive strength, which is usually needed in paving systems.

Another type of drainage mat is made from looped polyamide filaments and often has a geotextile filter fabric attached. This type of drainage mat is often very effectively used as an additional (not primary) conduit for drainage and as an aeration layer.

Drainage Panels

In either a vertical or horizontal application, a drainage panel also facilitates the movement of excess water and provides for some additional airflow. However, there is a fundamental difference in the fabrication of the panels depending on their intended application. A horizontal drainage panel can store water in reservoir “cups” and disperse excess water through openings in “cones.”

A number of products are available that can combine these functions of drainage conduit and reservoir. The most common of these is high-density polyethylene molded into a waffle-like array of “cups” (or “pegs”) thus retaining some of the excess water, and “cones” (or “domes”) that do have such holes for drainage once the cups are filled. These holes in the cones direct excess water back to the main drainage system and allow for ventilation and evaporation. If the “cups” (no drainage holes) are facing down, they retain water until the reservoir space is filled up and overflows through the holes in the cones. Conversely, if the “cups” are facing up (in which case they are often called “cones”), they cannot act as reservoirs; all of the excess water will drain through the holes. Through gravity all of the excess water finds its way to the roof deck or slab deck drains.

FIGURE 6-32 Drainage and reservoir panel as cones (pegs up).

FIGURE 6-33 Drainage and reservoir panel as cups (pegs down). Notice location of channels and drainage perforations.

FIGURE 6-34 Installation of EPs drainage and reservoir panel over waterproofing membrane and protection board.

FIGURE 6-35 Drainage and reservoir panel close-up. The panel is filled with lightweight aggregate and covered with filter fabric to facilitate drainage and capillary movement of water.

Typically, these panels are fabricated as large as 3 feet by 6 feet, varying in thickness from 1.5 to 3 inches. More often these proprietary panels might be referred to by their dimension in millimeters, such as D-24 (24 mm, 0.9 inches) or D-40 (40 mm, 1.6 inches).

If the drainage panel is specified to act as the water retention and drainage panel, the "cups" or "pegs" are installed downward. If, however, the drainage panel is specified exclusively as a drainage layer, the "cups" are installed upward.

There are also some drainage panels that are intended exclusively for drainage either horizontally and vertically. No excess water is meant to be retained or reserved; therefore, these panels do not have any penetrations or drainage holes. To an untrained eye, these fundamental differences can easily be overlooked and may not be detected upon delivery to site and even installation.

For living green roofs in temperate climates, where the primary function is to reduce stormwater runoff, it is important to retain and use the water from the most frequently recurring rain events, which is usually 0.5 to 1 inch of rain. Depending on the overall design and construction of a landscape over structure, the retention capacity of water in a deep soil profile depends on the amount of pervious surfaces in relationship to the impervious surfaces, but this may be less critical than the rate of drainage or the amount of airflow.

Aeration Mats and Panels

Aeration mats and panels are the same as or similar to the products described immediately above, but may be used in varying locations. The most common are noncompressive panels, fibers, or formed cones, which allow air to be incorporated into the system. Aeration mats and panels should also be incorporated on vertical surfaces of walls and planters, both to relieve hydrostatic pressure and to increase the airflow in the soil and enhance root production.

Moisture Retention Mats

Recently, moisture retention mats have been marketed as a way to help retain more moisture and nutrients and slowly release them to the root zone of the vegetation layer above while wicking away any excess water. Although their composition varies by manufacturer, most often they are made of polypropylene fibers stitched through a polyethylene sheet. In living green roofs and landscapes over structures, they are most commonly placed below the drainage/reservoir panel. Their inclusion, if at all, should consider depth and type of soil mix or growing medium, supplemental irrigation availability, and composite drainage system. The product selection may be made based on limitation of depth of overall drainage system profile, compressive strength, and moisture flow and retention rate of the mat.

Filter Fabrics

Filter fabrics are a type of geotextile, which are synthetic cloths used below grade to stabilize soil or facilitate and promote drainage, while separating different layers of materials. For application in living green roofs and landscapes over structure, the filter fabric is intended to keep the fines of a soil mixture or growing medium from migrating into the drainage and aeration layer. Typically, they are made of polypropylene fibers and are either woven or nonwoven. A woven fabric is produced from a number of filaments and strands, whereas a nonwoven is more uniformly manufactured filter fabric. Nonwoven fabrics are typically used in planting applications where the water flows in only one direction—in this case, from soil to drainage medium—and does not allow water to migrate upward for plant use.

Numerous products and types of filter fabrics are available, and the selection may ultimately be made based on differentiation of pore space, strength, weight, resistance to rot, and deterioration from ultraviolet light, which can affect their permeability and flow rate.

The key measurements of the physical and mechanical properties of filter fabrics are tear strength and resistance, puncture strength, permeability, and horizontal flow rate, as well as wicking capacity in either the horizontal or vertical direction.

Drains

The essential function of a drain in green roof systems is to collect excess surface and subsurface water from stormwater, irrigation, or washdowns and direct it to the overall stormwater drainage system.

FIGURE 6-36 Coordination of aeration, drainage, and drain cleanout in individual planting pits.

FIGURE 6-37 Roof drain access pit. (Photo © Jeffrey L. Bruce & Co.)

Numerous types of surface drains, roof drains, planter drains, drain bodies, and fittings are available commercially, and selection is dependent upon the required function and appearance. They all need to be protected against soil mix or growing medium washout and potential clogging. For living green roofs, the drain may be a conventional roof drain if specified by the waterproofing fabricator or installer. In general, the number of drains for a living green roof should be the same as for conventional roofs even though fewer drains may be necessary because less stormwater runoff is generated. For landscapes over structure, the surface drain may need to be coordinated with paving above and planter drains below. It is essential that the design of the entire surface and subsurface drainage systems be coordinated between the civil, structural, and MEP engineers, the waterproofing consultant or supplier, and the landscape architect or the designer of the living green roof. The drains must be sized adequately and the number, location, and elevations carefully coordinated to avoid oversized surface and subsurface configurations (which can conflict with planting and paving depths) or undersized configurations, which can lead to excessive standing water, anaerobic conditions, and overall system failures. It is also essential that all drains, fittings, and flashings be installed properly, remain accessible, and be kept free-draining. Construction detailing and installation guidelines are discussed more fully in Chapters 7 and 8.

Dynamic Components: Soils, Soil Mixes, Growing Media, Plants, and Irrigation

Because green roof systems are designed to grow and thrive in artificial environments, the basic needs of plants—a nutrient source and water—need to be incorporated into the system. The basic requirements for sustenance of the vegetation of living green roofs are quite different from those of landscapes over structure; however, each are often made up of similar components derived from both naturally occurring and fabricated sources.

In general plants grow best in their native soils, which often have a high content of organic matter and available nutrients. The in situ uppermost horizon of soils is often referred to as topsoil. It also often is "stripped" from its native location and used as a component in soil mixes for new planting. Depending on its parent material and previous use, this upper soil horizon will differ in its grain and particle size and may contain silts and fines. When used in green roof systems, these types of soils (without some type of remediation or augmentation) can eventually self-compact, impeding subsurface drainage. The silts and fines can also cause the filter fabrics to clog, further impeding drainage. The organic content in soils will also vary. Over time, organic content can decompose, which can lead to a reduction in soil volume and depth and reduction in water retention capacity. Natural soil types, such as sandy loams, can weigh about 10 pounds per square foot per inch of soil depth, which amounts to about 40 pounds per square foot for a 4-inch soil layer. If load restrictions apply, these natural soils will weigh too much (especially when saturated). They can be mixed with other materials, such as lightweight aggregates, to achieve the desired weight and composition for the required depth.

Lightweight aggregates may consist of expanded clay, shale, or slate, minerals that are often by-products from the coal and mining industry. These minerals are expanded by applying pressurized air and are then fired at very high temperatures to form stable lightweight particles. These materials weigh between 3 and 5 pounds per square foot per inch of depth. The expansion process alters the porosity of the material and thereby increases moisture retention capacity, which in turn increases the water available to plants.

Pumice or lava rocks are naturally occurring materials that can also be used as lightweight components, but their limited availability makes their use rare in green roof systems.

Because both naturally occurring soils and lightweight aggregates, as well as other additives, may be used as components in green roof planting systems, the following terms will be used:

- **Soil:** A naturally occurring material of differing horizons, of which the uppermost is often used as a component in a soil mix or growing medium.
- **Soil mix:** A mixture of several components intended to promote good growing conditions for the plants specified, but where the base component is derived from a naturally occurring soil. The mixture must be determined in conjunction with the loading requirements of the roof deck.
- **Growing medium:** A manufactured mix of mineral materials, stabilized organic amendments, and stabilized lightweight aggregates to provide a lightweight mixture that promotes good growing conditions for the plants specified and meets the loading requirements of the roof deck.

There is no exact "recipe" for soil mixes or growing media for green roof systems. The composition of either can vary greatly depending on the size of the green roof system, locally available materials, plant requirements, and project circumstances. Rather, it is important to understand the horticultural requirements of the plants, the availability and suitability of the various components, and the design requirements of the entire green roof system.

Growing Media, Plant Selection, and Irrigation for Living Green Roofs

The application of a living green roof in place of a conventional, stone ballast roof is ideal particularly for the purpose of stormwater management. The depth of a soil mix or a growing medium required for a living green roof is typically 2.5 to 4 inches (but can range from 2 to 8 inches). If the main component of the mix is a lightweight aggregate, a 4-inch depth will weigh only 12 to 20 pounds per square foot, which is equivalent to the stone ballast used on conventional roofs.

Using a high-mineral-content growing medium has the advantage that the depth remains the same over the life of the living green roof. The consistent depth maintains a consistent water retention capacity for stormwater. Additionally, unlike a natural-soil-based mix, there is little compaction or decomposition of the aggregate, which is important if the living green roof is used and permitted as a stormwater management device.

Plant establishment and plant growth, however, depend on the availability of the nutrients naturally derived from some type of organic matter. Site-specific requirements may apply, but as a rule of thumb, lightweight mineral aggregate is mixed with well-decomposed compost to add needed nutrients in the form of organic matter. The ratio of the components may range widely, depending on available materials. Generally, the ratio for living green roofs is approximately 75 percent lightweight aggregate to 25 percent organic matter. Other materials also can be incorporated into the growing media, such as sand to optimize drainage or a slow-release fertilizer to inoculate the growing medium with long-lasting nutrients to enhance plant establishment and plant growth.

The growing medium must consist of a range in grain sizes to provide sufficient drainage while allowing some water retention to ensure water availability to plants. If the medium is too granular, water is lost too quickly and plants may suffer from water shortage. All components and their ratio within the overall growing medium must be coordinated with any load restrictions.

The vegetation of a living green roof usually consists of low-growing, horizontally spreading, water-storing plants. As previously noted, most often (but not exclusively) the majority of plants are selected from among the hundreds of species in the genus *Sedum*. Sedums, in both their native and artificial rooftop environment, are typically succulents that store water in their leaves and stems for extended droughts and grow into dense vegetation mats of various colors, textures, and forms. However, the selection of plants for living green roofs should include a matrix of plant genera and species that provide adequate

FIGURE 6-38 This simple boardwalk shows a clear demarcation between accessible walking surface and the part of the living green roof not intended for access and dynamic load. (Photo © Zinco)

horticultural diversity and visual interest, such as herbs, perennials, and low grasses. Plants that are adaptable to and suitable for the artificial roof environment may differ from the native plant palette best suited to the regional environment. Often plants specified for a living green roof are selected from a palette of plants that are native or indigenous to a region or environment that most closely resembles the rooftop environment. An understanding of how the plants may act within a specific green roof system is important. Drought-resistant plants with extensive root systems may appear to be a good choice for living green roofs. In reality, they could add a potential fire hazard, because while in their native environment these plants have access to a high water table or aquifer, in a non-irrigated living green roof the grasses may dry out.

FIGURE 6-39 Integrating the ability for manual irrigation. (Photo © Jeffrey L. Bruce & Co.)

The primary purpose of a living green roof is to capture and detain stormwater, and in order to maintain the maximum stormwater retention capacity irrigation is usually not employed. The vegetation must be able to survive in a shallow growing medium and harsh, dry conditions.

Sometimes, if the living green roof is located in a regional climate with little annual rainfall and excessive summer temperatures, or if it is so large in size that even initial hand-watering is labor-intensive, it may be equipped with pressurized drip irrigation system to efficiently irrigate as needed.

The maintenance required for most living green roof planting might include hand-watering during installation and the adaptation period, weeding, fertilizing, and spot repair. Over the long term, planting maintenance is minimal, but it is important to understand that this ecosystem initially requires a serious commitment on the part of the owner to care for the plants. Plant establishment and growth is a process that can take up to two growing seasons before the living green roof reaches its maturity and 100 percent plant cover. (See Chapter 10 for more detailed information on maintenance of living green roof vegetation.)

Soil Mixes, Growing Media, Plant Selection, and Irrigation for Landscapes over Structure

The depth and composition of soil mixes and growing media for landscapes over structure will vary widely depending on the types of plants used, the plants' installation size and their expected size at maturity, overall configurations of fill sections, expected maintenance, and numerous other factors unique to the project. Obviously, the plants selected for a landscape over structure need to be able to flourish in the regional climate and in their specific solar orientation and microclimate. As with living green roofs, plants in landscapes over structure must survive in often harsh, dry conditions with desiccating winds.

Often more than one growing medium or soil mix will be required for a landscape over structure to emulate a natural soil horizon and provide the best possible growing conditions for plants in an artificial environment. Each type of mix will most likely need to be fabricated from several components. (Depending on the specific requirements, components might include local loams, sand, organic matter, lightweight expanded aggregates, and other aggregate materials.) The mix will also need to be fabricated to accommodate a number of variables such as:

- Specific horticultural requirements of the vegetation selected
- Local availability of components specified
- Depth allowed in specific locations
- Weight allowed in specific locations
- Ability to support paving
- Drainage system employed
- Irrigation system employed
- Expected maintenance regime and ability to replenish or amend

Similar to living green roofs, a major advantage of planting over structure is to provide additional permeable surfaces, which slow the pace of runoff and perhaps retain stormwater. The plants also add to the replenishment of oxygen and the depletion of carbon dioxide, among other beneficial environmental attributes.

Water does not move through a landscape over a structural deck in the same way water migrates through terra firma. Also, in many natural systems groundwater may be available and the water table may fluctuate greatly during different seasons; this groundwater is not available to the vegetation of a landscape over structure.

Although rainfall availability remains the same for planting over structure as it does for terra firma, the absorption rate, drainage rate, and discharge rate will be different for each specific landscape over structure. These rates will be dependent upon the type of soil or growing media, the drainage system, the depth of the soil and its ability to retain water, the desiccation factor of the wind, and a number of other natural phenomena specific to the site. Supplemental irrigation is required.

Supplying irrigation to landscapes over structure is generally similar to systems employed in terra firma conditions. One difference is that greater capacity needs to be anticipated for drainage and desiccation.

A major consideration in the design of the irrigation system is the coordination of the mechanical, electrical, and plumbing systems. It is essential to have a qualified, experienced irrigation designer in the design of the irrigation system.

The water source must be determined early on, along with the size of the feed line and the point of connection to the water source. Also, the design of the riser diagrams must ensure that the water pressure is adequate to transport the water to the highest levels required. It is also beneficial to install additional hose bibs and quick couplers for spot watering and washdowns of paving and site furnishings. Another major consideration is the coordination of the installation of the conduit for both the irrigation's water and electrical lines, because of the potential for damaging the waterproofing. It is also important to coordinate the layout of the conduit and any wall perforations required prior to the installation.

When an irrigation system leaks, it can go undetected for quite some time, exacerbating any weakness that may already be within the waterproofing system. Secondary shutoff and emergency detecting systems should be incorporated into the irrigation system to alert the maintenance staff to leaks or drops in pressure. Hydrometers are available to test and monitor the dryness of the soil. An anemometer may also be beneficial in assisting in detecting the wind in the desiccating ability of the winds.

FIGURE 6-40 Coordination of irrigation control valves. (Photo © Jeffrey L. Bruce & Co.)

FIGURE 6-41 Irrigation line failure. (Photo © Jeffrey L. Bruce & Co.)

FIGURE 6-42a Construction sequencing for the Great Lawn at Millennium Park, Chicago. (Photo © Jeffrey L. Bruce & Co.)

FIGURE 6-42b Installation of drainage lines over protection board. (Photo © Jeffrey L. Bruce & Co.)

FIGURE 6-42c Installation of drainage aggregate. (Photo © Jeffrey L. Bruce & Co.)

FIGURE 6-42d The Great Lawn in full swing. (Photo © Jeffrey L. Bruce & Co.)

A number of proprietary irrigation systems can monitor more than one location. This is particularly beneficial when the maintenance of several areas fall under the same maintenance responsibility. These systems also have the advantage of being monitored remotely, but each individual system should have the ability for local manual shutoff.

Decisions about an irrigation system should also consider the incorporation of nutrient injection systems, which can assist in monitoring and measuring fertilization or other required chemical alterations to the soil. Like all irrigation systems, the quality of the water is also important: it should have no long-lasting chemicals that can affect the plants or the soil or leave residual efflorescence on adjacent planters, buildings, walls, windows, or site furnishings.

Summary

The many products that are available today can make selecting components for a system mind-boggling but allow for the flexibility in design, installation, and performance required for the unique conditions encountered on every green roof system project. Many new proprietary "complete green roof" products have appeared in the green roof marketplace. While tempting to use a waterproofing manufacturer's system because of apparent simplicity and compatibility, the disadvantage of specifying and utilizing a sole-source system is that each project is different; not all the components may be the right ones for that particular use.

It is essential to understand the properties of each component of each system (waterproofing, insulation, drainage, planting, irrigation, paving, walls, stairs, fountains, site electrical, site furnishings, etc.) so that the entire green roof system may be designed and installed to produce the long-term desired effects.

Endnotes

1. Edward Allen, Joseph Iano. *Fundamentals of Building Construction, Methods and Materials,* 4th ed. John Wiley & Sons, Inc. 2004.
2. Theodore Osmundson, FASLA, *Roof Gardens, History, Design and Construction,* W.W. Norton & Co. 1999.
3. "Roof Decks Design Guidelines." CMHC Central Mortgage and Housing Corporations. Ottawa, Ontario 1979.

Chapter 7

Putting the Parts Together: The Design and Documentation Process

In the previous chapters the focus has been on the numerous important interfaces that need to be considered prior to producing the final construction documents required to bid on and build a successful green roof system.

Often, because of the interrelationship of the architectural, structural, and landscape infrastructure and associated costs, the successful implementation of a green roof system may require that all systems and even their component parts be agreed to very early in the project. Failure to consider all of the architectural, structural, and landscape architectural systems thoroughly will ultimately affect the constructability and cost of the envisioned project. When this happens, the results tend to reduce the possibility of implementing a green roof system.

At each phase of the project the owner must be completely aware of and in full agreement with the physical and cost implications of the required infrastructure and resultant finished materials and systems.

It is essential that the architectural, structural, mechanical, electrical, civil, and landscape infrastructure required to support the desired landscape elements and program be coordinated in concept or schematic design, and resolved with increasing detail during the subsequent design phases upon which this chapter focuses: design development and construction documentation.

This chapter begins to address:

- How the selection of components may be combined into a system
- How to coordinate and integrate the green roof system with the other design disciplines and properly document it through the drawings and specifications
- How to anticipate and recognize common areas of overlap
- How to avoid duplication of information
- How to avoid inadvertent omission of information assumed to be included within another discipline's documents

Coordination of information among the various design disciplines is essential because duplicated, missing, or confusing information will only cause further confusion during the bidding and construction of the project; which in turn will result in delay, additional cost, or incorrect installation.

Similar to previous chapters, this discussion will reflect terminology commonly used within current industry standards and requirements of practice as it relates to developing the design and providing construction documents for green roof systems.

Chapter 8 will focus on key considerations of the bidding and construction process. Both chapters will be augmented with construction details and images illustrating considerations of project-specific but substantive issues that must be addressed in order to achieve a successful project.

Early Project Phases

In the prior project design phases of planning at the scale of the city and master planning, specific projects will have been identified. Throughout the concept and schematic design phases, the programming requirements will have been identified and general organizational principles and size of project elements determined, including location, circulation and parking requirements, and building orientation, footprint, and height. Other site-specific elements such as general grading requirements, walls, stairs, fountains, and the amount of paved versus planted areas have been delineated. The inclusion of living green roofs and landscapes over structure has been determined and their locations and infrastructural requirements incorporated into the preliminary documentation of the related design discipline. The basic design direction is set, and perhaps even an initial range of suitable materials has been considered.

Ideally, the design team has identified key areas where close investigation and coordination are needed to accommodate the requirements of each discipline.

Geotechnical investigation has determined suitable conditions, and the design team has coordinated any necessary geotechnical infrastructural requirements. Floor sizes and heights have been established, landscape infrastructural requirements for locations of soil mixes as well as depth and weight have been determined, and the basic structural systems to support the architecture and landscape have been determined. Initial column or truss locations have been established, as have structural decking or slab thicknesses. Top of structural deck elevations, finish floor elevations, and exterior finish grade elevations have been initially coordinated. Mechanical systems and vent sizes and ideal locations have been coordinated to minimize their intrusion into highly visible, audible, or accessible areas. The required utility infrastructure has also been initially sized and coordinated to manage power usage and stormwater in an effective, efficient, and ecologically responsible manner.

The team has coordinated (perhaps by using USGBC and LEED guidelines and standards) their approach to sustainability and has integrated appropriate elements into the schematic design. The design team is respectful of each other's discipline and collaborative in their approach to resolving design issues. The owner has been apprised of overall projected cost implications as determined by a thorough cost estimate, particularly of the living landscape elements, and accepts them as an integral part of the project.

Typically, some adjustments may be necessary due to program, design, or cost issues. Upon the owner's approval of the schematic design, the project advances to the design development phase.

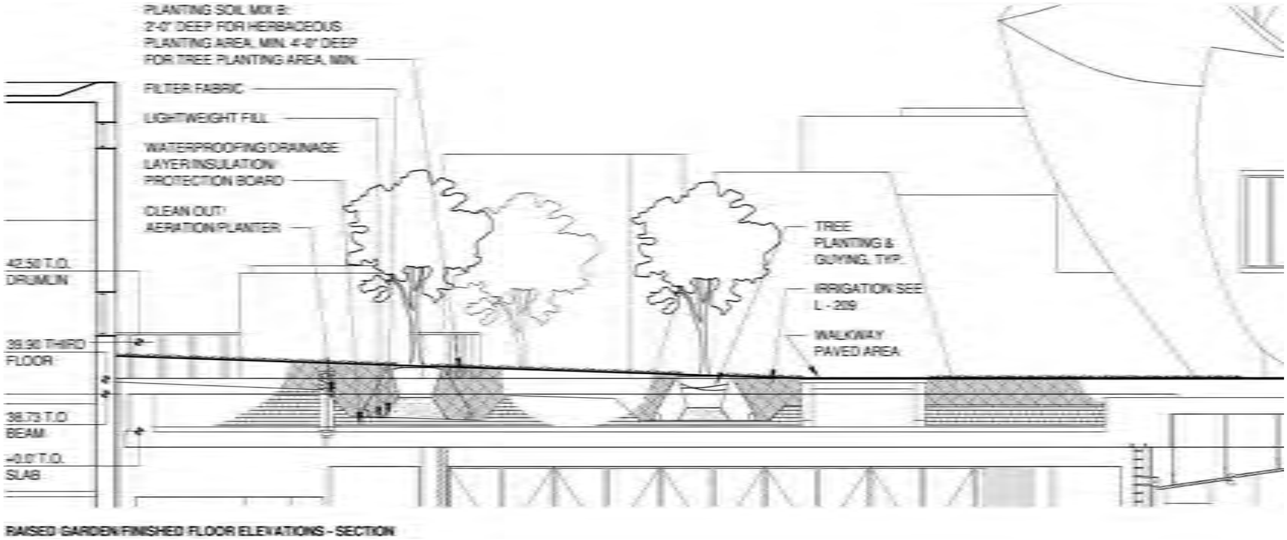


FIGURE 7-1 Coordination of finish floor elevations with exterior elevations.

Developing a Conceptual Framework

The project involved a redesign of a major public square, to be retrofitted over an existing parking structure. Prior to the design development phase, the following concept specifications were developed to provide the owner and cost estimator with a greater understanding of the system components typical of a project of this type. During schematic design outline specifications would be developed. These specifications are then more comprehensively developed during design development.

CONCEPT SPECIFICATIONS

Note that fabrication and placement of these materials, especially soils and trees over structure, are usually more expensive than on terra firma.

A typical system would comprise the following:

Waterproofing, Insulation, Drainage, and Aeration

- *Waterproofing:* fluid-applied or sheet, any reputable manufacturer and installer
- *Protection board:* felt, polyvinyl, fiberboard (anything which will protect the waterproofing from damage during installation of other components or subsequent repair or excavation and ensure material compatibility)
- *Insulation:* in areas of planting in a heated garage, an insulation layer of any high-density expanded polystyrene, R-value to be determined, usually about 4 to 6 inches thick
- *Drainage:* both of the following systems:
  - Base drainage: continuous in areas of planting and most likely paving; lightweight expanded clay or shale aggregate, coarse, 6 inches deep (if structure can support

gravel, then gravel may be used), 4-inch perforated drainage pipe laterals and 6-inch mains, connected to surface and storm drainage systems
- Secondary drainage and aeration in areas of planting: drainage/aeration matting, crush-resistant interwoven plastic mesh

Planting over Structure Basic System

- *Root barrier:* a polyvinyl or some other plastic membrane that inhibits root growth into the waterproofing layer and may be placed below the insulation or protection board
- *Water retention mat:* interwoven fiber mat
- *Drainage/reservoir panels:* high-density polyvinyl panels, 60 mm, sometimes filled with fine expanded aggregate
- *Drainage/aeration matting:* crush-resistant interwoven plastic mesh with nonwoven filter fabric

Soil Mixes

Use fabricated soils with lightweight aggregates. These soils will be fabricated using a base mix of sandy loams, combined with specific proportions of organic content and mineral aggregates to meet various horticultural and structural requirements (estimate premium costs per cubic yard).

Interstitial Fill

Root balls of trees will be 3 to 4 feet deep and 4 to 5 feet in diameter. Most areas of planting to employ a system where the zones around the root balls (8 to 10 feet wide) would be full-depth (3 to 4 feet); in interstitial areas there may only need to be continuous soil mix in the top 18 inches. Areas below this may be filled with expanded polystyrene blocks.

Planting

- *Trees:* assume minimum of 6-inch caliper, matched, nursery-grown, and underground anchoring systems (Duckbill or equal)
- *Shrubs/perennials:* in areas of planting indicated shrubs and perennials, assume 50 percent shrubs at 36-inch height, 50 percent perennials in 1-gallon pots 18 inches on center
- *Areas of changing display:* assume four annual changes, 50 percent 1-gallon pots 18 inches on center and 50 percent 1-quart pots 8 inches on center.

Irrigation

All areas of planting are to be irrigated.

Paving

Use the following components:

- *Drainage:* as above
- *Setting beds:* bedding sand (1-inch depth)
- *Pavers:* 2-to-3-inch depth and 18-to-24-inch faces (estimate some premium for specialty shapes, radial cutting, field cutting, etc.; in some areas—allow 40 percent—paving with open joints on pedestal systems)
- *Stone fines paving:* gravel base course of 5 to 6 inches, topping course of 2 to 3 inches of stone fines, and binder course.

Design Development

Design development is the phase of the project when all of the issues left unresolved at the end of schematic design must be worked out at a scale and to a level of detail that minimizes major modifications during final contract documents. For developing and documenting green roof systems, this is perhaps the most significant but most often underutilized period for refinement and coordination.

The primary objective of the design development phase is to define and describe all important aspects of the project that will fix the dimension and materials of the project. During this phase the emphasis shifts from overall relationships and functions of the various project parts that need to be coordinated on a broad scale to a level of detail that begins to address the actual constructability of the project. The essential development and selection of systems is advanced, as is the selection of components that will comprise the various systems.

The structural engineer will begin to determine whether the roof system is a truss system, slab over columns, beams and girders, or a post-tensioned system. The architect will develop floor plans, refine exterior elevations, and determine the most appropriate construction system. The mechanical and electrical engineer will determine the type and size of the mechanical system required for air exchange, as well as size power requirements and determine how best to distribute the power.

The landscape architect or green roof designer, along with the civil engineer, will determine the overall surface grading and drainage systems, the water holding capacity and locations, and types and depths of growing media and soil mixes. The location and weights of vegetation will also be determined. Paving systems and other site elements such as exterior walls, stairs, and fountains will be advanced.

This series of construction details shows the overall development of the planting and paving systems required for the retrofit of a new public plaza over an existing parking structure. The first series (7–2a, b, c) illustrates the progression of design and construction requirements related to the structural decking and wall. The second series (7–3a, b, c, d) provides the information required to sustain large-caliper trees in two different planting conditions.

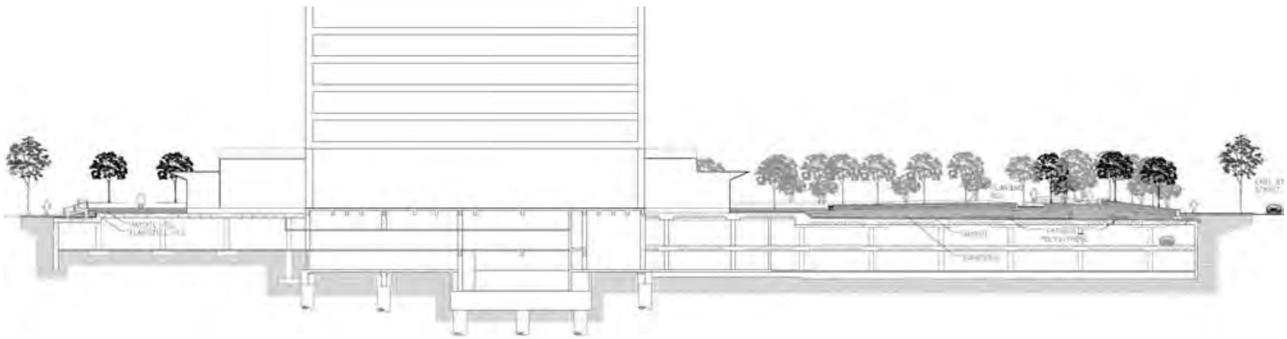


FIGURE 7-2a In the schematic design phase, the initial studies of the relationships and requirements of the fixed elevations of the existing street and the finished floor elevations of the building entrance needed to be coordinated with new paving and planting depth requirements and the top of the existing structural slab.

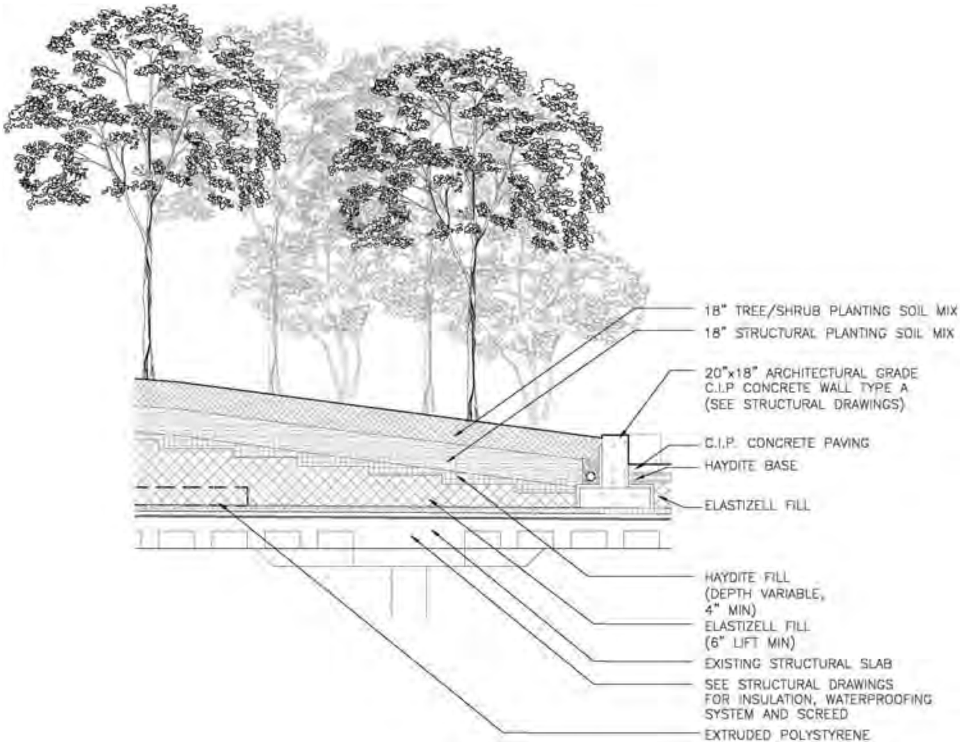


FIGURE 7-2b In this detail the specific types and depths of fill and growing media are determined as well as the relationship of planting to structural slab waterproofing systems and the security wall at the street.

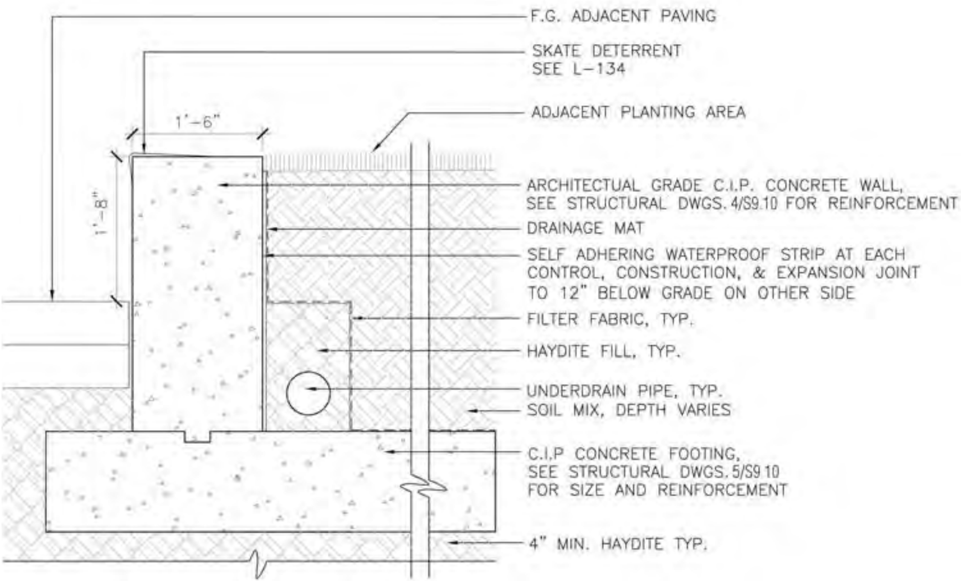


FIGURE 7-2c Upon completion, the construction documents provide, along with the written specifications, all of the information required for the contractor to build the project.

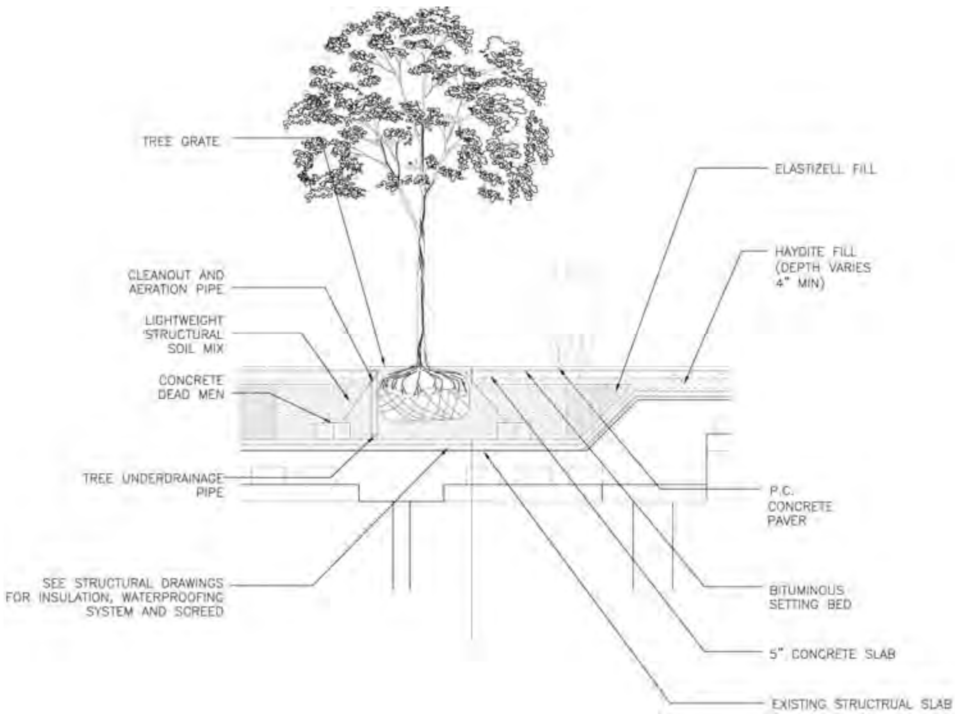


FIGURE 7-3a In the schematic design phase general considerations of the components of the planting system in relationship to finish grade, top of structural slab, and column spacing are proposed. Dimensions are used only to indicate minimum or maximum tolerances that must be coordinated, determined, and fixed early in the design process.

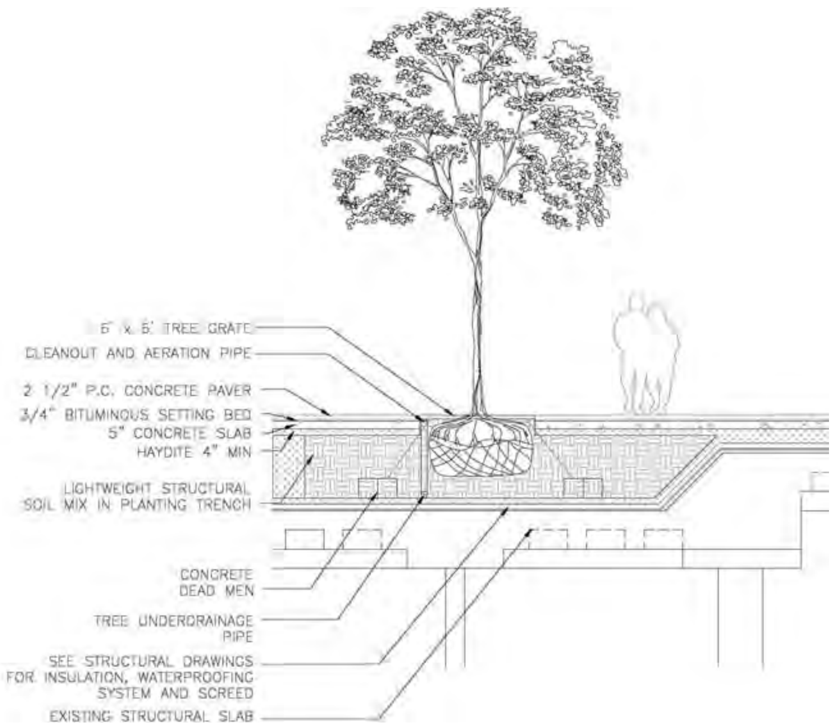


FIGURE 7-3b Two different planting systems are determined to be necessary.

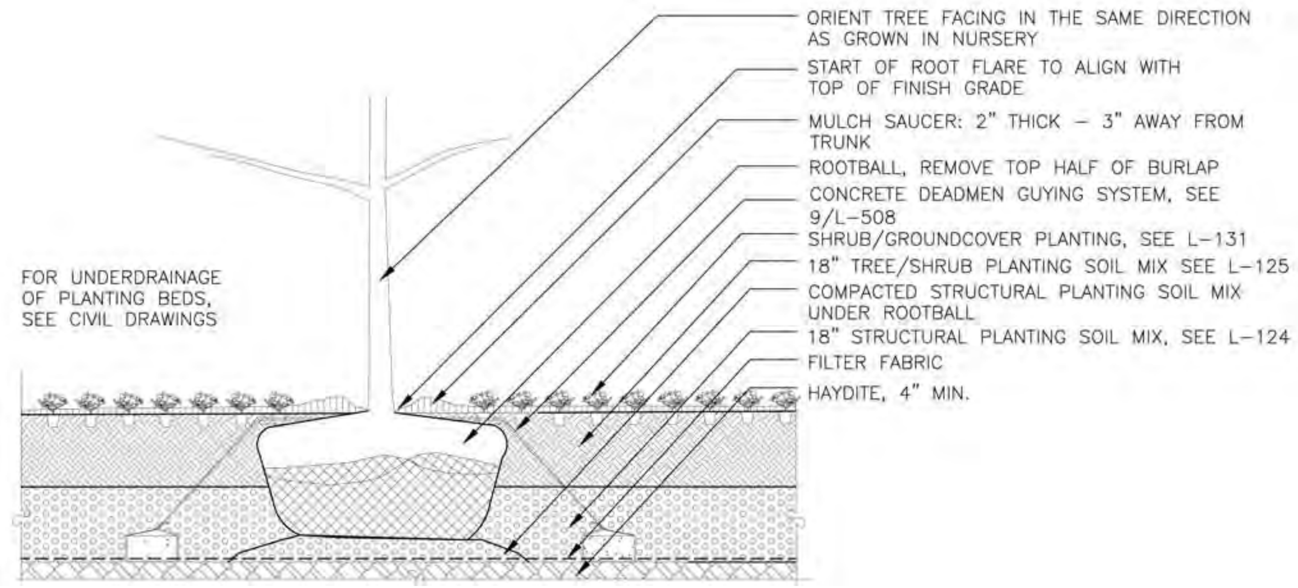


FIGURE 7-3c Planting system type 1 specifies the detailed information required to plant and sustain a large-caliper tree on a structural slab in an extended area of planting soil.

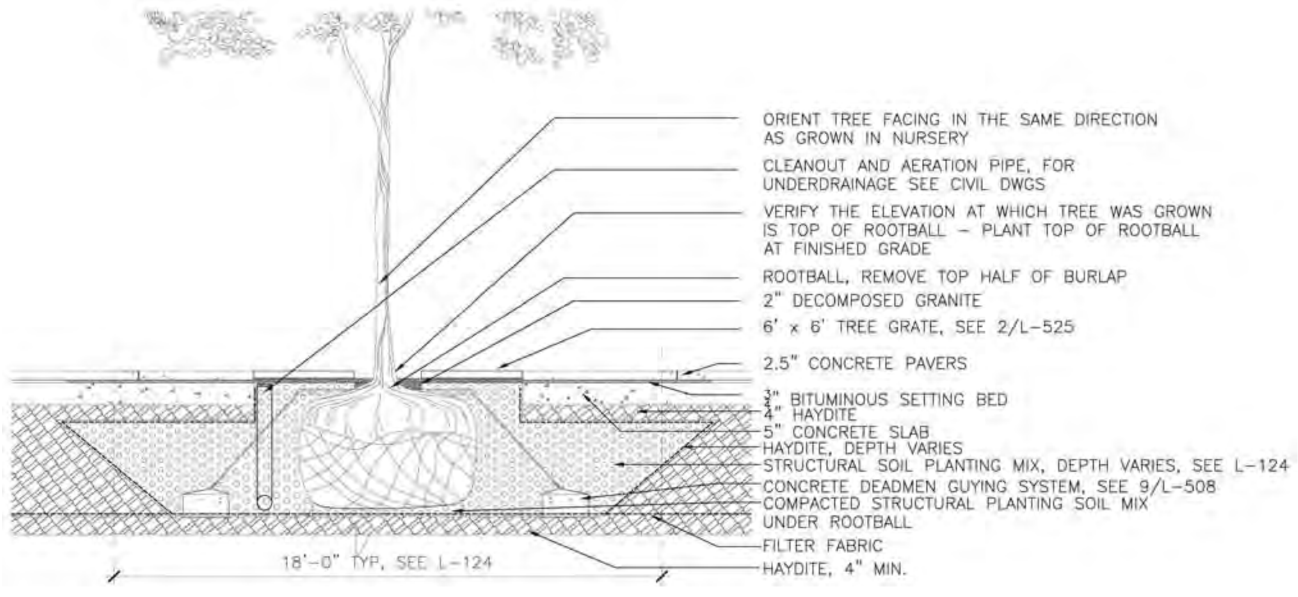


FIGURE 7-3d Planting system type 2 specifies the detailed information required to plant and sustain a large-caliper tree on a structural slab in a limited but continuous soil trench and under a paved surface.

While each system is being developed by individual disciplines, the importance of their integration with the other design disciplines cannot be underestimated. For example, while the landscape architect is trying to develop the planting system, the required depth of soil for the long-term sustenance of the trees, shrubs, and other plants must be determined. The depth must accommodate the root ball at installation and long-term root run. The weight and depth of the soil mix must be coordinated with the structural engineer in order to provide adequate structural support. The architect, meanwhile, is trying to adjust a floor-to-floor height and needs to lower the finish floor elevation, which means the exterior finish grade will be lower and not leave enough depth for the soil mix. The structural engineers would lower the exterior slab elevation, but the mechanical engineer needs another 2 feet below the deck to install the mechanical chases. In another part of the project, the structural engineer has to raise the top of the slab 6 inches to accommodate a mechanical system below, and can do this only by making the slab thinner; now it will not be able to accommodate the weight of the soil or root ball. In paved areas where the slab is close to finish floor elevation, even a small uncoordinated change in slab elevation or interior finish floor elevation could mean inadequate depth for the paving system or result in an exterior gradient in excess of accessibility requirements.

As an example, the diagram shown in Figure 7–4 was sketched by the structural engineer over the landscape architect's soil profile plan, which helped to advance the development of the structural truss design.

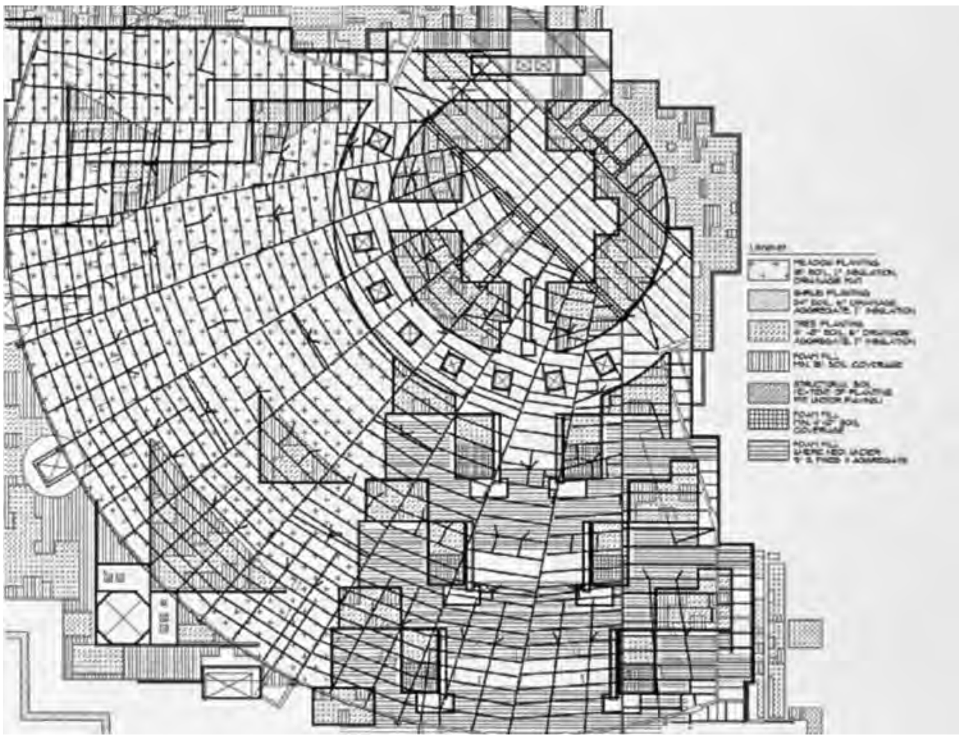


FIGURE 7-4 The structural engineer sketched over the landscape architect's soil profile plan, which helped to advance the development of the structural truss design.

Proprietary Systems

The burgeoning building green movement has fostered many new green products. This is perhaps most evident with the emergence of many proprietary green roof systems, sometimes referred to as "vegetated roof assemblies."

There is an almost stunning number of new systems available, of which many seem to be fabricated from similar components made from similar materials. This can make selection and proper detailing and specification even more demanding when it comes to sorting out the attributes and performance characteristics of either the individual components or the comprehensive system. The specifying architect of record is responsible for selecting the system and remains liable for the performance and functionality of a proprietary system.

Proprietary green roof systems may be new to the North American market, but they have been commonly available and employed in Europe for more than twenty years. Germany has long been a leader in the implementation of living green roofs, and also leads in product design, testing, and manufacturing of components and systems for the green roof industry. Among the companies offering proprietary systems in North America is Zinco, which offers one of the wider arrays of components and systems, including numerous types of rigid insulations with drainage capacities and products for use with vehicular traffic. Optigrun and Soprema systems are also available, with Optigrun sometimes marketed under a different name. Most of the proprietary systems also have appropriate accessories such as roof drains and flashings.

The basic components of most of these systems support the basic requirements of green roof systems: optimal water retention, drainage of excess water, and provisions for growing medium and airflow. Many also include additional waterproofing membrane protection, filter fabrics, root barriers, and wind erosion blankets. Some systems also provide the growing medium and plants as well.

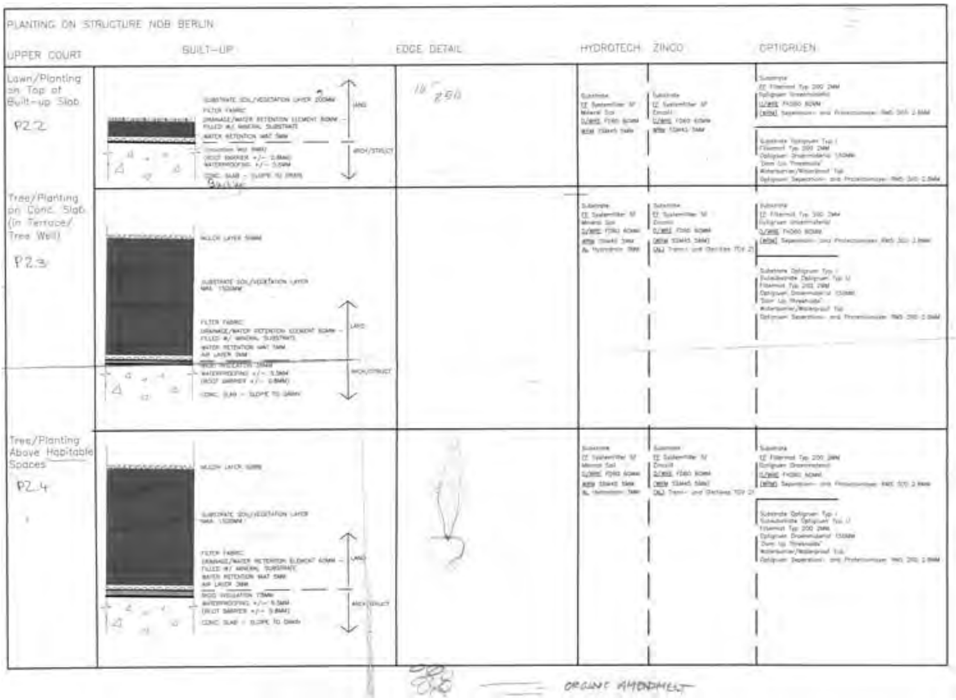
While the individual components can be used in either living green roofs or landscapes over structure, manufacturers tend to gear these systems more toward living green roof use. However, many systems can accommodate a full range of growing media and plant depths, from very thin profiles to deeper profiles for a wider range of vegetation or other exterior use. An advantage of proprietary systems is that by utilizing different profiles and layer depths the physical properties of the system components can be adapted to most climatic zones. Some are even adaptable to semi-arid climates, where they can be designed for passive or active irrigation. Another advantage is that some of these proprietary systems provide a wider range of components, such as erosion mats and battens, that are compatible with sloped roofs.

A disadvantage is that some systems may have more components than necessary for a particular application. It's important to understand the application of each component.

Many waterproofing membrane manufacturers also provide green roof systems. Among the better-known are Carlise, Novatan, Tremco, and American Hydrotech. An advantage to this is that all the components are compatible with the waterproofing membrane. A disadvantage is that some manufacturers will not guarantee the removal and replacement of the overburden of growing media or soil mixes and planting unless all of the components of their system are used. This often comes as a surprise not only to the design professional, who may specify the system but wish to diverge from some particular component within that system, but also to the owner, in the event the waterproofing membrane needs to be repaired.

Every project will have its own requirements. Most proprietary systems will likely fulfill many of those requirements; however, the more complex the requirements, the more carefully the components must be reviewed. The selection of the appropriate components or system requires careful review. Given the number of new products and systems available, costs may vary, but can still remain competitive. More importantly, the knowledge and technical understanding of all system components will lead to the ability to implement successful green roof systems commonplace, and the cumulative positive impact more attainable.

As the systems are developed and coordinated, the components that comprise them are determined and the initial selection of materials and surface finishes are made. The detailed graphic (plans, sections, elevations, schedules, etc.) are developed and written



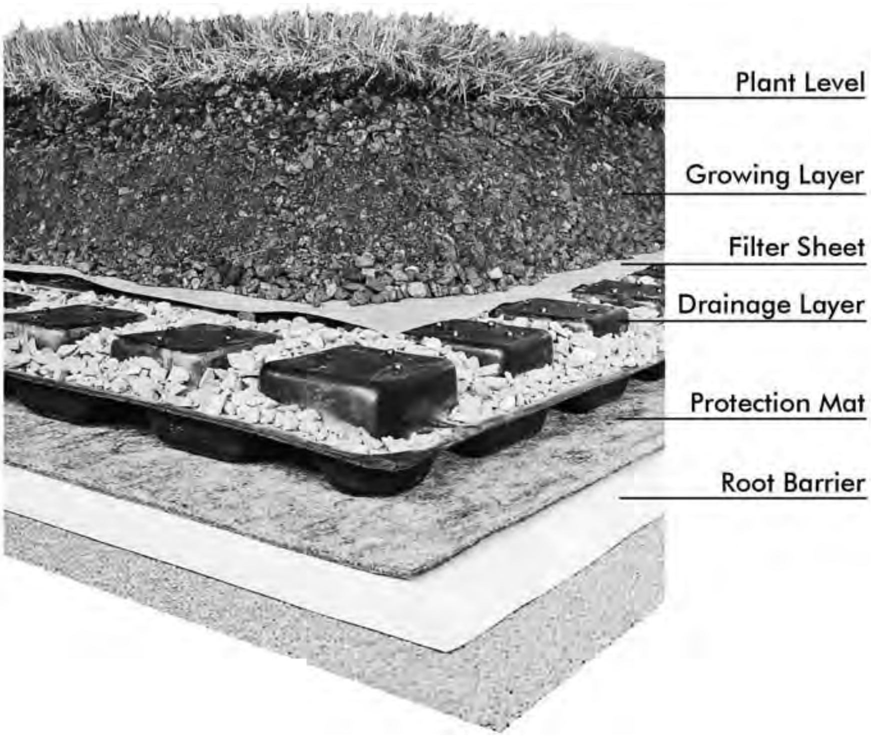


FIGURE 7-5a In-house comparison of proprietary systems.

FIGURE 7-5b There are numerous proprietary systems available. Many of them have similar components made from similar materials. (Photo © Zinco) (outline specifications) communications required to interconnect the systems, components, and materials are also developed.

Not only do these drawings and outline specifications advance the design of the project, but they also serve as a basis for revisions to the cost projections made after schematic design. More importantly, the documents produced in this phase may also determine the guaranteed maximum price (GMP) of the entire project.

The costs of living green roofs and especially the integrated, infrastructural requirements for landscapes over structure are not always fully understood by contractors or cost estimators who have not previously built a green roof system. As a result, the costs are often not adequately represented in schematic or even design development cost estimates. This is particularly true of estimating the premium resulting from structural requirements—either in upgraded columns, beams, and slabs, or in the costs of lightweight structural fills, structural soils, or other fabricated soils. Seldom are the costs of construction logistics considered in early cost estimates. Combined with lack of coordination of disciplines, such as information not properly included in the drawings or specifications, this can result in unreliably low cost estimates. In turn, this may provide a false sense of economic comfort to the owner. An enormous cost increase resulting from bids on the final drawings and specifications (contract documents) not only decreases the design team's credibility but also can significantly impact the owner's ability to complete the project as envisioned. When this happens, most frequently it is the green roof system that is minimized or completely eliminated.

Construction Documentation

The construction document phase is based on the approved design development documents and any further adjustments in the scope of the project or the project budget.

Construction documents are defined as all of the written and graphic documents prepared or assembled by the required design disciplines for communicating the design and administering the construction contract. The construction contract documents enable the owner's and design team's vision to be translated into reality.

The Construction Specifications Institute (CSI) lists the following categories for the documents:

- Bidding requirements
- Contract forms
- Conditions of the contract
- Drawings (graphic representations of the work upon which the contract is based, showing the materials in their relationship to one another, including sizes, shapes, and locations of key connections; they may include diagrams showing such things as mechanical and electrical systems, schedules of materials, and dimensions and finishes)
- Specifications (the qualitative requirements for products, materials, and workmanship upon which the contract is based, typically organized into the divisions recognized as an industry standard; however, sometimes it is necessary to coor-

SECTION 07122

HOT FLUID-APPLIED WATERPROOFING

PART 1 – GENERAL

1.1 SUMMARY

1.2

A. This Section includes the following, in addition to surface preparation and substrate treatment.

1. Waterproofing System 1, (Vertical Walls for F2): Unreinforced waterproofing membrane, protection course (board), Type 99 drainage panels (Type 99 drainage panels only required where gravel is not as required by the Geotechnical Report).
2. Other Waterproofings Drainage Systems are indicated on the Landscape Drawings.
3. Provide sheet flashings and accessories associated with systems.

B. Related Sections: The following Sections contain requirements that relate to this Section:

1. Division 2 Section "Excavation and Fill" for backfill against waterproofing.
2. Division 2 Section "Planting" for landscape materials over waterproofing.
3. Division 3 Section "Cast-in-Place Concrete" for concrete placement, curing, and finishing.

PART 2 – PRODUCTS

2.1 ACCEPTABLE MANUFACTURES

A. Membrane Products:

B. Insulation manufacturer

2.2 MEMBRANE

A. Single-component, 100 percent solids, hot-applied rubberized asphalt, complying with the following as determined by the test method indicated with each property:

2.3 AUXILIARY MATERIALS

A. Primer: "Surface Conditioner"

B. Sheet Flashing:

C. Sealants and Accessories:

D. Elastomeric Reinforcing Sheet:

E. Joint Reinforcing Strip:

F. Membrane Reinforcing Fabric:

G. Separate Sheet:

H. Root Barrier

I. Protection Board

FIGURE 7-6 This specification section, usually only used for waterproofing, was modified to accommodate the entire drainage system over the waterproofing system to ensure that the critical relationship was clear to the contractor.

2.4 AERATION AND DRAINAGE PRODUCTIONS

A. Type 99 Drainage Panels (F2 only):

1. Geotextile at vertical Surfaces:
2. Geotextile at other locations:

B. Drainage Panels at Other Locations:

C. Aeration Mat/Filter Fabric: Non biodegradable composite, with a permeable geotextile bonded to high-density polyethylene drainage core (two parallel layers crossing each other); designed to effectively convey water.

2.5 INSULATION

A. Extruded & Expanded –Polystyrene Board Insulation:

1. In Planters, Type
2. At other location, provide Type
3. Provide tapered insulation where indicated.

FIGURE 7-6 *(continued)*

dinate the specifications quite differently for living green roofs and landscapes over structure)

- Addenda (written and graphic documents issued to clarify or revise information in the original bidding documents or in previous addenda; typically issued prior to the opening of bids, to allow for negotiated adjustments of the selected bid after bid opening)
- Contract modifications (duplications, omissions, discrepancies, terminology differences)

A frequent error in documentation is to reference another discipline's drawings without proper cross-reference. For example, if the landscape architect makes the reference "See structural drawings" rather than referencing a specific drawing sheet and detail number, it may not be clear whether the cross-reference is meant only for one location or projectwide. Likewise, if the structural engineer in the meantime has made an adjustment to the documents without cross-referencing the landscape architecture drawings, confusion in bidding and construction are likely. This can lead to costly discrepancies or omissions.

The purpose of construction documents is to:

- Communicate in detail to the owner, contractor, and review agencies what the project involves
- Establish the contractual obligations of the owner and contractor to each other during the project, and establish the responsibilities of those parties administering the construction contract.

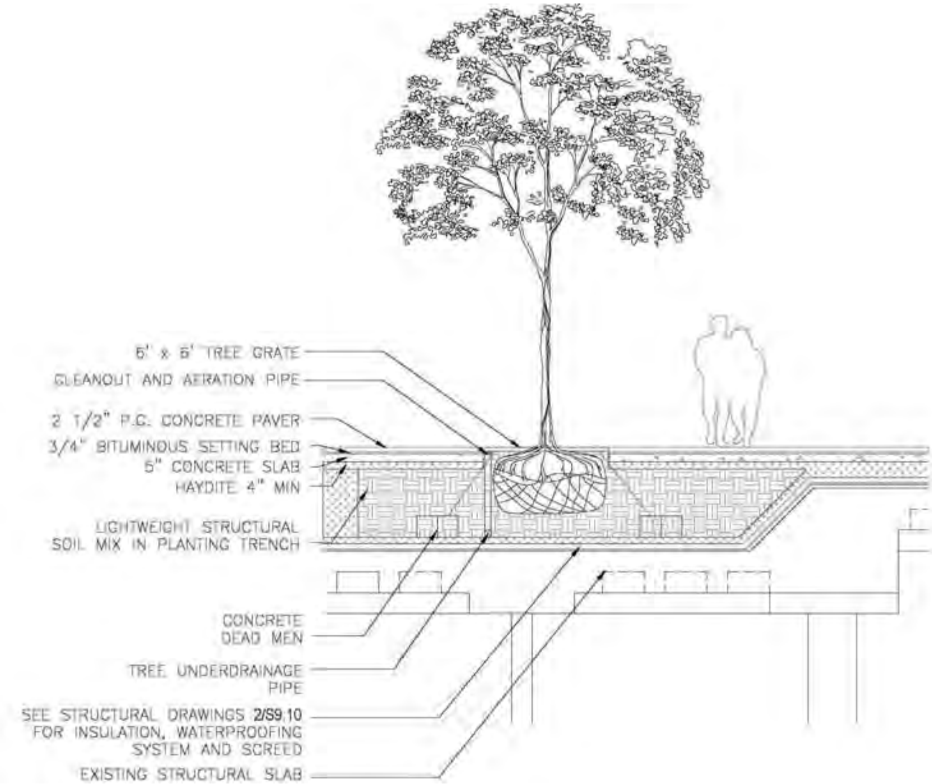


FIGURE 7-7a References to another discipline's drawings should always contain the proper cross-reference.

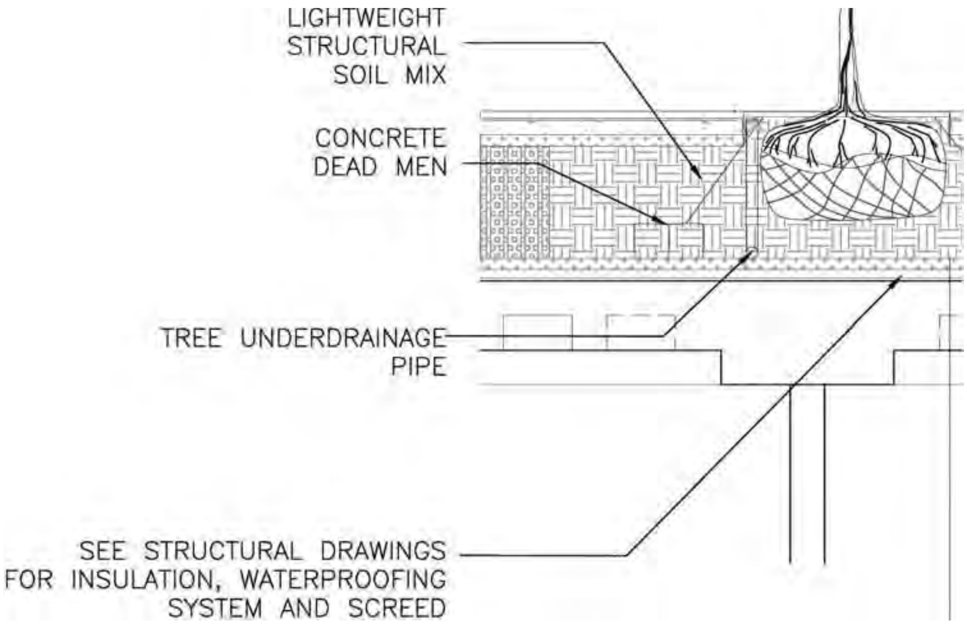


FIGURE 7-7b A frequent error in documentation is to reference another discipline's drawings without proper cross-reference, leading to costly discrepancies or omissions.

- Communicate to the contractor the quantities, qualities, and relationships of all work required to construct the project, so that the contractor may solicit bids from subcontractors and suppliers

While intended primarily to communicate the requirements of the project—what to build, what materials to use, and how to put them together—the contract documents become part of the legal contract for the agreement between the owner and the contractor. These documents may be the basis for obtaining regulatory and financial approvals to proceed with the construction. To advance these purposes, construction documents include three basic types of information:

- Legal and contractual information
- Procedural and administrative information
- Construction information

This type of documentation is often essential in seeking permits and approvals. With respect to nonconventional methods of construction such as living green roofs for stormwater management, it can be difficult to convince municipalities that the proposed design not only meets but exceeds code requirements.

Putting the Parts Together

Every living green roof or landscape over structure will have its own unique design and construction requirements. There is no one-size-fits-all way to properly develop and generate the drawings and specifications that will ultimately get the project built successfully. The following case study illustrates both common and unique green roof system requirements through a discussion of the design, documentation, and construction process of just one project.

Coordinating the Design, Documentation, and Construction Process for the Conference Center of the Church of Jesus Christ of Latter-day Saints

PROJECT BACKGROUND

As intended by its founders, Temple Square remains the spiritual and administrative center of the Church of Jesus Christ of Latter-day Saints. It is the epicenter of Mormonism. Temple Square was planned as the center of Salt Lake City and comprises the Temple, Tabernacle, visitor centers, libraries, and a number of administrative buildings. By the end of the twentieth century, the church had become one of the world's fastest-growing religions, with 5.2 million members in the United States and more than 5 million internationally, and the facilities had become overtaxed. This was particularly true for the twice-yearly general conferences attended by more than 30,000 members for each of six sessions. In 1996, Church leaders undertook the construction of a new facility for general conferences, theatrical performances, concerts, and assemblies.

CONFERENCE CENTER PROGRAM REQUIREMENTS

The site the Church selected for this massive project was one of Brigham Young's original city blocks, directly on axis with Temple Square and across the street from the Tabernacle and Temple itself. This huge parcel sloped upward 65 feet from the southwest to the northeast toward the toe of Capitol Hill and the ancient mountains beyond.

The design team selected for this undertaking was led by Portland, Oregon, architects Zimmer Gunsul Frasca, collaborating with numerous design consultants, among them the Philadelphia firm Olin Partnership as landscape architects; KPFF as structural engineers, also from Portland; and theatrical consultants Auerbach + Associates from San Francisco.

The program mandates—seating for 21,000 people, unobstructed views, space for lobbies and support areas, full facilities for theatrical and audiovisual productions, and below-grade parking for 1,400 vehicles—would make this 1.1-million-square-foot auditorium one of the world's largest religious or assembly buildings. The design mandate—to create "a magnificent, beautiful and utilitarian place for the people of the church and the community, a distinguished building in which visitors would experience a refinement of the spirit"—left the design team with some extraordinary challenges.

A building this large would have an extremely large roof—7 to 8 acres—and if not well designed would dwarf the Temple and surrounding buildings and compromise views of the mountain landscape beyond. Additionally, because of the design requirements to provide unobstructed views and acoustical clarity to every seat, the auditorium needed to be column-free and the cavernous space reverberation-free. Furthermore, this gigantic facility would need to be both functional for conference-day crowds of up to 50,000 people while at the same time nonintimidating, inviting, and of a human scale.

DESIGN SOLUTIONS

The solution that emerged as the result of an intensive collaboration with the architect, landscape architect, structural engineer, numerous other design professionals, the owner, and the contractors resulted in a building that becomes landscape itself.

Ultimately, utilizing the topography of the site was integral to the design solution. By taking advantage of the 65-foot difference in the elevation of the site and submerging a large portion of the building below street level, it was possible to integrate the roof, balcony, terrace, and orchestra levels of the auditorium with a comprehensive and integrated system of exterior stairs, gardens, fountains, and even an alpine meadow.

The back-of-house theatrical support functions such as catwalks and flyways, which require the greatest heights, were cut into the slope. The east, north, and rear auditorium walls would need to extend nearly 100 feet below finished grade. Along with four mechanical

FIGURE 7-8 An overriding concern of the team was how to make a building this big reconcile itself with the Temple, the city, and the landscape beyond. (Photo courtesy of ZGF Architects)

FIGURE 7-9 Merging the building with the landscape drew inspiration from Utah's natural landforms, native plant communities, and indigenous people's dwellings. (Sketch: L. Olin)

shafts, these walls would support terraced and cantilevered balconies and the massive roof structure. Additionally, these massive exterior walls could act as retaining walls for great stepped planters, to be filled with native plants, that would help to mitigate the scale of what would otherwise be enormous blank walls.

Another challenge was to determine the best way to engineer over 9 million cubic feet of building space requiring a clear span, and a roof to support a 6-acre garden with loads of up to 550 pounds per square foot.

This was accomplished by employing a radial long-span truss system with a 621-ton transfer truss over the stage. These trusses, portions of which would need to be 10 feet deep, would also need to span up to 290 feet to support the differing loads of the proposed sloping rooftop gardens.

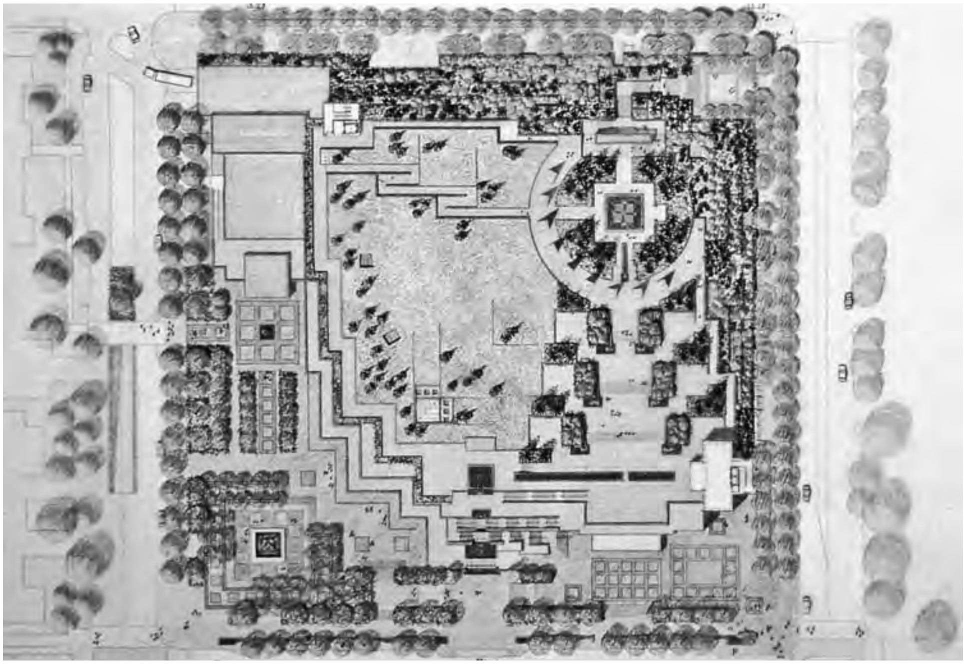


FIGURE 7-10a Ultimately, utilizing the topography of the site was integral to the design solution.

LANDSCAPE INFRASTRUCTURE

All planting and site work over structure requires careful design and construction. Rooftops in particular are inherently stressful environments for planting, as they are subject to heat, accelerated evapotranspiration, and desiccating and potentially damaging winds. Here the challenges were augmented by harsh desert summers and freezing, snowy winters. Additionally, to integrate the structural requirements and architectural expression of the interior, the roof needed to both step and slope. The slope meant it would be necessary to hold what might require a lightweight growing medium in place, and the stepping meant that the depths of soil mixes would be continually changing. The greatest loads and depths could be supported closest to the "king" truss and along the radial trusses closest to the bearing walls; only the thinnest loads could be accommodated along the outermost edges of the roof. Additionally, the various levels of auditorium and lobby entries needed to be physically accessible to all and visually accessible if not merged to the larger landscape beyond.

Building a usable, comfortable exterior space over structure required four fundamental elements: the structure to support it, waterproofing to protect what was below, protection boards to protect the waterproofing, and drainage systems to manage excess water. For stairs and paving, adequate stringer, slab support, and setting systems were required. For fountains and site lighting, enormous mechanical, electrical, and plumbing infrastructure needed to be coordinated.

Planting requirements included insulation from thermal fluctuation, sources for water and aeration, the selection of plants that could survive and flourish in this artificial environment,

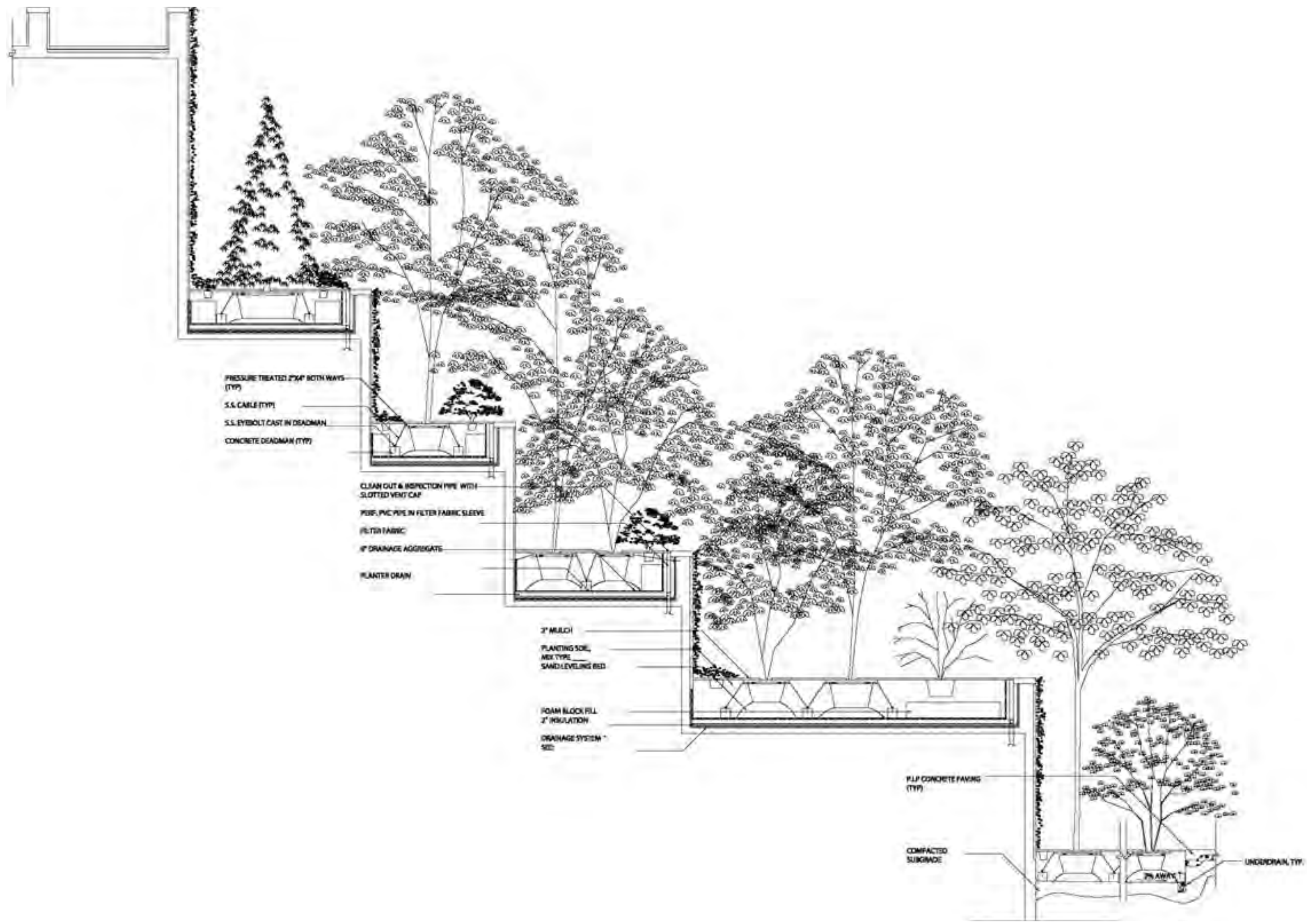


FIGURE 7-10b The massive exterior walls could act as retaining walls for great stepped planters filled with native plants.

and some type of growing medium in which the plants could gather nutrients and establish and maintain their root systems.

FIGURE 7-11 Loads and depths varied along the roof. (Photo courtesy of ZGF Architects)

BUILDING AND LANDSCAPE EMERGING

The "roof" had now become both a ceiling and a floor. Working from the structural slab upward, the waterproofing system employed was a liquid applied membrane covered by a protection board. For all areas of paving, fountains, and planting, the ability to collect and direct water was paramount. All surface, fountain, and planter drains needed to be connected below with a hydra of pipes conducting excess water to the appropriate storm system. Six different drainage systems were employed for the areas of planting and stone fines paving. These systems included aeration mats, drainage and filter fabrics, and drainage panels. No one system was appropriate for all situations; however, the components used to build the systems were often the same.

Extruded high-strength polystyrene was used both to insulate the planters from thermal fluctuation of the subsurface and interior uses below as well as to fill large areas of roof sections where loads were limited and soil mix depth could be reduced to 18 inches or less.

As in most construction projects, the supply of materials and work of each trade needed to be logistically sequenced to allow the steady progress of the work; however, also as in most construction projects, this logic did not always favor landscape construction. The mechanical, electrical, and plumbing systems were installed simultaneously with the planting, as were the paving and fountain stonework.

The various soil mixes were originally designed to take into consideration the height and sloped conditions of the roof, the initial and mature sizes of the planting (large-caliper trees 80 feet up into the harsh environment of Salt Lake City), the bearing capacity of the mix, provisions for a consistent and renewable nutrient source, and the weight of saturated soil. Ultimately the soil mix employed was designed by the Church staff and predominantly comprised lightweight expanded shale with organic amendment.

In selecting the plant palette the intention was not to re-create nature, but rather to evoke the natural landscape surrounding the valley. The selection and location of the plants reflected the natural communities of species native and indigenous to the Wasatch Mountains and valleys. The trees and shrubs of the stepped planters, such as gamble oak, big tooth maple, limber pines, and mountain mahogany, for example, are found within the varying elevations of the mountain slopes. The central gardens and source pool utilize poplars and evergreens, evocative of the mountains' middle elevations. In autumn, their combined colors mimic the ubiquitous swaths of gold against evergreen of the nearby mountain slopes.

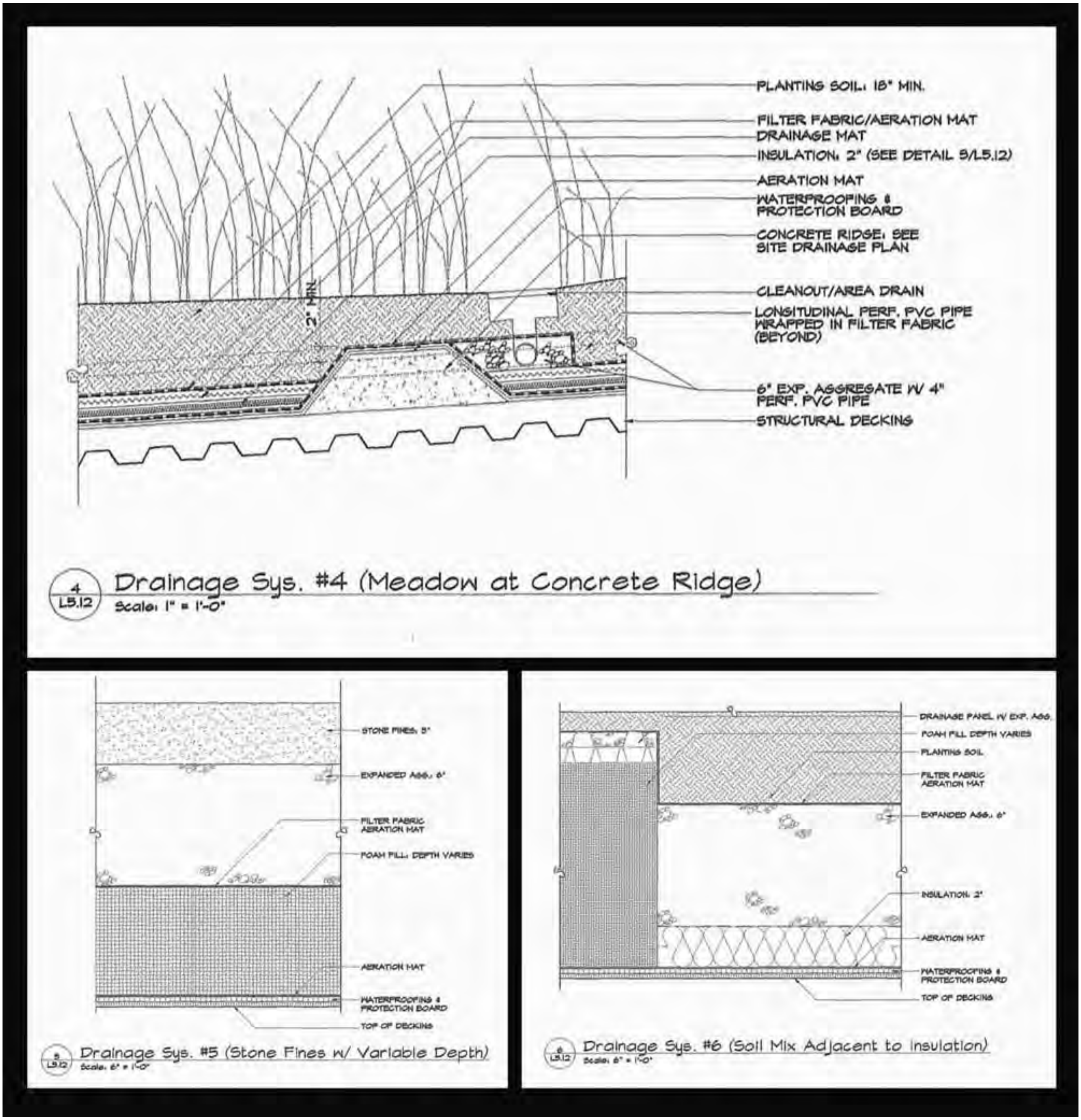


FIGURE 7-12 Three different drainage systems were employed for the areas of planting and areas of stone fines paving.

FIGURE 7-13 In all, nearly 1,300 trees, 27,000 shrubs, 36,000 bulbs, and 800 vines were planted.

At the highest elevation, the meadow comprises a matrix of grasses, annuals, and perennials found in regional alpine meadows. More than 75 species, including needle-and-thread grass, asters, and blazing stars, were selected for beauty, hardiness, and brilliant displays in the spring and early autumn, when tens of thousands of visitors attending general conferences would see them.

In an absolutely inspiring commitment to the importance and success of the meadow, the Church undertook with the landscape architect the extraordinary and almost unthinkable effort of contract-growing every perennial (more than 24,000 of them) and countless grass plugs and recruiting volunteers to hand-plant them. On two successive weekends the peren-

FIGURE 7-14 The perennials were contract-grown and hand-planted by volunteers.

nials and grasses were lifted to the rooftop, bucket-brigade style, by more than a thousand volunteers and planted in locations previously determined by the landscape architect and Church horticultural staff.

BUILDING AND LANDSCAPE MERGING

The resulting landscape design is experienced through varied sequences of arrival and moving in and out of the building and landscape, both visually and physically.

Entering the Conference Center from any side, the visitor is aware of the articulation of the façades. Setbacks, terraces, stairs, and water walls, integrated with the landscape, help

FIGURE 7-15 Western and southern approaches, with water as a major element.

(a)

FIGURE 7-16a–b The sequence of stairs, water, and plants that leads to the top of the roof, with the source of the water (a) and spectacular views (b; Photo: Eckert & Eckert).

to break down the mass of the building and make it perceptible in sequences rather than all at once.

From the north and east, the terrace planters step from the roof to street level and appear to envelop the sides of the building with native vegetation.

From the western and southern sides, water is introduced as a major element of the sequential experience of both the interior and exterior spaces, beginning with City Creek, a series of basins, and a wall fountain cascading along the main façade on axis with Temple Square.

For large events, the auditorium can be entered at the lobby, orchestra, and balcony levels. Once inside the column-free auditorium, which houses the 7,600-pipe organ for accom-

(b)

panying the renowned Mormon Tabernacle Choir, views from each of the 21,000 seats are completely clear, as are the acoustics. Spacious lobbies at the perimeter of the building include smaller recessed nooks that facilitate meeting, conversation, and the movement of overflow crowds. At each level, floor-to-ceiling glass walls and doors open to the garden terraces, allowing natural light into the spaces and reinforcing the connection with the immediate and greater landscapes beyond.

The continuing sequence of stairs, water, and plants leads to the top of the roof, ultimately revealing the source of the water, surrounded by conifers and prismatic skylights that illuminate the auditorium below and accentuate views to the Temple, meadow, and mountains beyond.

Summary

One of the most important elements in each green roof system project is understanding what is below the surface. Much of what supports the landscape is invisible. The enormous radial trusses, tons of concrete, miles of wiring and piping, expanded polystyrene fill, and fabricated soils are all integral physical components. Two of the most important components of this project's success, however, are not only invisible but intangible: collaboration and will.

This project is unique in its use and scale, but every project has its distinctive considerations. Slabs, drainage, aeration, soil, and plants may be the components of every system, but determining how to put them together is dependent upon the project program and goals, even as the research, technologies and materials used to create those systems become increasingly more developed.

Chapter 8

The Bidding and Construction Process

Perhaps the most exciting and daunting part of the successful creation of green roof systems is the moment the construction process begins.

Up to this point the vision is still a vision—well developed, coordinated on paper, but not a physical reality. The construction process starts with bidding, negotiation, and award of the contract. This phase of the project determines the negotiated price for the construction of the entire project. Schedules of materials are also priced for the duration of the project. Often this is also the period where any changes to the drawings, for either clarification, coordination, or changes in scope, are addressed by means of one or more addenda.

Many of the conditions, issues, and complexities of building living green roofs and landscapes over structure are similar to those encountered in conventional building and landscape architectural projects on terra firma. The focus of this chapter is the not-so-common conditions, issues, and complexities of green roof systems projects that need to be well understood, particularly by those bidding on the work, who are ultimately responsible for constructing it for the price bid.

While it seldom, if ever, happens so precisely, the goal of the bidding, negotiation, and award of the contract is to have the project built according to the drawings, specifications, and conditions of the contract, for the price bid and within the schedule established.

The coordination of the subcontractors will be less difficult and the project less prone to scheduling crises and construction errors if the construction manager fully understands and appreciates—from a green roof system construction viewpoint—the following:

- Extent of the scope of work
- Required integration of systems and the appropriate trades to install them
- Construction logistics and sequencing

Likewise, the subcontractors who have been awarded the work must build it for the price bid. If they have missed work in their scope that has been detailed or specified in a specification section not usually bid by them, or if they have underestimated the costs because of unfamiliar components and installation requirements, either the subcontractor or the project will suffer. Usually it is both.

FIGURE 8-1 Existing site conditions such as microclimate and borrowed views of the bay were significant elements of the design concept and development.

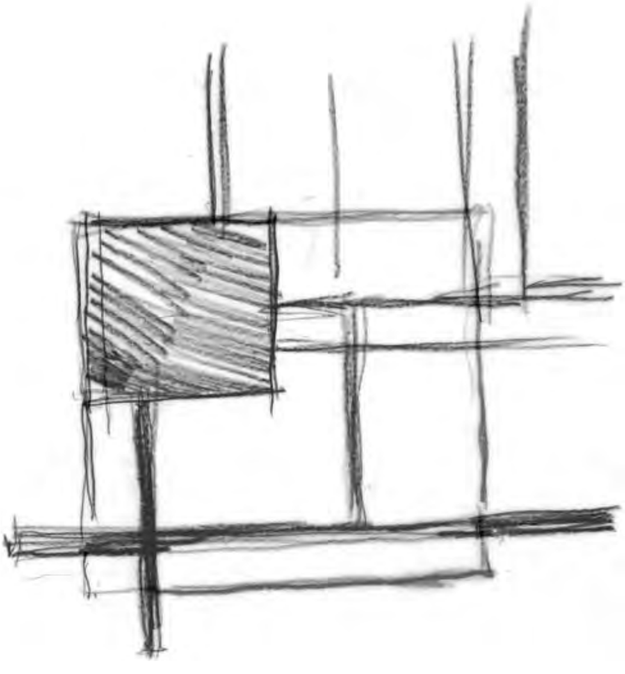


FIGURE 8-2 Early concept establishes linear relationships of circulation, wind mitigation, MEP, and structural considerations.

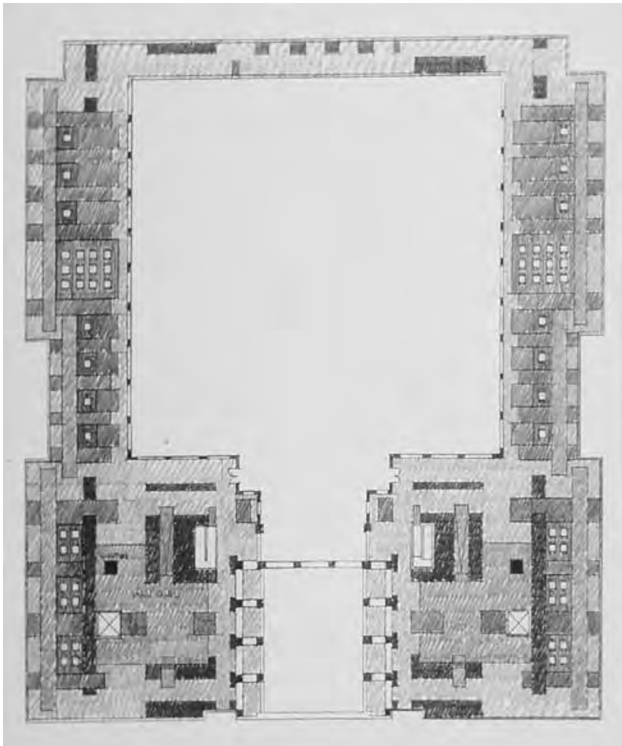


FIGURE 8-3 Development of the design utilizes planting beds and windscreens as organizational elements.

FIGURE 8-4 Study models help to understand scale and explore ways of mitigating the impacts of wind, sun, shade, and orientation.

Managing the Design and Construction of the Project

In designing and building green roof systems, it is important that all involved understand the interconnectedness of systems. Likewise, from project inception through completion, those responsible for the overall management of the project—the owner, prime professional consultant, and contractor—need to be clear and well coordinated with their individual and project team roles and responsibilities. This is particularly important when the owner determines the construction management structure of the project.

A *general contractor* (GC) is the person or entity who enters into a contract with an owner for the construction of the entire work, which can be accomplished by the general contractor and, if required, subcontractors. A general contractor might also enter into a separate contract with the owner for general construction of architectural and structural work of the project.

The owner or ownership entity will typically designate an individual as the official representative of the owner (owner's representative) on all aspects of the project. Based on the complexity of a project and the ability of an owner to manage the design and construction process of a project in-house, a construction manager may be hired even prior to selection of the project design team.

A construction manager is an individual or entity who provides management services to the owner during the design phase, the construction phase, or both, including advice on the time and cost consequences of design and construction decisions, scheduling, cost control, coordination of contract negotiations and awards, timely purchasing of critical materials and long-lead-time items, and coordination of construction activities. These construction management services can be provided by an architect, building contractor, or some other third-party entity. Such an individual or entity may remain in an advisory capacity during construction (CMa) or become the *construction contractor* (CMc). Colloquially, either might be referred to as the CM.

There are benefits and drawbacks of any of these arrangements. The primary benefit of having a construction manager, regardless of whether this entity is designer-led or constructor-led or whether the construction manager becomes the construction contractor, is that this manager acts on behalf of the owner to ensure the coordination of the numerous design and construction decisions involved in building the project. Ideally, when part of the project team from the beginning, the construction manager can and must work in concert and collaboration with the design professionals to serve the client and the project.

When the construction manager becomes the construction contractor, an advantage is that the entity has been thoroughly involved in all aspects of the project from the beginning and can bring that knowledge to the construction of the project. This is particularly helpful in the selection and coordination of the subcontractors. When collaboration is good, this can keep the project advancing on schedule and on budget.

The disadvantage is that the entity is always under pressure to keep the project costs down and in early design phases may have underestimated costs by using too low a contingency or having pressured the major trades to supply the lowest possible estimates. Because many of these trades will later want to be the successful bidder for the subcontract, they may tend to be competitive rather than realistic in their cost estimates.

Likewise, unknown conditions and unexpected spikes in construction costs due to materials or labor markets may not be accurately reflected in the construction manager's cost estimates. Later these estimates will not be in sync with the bid costs, but the construction manager, now the contract manager, may still be held to the guaranteed maximum price established months earlier.

Often for complex, large-scale projects, construction phasing requires the completion of early bid packages such as site protection, site demolition, excavation, site utilities, and fabrication of steel and precast concrete. Having the construction management entity become the construction contractor entity can facilitate the bidding, award of contract, and construction process. Because of the integrated nature of the design and construction process of successful green roof systems, this arrangement may also allow for the greatest project continuity and collaboration.

For clarity, this chapter will use the term *construction manager* through discussion of the bid and negotiation phases and *contractor* once the work has been awarded to the successful bidder as the construction contractor. The contractor then becomes the entity responsible for performing the work under the contract for construction.

Reference: *AIA Handbook of Professional Practice*

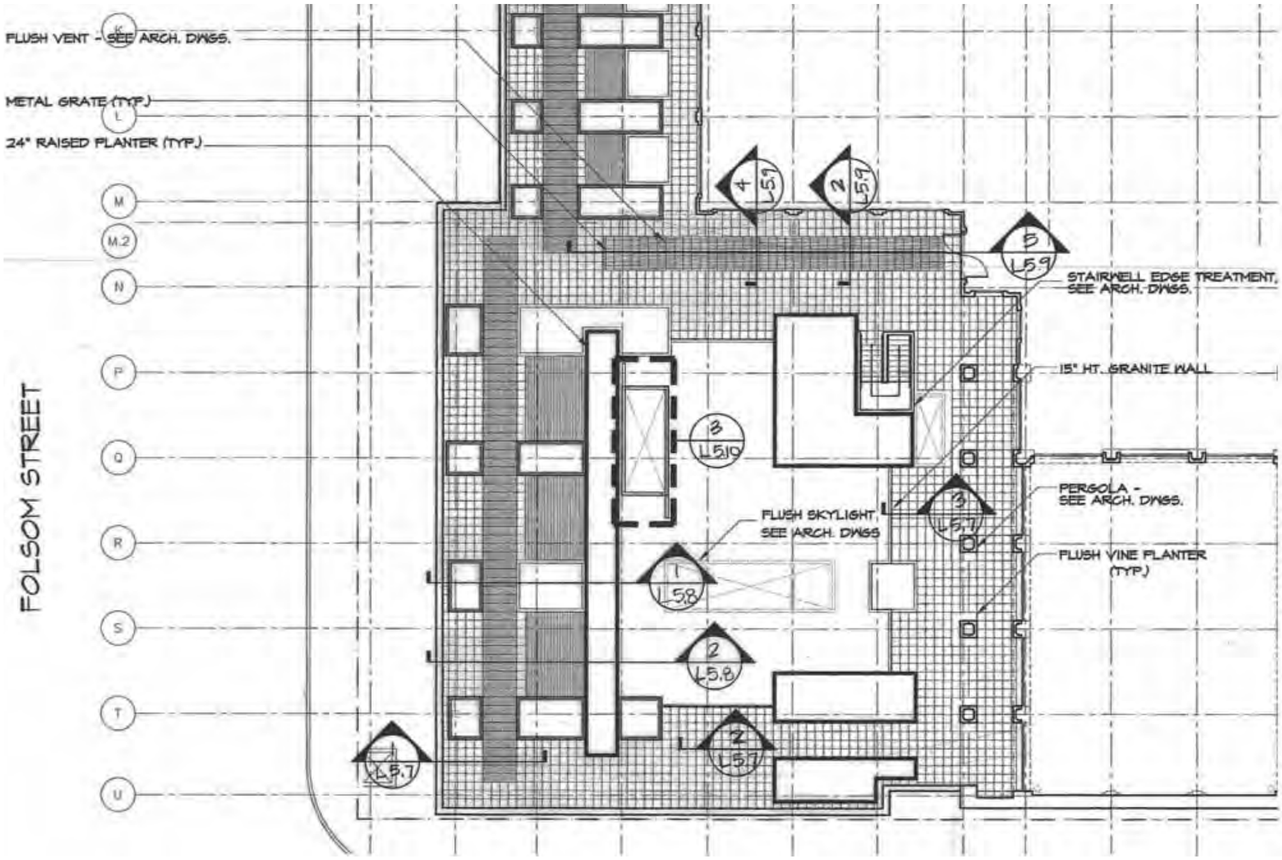


FIGURE 8-5 Partial detail from construction documents indicating materials and layout. Note the importance of referencing the structural grid.

If the project has been well run by the owner's representative, the prime consultant, and the construction manager, many of the issues and conditions that are out of the ordinary in terms of traditional construction but commonly found with green roof systems will already have been identified, coordinated, well understood, and accurately represented in interim cost estimates. These issues might include, for example, the premium for the structural system to support the loads of saturated soil mixes; depths required for root balls; complex configurations of slabs and beams; lightweight fill conditions; coordination of tops of slabs and finish floor elevations; waterproofing and drainage systems; coordination of numerous utilities; long-lead-time items; and construction logistics and sequencing. Most likely, project coordination will have included the completion and bidding of early packages such as site protection, site demolition, excavation, and fabrication of steel and precast concrete.

Ideally, the construction manager also will have been part of ensuring the accurate coordination of the construction documents, and when releasing bid packages will coordinate the appropriate trades and subcontractors with the scopes of work.

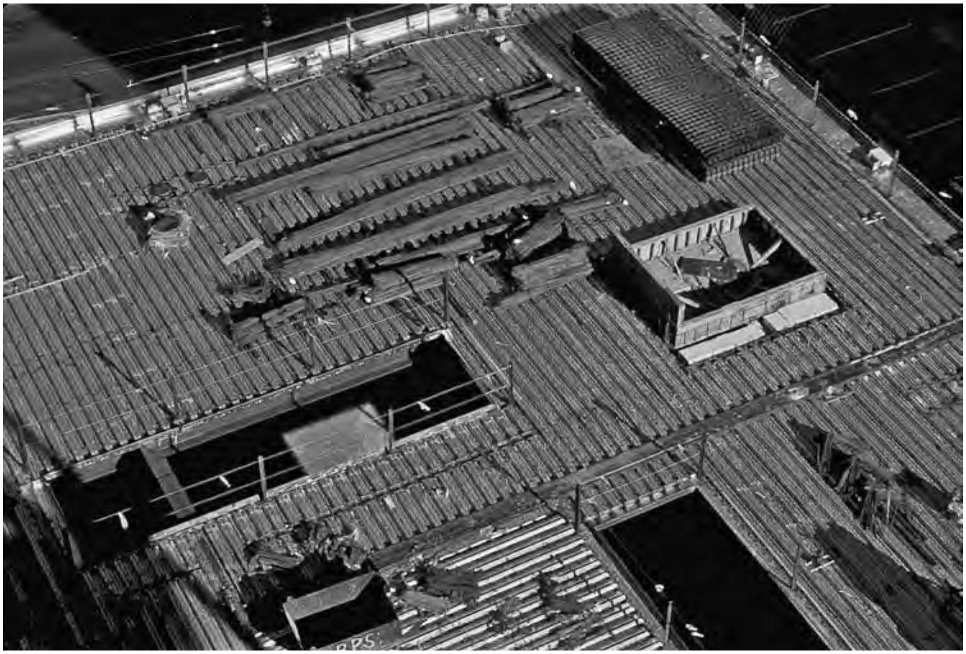


FIGURE 8-6a Metal decking supported by steel beams and columns prior to pouring the concrete slab. Formwork for planter and vent walls has been started, but that will be a separate pour.

FIGURE 8-6b Concrete slab being poured and screeded. Note the size of the planters. The workers are hand-troweling the concrete surface to attain proper slope.

FIGURE 8-7 The sides of planters and parapet walls are also waterproofed. Irrigation lines are installed at this time, rather than after soil mix installation, to avoid inadvertent penetration of the waterproofing membrane. Note the rolls of filter fabric/aeration mat that will be placed over the drainage layer.

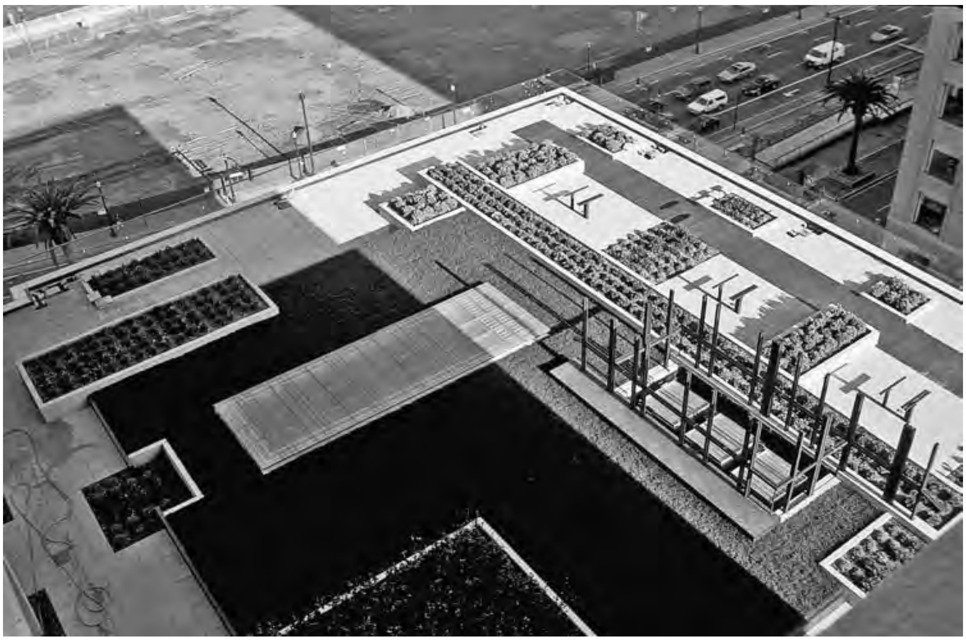


FIGURE 8-8 Bird's-eye view of early installation of plants, lawn panel, and metal framework for wind and vent screens.

FIGURE 8-9 Eye-level view of planter, windscreen, and Bay Bridge.

Bidding, Negotiation, and Award of Contract

During this phase, construction bids are solicited by invitation or advertisement. Sets of bidding documents, which typically include the drawings, specifications, and conditions of the contract, are distributed on behalf of the owner by the construction manager.

The bidding documents include all necessary bidding requirements, including bid solicitation, instructions to bidders, bid forms, supplemental information, and identification of other information available to bidders, such as geotechnical data, property surveys, or environmental assessments. For distribution and convenience of handling, most construction managers assemble the copious written bidding documents, including those furnished by the owner, into a project manual. Bidding requirements may also be included to establish fair and equitable procedures for obtaining bids.

Qualified bidders are asked to prepare and submit a complete bid for a specific scope of work, unit prices for material, and other requested information such as qualification data, references, or financial statements.

There is a thorough review of bids, usually by the construction manager, owner's representative, and design team, and then finally an acceptance of the bid and an award of the contract.

FIGURE 8-10 Existing conditions: underutilized urban space. Note the limited planting of trees in tubs over selected columns of the parking structure below.

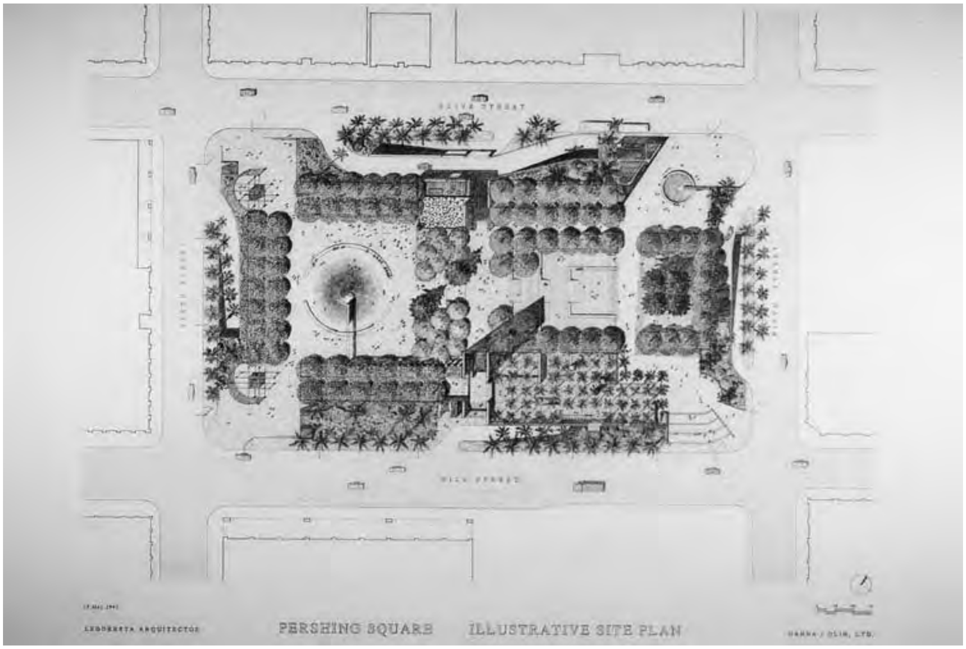


FIGURE 8-11 Illustrative plan showing multiple areas of use, segregation of pedestrian circulation from vehicular access to garage below, accessible corner entries, and extended planting areas.

FIGURE 8-12 Perspective showing ease of entrance for pedestrians and a variety of uses.

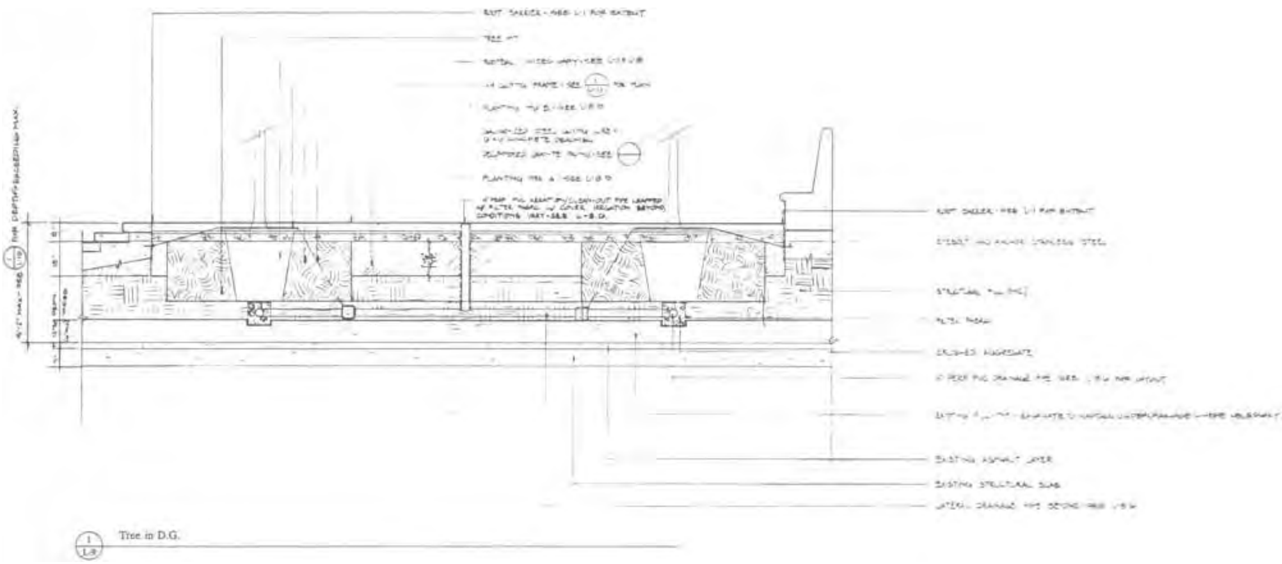


FIGURE 8-13 Design development detail showing depth of large continuous planters and integration of site benches with planter walls.

Key Considerations in the Bidding, Negotiation, and Award of Contract

Following are some considerations that should be taken into account in the bidding and award of projects involving green roof systems. Including these factors will help increase the likelihood that the scope of work is appropriately understood and accurately incorporated into the contractors' bids, and that costs for materials and installation will be reasonable.

Prequalification of Bidders: Selection of Contractor

If the construction manager is not acting as the contracting agent or contractor, one will be solicited through advertising or invitation to bid on the project. It is essential to ensure that the contractor is knowledgeable about green roof systems (parts, interconnectedness of systems, logistics, sequencing, costs) and the owner's expectations, including the guaranteed maximum price. It is also essential that the distribution of bid documents to subcontractors is appropriately coordinated and that all the green roof systems included in the scope of work or which need to be coordinated with their installation are included in individual subcontractor bid packages.

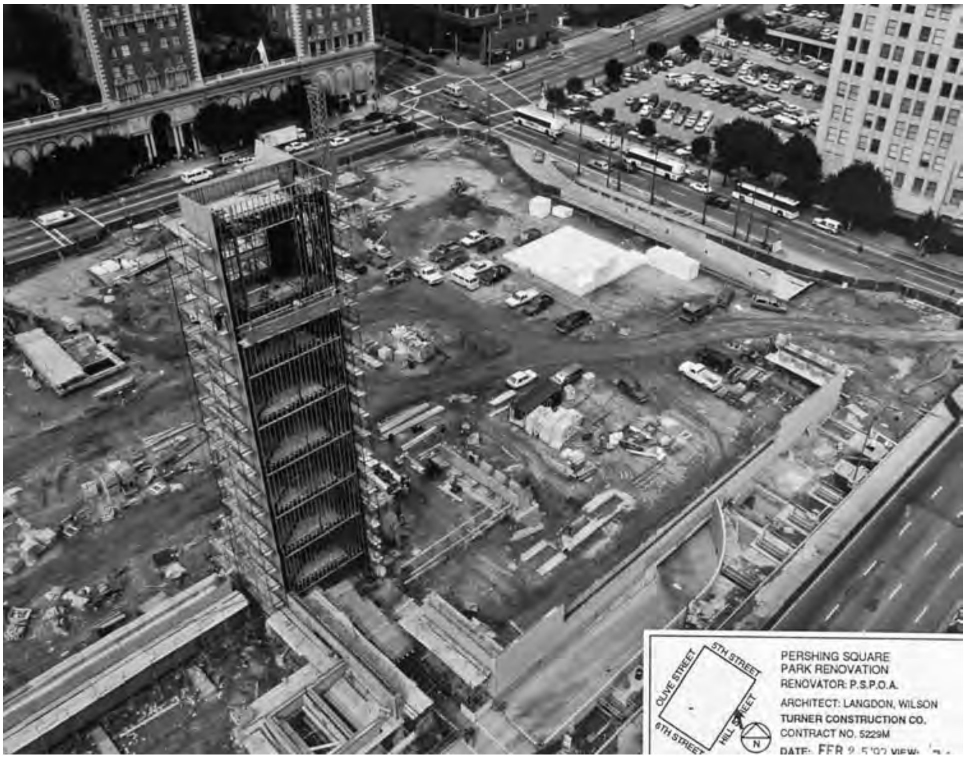


FIGURE 8-14 Construction photo. Note the scale of the square, multiple levels of the structural system, construction vehicles compacting soils, and large stockpile of EPs fill in the upper right corner.

FIGURE 8-15 Installation of setting bed over protection board and waterproofing membrane. Construction sequencing required that these trees be installed early—even before all the concrete formwork and pouring was complete. Although workers must be careful, trees also should have some visible, physical means of protection from damage.

Prequalification of Bidders: Subcontractors

Subcontractors, obviously, should be qualified to do the work and, if required, supply the materials. Since presently, at least in the United States, there are few subcontractors who have successfully completed the construction of living green roofs and landscapes over structure, it may not be possible to insist on previous similar experience as a prequalification. It should be a prequalification, however, that the subcontractor have sufficient, proven experience in conventional project construction of equal or greater size and complexity. This includes familiarity with working over or adjacent to another trade's work, such as waterproofing, electrical, plumbing, masonry, soil placement, planting, irrigation, and other site work elements.

Specifications and Quality Assurance

It is the responsibility of the documenting design discipline to specify the qualifications in the quality assurance portion of Part 1 of each specification section. It is the responsibility of the contract manager to ensure that the bidder meets these qualifications.

FIGURE 8-16 Rather than occasional trees planted in single tubs, larger continuous planters of varying depths allow for a greater variety of types and sizes of vegetation as well as significantly better growing conditions.

FIGURE 8-17 Although lighter than saturated soils, water is heavy; its use over structure can be limited by localized restrictions of the structural system. Fountains can be of varying depths and edge conditions.

Subcontractor Scope of Work: Have the Correct Trade Bid the Work

Unfortunately, some subcontractors still believe that the site work involved in living green roofs and landscapes over structure requires only a wheelbarrow, shovel, dirt, trees and bushes, and the ability to get plants in the ground green side up. The contract manager must ensure that the correct trade is bidding on the specified scope of work. A concrete subcontractor might be the correct bidder for installing the lightweight concrete fill but should not be allowed to bid, let alone install, the drainage systems or growing media. The excavation contractor might be the right subcontractor to place and rough-grade the sub-base and maybe even the finished grade soil mix on a terra firma project, but not for a living green roof or a landscape over structure. A masonry subcontractor should not be allowed to bid or install trees or irrigation. There are many landscape contractors who are quite experienced and excellent in planting, paving, and masonry installation but may not be qualified to install lightweight fill or fountain copings.

Pre-Bid Conferences

The pre-bid conference allows the owner's representative, design team, and construction manager to accurately convey the scope and intent of the project to the subcontractors bidding the work. It is important that all of the design disciplines are represented at this meeting as well as all of the bidding subcontractors. The pre-bid conference provides any needed clarification for the subcontractors and allows for the design team to stress signifi-

FIGURE 8-18 Independence National Historical Park prior to master planning, design, and construction.

cant issues, such as construction sequencing or protection of previously installed materials of other trades, the significance of which may not be obvious to the multiple subcontractors.

Bidding the Correct Scope of Work and Review of Bids

The contract manager should ensure that the correct drawings and specifications are being bid by the sub-contractor. Often because of the interconnected systems, the drawings and specifications may be in unconventional sections. For example, the drainage

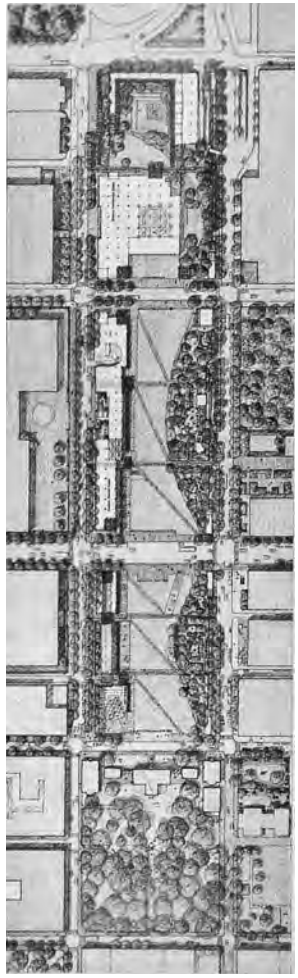


FIGURE 8-19 Rendering of master plan for Independence National Historical Park. Portions of the second block remains over an existing parking structure, and portions of the third block is over a new parking structure. The central axis from north looking south to Independence Hall remains open, but with generous lawn panels and diagonal walkways. East-west walkways revive historic, extant cross streets. New buildings for the Liberty Bell Pavilion, the Visitor Center, and the National Constitution Center are placed on the west side of the park, balancing the existing city street wall. To the east, views to the historic Olde City are preserved and generous groves of native planting offer verdant settings for cafés and respite.

FIGURE 8-20 Existing conditions at the Liberty Bell Pavilion.

FIGURE 8-21 Existing conditions at the site of the new Visitor Center. Note the large expanse of impermeable paved surface in this rarely used or visited civic space.

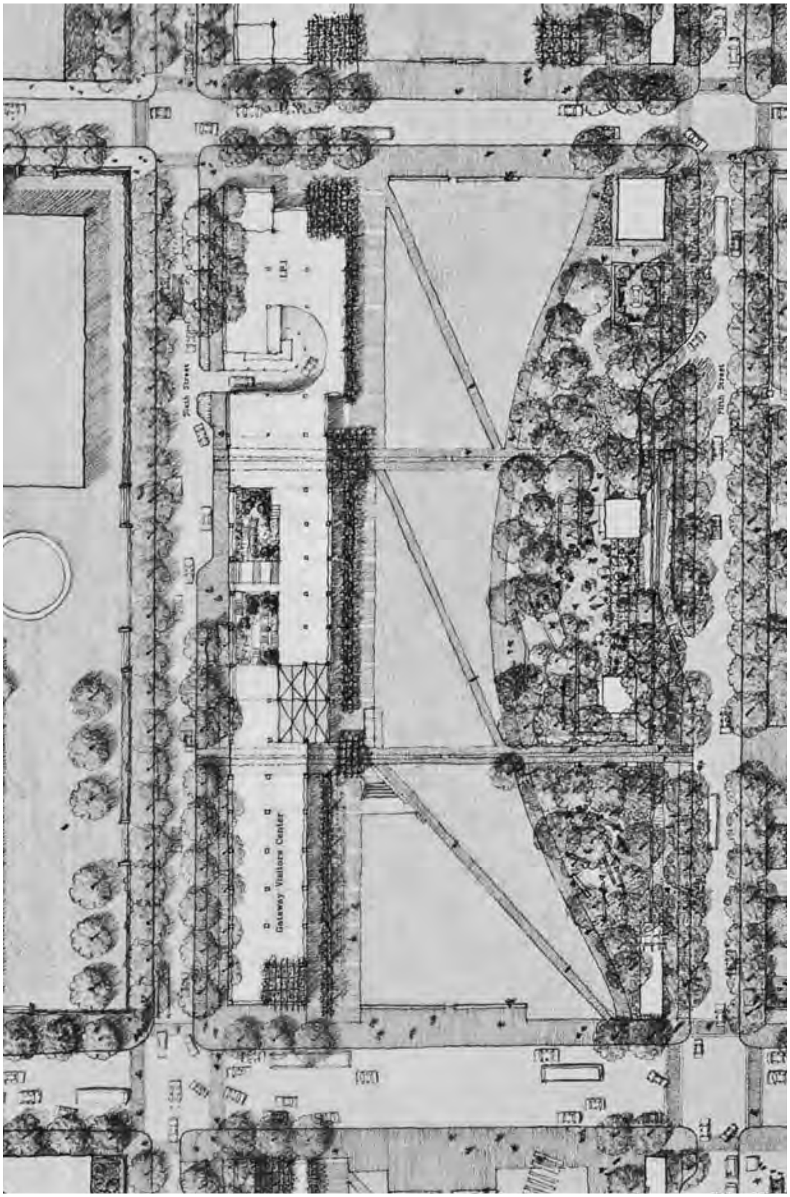


FIGURE 8-22 The site development of the middle block posed significant constraints, as the existing parking structure below could not be altered and the structural system to support the landscape above had to be suspended above it.

system, usually associated with the planting underdrainage, intentionally might be included within the civil engineering drawings and specifications, or even in the architectural waterproofing drawings and specifications, for reasons of coordination.

In reviewing the bids, the documenting design discipline should ensure the work has been bid appropriately, although any related or affected discipline should review and concur.

FIGURE 8-23 Construction photo. Note construction of the National Constitution Center (far block) and Visitor Center (second block) under way. Construction sequencing requirements keep the existing plantings and Liberty Bell Pavilion until the new Liberty Bell Pavilion (on first block) is completed.

FIGURE 8-24 Construction photo. The Visitor Center is open and the lower half of the block is complete. Note large areas of EPs fill being placed in the upper half of site.

Estimating Project Costs and Bidding of Contract Documents

As discussed in previous chapters, ideally there will have been cost estimating exercises at key project phases, such as:

- Project feasibility
- Concept, preliminary, or schematic design
- Design development (50 percent completion and 100 percent completion), which may have established the guaranteed maximum price (GMP)
- Construction documentation (50 percent and 90 percent completion)

The completed construction documents most often are considered the bid documents.

Each cost estimate is based on the information available at that particular time. The more developed the drawings and specifications are, the more accurate the cost estimate should be and the lower the contingency should be. (That is, in very early phases of a project a contingency as high as 25 percent of the estimated total project costs may be used, while nearly completed construction documents may carry only a 5 percent contingency.)

Even under ideal conditions of project and construction management, where cost estimates may have been timely, thorough, and as accurate as possible, cost estimates are still estimates. Likewise, even with numerous changes made to meet budget goals or make the project more efficient, such as reducing project scope, selecting and specifying different materials, or utilizing less labor- or time-intensive construction methods, the revised estimates indicating realized cost savings are still estimates.

Often in the cost estimating process, the construction manager will have the work estimated by a potential project bidder for that trade. In a project where there is good communication and collaboration among the design disciplines, the construction manager, and the owner, these estimates will have been reviewed, vetted, and agreed upon not only by the prime consultant, construction manager, and owner but also by each design discipline. Items determined to need revisions either for cost reduction reasons or for constructability are agreed upon, with a target value to be met. Revised estimates will be made and agreed upon.

The clearer and better coordinated the drawings and specifications, the better and more reliable the interim cost estimates should be, which in turn should increase the likelihood that bids will come in at expected budget.

Sometimes there are unrealistic expectations from all involved. The owner wants the highest quality for the lowest price. The construction manager wants to keep the owner happy and wants the trades estimating the work to keep their pencils as sharp as possible. The trades estimating the work want a chance at bidding on the work when the bid packages are issued. The design team also wants to keep the project on schedule, on or under budget, and with the design intent and material expression intact, but can only compare estimates with recent like projects and like costs.

When the construction systems and materials specified in green roof systems are unfamiliar, the cost estimates may be either too high or too low because the complexity of construction sequencing, installation of materials, or the premium for structural and horticultural support are not well understood. Sometimes, too, the CM's contingency has been set too low in early estimating phases, artificially lowering the overall cost.

Common Issues and Areas of Subcontractor Overbidding, Competitive Bidding, or Underbidding

The Fear Factor and Overbidding

Submitting a bid is a risk. The risk varies depending on the size and complexity of the project, the subcontractor's experience, and the available workforce. Because green roof system projects are still viewed as uncommon, most subcontractors will not have extensive experience in this type of construction. The drawings and specifications may look more complex, and so it may be assumed that the job is more complicated and therefore justifies a higher bid. If there are a number of trades involved adjacent to the green roof subcontractor's work, a greater risk may be perceived by these trades as well. If more than one bidder cites the same risks, the costs may be inflated.

Familiarity with the Installation of Green Roof Systems: Competitive but Comprehensive, or Competitive and Incomplete

Ironically, bids that may appear too high or too low often derive from the same source: level of experience in the construction of living green roofs and landscapes over structure.

A bid that appears high may come from a knowledgeable bidder who is experienced in the integrated nature of green roof system construction and who has prepared a comprehensive bid addressing the complexities of the project. Conversely, a bid that may appear low may still be comprehensive because it comes from a knowledgeable bidder who knows the costs involved but wishes to be competitive.

A bidder who has less experience or is less knowledgeable about green roof projects might bid low believing the bid to be competitive, but because the job's complexity is not completely understood, the full scope of the work was not included in the bid.

Bids need to be carefully reviewed not only by the design team discipline associated with the work but also by those team disciplines whose work might be affected. For example, the structural engineer should ensure that the landscape architect has reviewed bids for structural work affecting the landscape architectural work, and vice versa. The civil engineer should ensure that the MEP engineer has reviewed bids for work affecting civil engineering work, and vice versa.

Complexity of Integrated Site Work

In conventional construction, the implications of implementing site work associated with the landscape architecture of a project are often poorly understood by allied design disciplines, subcontractors, and sometimes even the construction manager and the owner. For the implementation of green roof systems, the complexities of implementing associated site work can be even more poorly understood.

Because site work is usually not directly associated with the building architecture or the structural or utility systems, it is often thought of as the "finishing touches"—the last to be done, if not the least. Because much of what supports green roof systems is concealed below the finished surface, integrated construction knowledge is essential. For example, the excavating subcontractor does not normally have to worry about compaction of soils that must later support plant growth and drain water, so overcompaction is common. The care with which all systems need to be installed and protected during construction is often overlooked. The time and costs to accommodate and monitor this extra care are not usually reflected in a bid, and having to redo work is even more costly.

Construction Sequence Logistics and Seasonal Constraints

Early bid packages often include excavation, installation of utilities, and concrete foundation work. Often the full sequencing of utility installation is overlooked in both living green roof and landscape over structure projects, where more site infrastructure might need to

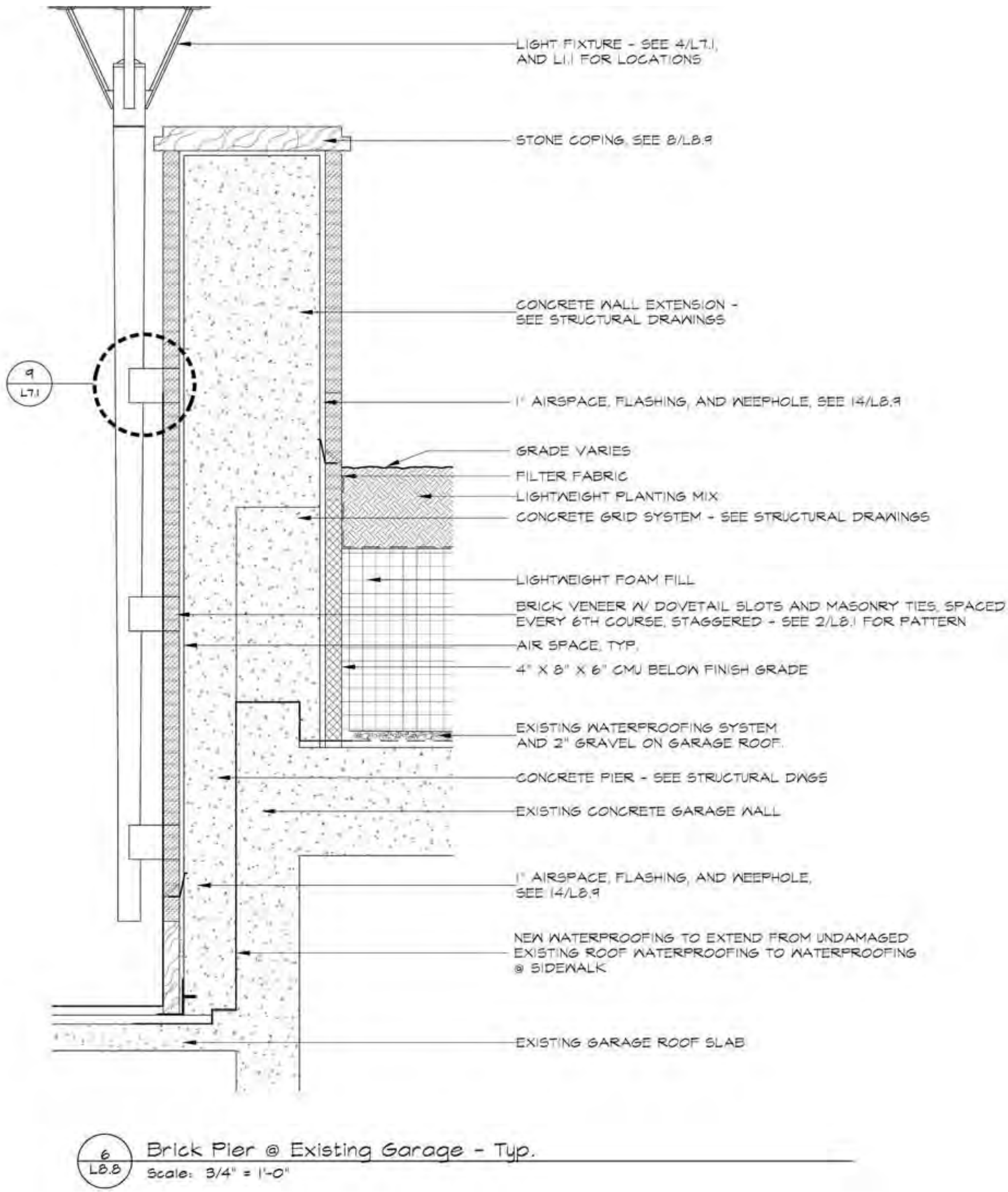


FIGURE 8-25a Construction detail for integration of existing parking structure below and lawn panel over EPs fill contained by new perimeter brick wall and light standard.

FIGURE 8-25b Completed wall and light standard are visible; existing parking structure, new structural system, and planting infrastructure are not visible.

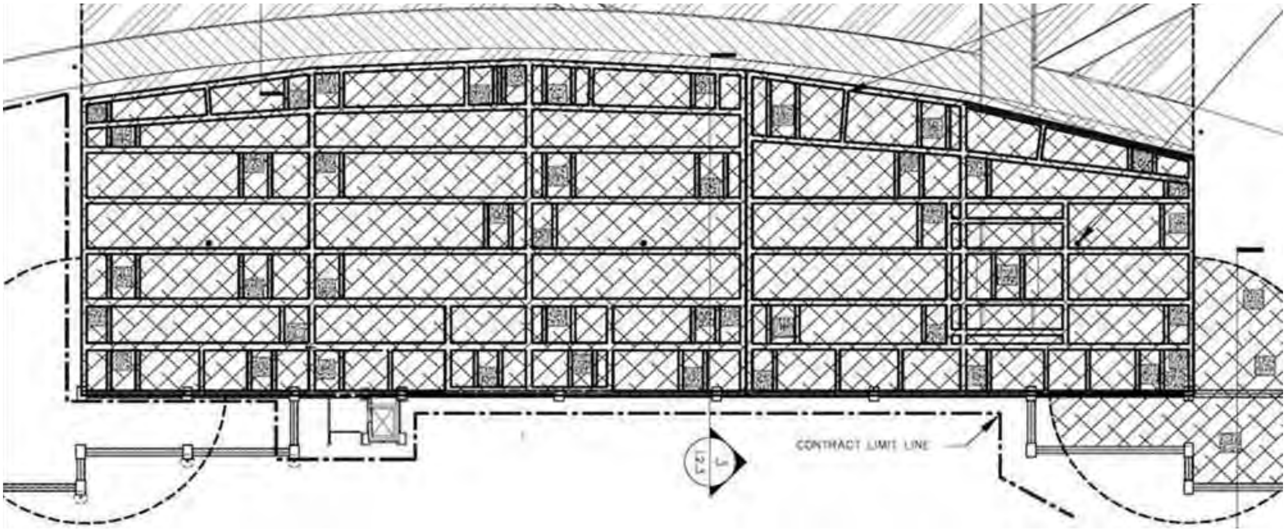


FIGURE 8-26 Construction detail of the structural framing plan developed for a heavily planted area suspended over the existing parking structure.

be included earlier in a project than is usual. The full construction sequence, from early foundation and utility installation through planting and paving, needs to be considered. For example, the sequence of installing plants, especially large-caliper trees, needs to be determined early in the construction phasing plan because the required structural and horticultural infrastructure needs to be in place prior to the installation of plants. This includes accommodations for connections to stormwater and subsurface slab drainage,

FIGURE 8-27 Concrete formwork and pouring of structural framing.

waterproofing membrane system, insulation, drainage system, electrical and water stub-outs for irrigation, and placement of the growing medium. This is particularly important in areas of the site where there will be limited access for placement of growing media or for the heavy machinery needed to install large-caliper trees. The procurement of plants also has to be properly sequenced, especially in climates having wide seasonal variance, because most plants can only be dug in the nurseries and planted under optimal seasonal conditions. Often trees, shrubs, and herbaceous plants will need to be procured several seasons prior to installation, and provisions made for their proper handling and storage.

Other seasonal constraints of construction affecting soil placement, mortared stonework, fountain work, and irrigation start-up are also often not considered in bidding a project.

If the construction manager has provided the subcontractors with adequate construction logistics and sequencing information, the bids should accurately reflect cost premiums or cost savings.

Qualifications to Perform the Work

Until green roof systems become commonplace, the pool of qualified, experienced subcontractors may be limited. Sometimes there may not be any subcontractors who are fully qualified to bid the work and so an allied trade perhaps not fully understanding the subtleties of the work will be asked to provide a bid. As an example, the excavating subcontractor may be asked to bid on the installation of the planting soils or growing media. The bid may be based on using the equipment normally employed for moving earth, which may be too heavy for the structural deck. As a result, the subcontractor will need to use lighter equipment that may not be in the existing fleet, and it will take much longer to move

FIGURE 8-28 The existing waterproofing and minimal insulation system needed to be replaced.

FIGURE 8-29 Installation of the drainage system: drainage/reservoir waffle filled with lightweight fine aggregate over moisture retention mat, over aeration mat, over EPs fill.

FIGURE 8-30 Installation of drainage and aeration pipes. The coring of walls for lateral drainage connections has been completed and the pipes installed.

FIGURE 8-31 Installation of large blocks of EPs lightweight fill.

planting soil on a structural deck than on terra firma. The bid will probably turn out to have been too low.

Costs and Timing of Testing Not Incorporated Appropriately, Missed Scope, Imprudently Low Bid

If a subcontractor has not read the specifications thoroughly, the bid may not include the costs of testing, costs associated with correct timing, or costs associated with fabrication, storage, protection, and placement. (This is particularly important with soil mixes or growing media.)

Sometimes critical items used sitewide are missed by the bidder because they were in a specification section unfamiliar to the subcontractor. For example, filter fabric or drainage panels may be specified under earthwork or drainage systems rather than planting.

And finally, just as in cost estimation, the bidding contractor may tend to encourage low bids. While there is nothing wrong with encouraging or submitting a low bid, a bid that is lower than prudent will ultimately affect the ability of the subcontractor to do the work with the materials specified and at the level of quality expected.

FIGURE 8-32 Mockup of wall: stone veneer on cast-in-place concrete. The entire wall and the decking system to support the landscape span the structural decking of the existing parking structure below.

FIGURE 8-33 Finished planting and site work after the initial planting season.

Prepurchase of Plants

FIGURE 8-34 Prepurchase of plants can be particularly useful when large-scale, hard-to-find specimen trees are to be installed.

FIGURE 8-35 Trees were selected in the nursery almost two years prior to installation.

FIGURE 8-36a Trees to be used as an aerial hedge were pruned in the field using this template.

FIGURE 8-36b Diagram for pruning of trees allowed for row, end, and corner trees.

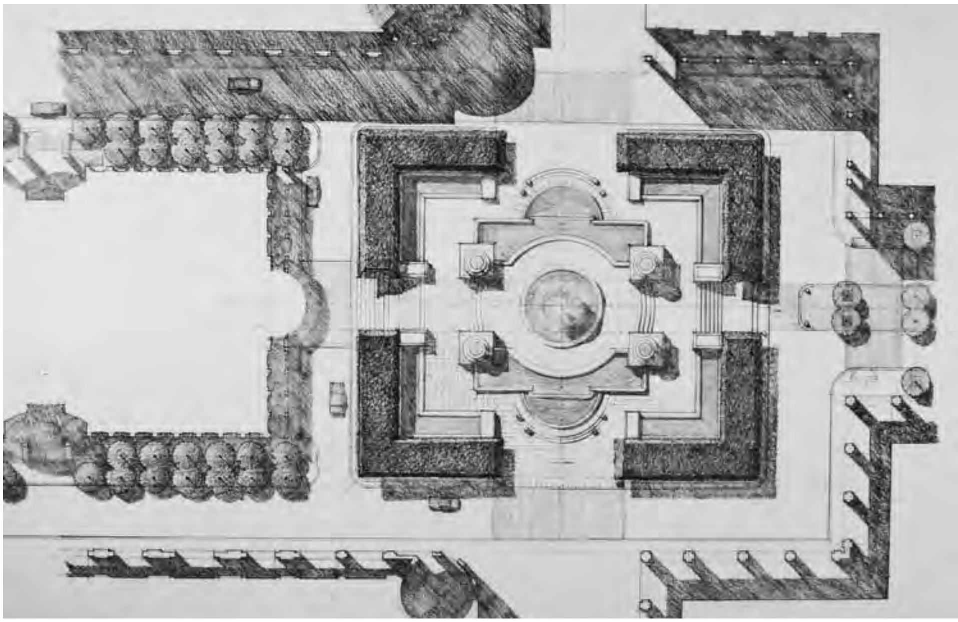


FIGURE 8-37 Numerous species of cactus were prepurchased to ensure availability at installation.

FIGURE 8-38 Prepurchase can also be used when large quantities of smaller scale plants are required.

FIGURE 8-39 Flats of one of the species used for a living green roof, inspected at the nursery.

FIGURE 8-40 Healthy plants should be inspected routinely during the growing contract period. Here plants are grown as plugs.

Value Engineering

A final value engineering exercise may be done after the selection of the contractor, but prior to award of the contract. Value engineering is a process of analyzing the elements of a project design in terms of their cost-effectiveness, including the proposed substitutions of less expensive materials or systems for those initially specified. Prior to this final value engineering exercise, this process often will have happened at key phases of the project. Usually value engineering exercises will be associated with the cost-estimating phases discussed earlier.

Value engineering may result in changes in materials or even whole systems, and those changes must be coordinated with other systems. For example, if a more conventional drainage and planting system is proposed as a substitution for a more expensive lightweight drainage and planting system, it is very important that the substitution be coordinated with the structural capacity of the deck. The structural upgrades required may be more costly than the lightweight system. If not, then it may be an acceptable alternative.

Unlike interim value engineering exercises, where a redesign of a system can be accommodated and coordinated with other disciplines, value engineering after construction documents have been completed can have disastrous effects on the success of green roof systems. Because of their dependence upon integration with building systems, both living green roofs and landscapes over structure are vulnerable to partial or even complete deletion up until project completion. It is important to understand not just how to defend their full value but also how to articulate their value in terms of what should not be allowed to be value-engineered out of a project. This is particularly important after the completion of construction documents, when redesign and recoordination of entire systems cannot be easily accommodated. The following provides some guidance in determining the appropriateness of accepting or rejecting components or systems that are commonly suggested as a savings to project costs. It is particularly important to consider not only the entire system as documented and specified, but also each component within the system.

Waterproofing, Insulation, and Drainage Systems

These components make up the systems that are the infrastructure supporting the long-term health of plants and the long-term durability of paving or other site systems.

If a different supplier or fabricator or a similar component is suggested as a cost savings, it is important to ensure that the component will have the same performance and that it is compatible with other system components. For example, there are many suppliers of drainage boards, protection boards, and filter fabrics. Unless a proprietary system has been documented, a similar product that is suitable and performs equally well should be considered.

If a material or component substitution is suggested, ensure that the entire system will still function and that it is compatible with adjacent components. For example, if a particular type of nonwoven filter fabric or water-holding gel is targeted as a less costly substitution for a water retention mat, it is important to ensure that the system will still function as intended. In this instance, will the growing medium depth be able to compensate should there be prolonged drought conditions?

The deletion or minimization of a component as a cost savings should almost always be rejected. Only if a component is being used for redundancy, in a belt-and-suspenders manner, should deletion or minimization be very carefully considered. An example of this might be reducing the depth of a drainage layer from 8 inches to 5 inches. If the depth can still accommodate the size of the drainage pipe but not affect the overall effectiveness of the underdrainage and aeration of the growing medium, it should be considered. If the drainage layer is targeted for deletion, the proposal should be rejected.

Lightweight Fill

Typically, if a system or component of a system has been intended to lessen the structural load, it cannot be eliminated unless it is replaced with a component or system that provides the same function the lightweight fill was intended to serve. The coordination of lightweight fills with structural design and site element requirements is one of the first issues that should be reviewed and agreed upon. If a change is proposed for cost savings, it should be vetted very early in the design and documentation process, not during the value engineering of the bid documents. The substitution must be compatible with the structural system. Consider the previous example of a proposed reduction of a drainage layer from 8 inches to 5 inches. If the drainage layer specified is a lightweight aggregate and its depth is intended to both drain and aerate the soil and to reduce the structural load, replacing 3 inches of lightweight aggregate with (potentially saturated) soil mix may not meet load restrictions.

Likewise, EPs cannot be replaced with a soil mix or growing medium that will likely be heavier. If, however, for some reason a flowable lightweight concrete is less expensive than EPs, then it should be considered.

Paving System

Similarly, finish grades are tightly controlled in green roof systems. Deletion or substitution of a component must be coordinated with what is above and below it.

As an example, adjustable-height pedestals are often used to support pavers in an open joint system where water on a dead flat surface is allowed to drain through the joints to a sloped surface below. There are many fabricators of pedestals, so a substitution of a pedestal other than specified may be suitable. But the deletion of a pedestal in favor of a setting bed or additional lightweight topping slab can lead to subbase conditions inadequate for subsurface drainage and surface load-bearing capacity. Additionally, the paving setting and drainage requirements would be altered. All of these factors, if not properly addressed, can lead to the eventual deterioration or potential failure of a paving system.

Often the actual paving material may be targeted for cost savings; for example, one type of granite may be less expensive or have a shorter lead time than another. If the substitution meets the material and aesthetic requirements, then it may be an appropriate cost savings. It might also be necessary to substitute less expensive precast pavers for stone pavers. If it is appropriate, then it should be considered if the design intent is not seriously affected. However, a less expensive but thinner stone paver may not be appropriate if the surface was intended to accommodate vehicular traffic or other heavy equipment, because the thinner pavers may compromise the structural integrity of the paving system.

A decrease in paver thickness might also imply an increase in thickness of the setting bed. This can allow too much movement between joints, causing chipping or spalling of pavers and eventual deterioration of the entire system.

Significant changes in paving systems almost always require a complete redesign of finish grading, drainage, and paving setting systems. If there is a cost savings proposed for value engineering, it should be vetted very early in the design and documentation process, not in the value engineering of the bid documents.

Planting Systems: Soil Mixes and Growing Media

As noted in Chapter 6, every living green roof or landscape over structure requires water and nutrients derived from both naturally occurring and fabricated sources. Both *soil mix* and *growing medium* are terms used in this book. *Soil mix* is defined as a mixture of nutrient-providing components where the base component is derived from naturally occurring soils. *Growing medium* is defined as a manufactured mix of mineral materials, stabilized organic amendments, and stabilized lightweight aggregates. Because both need to be carefully and consistently fabricated, tested, and placed, they typically are more costly than soils used in conventional planting. For green roof system projects, both consistently become a significant target of cost savings, even after the project has been bid and is in construction. One of the reasons for this is that a contract manager or subcontractor may be unfamiliar with the drawings and specifications, and in turn may not have experience with securing component materials, fabrication, testing, and installation of soils. This can result in underbidding the costs as well as significant delays in project schedules resulting from delays in submitting samples and test results and poor preparation for the logistics of batch mixing and placement.

If contractors and even owners are allowed to think that “dirt is dirt,” the potential of failed green roof systems increases greatly. A significant cause of failed projects is the use of poorly fabricated and handled soils. Soil mixes, if not appropriately specified, fabricated, and installed, can easily become either overly dry or saturated. As previously discussed, saturated soils lead to anaerobic conditions and the demise of the plants. Saturated soils also become potentially detrimental to the waterproofing and supporting structural systems.

Premixed growing media are becoming increasingly available, especially for living green roofs, where the depth of growing media is consistently shallow and the horticultural requirements of the plant palette (low-spreading, water-storing, and able to withstand harsh desiccating conditions) are more predictable and consistent over a wider range of project needs. It may be appropriate to use a premixed soil if it meets the project’s requirements. For a landscape over structure, where the depth and composition of the soil mixes must accommodate a wide range of shrubs and trees, the mixes will need to be specifically designed for those conditions.

Often in the construction of landscapes over structure or living green roofs, the soil mixes, growing media, and plants must be installed early in the project because of later inaccessibility of that portion of the site or other construction logistics. If the specified materials are not available or in place and a significant delay of the project results, the owner may decide to use whatever nonfabricated soils are available, regardless of their appropriateness.

Given the costs involved in replacing plantings, especially large-caliper trees, in inaccessible locations, that fail to thrive because of avoidable conditions, it is important to be vigilant throughout all stages of the design, cost estimating, and bidding phases, not just during the construction process.

Planting Systems: Quality, Quantity, and Size of Specified Plants

As often happens with conventional planting as well, the reduction in size and quantity of plants will often be suggested as a cost savings. Decisions surrounding what to allow as a cost savings will be similar to those made in conventional terra firma projects. Following are some additional considerations for living green roofs and landscapes over structure.

For living green roofs, it is important to ensure that the specified mix of plants is used and that significant substitution of species is not allowed for cost reasons. The overall selection of plants—the matrix—is based on numerous requirements, including extent of planting, depth of soil mix, climate, orientation, maintenance requirements, visibility, and intended aesthetic appearance. However, in some cases where the area of installation is small and the owner has the ability to provide greater initial maintenance, it may be appropriate to allow the use of buds rather than established plants grown in flats or pots.

(See Chapters 6 and 10 for additional information on selection of species for living green roofs.)

For all green roof systems, using the highest-quality and healthiest plants of the greatest practical installation size will allow for greater ease of establishment. The sooner plants can become established, the sooner the planting system can provide the intended environmental and social impacts.

For landscapes over structure, the specified size of trees and shrubs may have significant cost implications for purchasing, handling, installation, and construction sequencing or logistics. As with conventional planting projects, a reduction in size is not as cost-effective as reduction in quantity. Additionally, the structural and planting support systems have already been designed to accommodate the specified location and size; sometimes those systems will already have been installed.

Deleting plants, especially trees and large shrubs, will usually yield too sparse a planting. This can lead to a very disappointing result for the owner (and design team), particularly in light of the premium for the infrastructure required to sustain planting over structure. Unlike conventional projects, with a landscape over structure the likelihood that deleted trees and shrubs will be installed at a later time is small.

In projects where there are significant and potentially damaging impacts from wind, it may be important to have trees of a size that can buffer each other and ameliorate the microclimate. In this case it may not be appropriate to allow a reduction in size. As noted, the costs of replacement, often in difficult or not easily accessible conditions, generally are not worth the initial cost savings.

It may be appropriate in some cases to allow reduction in the size of large-caliper trees, particularly where there are significant additional costs because of construction logistics or structural constraints for the use of heavy installation machinery. However, the overall appearance of the project may turn out to be too immature, so it is advisable to selectively retain some larger-caliper trees, particularly in areas where installation costs may be lower.

Length of Specified Maintenance Period or Guarantee of Plants

The required installation and long-term maintenance requirements for planting need to be reviewed and accepted by the owner prior to the completion of documentation and bidding. This also includes agreement on the period of guarantee for plants, especially large-caliper trees. The costs of both maintenance and guarantee should have been identified in the earlier cost estimates.

Unlike conventional projects, where planting may be the last phase, the installation of plants for green roof systems can extend over long periods of project construction. In projects where trees or other plants need to be installed early because of construction logistics, they need to be well protected from subsequent construction damage. The remaining planting may not occur until the end of the project. By this time, even the contract manager may not be present on the site full-time, and proper installation and protection may be difficult to enforce.

Often any construction damage or lack of maintenance may not become apparent for several growing seasons. Replacement planting can be difficult and costly. It may be difficult to find plants that match those installed, either in species or in size. The accessibility of the site for planting may be restricted. The original construction crew, familiar with protection of drainage and waterproofing systems, will be gone. Therefore, prior to final bidding it is very important to determine with the owner the conditions and costs of maintenance and guarantee of any planting, ensure that it has been included in previous cost estimates and bids, and not allow it to become a final value-engineered cost savings.

Addenda

After the bidding process, often there will be amendments to drawings and specifications to ensure the construction set is completely coordinated, to include missing information, and to reflect agreed-upon cost savings resulting from the final value engineering process. These changes are made via an *addendum*. This addendum is then used as the basis of the award of contract and beginning of construction. Numerous other addenda may be made over the course of the construction to address other unforeseen changes or clarifications.

Construction and Administration of the Construction Contract

> *For many design professionals, the construction phase of services often seems to be as much a test of nerves and stamina as an exercise of professional skill and judgment. It is typically the most dynamic phase of project delivery and when one party has a problem during the construction phase, usually all parties have a problem. . . . [T]he very dynamics and uncertainties inherent in the construction process demand that the administration of the contract for construction be intelligent, informed, objective, and responsive.*
>
> —Victor O. Schinnerer & Co., Inc., "Critical Issues in Construction Contract Administration"

Perhaps the most trying part of a project is construction. During this phase every trade, usually as a subcontractor contracted to the contract manager, builds its portion of the project according to the drawings and specifications. Numerous conflicts can occur, and numerous field changes must be accommodated to reflect actual conditions, discrepancies in documents, or required changes to scope or materials. Additionally, despite excellent collaboration and coordination in earlier phases of the project, construction is a time when each design discipline is extraordinarily focused on the execution of its own documentation and construction and can be less available for timely coordination or response to another discipline's query. (This is why attendance at regularly scheduled project meetings is essential.)

Preconstruction Meeting

Similar to the pre-bid conference, the preconstruction meeting allows for the owner's representative, the design team, and the construction manager to accurately and in a unified voice convey the scope and intent of the project to the subcontractors who have been awarded the work. Although much of the content of the preconstruction meeting will be similar to conventional project preconstruction meetings, it is important that all of the design disciplines are represented at this meeting as well as all of the job captains for the subcontractors. The meeting should set the tone and ground rules for building the project as well as clearly convey any project protocol, construction sequencing, or construction techniques that may not be commonly found in conventional construction.

FIGURE 8-41 Construction sequencing required that these gabions be installed first. The gabions form a permeable shelved edge for the stormwater systems and were constructed on site. Note that the lowest level of the gabions is constructed with smaller aggregates. Smaller aggregates provide a graded system for the settling out of stormwater particulates.

FIGURE 8-42 After the gabions were installed, the boulders of the glacial drumlins and stormwater garden were installed. Note that some trees also needed to be installed even prior to the placement of the boulders, despite potential for construction damage.

If "early packages" for site demolition, excavation, or fabrication of long-lead-time items have been contracted and started, there may not be a full preconstruction meeting at which all design disciplines and subcontractors are in attendance. It is incumbent upon both the contract manager and the design disciplines whose work is most affected by the construction of living green roofs or landscapes over structure to ensure that a preconstruction meeting takes place.

Until green roof systems become common, it will be important to set the expectations of the project, particularly from a construction logistics and sequencing process. The integration of the systems and protection of previously installed components are essential. More importantly, because many of the components and systems that are required to support living green roof systems are below the surface, construction errors or inadvertent damage to components are hard to detect and may only become apparent after significant deterioration or damage has taken place.

(Chapter 9 more fully addresses the reluctance of some insurance companies to provide coverage for both professional liability and construction liability for just this reason.)

Also, because the team has now widened beyond the owner, design team, and construction manger, this is the best time to ensure a collaborative environment, where administration and execution of the contract are intelligent, informed, objective, and responsive.

In a preconstruction meeting for green roof system projects, the following should be considered:

- With the widening of the team, new collaborations and project relationships need to be forged.
- Scope, schedule, and responsibilities must be defined.
- Project participants and protocols must be established.
- Construction sequencing needs to be clarified.
- Seasonal limitations of site construction should be highlighted.
- Site logistics, such as protection and storage of materials, must be agreed upon.
- Protocols for required submittals such as product data, shop drawings, and testing (particularly for those items with long lead times) are presented.
- Coordination among trades is discussed.

Site Control

Essential to success of the project is clear responsibility and oversight during the construction process. A complex project may have initial phases of construction being completed (such as excavation, utilities installation, and foundations) while the remaining drawings are still being completed. This may reveal unforeseen subsurface conditions that can significantly alter the design of the project. Similarly, if construction techniques change or construction errors are detected, there will likely be an impact on the remaining documents and subsequent construction. Also, because the site work is often the last portion of work to be installed, schedule and budget overruns can affect its completion as intended and as documented by the drawings and specifications.

Many issues that crop up with green roof systems are the same as those in projects on terra firma. Because much of the infrastructure is not visible, however, constant coordination should be expected and demanded.

Contract Administration Responsibilities for the Design Team

In green roof system projects, most of the contract administration responsibilities for the design team are the same as for conventional terra firma projects. The following are additional responsibilities for the design team in the construction of living green roofs and landscapes over structure:

- Accurate project records must be maintained and provided, particularly to facilitate coordination of trades and protection of previously installed components.
- Because trades change throughout construction, and some portions of the site work may need to be installed early in construction process. Attendance at project meetings should become routine early in the process to facilitate coordination of work.

Review of Submittals

Timeliness of submission and review of required submittals is imperative, particularly in relationship to construction sequencing. Jobs can be held up because of incomplete or inaccurate information, especially for:

- Product data (waterproofing membrane system, drainage materials, filter fabrics, lightweight fills, paving pedestals, etc.)
- Samples (stone for paving or copings, soil components, etc.)
- Shop drawings (structural steel, paving, stone copings, EPs fill, fountain equipment, etc.)
- Testing (concrete, flood testing, soils and growing media, drainage materials, lightweight fill materials, setting bed materials, stone characteristics, etc.)
- Mock-ups (paving, lighting, walls, copings, drainage section, etc.)
- Reports (geotechnical logs, maintenance programs, etc.)
- Work plan (delivery, storage and handling, coordination with other trades, etc.)
- Nursery sources (size, quality, location, field selection of material, seasonal constraints)
- Maintenance plan for all planting

FIGURE 8-43 Submittals for all components of green roof systems should require samples of materials. Here the aggregate used for the gravel edge required around drains and the perimeter of plantings is submitted for approval.

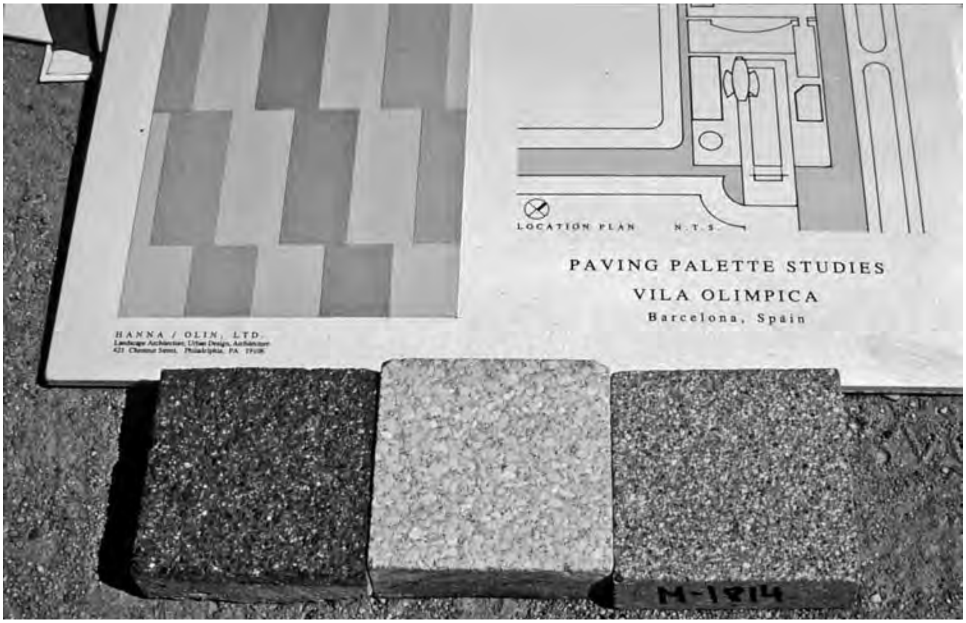


FIGURE 8-44 Here initial samples of precast paving modules are compared against the paving palette studies, which narrowed the range of colors for this polychromatic paving system.

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MATERIALS TEST REPORT FOR
Cornell Life Science Building

REPORT TO:

DATE RECEIVED: November 17, 2006
TEST DATE: November 17 - 22
REPORT DATE: November 22, 2006
Condition of sample: Normal

PARTICLE SIZE ANALYSIS (ASTM F-1632)

			Soil Separate %			Sieve Size/Sand Fraction Sand Particle Diameter % Retained				
Lab ID No.	**Sample**	**Gravel**	**Sand**	**Silt**	**Clay**	**No. 18 V. coarse 1 mm**	**No. 35 Coarse 0.5 mm**	**No. 60 Medium 0.25 mm**	**No. 140 Fine 0.10 mm**	**No. 270 V. fine 0.05 mm**
21749-1	Plant Mix A1	28.7	60.0	27.0	13.0	18.3	16.5	12.8	8.5	4.0
	Corrected for organic content		56.7	37.8						
	Specifications		**63 - 67**	**26 - 30**						

Dispersion Method: Reciprocating shaker

SOLUBLE SALTS//TEXTURAL CLASS /ORGANIC MATTER/pH

Lab ID No.	**Sample**	**Soluble Salts mmho/cm**	**pH[1]**	**Organic Matter[2] (%)**	**Textural Class**
21749-1	Plant Mix A1	0.93	7.0	5.47	Gravelly sandy loam
	Specifications	**≤2**	**6 – 7.2**	**6 – 8%**	

1 ASTM D4972
2 ASTM F1647, method 1

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Turfgrass Soil Consulting and Testing Services

FIGURE 8-45a Submittals for soils testing. Results include mix type; content of gravel, sand, silt, and clay particles; and a sieve size analysis. The specification requirements are listed at the bottom for easy comparison.

SUBMITTAL COVER FORM

GENERAL SUBMITTAL INFORMATION

Cornell Life Sciences Technology Building
Owner: Cornell University
Architect: Richard Meier & Partners
Construction Manager: Skanska USA Building Inc.

PRODUCT INFORMATION	
Subcontractor:	
Date:	12-06-06
Product:	**Reports on soil samples tested by Hummel & Co.**
Manufacturer:	Paolangeli Contractor, Ithaca NY
Supplier:	Angelo's Sand & Gravel, Ithaca NY

SUBMITTAL INFORMATION	
Submittal Register No.:	~~029040~~ 02910-0009 – 0
Submission No.:	1
Type of Submittal:	Report
Contract Document Ref.:	1.8.G
Applicable Standards:	Agricultural Chemist

CONSTRUCTION MANAGER

( ) Reviewed
( ) Make Corrections Noted
( ) Revise and Re-Submit
( ) Rejected
( ) Other:

Corrections or comments made on this submittal during this review do not relieve subcontractors from compliance with requirements of the drawings and specifications. This check is only fro review of general compliance with the information given in the contract documents. The subcontractor is responsible for confirming and correlating all quantities and dimensions, selecting fabrication processes and techniques of construction, coordinating his work with that of all other trades, and performing his work in a safe and satisfactory manner.

Reviewed By: bc

Date: 12-8-06

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ARCHITECT

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Page 1 of 2

FIGURE 8-45b Analysis of soil composition results in recommendations for acceptance, rejection, or amendment required for use.

Requests for Information and Change Orders

It is essential to provide accurate and timely responses to requests for information (RFIs), particularly those that will result in a change order, which is nearly always linked to an increase in project cost. Because of the integrated nature of the systems, the work of one design discipline will affect others. With green roof systems, it usually takes longer to coordinate the information and response than in conventional construction.

Site Observation Reports

Routine site observation and subsequent accurate written site observation reports are perhaps the most important follow-up for each individual discipline in order to identify potential issues. They provide a way to communicate with subcontractors who need the information but may not be currently present on the site or at a particular job meeting.

Such reports should be accurate and describe actions that need to be taken, identify problems, note resolutions that have been agreed upon verbally in the field, and specify who will take responsibility for the specified actions. Usually these will be a supplement to the official job meeting report. Responses and follow-up will be necessary if the issue is complicated or difficult to resolve.

For green roof systems, topics frequently include slope of deck or topping slab, placement of drainage components, location and elevations of drains, soil mixes or growing media placement and compaction, utility rerouting, disturbance of another trade's work, and issues affecting living materials such as soil mixes and plants (delivery, storage and handling, or damage by others).

FIGURE 8-46 Two paving types are mocked up in situ and adjacent to each other to ensure that jointing patterns and setting systems are compatible. One type of paving is concrete poured in place directly over waterproofing membrane and protection board; the other utilizes irregular stone pavers installed on a setting bed over protection board and waterproofing.

Site observation reports are done also upon substantial completion of site work (especially planting, and often for other trades) and will be used to compile the punch list. Closeout requirements should focus on maintenance manuals, paving, irrigation testing, fountain testing, and similar items. Review of applications for payment should note the amount of work that has been completed, retainage, and so on.

Common Recurring Construction Issues in Building Green Roof Systems

The following provides a broad overview of glitches that may occur in green roof system projects during construction, and the potential consequences of not resolving them. The intention is not to make owners wary of building living green roofs and landscapes over structure; rather, it is to alert designers, contractors, and owners to potential problems and how to avoid them.

Prioritization Issues

The first common dilemma in the construction of living green roofs and landscapes over structure is that, similar to conventional construction, the execution and completion of site work are often subordinated to the completion of the building. From the very beginning of construction of early packages through the completion of a project, the coordination of trades, protection of materials, sequence of construction, effects of seasonal climate,

FIGURE 8-47 Construction of the concrete slab. Rebar is being installed prior to the concrete pour. Note the expansion joints and the footings for light posts.

FIGURE 8-48 Large-scale concrete installation for site infrastructure, including the planting pits. Roof-deck ramps for pedestrian movement can be identified.

project costs, and time issues involved in the green roof system must be brought to the attention of the construction management entity.

Survey Data and Project Layout Control

As with all projects, proper horizontal and vertical control is important. However, because typically the tolerance in horizontal and vertical layout of landscapes over structure is quite limited, discrepancies between the survey data and the actual field conditions can lead to layout inaccuracies and poor coordination of elevations.

Discrepancies in survey data, including elevational information, horizontal data, and utility layout, can occur when a city or municipality uses one set of data and the overall survey information (aerial, USGS, etc.) uses another. Utilities may be in different locations or at different elevations or may be missing altogether, which can impact stormwater drainage construction and other systems. For living green roofs and landscapes over structure, this can become a particularly difficult complication if conduits must be larger than anticipated, raising invert elevations and designed finish floor or grade elevations.

Inaccurate or missing survey data can also have structural impacts—for example, making it difficult to achieve designed top-of-slab elevations and resulting in sections that are too shallow to support the designed site load.

Geotechnical Conditions

Unforeseen geotechnical conditions can impact the designed horizontal or vertical layout, but more significantly, they can have limiting structural implications. An example of this is an unforeseen high localized water table, which can have a "bathtub" effect. A different type of slab construction may then be required, affecting the horizontal elevations.

Subsurface Water and Drainage

Similarly, if the construction itself causes an interruption of subsurface flow, drainage throughout the landscape over structure can become a problem, particularly when the project is at street or grade level: too much water with no outfall can saturate soil. This may not become apparent for some time, until plants decline and die.

Another major issue that can negatively affect site and roof deck drainage is poor coordination of trades and protection of materials. Early in the construction phase, during excavation or concrete work, overcompaction with heavy machinery can produce impermeable layers of soil, which in turn will impede drainage and airflow.

Later in the construction sequence, it is important to protect not only the waterproofing membrane from damage but also the drainage system. Drainage boards, drainage pipes, and drainage aggregate can easily become crushed or clogged with construction dust.

Location of Utilities

Site utilities may be discovered to be located differently than documented, both horizontally and vertically. Sometimes this is because of unforeseen subsurface conditions, and sometimes it occurs because the contractor or civil engineer is not aware of the tight tolerances that are essential in green roof systems. At a minimum this can cause numerous field changes, but when a project has very tight tolerances, particularly in top-of-slab elevations or where core drilling for later connection to utilities is not feasible or will disturb or damage completed work, the negative consequences can be significant.

Concrete Installation

For living green roof systems where concrete must be installed, perhaps the most important consideration is to ensure the correct elevations, pitches, and finishes of horizontal concrete surfaces that will support green roof systems. In paved areas it is important to ensure that the expansion joints are in the correct locations. Likewise, it is important that vertical and horizontal surfaces for planter walls, site walls, stairs, fountains, or footings for lights or other site elements are in the correct locations and at the correct heights.

Drainage structures should be properly located and any coring for utilities should be completed in the correct locations before any subsequent work is completed, particularly the installation of the waterproofing membrane. It is very difficult to achieve proper installation and performance of any of the remaining systems—drainage, planting, paving, other site elements—if horizontal and vertical concrete surfaces are not installed in the proper locations and to the correct elevations.

Installation and Protection of the Waterproofing Membrane

After the concrete is correctly installed and cured, and openings for utilities are correctly located, the waterproofing membrane will be installed. The waterproofing consultant and manufacturer's representative should be present during its installation. Flood testing should be completed and the protection material installed immediately. If a leak detection system is installed, it should also be tested and immediately protected.

Chapter 6 provides detailed information on waterproofing components and systems.

Insulation and Drainage Systems

The installation of the insulation is usually quite conventional, particularly if board insulation is being used. If tapered or grooved, it needs to be installed in the correct orientation to achieve appropriate slope and facilitate drainage. If the insulation was chosen for its high density and compressive strength to support paving, site elements, or some types of vehicular traffic, it is essential that it is the correct material and that it is being installed properly. Often it is placed in interlocking layers to avoid movement.

Getting the drainage system in correctly is perhaps one of the most important aspects of successful green roof system projects. This starts with proper pitch of the slab, with the water directed to drains of appropriate size and in the correct locations. Everything that makes up the drainage system—drainage mat, drainage/aeration mat, drainage

FIGURE 8-49 Flood testing of a waterproofed structural deck.

FIGURE 8-50 Waterproofing over complicated sloping and stepped structural slab. Here the landscape architect inspects the slope of the deck, the installation and sealing of drain connections, and openings for planting pits.

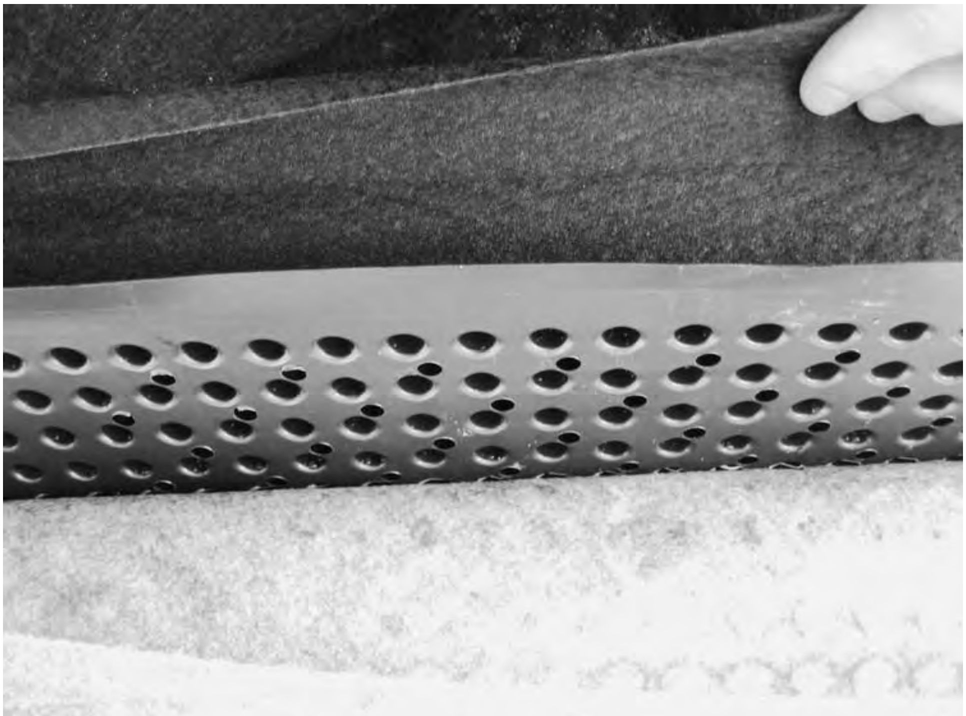

FIGURE 8-51 This entire drainage system—panel, water storage reservoir, and filter fabric—was installed upside down, requiring removal and reinstallation.

FIGURE 8-52 Removal of drainage system components in order to install correctly.

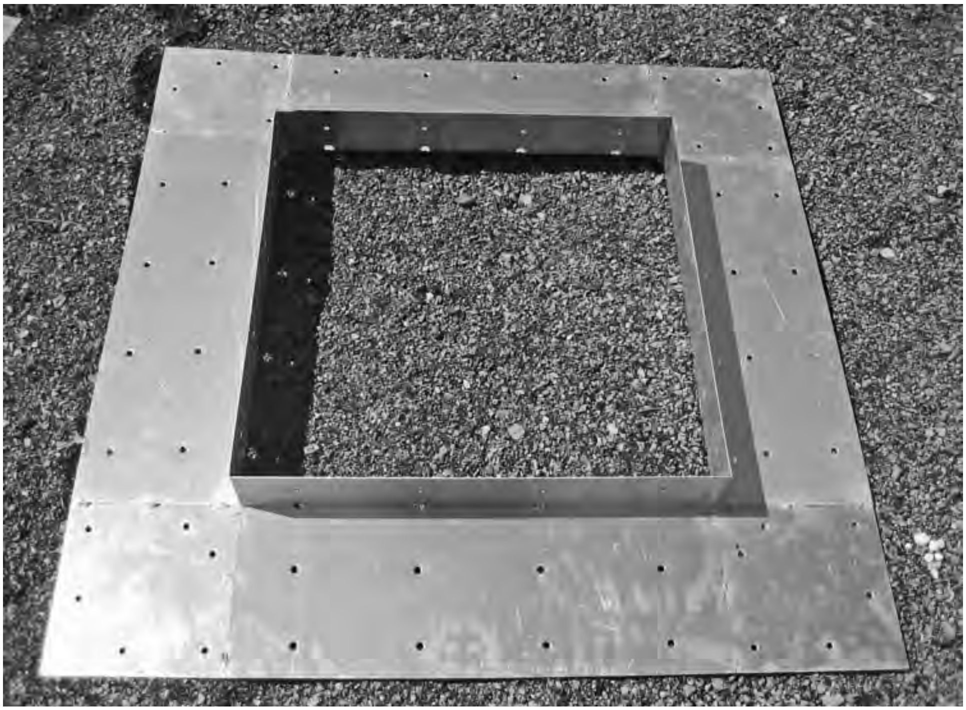

FIGURE 8-53 Installation and inspection of drain collars and flashing are very important in ensuring that the waterproofing system functions properly. Drain body components can be easily misaligned and the waterproofing membrane damaged.

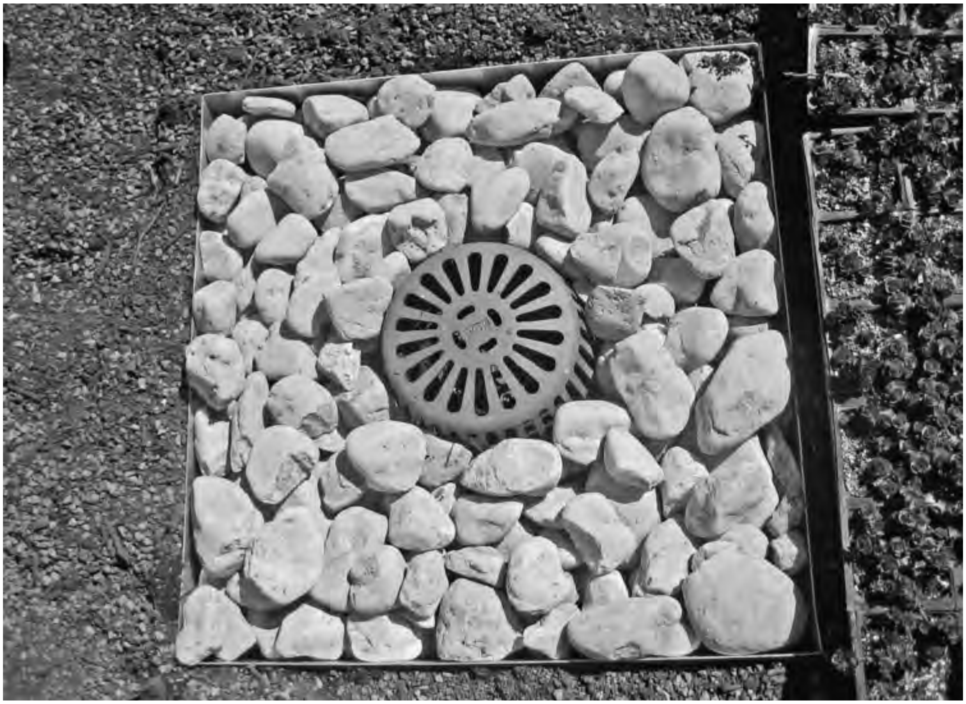

FIGURE 8-54 Drain collar installation. Drainage gravel surrounds the drainage opening for this living green roof to help ensure the free flow of excess stormwater. Growing medium is then installed around the collar.

FIGURE 8-55 Drain fit-out and placement of soil mix were not sequenced correctly—delaying the project. (Photo © Jeffrey L. Bruce & Company)

FIGURE 8-56 Drainage utility lines retrofitted from below structural deck. (Photo © Jeffrey L. Bruce & Company)

FIGURE 8-57 Stormwater and planter drainage systems must accommodate the flow of water. Runs must ensure positive drainage. Here, the blocking for pipe support and cleanouts is visible.

FIGURE 8-58 Utility systems can be extensive and can compromise areas that must support significant landscape. Access to them is by manhole, which requires surface expression.

FIGURE 8-59 Stormwater is carried from surface drains through the planter to outfall. Drainage for the planter itself is through a waffle panel and the planter's sloped bottom to the planter drain. The flows from planter drains are then collected below the surface of the structural deck and carried to outfall. The vertical pipe at the middle of the planter is for additional aeration and inspection of the planter drainage system. Where there are lateral underdrainage pipes, this aeration inspection pipe can also serve as a cleanout access point.

FIGURE 8-60 Planters are being filled with soil mix. Here the planting areas were made as wide and continuous as possible to allow for unrestricted root growth. Note the already installed irrigation lines and the plywood protection of stone copings. Planting of large-caliper trees (in background) was completed in late winter, when fluctuation of temperatures can be of concern.

FIGURE 8-61 In late spring construction is still under way. However, there is no evidence of protection for stone copings and previously installed plants. Irrigation system repairs are being completed. Here the waterproofing membrane has been disturbed.

panel, drainage aggregate with drainage pipes, filter fabrics, moisture retention mats—must be installed correctly. Sometimes because of lack of familiarity with materials, components may be installed in the wrong order or even upside down. Because these components and systems will soon be covered with soil mixes, plants, paving, or other site elements, if it is not installed correctly it will likely go unnoticed until the entire system starts to fail. Replacement is usually complicated and costly.

If underdrainage pipes are being used, ensure that there are adequate locations for cleanout and that cleanout access is installed in the correct locations and visible.

Specify that testing of the drainage system is required, and ensure that testing is performed and approved prior to the placement of any paving or soil mixes.

Lightweight Fill

Lightweight fill can consist of a number of materials, ranging from XPs board insulation to large blocks of EPs and lightweight concretes. Each of these components should be installed to the manufacturer's instructions and specifications. Large blocks of EPs can be easily wire-cut on site. If the placement of them is quite specific in terms of the profile of the finished grades, it may be necessary to specify that shop drawings indicate their configuration, stacking pattern, and any connection details such as cleats or taping.

Paving

When paving over a structural deck, many of the same construction issues encountered will be similar to those in conventional paving projects. However, the two most challenging

FIGURE 8-62 Installation of a subsurface stormwater holding basin. To the left, the larger drainage pipes allow water in and out.

FIGURE 8-63 Installation of boulders required careful placement both because of size, location, and potential damage to waterproofing and drainage systems below.

FIGURE 8-64 Waterproofing of the structural decking is complete. Note the slope of the slab, for drainage, and the weep holes in the block wall. Often site walls may be constructed separately and with a different building system than the structural system. Here concrete block is used rather than cast-in-place concrete.

FIGURE 8-65 Construction sequencing required planting of the far end of the project while this area was still being waterproofed and site elements being constructed. Note the radial layout of planting areas, and the stormwater pipes through planters with stub-outs for connection of planter drains. Also note the construction debris that readily accumulates on large, complicated sites with constrained staging areas. Insulation is about to be installed.

FIGURE 8-66 In this project construction sequencing required early installation of large-caliper trees suspended in a raised surface deck. Planting soils were installed in separate phases, followed by finish carpentry work and paving installation.

FIGURE 8-67 Installation of large granite pavers on pedestal system. Open joint paving systems allow surface drainage through the joints of pavers. The surface is generally dead flat, with the top of the deck below sloped to drain. These systems require precision in installation. Here, because of the size of the pavers and to avoid "hollowness" or potential rocking, pedestals were oversized, and large squares of compressible material were used for a consistent shim.

FIGURE 8-68 Pavers set on pedestals comprised of numerous layers of blue board (XPs). (Photo © Jeffrey L. Bruce & Company)

are ensuring positive drainage and establishing the proper depth of the setting bed. Positive drainage should be both across the paved surface to surface drains and below across the top of the deck to the deck drains.

Often if the elevation of the deck has been poured too high or too low, the temptation is to make up the difference in the thickness of the setting bed. If a setting bed is too thick, however, the pavers will rock and tend to chip at the corners, leading to deterioration of the paving system. If a setting bed is too thin, it will be difficult to achieve a uniform finish grade, because there is generally an allowable tolerance in pavers, both in width and in depth. A variance in depth can cause a “lip” that can alter drainage flow and cause the same rocking and chipping as noted above. A setting bed that is too thin can also be detrimental to the interlocking of pavers and most importantly to the protection of components below, such as the drainage system and the waterproofing membrane.

If an open-joint paving system is used, where pavers are set dead flat on pedestals, allowing the surface drainage water to flow through the joints and across the surface of the sloped deck, the placement of supporting pedestals must be extremely accurate, as should be the joint size and spacing. Ensure that the concrete deck has been poured to the proper elevation and pitch and that drains have been located in the proper locations.

Planting and Irrigation

When planting living green roofs and installing irrigation for planting landscapes over structure, many of the construction issues encountered will be similar to those in conventional

FIGURE 8-69 Site walls, stairs, and planters are all part of the numerous landscape elements that need to be designed, documented, and installed as integrated site systems.

FIGURE 8-70 Palms in boxes were installed early in the site construction process.

FIGURE 8-71 Installation of soil via a conveyor system. (Photo © Jeffrey L. Bruce & Company)

planting projects. The two most challenging are ensuring positive drainage and ensuring the proper composition, placement, and depth of growing media. With planting, as with paving, positive drainage should be both across the planted surface to surface drains where practical and, most importantly, across the top of the deck to the deck drains.

Just as in paving, ensuring positive drainage begins with ensuring that the concrete deck has been poured to the proper elevations and pitch, drains have been located in the proper locations, and the waterproofing membrane system has been installed as documented. In addition to flood-testing the waterproofing membrane, the drainage system must have been installed correctly, tested, and approved.

Key to the success of the planting and its long-term health are proper installation of the appropriate soil mixes or growing media and careful planting of all trees, shrubs, ground covers, and succulent plants. Often because of construction sequencing and lack of later accessibility for planting to a portion of the site, some plants may need to be installed at unexpected times—sometimes quite early in construction. This means that the entire infrastructure for the planting system, such as waterproofing system, insulation, drainage system, lightweight fills, irrigation, guying, and growing medium, must be available on site and properly installed and functioning prior to installing the plants. Then they must be maintained and protected for the duration of the project's construction until accepted.

FIGURE 8-72 Fabrication of soils off site.

FIGURE 8-73 Large continuous planters with waterproofing and protection board on both horizontal and vertical surfaces, insulation, and a drainage medium of lightweight aggregate. Lateral drain pipes lead to the planter drain and a cleanout and aeration inspection pipe.

FIGURE 8-74 Aeration drainage mat with filter fabric placed over drainage layer; placement of planting rings.

FIGURE 8-75 Construction sequencing required placement and compaction of different soil mixes at separate times. Large rings of corrugated metal were used to facilitate the subsequent exact placement of trees with root balls more than 6 feet in diameter. Once the trees were placed and partially backfilled with a different soil mix, the rings were removed and planting and subsurface guying were completed.

FIGURE 8-76 Completed planting of outer double row of trees.

FIGURE 8-77 Completed inner park planting.

FIGURE 8-78 Construction staging required on-time delivery, suitable storage, and careful handling of plants on site. (Photo © Jeffrey L. Bruce & Company)

FIGURE 8-79 For this living green roof, areas were marked off according to the type of plant to be installed. Because plants used in living green roofs can appear very similar, here a flat of each type of plant to be used was placed within its sector, to ensure that the planting contractor installed the correct materials in the correct locations.

FIGURE 8-80 Plants were also carefully identified on site for easy reference.

FIGURE 8-81 Installation of plants on living green roofs.

Seasonality

Often planting can be adversely affected if there are seasonal considerations: availability of plants, digging seasons, spring-only planting, or planting in excessively hot or cold weather. It is important to have considered seasonality constraints early in project planning.

Proper Installation, Operation, and Maintenance of Systems

Another complication that also occurs in conventional construction is that the final portions of site work and planting may occur when most other trades have already completed their work and left the site. Sometimes even the construction manager will have only a skeleton team on site to ensure proper installation and maintenance of planting and follow-up on punch list deficiencies. It is important that the landscape architect or green roof designer be especially diligent and attentive to planting installation, maintenance, and follow-up on punch list items during this time.

It cannot be overstressed that because much of this infrastructure will be below finish grade and not readily visible, poor or improper installation of any of these systems may not become apparent until the plants are stressed, in decline, or even dead. At this point the result of the poor installation—a distressed landscape—is quite visible. In view of the logistics and significant costs of replacement, the initial costs of proper installation, protection, and maintenance are really quite minimal.

FIGURE 8-82 Completion of a landscape over structure often involves the coordinated installation of planting and site elements such as paving, walls, benches, and large-scale art elements.

FIGURE 8-83 Construction sequencing often requires protection of large-caliper specimen trees against damage, as well as protection of the growing medium against excessive compaction.

FIGURE 8-84a Installation of a palm grove.

FIGURE 8-84b Completed palm grove.

FIGURE 8-85 Boulders selected from the nearby Sierra Nevada were carefully placed on the site. Trees (in boxes) were installed subsequently.

FIGURE 8-86 Completed fountain with planting beyond.

Postcompletion

When the project is complete and the owner has occupied the building and site, contract closeout for both the consultant team and the owner takes place. Although at this point of the project it is difficult to sustain enthusiasm and the required level of accuracy, because so many of the components sustaining green roof systems are below-grade and not readily invisible, the importance of this phase of the project cannot be underestimated.

It is also the time for the following critical operations:

- Maintenance manuals for project site systems are handed over to the owner and reviewed. These may include:
  - Planting (routine maintenance, pruning, fertilizing, replacement, soil testing and amelioration)
  - Irrigation operations (routine maintenance, calibration and repair, testing, and seasonal shutdown and start-up)
  - Drains and drainage systems (routine maintenance, cleanout, and testing)
  - Paving and curbs (routine maintenance, repair or replacement, loading limitations, cleaning, snow removal and approved deicing agents)
  - Fountains and fountain equipment (routing, maintenance, calibration and repair, seasonal shutdown and start-up)
  - Other site elements (maintenance of site lighting, site furnishings, stairs, walls, or other project-specific site elements)
- Production and review of as-built drawings
- Project feedback
- Postoccupancy analysis regarding the success and use, as well as any change in program requirements or ownership

For each consultant, this is a good time for in-house project archiving, which should include documentation of project records for future reference.

It is also a good time to review actual project costs for the design and construction as well as to document the project through formal project narrative and photography.

Summary

Many of the conditions, issues, and complexities of building green roof systems are similar to those encountered in conventional building and landscape architectural projects on *terra firma.* However, the integration of the components and systems requires more attention to construction logistics and sequencing, the coordination of trades, and protection of previously installed work. More importantly, because many of the components and systems that sustain green roofs are below the surface and not visible. Construction errors or inadvertent damage to components are hard to detect and may only become apparent after significant deterioration or damage has taken place. Until green roof systems become commonplace, it will be important to set and maintain clear expectations for an integrated construction process.

Chapter 9

Minimizing, Managing, and Insuring Risk

Successful green roof systems that minimize potential problems and lower unknown risk require good design, suitable high-quality materials, and excellent construction and long-term maintenance. Despite numerous examples of successful green roof systems and regardless of their multiple environmental, economic, and social benefits, there are still misgivings and hesitancies surrounding their use. Apprehension is shared by existing and potential owners, design professionals, contractors, and product fabricators.

Owners, in addition to all of the concerns of conventional construction, tend to worry about:

- Inaccessible and damaging leaks
- Unfamiliar maintenance requirements
- Safety hazards
- Costs

Design professionals worry about many of the same things as owners but are also concerned with:

- Effectiveness of design and engineering
- Long-term performance of materials and systems
- Drainage
- Viability and long-term success of the vegetation

Contactors can be uneasy for several reasons:

- Complex construction logistics
- Costs
- Schedules
- Subcontractors' unfamiliarity with the bidding and installation of green roof systems

Product manufacturers are anxious to design and produce new, effective components but want them to be utilized, installed, and maintained as intended.

There are two basic reasons why owners, design firms, contractors, and product manufacturers are disinclined to take on green roof system projects and why insurers are reluctant to issue coverage of such undertakings. First, there is a lack of accepted, industry-wide standards for living green roofs and landscapes over structures. Second and more disquieting, there is the perception that rooftop installations create a greater risk than conventional roof construction and conventional landscape construction on terra firma.

As discussed in Chapter 6, the German FLL provides wide-ranging guidelines for liv-

Liability Insurance

Some insurance companies have specifically excluded projects comprising green roof systems. Until they become commonplace, it is important to review potential risks and exposures with an insurance agent or broker before undertaking them.

In general, the following types of liability insurance apply to the design, construction, and use of commercial (nonresidential) green roof systems:

- Commercial general liability insurance
- Owner's liability
- Contractor's liability
- Professional liability insurance
- Product liability insurance

Workers' compensation insurance (covering the liability of an employer to employees for required compensation for injury arising from their employment) also applies, but this is general to all employers and employees in the design, construction, and use process.

COMMERCIAL GENERAL LIABILITY INSURANCE

Commercial property insurance provides protection for business owners against unforeseen damages to the building and its contents once the green roof system is installed. Commercial general liability insurance is a broad form of liability insurance covering claims for bodily injury and property damage that combines coverage for business liability exposures and new and unknown hazards that may develop. It also includes contractual liability coverage for certain types of contracts and personal injury coverage.

OWNER'S LIABILITY INSURANCE

Owner's liability insurance protects the owner against claims arising from its ownership of property.

CONTRACTOR'S LIABILITY INSURANCE

Contractor's liability insurance is purchased and maintained by the contractor to insure the contractor against claims for property damage, bodily injury, or death.

PROFESSIONAL LIABILITY INSURANCE

Professional liability insurance is coverage for the design professional's legal liability for claims arising out of damages sustained by others allegedly as a result of negligent acts, errors, or omissions in the performance of professional services.

PRODUCT LIABILITY INSURANCE

Product liability insurance is coverage for liability imposed for damages caused by an occurrence (after possession by a third party) arising out of goods or products manufactured, sold, handled, or distributed by the insured or by others trading under the insured's name.

WARRANTIES AND GUARANTEES

Warranties and guarantees are meant to confirm that a standard is met. A warranty is a legally enforceable assurance of quality or performance of a product or work, or of the duration of satisfactory performance.

Warranty is often incorrectly used interchangeably with *guarantee* and should only be used in assuring a standard of product performance and workmanship of installation and not for establishing a standard of professional service.

Sources: *AIA Handbook of Professional Practice*, "Managing Risk Through Contract Language," V. O. Schinnerer and Co., Inc.)

ing green roofs and to some extent for landscapes over structure. Efforts continue by the American Society for Testing and Materials (ASTM) Green Roof Task Group (E.06.71) to develop acceptable industry-wide standards for green roof systems that will allow for increased opportunity for the insured to utilize them and a decreased risk to insurers.

Like most things in life, the risk must be evaluated against the gain. The costs of green roof systems must be weighed against the numerous short- and long-term economic, social, and environmental benefits. However, not all costs or benefits are easily identified. Likewise, not all risks can be easily identified, quantified, or equitably allocated—but then neither can the significant gain.

Assessing and Spreading the Risk

In return for an agreed-upon premium, insurance companies assess risk and, by spreading the risk over a large number of insureds, agree to protect a person or entity against claims arising from a failure to fulfill an obligation or duty to a second- or third-party incidental beneficiary. Many insurance companies understand that replacing dark, hard-surfaced roofs or pavements with green roof systems is critically important to urban areas and that their utilization can minimize hazardous environmental consequences. Many insurers and building owners also realize that green roof systems can reduce the building's liability exposure because of prolonged roof life, energy efficiency, and hence reduced life cycle costs. However, greater risk exists when projects require work by one discipline or trade atop another's. As an example, this might occur when one subcontractor installs the architect's specified waterproofing membrane over the structural engineer's deck but below the MEP-specified insulation, while several other subcontractors install the landscape architect's drainage, planting, and paving systems over all that.

An information exchange and continuous dialogue between designers and insurers is important to translate the social and environmental benefits of green roof systems into benefits for individual building owners and insurers (lower risk for the former, profit realization for the latter). Thus, industry-wide green roof design guidelines will ultimately allow for wider application without posing an increased risk to the insurer or a loss of opportunity to the insured.

The insurance industry seeks to minimize risk by spreading it over a large number of insured entities. Since the green roof industry is still relatively small in the United States, carriers are sometimes reluctant to provide coverage for projects incorporating a green roof system because they do not have a large enough policy base to truly assess potential liability exposure and related losses.

Fortunately, with the rapid changes in construction technology and materials available for green roof systems, industry-wide guidelines and standards will continue to evolve and gain wider acceptance. Furthermore, several major companies in the commercial and professional liability insurance markets believe that their analysis of green-roof-system-related claims shows that liability exposure is manageable through sound continuing education and prudent practices, and they expect to continue offering coverage for those who wish to undertake these projects.

These farsighted underwriters operate under the premise "one at risk, all at risk" and actively provide information for the continuing education of owners, design professionals, and contractors: providing technical information; developing commonly accepted definitions and appropriate contract language; establishing effective methods of communication among clients, design teams, and contractors; pinpointing common areas of liability risk; and identifying methods and processes that lower risk during all project phases, from project inception through documentation, construction, and long-term maintenance and use.[1]

Two companies that lead the industry in their support of green roof systems are FM Global and CNA/Schinnerer. In helping to ensure that green roof system installations proceed without creating unforeseen hazards to buildings and occupants, they have a vested interest in helping design professionals, contractors, and owners plan and build in the best possible way. When clients can remain in business and the potential for accidental injury, building damage, or equipment breakdown is minimized, insurance claims are ultimately minimized.

FM Global is an active participant in the successful application of green roof systems, particularly in terms of testing and evaluation. FM Global has developed its own Property Loss Prevention Data Sheets, which recommend methods to prevent damage caused by property-related hazards, such as structural overload, wind damage, or fire, based on scientific research, engineering experience, and loss history.

In FM Global's experience, the most common cause of failed roofs is severe weather conditions. Roof and property damage caused by high winds, rain, hail, or fire is unpredictable but can be prevented or minimized by following FM Global's engineering guidelines. Their Property Loss Prevention Data Sheets 1–28 and 1–29, "Design Wind Loads" and "Roof Deck Securement and Above-Deck Roof Components," address wind and structural loads. The newly issued Property Loss Prevention Data Sheets 1–35 specifically address Green Roof Systems.

In a similar way, CNA Insurance (underwritten through Victor O. Schinnerer and Company) has also taken the longer view. In assessing risk, they have sought to understand the historical and contemporary applications of green roof systems, and they believe that the integration of research and design makes such installations "prudent risks."

Professional liability insurers perceive the risks resulting from living green roofs and landscapes over structure very differently. In general, living green roof designs represent a lower risk because both the structural and landscape design and the construction techniques are not unique. Living green roofs are usually built to support and accommodate a relatively low design weight, which, from an insurer's perspective, greatly reduces the risks.

Landscapes over structure, however, present an additional risk because they are usually heavier in design loads and are much more complex in all aspects, including the waterproofing system. This makes it difficult for the insurers to protect the work of just one profession among all those involved with the roof's design and installation. Some insurers have opted to exclude landscape over structure projects from their policies because their clients are not in control of all aspects of the design process and because of the more complicated construction and installation methods. They believe that when things go wrong, everybody who worked on the project ends up in litigation regardless of the merits of the claim. However, exposure is usually related to structural engineering issues, drainage difficulties, and growing medium, as well as contractor delays and extra costs.

This does not imply that green roof systems are risk-free. Living green roofs and landscapes over structure present unique design issues and liability exposure. But to two major insurers, each presents manageable risks to the insured and the insurer. The CNA/Schinnerer program, for example, has identified only a few claims against landscape architects related to living green roofs and landscapes over structure. As a result, CNA/Schinnerer believes that insurers and insureds who focus on sound risk management principles can negotiate the intricacies and specific issues presented by green roof systems. Clear communication and documentation are the two key areas that help avoid liability exposure.

They have identified six common areas of liability risk:

- Unfulfilled client expectations
- Expectations for recovering costs
- Implied or expressed warranties
- Misrepresentation or fraud
- New materials and systems
- Insufficient documentation

The expectations of a client may not be fulfilled when a design professional has insufficient knowledge of green roof systems. This might include misapplication or misrepresentation of a living green roof as an accessible space for owner or tenant use. Or, if there is a lack of thorough understanding of the structure and soil depth needed to support the significant vegetation envisioned by the owner, the costs to achieve this can be an unpleasant factor for both the owner and design team.

If the design team does not adequately represent the short- and long-term benefits of living green roof systems, or design and construct to defined certification levels (such as LEED), the owner's expectations of immediate cost savings implied by certification may be unfulfilled. Likewise, the higher initial investment required for longer-term savings in life cycle costs may not be fully understood by the owner, leading to a sense of misrepresentation or even fraud, thus making the insurer vulnerable to such a claim.

The materials within a system must be well understood by the design professional, whether as individual components or as a proprietary system. This is particularly important in retrofit situations, where longer-term deleterious impacts of existing components may not be obvious. Substitution of system components put into place without adequate research, especially under the pressure of construction deadlines, can have disastrous consequences.

Lack of communication and documentation (which here means an accurate understanding of problems and solutions and timely, factual reporting) can be easily corrected without sacrificing or compromising the design or implementation of a green roof system. It is even more important to make sure that the client or owner has a complete understanding of the challenges such installations present and gives informed consent to design recommendations.[2]

Contracts

One issue that arises over and over again in regard to insuring green roof systems is the need for properly written contracts that clearly define professional liability. In addition, insurers are concerned about the inherent job site safety associated with working on elevated landscapes. Insurers become their clients' watchdogs to avoid unnecessary professional liability exposure and to avoid risks that would pose a threat to worker safety and potentially result in claims for worker's compensation.

Most professional liability insurance is written on a claim-made basis. As long as the existing policy includes protection for past acts, this is the policy basis. The carrier will assume responsibility for the claim, even though the act may have occurred prior to policy inception.

The statute of limitation or statute of repose (dependent upon the state) defines the timeframe within which a claim must be filed. This time period suffices to discover and investigate whether damage or failure was a result of negligence in design, installation, or operation.

Insurers continually stress the importance of contracts that clearly qualify and quantify the role of the designer throughout the construction process. The contract between the green roof system design professional and the client must be explicit about the designer's scope of services in an effort to avoid legal ambiguities. For example, worker safety and job site safety associated with a living green roof or landscape over structure installation are usually not the designer's responsibility; they are typically the responsibility of the contractor, who controls the site. Proper contract language spells out the scope and assigns responsibilities, and these must be adhered to by employees.

Both the design profession and insurers benefit from precisely written contractual agreements. A clear contract defines the scope of services, articulating the quantitative and qualitative aspects of services. This includes what is and is not within the scope of service, and is particularly important when it comes to the maintenance requirements of green roof systems. It is also critical to define the use of the space and its limitation at the time of the design. This protects the designer against unforeseen changes in use that could potentially lead to claims. For example, a living green roof is initially designed and installed to help reduce stormwater runoff and to provide a pleasant visual amenity for the owner. If the property changes ownership and the new owner starts to use the roof as an accessible landscape, this could result in a system failure and subsequent costly litigation. Proper foresight and explicit detail in the contract will protect the designer from undue blame.

Maintenance

Drawings and specifications are prepared by the design professionals to ensure proper installation of all supporting systems (waterproofing, drainage, planting, paving, etc). The specified installation of these various systems is the responsibility of the contractor. The responsibility for the maintenance is not always so clearly defined. A maintenance manual is generally provided by the designer or submitted by the installer as part of project requirements. Such system manuals should be used by the owner's properly trained and qualified personnel responsible for the overall green roof system's maintenance—especially for the maintenance of the waterproofing systems. Architect/owner contracts must also include specific language requiring the owner to waive any claim for negligence or indemnity against the designer and installer for any failure of the green roof system arising out of or resulting from the owner's failure to follow the manual.

Managing Risk: Avoiding Fundamental Problems

A successful installation of a green roof system that minimizes potential problems is highly dependent on its waterproofing system, which requires good design, suitable high-quality waterproofing materials, and qualified contractors. Building owners can and should expect that reputable roofing system manufacturers will stand behind their products and services and that they will offer industry-standard warranties. However, the most commonly cited reason for deciding against a green roof system is a history of poorly installed, conventional waterproofing systems, completely unrelated to green roof systems and their installation.

Leaks and Waterproofing Membrane Systems

In conventional construction, roofing usually takes up less than 5 percent of the overall building budget for low-rise buildings, and even less on multistory or high-rise buildings. Yet leaking roofs account for over 50 percent of all postconstruction insurance claims and litigation, regardless of roofing type or manufacturer. That is four times higher than wall systems, the building envelope component that ranks next in postconstruction litigation. The National Roofing Contractors Association (NRCA) confirms that 75 percent of roof leaks develop within the first five years and that improper design and detailing account for about 20 percent of these failures.[3]

Leaks can have many different origins and must be addressed quickly when they are detected. Eighty percent of all leaks occur in areas where vertical and horizontal surfaces meet, such as along deck edges or where the deck is tied to walls, around drains or skylights, at penetrations for vents or chimneys, at expansion joints, or in other areas that interrupt the waterproofing membrane.[4]

Parapet walls can also contribute to leaks even though the actual waterproofing membrane is watertight. The integrity of the waterproofing can be undermined when water finds its way behind the waterproofing through cracks or degraded joints at a parapet. The water can travel underneath loosely laid single-ply waterproofing membranes or into walls on fully adhered systems. Either way, these leaks are hard to trace and to repair.

A roof leak may be caused by incorrect roof design, inappropriate selection of materials, or poor quality of the waterproofing installation. Proper detailing and installation are important, especially for protective roofing systems. Inverted roofing membrane assemblies (IRMAs) and green roof systems are protective roofing systems because they cover the waterproofing. Once the protective layer (stone ballast or green roof system) is installed over the waterproofing membrane and roof decking system, leaks become more difficult to trace and repair.

At the source of most leaks is insufficient drainage. Ridges and valleys in the roof surface and subsequently the roofing membrane cause water to collect and stand in the valleys, which exposes the roofing system to unnecessarily long periods of inundation. The standing water often dissipates only through evaporation. Drainage problems can also occur in connection with surface drains or roof deck scuppers that are installed too high, at internal or subsurface drain locations, at wall connection points, and at any horizontal or vertical pipe run. Condensation associated with insulation can also be the source of some water damage.

Product Selection, Warranties, Documentation, Construction, and Maintenance

Developing sufficient and clear construction drawings and specifications is the most responsible and practical approach to reducing risk and liability and for protecting all involved parties against potential system performance problems. These contract documents are essential for bidding and are the documents against which adherence to installation standards and quality assurance can be measured and monitored.

Obviously, a critical item that needs to be clearly documented and specified for all green roof systems is the waterproofing membrane system. Whether hot-applied, fully adhered, or mechanically fastened, the waterproofing membrane system needs to be selected for site-specific conditions and in accordance with its intended use and performance goals. Wind uplift potential can be greatly reduced by specifying fully adhered or mechanically fastened waterproofing systems. Fully adhered systems don't allow water to travel underneath, and leaks on fully adhered systems can usually be more quickly identified, located, and repaired.

Rigorous inspections and quality control during installation is the best and easiest protection against potential leaks. Selecting membranes that minimize the number of seams and checking membrane seams repeatedly for faulty heat welds and for signs of delamination also help prevent leaks.

Green roof system specifications that can significantly reduce the risks for potential leaks after the system is completed include:

- Requirements for a preinstallation conference
- Requirements for submittal of a work plan, including provisions for the protection of the waterproofing system against any damages during the landscape overburden installation
- Requirements for flood-testing of the waterproofing system
- Field mockup of the green roof system assembly

Precautions for Retrofit Installations of Living Green Roofs

During retrofit of roofs with an existing parapet, repairs to the parapet or parapet flashing must occur simultaneously with installation of the new waterproofing system to eliminate the potential of water intrusion, which could jeopardize the integrity of the new waterproofing.

Understanding Waterproofing Warranties

Warranties state a commitment on the part of the manufacturer that should leaks occur during a certain period of time, they will be fixed. Warranties often include stipulations that significantly reduce the liability of the warrantor or limit repair costs to a certain amount (called the *upset* or *not-to-exceed* amount) while excluding warranty claims under certain conditions. Reliance on long-term warranties can have costly consequences for both the building owner and the waterproofing system manufacturer.

Negotiating warranty terms for the waterproofing system beneath a green roof system is not always as straightforward as for a conventional roof. This can be exacerbated when manufacturers extend a regular waterproofing warranty for replacement and removal of the landscape overburden (growing media, plants, paving, etc.) only if their proprietary green roof system is used over their proprietary waterproofing system.

Understanding the underlying reasons for any perceived or real limitation of the manufacturer's warranty or insurance provider's assessment of associated risk will help to address potential issues before they become a problem.

Manufacturers' Concerns

Roofing system manufacturers generally approve and certify contractors as licensed installers of their roofing system. The manufacturer and contractor often enter warranty agreements together. For a specified period of time the installer becomes the designated contractor for service calls to repair leaks, either because of material defects or because of lapses in workmanship. The manufacturer bears the cost of repairs after that specified time period. Warranties must clearly state terms and areas of coverage to avoid ambiguities, but must also clearly outline the owner's responsibilities for proper maintenance and regular inspections to minimize waterproofing membrane or roof deck damage. It is important to repair the damage without unnecessary delay, before damages and expenditures to fix them increase exponentially. Clearly stated warranty agreements help to minimize delay when timely responses to problems are critically important.

Warranties for both living green roofs and landscapes over structure usually include a so-called overburden clause that exempts the waterproofing manufacturer or warrantor from having to remove and replace any components of a green roof system above the waterproofing membrane. This means that in case of a leak, the building owner is responsible for removing all green roof system components in order to provide access to the waterproofing for repair. This could include growing media, plants, drainage systems, paving—anything above the waterproofing system. Likewise, the owner is responsible for replacing all green roof system components after the repair has been carried out. This often comes as a surprise to the building owner and has caused some agony in the past. Some ambitious installing contractors fill this void or lapse and offer overburden removal and replacement as part of their services and first-year maintenance contracts. But this service is neither without cost nor provided without request. Proper construction drawings and specifications, which can be clearly defined within a contractor's scope, are essential to decrease the potential of leaks and costly repairs. This might mean that the bidding documents include installation and maintenance requirements, separated by trade, including a requirement for overburden removal and replacement should repair be necessary.

Insurers' Concerns: Structural Design

The primary concerns in regard to green roof system design as it applies to risk liability involve structural load calculations, which need to account for saturated material weights to ensure adequate structural support of the green roof system—essentially to prevent structural failure and collapse. Insufficient drainage and subsequent ponding of water may add excessive and potentially unaccounted-for weight in the event of sustained full saturation of the entire green roof system assembly. Clearly this could have detrimental or even disastrous consequences. Similarly, retrofitting existing roofs with a green roof system requires a careful structural evaluation to determine if the existing roof, building, and structure possess the necessary load-bearing capacity to safely sustain the additional green roof system load at full saturation. It is the responsibility of the owner and the team of licensed design professionals to ensure that the roof deck adequately supports the expected load and that the design is in compliance with applicable local and national building codes.

In earthquake-prone areas, it is particularly important that the added weight of the green roof system not compromise the building's lateral-force-resisting system. The structural engineer must include the green roof system weight and added loads at the most saturated conditions into seismic analyses. In buildings with concrete frames the additional weight of the green roof system may be negligible or can easily be adjusted in new building structural designs. The heavy mass of concrete-framed structures or metal-framed structures with heavy infill and facades may not require seismic upgrades. However, light-framed steel structures may require seismic reinforcements.

Windborne debris is also of concern to FM Global. While the green roof industry sees great potential for using green roof systems as replacement for stone ballast on single-ply waterproofing systems, FM Global considers both stone ballast and living green roofs to be prone to an increased risk of damage from wind uplift and windborne debris. The stone ballast serves as protection against wind uplift of the membrane, but if the ballast itself becomes windborne during high winds, uplift protection is compromised. The entire living green roof system becomes vulnerable to wind uplift and tear-off, which could then lead to roof failure. There are no FM Global approval standards for stone-ballasted single-ply roofing systems, but they are widely installed nevertheless. Windborne aggregate can cause serious damage to buildings, especially to the building envelope. Glazing, such as skylights, windows, and doors, is particularly susceptible to damage from windborne debris. In addition to the direct building damage of broken glass windows and doors, the more significant danger lies with the possibility that the building envelope will breach. High winds entering the building interior through broken windows on the windward walls can increase the internal building pressure substantially. The increased internal building pressure and the external wind pressure can combine to create greater suction force on the leeward wall (as much as 30 to 40 percent more) and a greater uplift force at the roof (up to 15 to 30 percent greater).[5] The combination of internal and external forces dramatically increases the risk of roof failure and consequently the risk of exposure of the interior building contents to damage and destruction by wind and water, especially in hurricane- and tornado-prone areas.

A living green roof is not attached to a roof but only resists normal wind uplift loads by its own weight. Therefore, it is important to specify, according to applicable standards, the living green roof growing medium with a critical minimum weight to withstand normal wind uplift loads. (Please see Chapter 6 for additional information on growing media.)

As discussed above, stone ballast can become windborne due to wind uplift. This exposes the roof deck and the building to the elements. For a living green roof used in lieu of stone ballast, similar concerns exist about the growing medium and plants. If the living green roof ballast is eroded by wind or water (particularly during the initial period when the plants are not yet fully established), the roof deck and building are left unprotected against wind uplift along roof perimeters and corners. A stone ballast or a paver will provide a greater resistance against wind uplift than the lighter-weight living green roof growing medium and planting. Because the smaller stone can still become windborne, it is advisable to use pavers as ballast around the perimeter and at the corners. (Typically these pavers might be precast concrete with a minimum dimension of 12 inches square.)

Available Standards for Designing for Loads

The Structural Engineering Institute and the American Society of Civil Engineers have developed and published the SEI/ASCE 7–02 Minimum Design Loads for Buildings and Other Structures. (The International Building Code [IBC], which is the governing building code for most states, adopted many ASCE 7 guidelines. FM Global, a farsighted major underwriter of liability insurance, references these guidelines in its Property Loss Prevention Data Sheets). This document defines the width of roof perimeters including the corners. Depending on the roof area and the footprint of the building, the width of the perimeter can vary from 3 to 6 feet. The wind loads in corners and along the roof perimeters should be 50 to 150 percent higher compared to the field (middle) of the roof, and therefore perimeters and corners must be designed with greater wind uplift resistance. Nonvegetated roof perimeters are often finished with stone ballast or pavers because each provides a greater resistance per square foot against wind uplift compared to lightweight living green roof growing medium.

SEI/ASCE 7–02 includes the definition of the exposure (also referred to as ground roughness) of the building site. The exposure depends on the natural and built environment surrounding a building and its roof and is categorized as B, C, or D. A was eliminated in the most recent revision. Category A formerly represented the least exposed building to wind uplift or damages by winds, for instance a building in the middle of a city whose roof is well protected by surrounding buildings. A suburban office building with some neighboring buildings of various roof heights that break up wind velocities may be a category B exposure, whereas a commercial single-story strip mall with little to no protection from surrounding buildings or trees is classified as a category C exposure. Buildings on the coast without any wind protection fall into category D, the highest wind exposure.[6] Residential buildings have much smaller roof surfaces compared to commercial or industrial buildings and are therefore not graded by exposure category. Additionally, residential homes are usually well protected by surrounding structures and trees and generally are well suited for living green roofs.

The SEI/ASCE 7–02 Minimum Design Loads for Buildings and Other Structures includes guidelines and building requirements that have great relevance for the green roof industry. The guidelines cover design loads, load combinations for dead and live loads, rain loads, flood loads, wind loads, snow loads, earthquake loads, atmospheric ice loads, earthquake loads, and growing medium loads. Because weight limitations pose the single greatest restriction for new and retrofit green roof systems, a competition to create an ever-lighter growing medium has arisen. However, the growing medium for living green roofs must have a minimum critical depth and weight to effectively serve as roof ballast in compliance with SEI/ASCE 7–02 and to withstand certain wind loads.[7]

As an example of compliance, buildings and roofs in hurricane-prone areas such as south Florida and Puerto Rico must be able to resist sustained winds up to 150 miles per hour. Roof pavers that meet a specific density and unit weight can be used as ballast in wind speeds that exceed 120 miles per hour. Parapet walls of sufficient heights can be effective in negating pressure and greater wind uplift, especially in corners. Concrete and masonry parapet walls can pose a risk in high-seismic-activity areas because they are sometimes the first things to topple.

Reducing Fire Hazard

Properly designed, constructed, and maintained living green roofs and landscapes over structure do not pose an inordinate fire risk. For a living green roof, the succulent plants as well as the mineral substrate layer of the growing medium are fire-resistant. Unsuitable plants atop a roof environment without supplemental irrigation can dry up and pose a fire hazard and some risk for ignition at a relatively low ignition point when left unmaintained. Plant selection criteria must include some consideration for the prevention of fire hazards.

The National Fire Protection Association (NFPA) 5000 Building Construction and Safety Code provides guidelines for conventional roofing systems. These codes help to determine the requirements for good thermal insulation between the roof deck and any combustible roofing materials, but they do not provide guidelines or regulations for the materials used in green roof systems. Regulations in Germany, for example, consider a living green roof to be fire-resistant only if the growing medium is at least 30 millimeters deep and contains less than 20 percent organic content. It is also required to have a 1-meter-wide area of crushed stone or pavers every 40 meters or where any structure penetrates the roof deck.

These "fire breaks" easily can be incorporated within living green roofs or landscapes over structure in the coordination of intentionally paved surfaces or as maintenance or access paths.

Reducing Potential for Mold

Insurance claims and legal disputes over molds that are known to be detrimental to human health are on the rise. Some insurers are excluding or limiting mold coverage. Leaks and trapped water on roofs and in walls can also lead to indirect property damages including mold. Proper drainage is essential. The added mass of a green roof system and the resulting reduced temperature fluctuations of the roof deck may reduce potential for condensation and resultant mold growth.

Summary

Rather than fear the worst, many owners, design disciplines, contractors, and insurance companies are moving toward a wider understanding of the shared risk involved in taking on any project that is of ultimate benefit to its users. A focus on sound risk management principles can help to inform the design, construction, and use of green roof systems. With effective communication and careful documentation from job inception through use, green roof systems will not be viewed as specialized construction with impractical risks. Rather, more and better examples of successful green roof systems will emerge and become commonplace.

Endnotes

1. Victor O. Shinnerer and Company, Inc., "Managing Risk Through Contract Language," 2002; FM Global, "Insurance Guidelines for Greenroof Construction," 2007.

FM Global Property Loss Prevention Data Sheets 1–35 Green Roof Systems, January 2007.

2. Kevin Collins, "Green Roofs and Rooftop Gardens—A Growing Source of Claims?" Victor O. Schinnerer & Co, Inc., 2005.
3. John A. D'Annunzio, "Proper Roof System Design Standards," *The Construction Specifier*, January 2004, 34–40.
4. Ron Holzhauer, "Comparing Roofs," *Plant Engineering*, June 1997, 72–76.
5. Structural Engineering Institute and American Society of Civil Engineers, "Minimum Design Loads for Buildings and Other Structures," SEI/ASCE 7–02, Chapter 6.
6. FM Global, Property Loss Prevention Data Sheet 1–28, "Design Wind Loads," September 2005.
7. FM Global, Property Loss Prevention Data Sheet 1–29, "Roof Deck Securement and Above-Deck Roof Components," May 2005.

Chapter 10

Maintenance Requirements and Performance Evaluation

All roofs require maintenance, and living green roofs and landscapes over structure are no exception. Their components and systems require careful protection and maintenance from the moment they are installed. Fortunately, many of the protection and maintenance requirements for green roof systems are the same as for conventional landscape planting and site construction projects.

It is essential that maintenance requirements for all project elements be fully discussed with the owner early in the design and documentation process. The owner must understand and commit to the maintenance needs, the labor and resources required, and the overall costs of maintenance *prior* to final design and construction. This is also true, of course, for conventional construction of buildings and landscapes on terra firma. However, because of the specialized construction, specific layering of components, and artificial growing conditions for living vegetation, the need for careful immediate and long-term maintenance must be understood.

Sometimes when living green roofs are cited as effective, innovative stormwater retention systems, it is mistakenly inferred that their relatively low level of maintenance means no maintenance. In fact, green roof systems introduce additional maintenance challenges, because in addition to needing a trained eye for vegetation maintenance, much of what supports and sustains their systems is below the surface and not easily visible to those responsible for their care. The structural system required to support green roof systems is integral to the design, and the owner's investment in construction time and costs is usually higher than for conventional construction. The stakes can be high, but even more is at stake if proper monitoring and maintenance are not undertaken initially, and immediately after installation.

Because problems perpetuate projects can be devastated and rendered unusable, even unsafe, if proper maintenance and protection are not established as an integral and continuous part of the work.

This chapter addresses protection, maintenance, and monitoring practices that, while seemingly routine, are essential to the continued successful use and performance of thriving green roof systems.

The first portion will set out terminology common to the design and construction industry and introduce basic objectives of proper maintenance for green roof systems. The next portion will provide recommendations specific to living green roofs, as well as

FIGURE 10-1 Very few types of living green roofs are maintenance-free.

maintenance considerations specific to larger-scale planting and site elements commonly found in landscapes over structure.

Project Conditions and Specific Maintenance Requirements

Logically, site work and planting should be implemented closer to the end of a project, when this work would be less subject to damage by the work of other trades. But because of construction logistics, the numerous trades on a project, project scheduling, and construction delays, this seldom happens. This is particularly true for complex projects where utilities, site lighting, paving, water elements, irrigation, trees, or other plantings may have to be installed well before other building or site work is complete because of construction sequencing requirements or limited opportunity for site access. Often, large-caliper trees need to be installed at times required by project sequencing even if it is "out of season" for specific plants.

Responsibility for Maintenance During Construction

The maintenance of plants and site work as well as protection from damage, even if installed early in the construction sequence, remains the responsibility of both the prime contractor and subcontractors until it is accepted as complete by the owner.

The project specifications should include clear identification of maintenance requirements and responsibility:

- During delivery and storage
- During installation
- Throughout project construction
- Throughout any defined warranty, maintenance, or guarantee period

The specifications should include the submittal by the installing contractor of written requirements for a maintenance program *prior* to installation. While this is often limited to planting specifications, it should also be required of all major site systems such as paving, water features, and site lighting.

Protection and Maintenance of Components and Systems: Delivery, Storage, Handling, and Installation

Protection and maintenance of the individual components and the ultimate composite systems begin when a component arrives on site. The subcontractor is responsible for receiving it on site and maintaining its good condition through installation and acceptance of the work by the owner.

FIGURE 10-2a Construction sequencing and site access can dictate when trees must be installed, even when they can be easily damaged during the rest of construction.

FIGURE 10-2b Complicated phasing and constricted sites can pose the challenge of keeping stockpiled materials protected during storage. (Photo © Jeffrey L. Bruce & Company)

FIGURE 10-3a The contractor's responsibility for the care and protection of trees can start as early as their preparation at the nursery.

FIGURE 10-3b Excellent care and protection throughout all phases of the project result in well-established, beautiful landscapes over structure.

Industry Terminology

SUBSTANTIAL COMPLETION FOR SITE WORK AND PLANTING The work of a contractor or subcontractor, when finished as specified, is usually accepted as substantially complete. *Substantial completion* signifies that the work has been completed in a way that satisfies the requirements of the project according to the drawings, specifications, or other conditions of the contract. For a living green roof this may mean that planting has been completed as specified, but full plant coverage has not been achieved. In addition to planting, there may be some minor work that needs to be repaired or coordinated with other trades to be considered fully completed. These types of repairs or finishing touches are usually identified in a punch list by the architect, landscape architect, or specialized green roof designer.

MAINTENANCE AND GUARANTEE PERIOD FOR PLANTING Once the project is accepted as substantially complete, the *maintenance period* begins. For green roof systems, this usually only applies to the planting because, unlike most other components, it is living. Typically, the installing contractor will be required to maintain any planting installed under contract for a specified period of time, to a specified appearance or area of plant cover and to a specified level of performance. This helps to ensure that the plants in the most vulnerable stages of transplant shock and development are being cared for by the contractor responsible for their purchase, delivery, and installation. Both the time period and level of care will vary with project conditions but should be clearly defined in the specification section governing the work.

Substantial completion also may commence the *guarantee period* for any materials installed by the contractor. Typically, this also applies to all planted areas and provides the owner with some guarantee that plants installed (under any project conditions) will live and thrive. A planting contractor should be required to guarantee that the plants will still be alive and healthy for a specific period of time. If they become stressed or die, the contractor must replace them at no cost to the owner. This guarantee period will vary depending on:

- Owner needs
- Climate and growing seasons
- Complexity of installation
- Potential for removal or replacement, including for repair of subsurface systems
- Type and size of the plants (especially large-caliper trees)

Often the guarantee period is one or two years, but it can be more or less. The cost of longer guarantee periods is usually reflected in the contractor's bid.

FINAL ACCEPTANCE FOR SITEWORK AND PLANTING Once all of the items identified in the sitework punch list have been corrected, the owner will acknowledge *final acceptance*. The terms and conditions of completion and subsequent acceptance are usually defined in the up-front portion of the contract documents and in the specification section particular to the work.

For planting, sometimes the punch list cannot be completed until the following planting season because of specific plant types and regional climates. The final acceptance of planting might also be tied to the length of the guarantee period.

FIGURE 10-4a When trees must be stored on site for unexpectedly long periods of time, excellent horticultural protection practices are required. Basal sprouts on this unplanted and unprotected on-site tree already show signs of stress and potential decline. (Photo © Jeffrey L. Bruce & Company)

FIGURE 10-4b These trees needed a temporary watering system because they were planted early to accommodate the masons' installation of paving, before the automatic irrigation system was operational. (Photo © Jeffrey L. Bruce & Company)

The significance of substantial completion, maintenance period, guarantee period, and final acceptance for conventional construction and for green roof systems is that they:

- Define when the work is complete
- Specify who is responsible for the maintenance of the work
- Define what maintenance and protection include and entail
- Define the period of time the maintenance and protection are to be performed

Maintenance Responsibility After Construction

Once the work is finally accepted by the owner as complete, the responsibility for maintenance and permanent care of site work or plants may be the owner's or the contractor's, depending on the conditions of the contract.

If the installing contractor is responsible for the maintenance, the scope and duration should be identified within the specifications and performed accordingly. If the plants are not yet established or still under guarantee, the installing contractor remains responsible for their replacement if required. It then becomes necessary for the installing contractor to establish the requirements for the maintenance by the owner, to ensure the vitality of the plants that are under the contractor's guarantee. Again, these responsibilities and associated time frames must be clearly identified in the specifications.

Conversely, the owner may want to have immediate control over the maintenance. If the owner assumes responsibility, the owner's staff or subcontractors should be experienced professionals who understand the construction and function of living green roofs and landscapes over structure. For planting, maintenance personnel should be knowledgeable and well trained in irrigation, soil conditions, plant and weed identification, and plant health evaluation.

General Maintenance and Care of Green Roof Systems

The following discussion of general types and extents of maintenance regimes may be beneficial to the owner in determining and developing appropriate maintenance programs for a specific living green roof or landscape over structure.

Maintenance Manuals

The owner may request the preparation of a maintenance manual that expands upon the maintenance requirements previously submitted by the installing subcontractors. This might be completed by the architect, landscape architect, specialized green roof designer, contractor, or horticulturist, or by a collaborative undertaking. This maintenance manual may vary in breadth, specificity, and number of systems covered, depending upon the complexity of the project and the specific needs of the owner. Although it may only be requested for maintenance of planting, it should include an overview of the intended appearance and function of the project and maintenance programs for all site systems, such as irrigation, paving, site lighting, and fountains. It cannot be overstated how important it is for whoever is responsible for the maintenance of a living green roof or a landscape over structure to understand that the maintenance and protection of what is below the surface is as important as what is above.

This manual allows the maintenance personnel to follow the checklist of tasks to be performed during every inspection and according to seasonal requirements. It provides guidance for maintaining the living green roof or landscape over structure for appearance, intended function, and performance. Preferably, the maintenance manual, a full set of project drawings and specifications, and a maintenance log should be stored in the facility manager's office for ease of reference.

Planting

At a minimum, for planting systems, it should include the recommended frequency for site maintenance inspections, the list of tasks to be performed during each inspection, the original plant list, and the plant schedule. Access to the original and as-built planting plan, plant schedule, and planting details will make it easier for maintenance personnel to replace or substitute certain plants that do not establish within a desired time frame or do not survive certain roof conditions. Removal of undesirable plants is especially important during the first two growing seasons to allow the specified plants to establish themselves as intended.

Site Work

At a minimum, for site work systems, it should include the recommended frequency for site maintenance inspections, the list of tasks to be performed for each system during the inspection, the site materials and layout plan, and a list of site materials and suppliers. (This should also include any cleaning or deicing products recommend to be used on paved surfaces.) Access to original and as-built drawings and specifications will help those responsible for the maintenance to have the required background knowledge of the various site systems.

Maintenance Personnel

The owner may employ in-house trained professionals or contract with a consulting trained professional for routine site inspection and maintenance. The frequency for the required regular site visits will be largely determined by the specific project conditions and seasonal conditions. It behooves the owner to ensure that scheduled visits occur and required tasks are performed.

Maintenance Requirements for Green Roof Systems

Many of the maintenance requirements for the surface of green roof systems are the same as for conventional landscape planting and site construction projects. Because the roof essentially becomes the floor for green roof systems, the maintenance requirements for both the roof and floor need to be considered. The essential difference is how this floor is used in relationship to the roof:

- Living green roofs are not meant to be directly accessible for human use aside from paved walkways that may accommodate roof access. Therefore, the considerations of maintenance are primarily for the thin layer of soil, vegetation, drainage and the roof just below it.
- Landscapes over structure are meant for human use and therefore have more systems to support them, such as paving, stairs, walls, lighting, and planting. The requirements for maintenance will be the same as those for conventional landscapes meant for human use, as well as for all of the site and planting systems on the roof and the roof itself.

FIGURE 10-5a A freshly installed living green roof.

FIGURE 10-5b The same living green roof after two growing seasons.

Primary maintenance must include the following tasks during regular site inspections:

- Routine inspection of waterproofing membrane system, including insulation
- Routine inspection of drainage and aeration systems
- Maintenance such as cleaning drains, adjusting or repairing flashing, and cleaning gutters
- Directing and assisting with replanting efforts on roof areas that were temporarily removed for waterproofing inspection or repair
- Removal and proper storage of plants when roof inspection or repair is required
- Inspection and monitoring of plant health
- Monitoring of plants and soils for potential irrigation and fertilizer needs
- Relocation or augmentation of plants to ensure uniform plant cover
- Application of slow-release fertilizer (usually annually or every other year)
- Weeding—removal of undesirable plants

Maintenance Requirements of Living Green Roofs

The following provides maintenance guidelines that, although more directed toward living green roofs, may also be applicable for maintenance of landscapes over structure. Once a living green roof is installed, protection, maintenance, and care should begin immediately. A living green roof is considered established once the plants have grown to a mature vegetative cover, uniformly covering a minimum of 90 percent of the intended roof surface. This process typically takes two growing seasons or more.

Every planning and design decision, including plant selection, has consequences for the maintenance requirements. Green roof maintenance and care may be divided into three stages:

- Maintenance before and after substantial completion
- Developmental maintenance during the maintenance period and guarantee period
- Long-term maintenance and care

Maintenance Before and After Substantial Completion

Maintenance before and after substantial completion is the responsibility of the installer. This stage includes all tasks necessary for the proper installation of green roof plants and as they start growing. Often this period requires initial, supplemental irrigation. For instance, most areas experience the majority of their natural precipitation during spring and fall. During these times, supplemental irrigation may not be as crucial.

Developmental Maintenance During the Maintenance Period and Guarantee Period

This developmental maintenance is also the responsibility of the installer. This stage includes getting the seeds, buds, plant plugs, or cuttings fully established. While the contractor must perform adequate maintenance to ensure the sustained health and development of the plants throughout the guarantee period, the primary responsibility for ongoing maintenance usually is the owner's.

Long-term Maintenance and Care

The developmental maintenance slowly progresses into the final stage of long-term maintenance and care, which is the responsibility of the owner, but many times the owner

FIGURE 10-6 A safety cord housing anchored into the roof deck.

FIGURE 10-7a A living green roof overgrown with weeds.

FIGURE 10-7b The weeds got out of control because the soil—street leaf mulch—was not sterilized and contained abundant weed seeds. Weeds quickly outcompeted the intended planting partly because maintenance was not performed as diligently as this unique situation required.

FIGURE 10-8 Despite the well-established living green roof plant cover, weed seeds embedded in the growing medium sprouted and need to be removed meticulously. Here, Canadian horseweed (*Conyza canadensis*), which can spread widely via windblown seeds, fortunately can be pulled easily.

chooses to contract for these services. The objective during this final part of the process is to both protect and preserve the living green roof and ensure that it performs as intended. Weeds, however, may sprout quickly and the green roof may require more frequent weeding. During other times removal of undesired plants may be reduced to quarterly site visits—enough to stay ahead of weed growth—especially during the first two growing seasons. Weeds must always be removed before they flower and set seeds. After the second full growing season, annual maintenance walks may suffice to monitor plant health and to pull an occasional sprouting sapling.

Weeds grow aggressively, compete for nutrients and water, and often shade out desirable plants and hence prevent the establishment of the intended green roof vegetation cover. Weeding is one of the most important initial maintenance tasks and requires excellent knowledge of plants. Weeding will ultimately determine the success of the green roof. An unattended, weedy, overgrown living green roof is a common reason for the public perception of a “failed” green roof. Beyond perception, in reality it is also a common reason why living green roofs do fail to perform as designed, causing reinstallation or complete removal by disappointed owners at great expense.

Once the desired and appropriate plant community is established and has grown into a uniform plant cover, little or no exposed growing medium remains, and weeds are no longer a problem. Note that one exception to this assumption is if a “weed seed bank” has been embedded in the growing medium itself. If this occurs, meticulous removal of these undesired plants will be necessary for several growing seasons.

Inspecting and Monitoring Plant Health

Weeding living green roofs requires a trained eye and plant knowledge to carefully distinguish between suitable and undesired plants. Weed identification is pertinent in determining the living green roof performance. Sedges, for instance, are indicator plants for wet conditions and may possibly point out a drainage problem over the roof deck. The appearance of mushrooms and other fungi may also indicate wet and acidic conditions, but they may also be benign, indicative only of moist and shaded roof areas and hence greater soil moisture retention. What becomes tricky is deciding between wanted and unwanted plants that are very similar in appearance. Stringy stonecrop (*Sedum sarmentosum*) has all the characteristics of a hardy plant for rooftops, but it spreads so aggressively and quickly that it outcompetes wanted noninvasive sedum species. Purslane (*Portulaca oleracea*) is also a succulent plant that stores water in leaves and stems, but it spreads aggressively and grows to a height of 6 inches; it may shade desired plants, compromising their growth and survival.

Table 10-1 lists a selection of common weeds and undesirable plants that should *not* be allowed to grow on living green roofs.

Beyond plant and weed identification, maintenance personnel should monitor plants for irrigation and fertilizer needs, potential diseases, and insect infestations. Plants commonly display signs of distress in a change of foliage color, a lack of flowers, or both. In drought stress, succulent plants on living green roofs frequently go dormant; the slowing of growth helps preserve energy and ultimately helps the plant survive the temporary adverse conditions.

Damage to plants can be the result of different causes, including:

- Persistent excessive soil moisture
- Drought
- Oxygen deprivation
- Incompatible soil and growing medium compositions
- Wind and water erosion and subsequent root exposure
- Vegetation heave during freeze-thaw cycles
- Excessive sun exposure on highly exposed roofs
- Overfertilization or nutrient starving
- pH imbalances with acidification or salinization

Applying Slow-Release Fertilizer

The relatively thin soil profile of living green roofs has a tendency to turn acidic over time because of atmospheric nitrogen depositions and continuous plant uptake. Replenishing the growing medium once a year or every other year with a slow-release fertilizer (for example, Osmocote 14-14-14) will typically provide adequate nutrient amounts. Overfertilization will result in plant damage, but more importantly it becomes a source of pollution because nutrients are washed out during larger rain events. This result compromises the purpose of green roof systems by increasing, rather then reducing or eliminating, nonpoint-source pollution, particularly nitrogen from runoff.

TABLE 10-1: Weeds Commonly Found on Living Green Roofs

Botanical Name	*Common Name*	*Image*
Acer rubrum	Red maple treeling	
Ailanthus altissima	Tree of heaven (invasive/exotic)	
Brassica spp.	Mustard	
Chamaesyce serpens	Creeping spurge	

(continues)

TABLE 10-1: *(continued)*

Botanical Name	*Common Name*	*Image*
Chenopodium album	Lamb's quarters (edible)	
Cirsium vulgare	Common or bull thistle (medicinal)	
Conyza bonariensis	Hairy fleabane	
Cynodon dactylon	Bermuda grass	

TABLE 10-1: *(continued)*

Botanical Name	*Common Name*	*Image*
Cyperus spp.	Nutsedge	
Digitaria spp.	Crabgrass	
Juncus spp.	Rush	
Plantago major	Broadleaf or common plantain (medicinal)	
Portulaca oleracea	Purslane (edible)	

(continues)

TABLE 10-1: *(continued)*

Botanical Name	*Common Name*	*Image*
Sedum sarmentosum	Stringy stonecrop	
Stellaria media	Chickweed (edible)	
Taraxacum officinale	Dandelion (edible)	
Trifolium fragiferum	Strawberrry clover	

The Weed Identification Photo Gallery is an excellent weed identification tool. The Photo Gallery can be found at the University of California Davis Agriculture and Natural Resources Statewide Integrated Pest Management Program: http://www.ipm.ucdavis.edu/PMG/weeds_common.html.

Irrigation

Temporary irrigation is necessary on almost all living green roofs following installation. Plants need sufficient water to establish themselves in their new environment and to start growing. Counter to intuition, initial irrigation is particularly important for deeper-profile green roof systems to help initiate capillary forces within the soil or growing medium.

Should the planting installation occur during hot summer days, it is crucially important to irrigate—not just supply plants with water but keep the soil surface moist. This will lower the surface temperature of the dark-colored growing medium and reduce or prevent plant damage due to "baking" of plants from above and below. On the other hand, it creates ideal surface conditions for airborne seeds to settle and germinate as well, so weeding should be performed at the first sign of emergence.

Permanent irrigation is usually not required for living green roofs. The selection of plants must include those that can survive in the artificially created environment. These plants also need to be self-sustaining through extended drought periods, high exposure to wind and sun, and little access to water.

Climatic differences due to geographic location do not make a significant difference as to the need for irrigation. Assuming the selection of an appropriate matrix of plants in dry climates, such as in the U.S. Southwest year-round or the Midwest during the summer, living green roofs can survive without permanent irrigation. Arid climate zones typically experience a great temperature differential between night and day, and, the morning dew that collects on the plants may be sufficient for plants to survive. The thick-skinned foliage of succulent plants prevents excessive transpiration.

For large-scale projects, or in severe climatic conditions where supplemental hand irrigation during establishment may be too labor-intensive, it may be advisable to install a drip irrigation line. The minimal additional cost will more than offset replacement costs in the event of excessive plant loss induced by stress in atypical drought periods.

After one full growing season or one year, the green roof should be assessed for its plant cover, performance, and general appearance. If the original plant selection shows deficits in adaptability and survival, replanting of bare spots must occur to reduce the time of soil exposure to airborne weed seeds and to protect the growing medium against erosion. It may be necessary to select different plants to replace those that have failed to thrive in a particular microclimate.

Safety Devices

In some cities, particularly in Germany, it is a requirement that safety lines be anchored into the roof deck at specified intervals. Maintenance workers can then attach themselves to the safety lines when they are working on high or windy roofs. Similarly, some cities have strict regulations for fire prevention that can impact the design and construction of living green roofs. It usually requires the simple installation of precast pavers every 20 yards or so to provide a fire break should there ever be an occurrence of fire. (Living green roof vegetation, mostly consisting of water-storing plants, does not in itself pose a fire hazard; however, dried-up mosses or grasses may provide fuel for self-ignition when roof conditions are extremely hot and dry.) Maintenance for safety features such as these

Performance Evaluation of Plants and Growing Media for Living Green Roofs

As part of their maintenance regime, every green roof system should be monitored for performance to assess if it functions according to the design intent. Several criteria are used to judge performance in each of the three stages of living green roof maintenance and care.

During the period before and after substantial completion, the following criteria can be used:

- Plants should be established and securely rooted.
- Plants should be resistant to wind uplift or slight pulling.
- Plants should exhibit vigorous growth, new roots and shoots, healthy foliage, and the development of flowers.
- Plant cover must be species-specific and adapted to the roof environment (note that low-slope roofs applied with sedum cuttings should display about 60 percent plant cover, whereas a sloped roof must be covered to approximately 75 percent).[1]

During the developmental maintenance phase, the following criteria can use used:

- Approximately 75 percent of plant species must be present after the first growing season, including summer and winter, and 75 percent of each species must be well rooted.
- Weeds or voluntary plant establishment should make up less than 10 percent of the total plant cover.
- The entire system should in general be free of persistent soil moisture, signs of rotting, or fungi infestation of any sort.
- This task of evaluating the living green roof completion is best performed after one whole year during July or August when plants have endured all winter and summer stresses.[2]

Finally, during the long-term care phase, living green roof performance evaluation includes:

- Solar exposure resistance
- Heat resistance
- Wind resistance
- Winter and frost hardiness

Beyond that, living green roof plants must prove drought-resistant, healthy, and suitable for the rooftop environment. They should show good regenerative power following stressful periods, and they should be able to outcompete detrimental, aggressive "volunteer" plants.

[1]Bernd Krupka, *Dachbegrünung: Pflanzen-und Vegetationsanwendung an Bauwerken* [Green roofs: application of plants and vegetation on structures] (Stuttgart: Ulmer, 1992).
[2]Krupka, *Dachbegrünung*.

Performance Evaluation of Expected Benefits

Living green roof projects may receive great attention during design, during installation, and at completion, but post-occupancy evaluation of the expected benefits of green roofs can be challenging to measure. The German Green Roof Association created a table that helps to evaluate the typical benefits for four different green roof constructs.

Monitoring a living green roof for specific performance criteria helps in accurately assessing its efficacy. The more benefits they provide to more people, the more common they will become. The most beneficial data and information collected from a living green roof should include:

- Total precipitation, discharge times, duration, and flow rate
- Soil and ambient air temperatures
- Nutrients and sediment content of the discharge
- Soil moisture content and evaporation rates based on wind and total humidity

It is always advisable to collect the same set of measurements from the living green roof and a nearby conventional control roof for quality control and accurate qualitative and quantitative analysis.

Total precipitation is the total amount of rain and snow

TABLE 10-2: Evaluation of Common Living Green Roof Systems

Criteria	*Single-layer living green roof with lightweight aggregate mineral growing medium*	*Multilayer living green roof with mineral drainage layer*	*Multilayer living green roof system*	*Multilayer living green roof system for additional insulation*
Diversity of species (self-sustaining vegetation)	– Low species diversity, often with bare spots and non-self-sustaining vegetation	+ Self-sustaining vegetation with relatively high species diversity	+ Self-sustaining vegetation with relatively high species diversity	+ Self-sustaining vegetation with relatively high species diversity
Environmental compatibility of materials	– Materials with high embedded energy, long transports, and energy-intensive manufacturing methods	+ Positive environmental impact if recycled materials are used	+ Positive environmental impact if recycled materials are used for sublayers	+ Positive environmental impact if recycled materials are used; predictable energy savings
Cost benefit, economy, and technology	o Cost-effective installation but considerable maintenance requirements to ensure long life; limited suitability on flat roofs because of drainage	o Slightly more expensive but lower maintenance requirements; higher weight associated with permanent water retention	o Slightly more expensive but lower maintenance requirements; lightweight, permanent drainage and water retention per manufacturer's specification	o High installation costs; potential payback from energy savings; permanent definite drainage and retention

Legend: + Positive o Neutral – Negative

The evaluation in this table, although simple in concept, provides an understandable and usable means of measuring the efficacy of various living green roof construction systems. It should be noted that the cost-to-benefit analysis indicating a neutral value for all four construction types (last row) can be interpreted to mean that there is no increase of initial roof installation costs over conventional roofs if stormwater and energy credits can be claimed.

Source: German Green Roof Association (Deutscher Dachgärtnerverband), http://www.dachgaertnerverband.de/bewert.htm.

that falls on any roof. With a tipping bucket rain gauge, every 0.01 inch of rain causes the collector bucket to tip and record the data in a data logger. Rain intensity measured in inches per hour and total accumulation measured in inches is calculated by the data logger.

As previously discussed, the greatest potential economic and environmental benefit of living green roofs lies in mitigating the impact of stormwater runoff from impervious surfaces. Measuring discharge times, duration, and flow rates will help quantify runoff reduction and help predict effectiveness for stormwater management and control. The total runoff volume and runoff rates from living green roofs during low-intensity rain events are insignificant. While total runoff volume can be simply and easily collected in a bucket, drum, or vertical pipe configuration, measuring low flow rates is more challenging. The operating range of various flow sensors is limited and therefore cannot be considered reliable and cost-effective for measuring very low or very high flow rates. Most living green roofs have soil depth as thin as 3 inches and can absorb 0.5 to 1 inch of rain. Concentrating therefore on measuring moderate to high flow rates for larger storm events offers a workable alternative. Choosing flow sensors that register moderate to high flows allows for optimizing sensor abilities at reasonable costs.

Soil and ambient air temperature measurements can be recorded by data loggers, collecting data every 30 minutes. Temperature can also be measured with an infrared thermometer. Although this method is less accurate than using a data logger, a handheld infrared thermometer allows for instantly measured and recorded surface temperatures.

For comparison, temperatures should be measured in at least three vertical roof locations:

- Above the roofing membrane and underneath the soil and vegetation layer
- Immediately above the green roof vegetation cover
- Ambient air about 5 to 10 inches above the green roof

It is also advisable to measure the water temperature from discharge to ascertain the cooling effect of the living green roof filter on roof runoff.

Water quality of the roof discharge can be assessed by measuring nutrient and sediment content. It will require a collection point at which water samples can be taken and sent for laboratory analysis.

It should be noted that after initial installation, a temporary increase in sediment and nutrient discharge can be expected from the growing medium washout. The system should reach its equilibrium after a few months or several rain events. However, if sediments and nutrients continue to wash out, the growing medium should be reevaluated for potential exchange. It is therefore important to avoid growing media with a high content of fines or compost that is not yet fully decomposed.

should include routine removal of unintended mosses or grasses, and inspection and repair to ensure all safety devices are in excellent working condition.

Special Considerations for Maintaining Landscapes over Structure

In addition to the maintenance periods, responsibilities, tasks, and guidelines above, which are obviously also applicable to landscapes over structure, the following augments their potential maintenance requirements.

Landscapes over structures are a system where the growing medium is greater than 6–8 inches and, based upon programmatic requirements, may be designed to accommodate its use as accessible open space. Horticulturally, with a growing medium typically greater than 12 inches, landscapes over structure can support a greater diversity in size and type of vegetation. Greater size and diversity of plants usually require a deeper soil profile, supplemental irrigation, and a more complex infrastructure to support and sustain plant growth in an artificial environment. The combined depth of component parts may exceed several feet, and related systems required to support the uses often become more complex.

Invariably, the maintenance requirements become more complex, and because of the greater potential for something to go awry and remain undetected for a longer period of time than on a conventional or living green roof, the need for diligent routine maintenance and inspection can be more intensive. (Hence the German use of “intensive” to describe landscapes over structure.)

Depending on program requirements and use, the ultimate physical expression of the landscape-over-structure design, as with any built landscape, can take many forms. Because of the wide range of potential physical expressions and compositions, it is not reasonable to attempt to anticipate or prescribe the requirements for inspection and maintenance. Many of the requirements are the same as in maintaining terra firma landscapes of like complexity and composition. The intent of this section is to identify key issues and potential problems that are specific to landscapes over structure and of which owners and maintenance personnel should be aware.

Soil Mixes and Growing Media

Unlike conventional landscape planting in natural or amended in situ soils, the soil mixes or growing media for landscapes over structure generally need to be fabricated off-site. Monitoring the growing media for the following criteria is a significant maintenance requirement.

- Moisture content
- Nutrient level
- Organic content
- pH
- Beneficial root production, especially in the upper horizon

When the growing medium has either a high organic content or an inert aggregate that might tend to break down over time, it is important to monitor it for:

- Loss of volume
- Nutrient depletion

Because each soil mix or growing medium is so specific to site conditions, plant selection, depth, placement requirements, and local availability of component materials for fabrication of the mixes, it is very strongly recommended that a soil scientist knowledgeable in fabricated soils be part of the project team from the beginning of design through construction. It is also prudent to have this soil consultant available for follow-up testing and monitoring of soils required for maintenance.

Plants

Keeping trees, shrubs, ground covers, and perennials in continual good health will provide the best long-term care for landscapes over structure. This entails employing the best horticultural practices and careful monitoring for:

- Physical or mechanical damage to plants
- Balanced, normal growth
- Stability of tree guying systems (below grade) until fully established
- Excessive root mass development in unlikely areas that can indicate plants being "pot-bound" or which can increase the potential for "wind throws"

Potential for Damage of Waterproofing or Utilities During Routine Maintenance or Repair

Because all of the systems that support landscapes over structure must be completely integrated, so must their maintenance. Their maintenance must also be integrated with the maintenance of the building.

Many projects can easily sustain damage, which can sometimes go undetected. It is

FIGURE 10-9 Many of the requirements for maintaining landscapes over structure are the same as in terra firma landscapes of like complexity and composition. Keeping trees, shrubs, ground covers, and perennials in continual good health will provide the best long-term care for landscapes over structure.

FIGURE 10-10 Many future maintenance problems can be avoided by careful protection of the waterproofing membrane or other components during construction.

important to have skilled maintenance personnel who are familiar with the site and can *avoid* damage to utilities or waterproofing through:

- Repairs with sharp tools without knowing subgrade conditions
- Installation of new utilities such as communication lines
- Improper adjustment of irrigation systems
- Improper use of fertilizers, herbicides, or deicing and cleaning agents

Paving can easily be damaged during:

- Cleaning with improper equipment or cleaning agents which can erode joint filler
- Snow removal
- Use of salts or other deicing agents that can damage paved surfaces or reinforced concrete slabs below
- Mechanical damage from use of equipment that is too heavy for design load

Drains and drainage systems should be monitored frequently for:

- Free flow of drainage water to proper stormwater outlet
- Crushed drainage pipes
- Clogs in drain covers or drainage pipes or filter fabrics
- Leaks around framing or flashing

Any change in use or programming should be verified as compatible for:

- Design load (live and static)
- Depth to top of structural deck below
- Location of all utilities below surface
- Profile and composition of system below surface
- Potential detrimental impact to systems below grade

Summary

The intent, design, and use of green roof systems are only as successful as their long-term programming and maintenance. The integrated systems that comprise them, though not complicated, can be complex. Much of what supports and sustains their systems is below the surface and not easily visible to those responsible for their care.

The owner's initial investment in construction time and costs is usually higher than for conventional construction in a simple roof to roof comparison. Foresight in planning, design, and good long-term care and maintenance will protect the owner's investment. The owner as well as the community will benefit from green roof systems, ultimately resulting in a positive return on investment.

Index

A

Above-grade parking space, cost, 46
Adjustable-height pedestals, usage, 233
Aeration, 177–178
  drainage/drain cleanout, coordination, 165f
  drainage mat, filter fabric (placement), 261f
  mats/panels, 164
  pipes, installation, 227f
Air quality, 35–37
Allometry, 111
Ambient air temperature, 36f
American megalopolises, span, 20
American Society for Testing and Materials (ASTM) standards, 126–127
American Standard for Nursery Stock (ASNS), root ball sizes, 110
Architectural considerations, 63
Arena roof, design alternatives, 58f

B

Basins, 118–119
Bay Bridge, eye-level view, 210f
Beam, 98
Beams, structural engineer loading diagram, 101f
Best management practices (BMPs), 32
Bidders, prequalifications, 213, 214
Bidding documents, components, 210
Bidding process, 203
Bids, review, 217, 219
Black tar surface roof, ambient air temperature, 36f
Blue board, 150
  usage, 257f
Boardwalk, demarcation, 168f
Boulders
  installation, 254f
  selection, 267f
Brooklyn Atlantic Yards, 59f
  aerial photograph, 50f
  urban design study, 49f
Bryant Park, value (providing), 5f
Builders, roles, 48
Building code, 98
Building green market, 46
Building green movement, 1
Building landscapes, relationships, 55f
Building roof, stormwater (impact), 28–29
Built-up roofing, 135
  installation techniques, 135
  material composition/fabrication, 135

C

Cacti, prepurchase, 231f
Canary Wharf
  interconnected open spaces, 41f
  plan, 68f
  revitalization, 68
Cast-in-place concrete, 228f
Chesapeake Bay, estuary (diversity), 6–7
Circulation, linear relationships, 204f
Circulation and connection diagrams, 52f
Cities
  growth, continuation, 8
  problems, 31
  scale, planning/design, 41f
Clean Water Act (1972), passage, 30
Cleveland, buildings (conditions), 75f
Client group/design team review, 47f
Climatic differences, 301
CNA Insurance, 272
Coal tar, 135
Collaboration, trade-offs, 86–87
Collaborators, role, 44
Column, 98
Combined sewer overflows (CSOs), 31
Comcast Center Plaza, perspective, 47f
Community workshop, 60f
Competitive bidding, 221
Components
  deletion/minimization, 233
  parts, 120
  protection/maintenance, 284
Composite drainage products, 160–161
Composite membranes, 139
Comprehensive planning, usage, 50–52
Concept design, 55–60
Conceptual framework, development, 177–178
Concrete installation, 245
Concrete slab
  construction, 243f
  pouring/screeding, 208f
Conference Center (Church of Jesus Christ of Latter-day Saints)
  building
    emergence, 196–199
    landscape, merger, 199–201
  design
    process, coordination, 190–201
    solutions, 191, 193
  documentation/construction process, coordination, 190–201
  drainage systems, 197f
  exterior walls, 195f
  landscape
    emergence, 196–199
    infrastructure, 194, 196
    merger, 193f
  loads/depths, variation, 196f
  perennials, usage, 198f
  program requirements, 191
  project background, 190–191
  reconciliation, 192f
  stairs/water/plants, sequence, 200f–201f
  topography, utilization, 194f
  trees/shrubs/bulbs/vines, planting, 198f
Construction, 276
  contract, construction/administration, 236
  contractor (CMc), 206
  documentation, 62, 186–190
  documents
    information, 180f
    partial detail, 207f
    purpose, 188, 190
  manager, 206
  photo, 213f
  process, 203
  seasonal constraints, 226
  sequence logistics, 222, 224–225
  sequencing, 237f
    impact, 285f
    large-caliper trees, protection requirement, 265f
    planting, requirement, 255f
    soil mixes, placement/compaction, 261f
  staging, requirements, 263f
  technology/materials, changes, 271
Continuous planters, usage, 260f
Contractor, selection, 213
Contracts, 273–274
  award, 210
    considerations, 213
  bidding, 210
    considerations, 213
  documents, bidding, 221
  importance, 274
  negotiation, 210
    considerations, 213

Conveyor system, usage, 259f
Cross-references, 189f

D

Dead load, 97
Decentralized stormwater management practices, 31
  usage, 32
Deck, 98. *See also* Structural deck
  configuration, size/complexity, 142
  drainage matting, placement, 149f
  slab, 131–134
Delaware River, water quality decrease/flooding increase, 20
Density, 98
Design
  considerations, 89
  development, 62, 179
    detail, 212f
    planting beds/windscreens, usage, 204f
  load, determination, 99
  process, 49, 175
  professionals, concerns, 269
  requirements, providing, 61f
Designers
  insurers, information exchange, 271
  roles, 48
Design team
  collaboration, 61f
  contract administration responsibilities, 239
  requirements, 48
Developmental maintenance, 292–293
Development projects, proposal, 51f
Diaphragm, 98
Documentation, 276
  error, 189f
  process, 175
Documents, CSI categories, 186
Drainage, 177–178
  aeration/drain cleanout, coordination, 165f
  aggregate, installation, 173f
  board, installation, 153f
  course, insulation, 157–158
  increase, 158–159
  lines, construction, 172f
  materials, 158–164
    insulation, relationship, 157
  mats, 161–162
  matting, placement, 149f
  panels, 162, 163f, 165
    cones/cups, design, 162f
  pipe, 159f
    installation, 227f
  structures, location, 245
  utility lines, retrofit, 250f
Drainage systems, 232, 246, 253
  components, removal, 248f
  indication, 108f
  installation, 226f
  upside down installation, 247f
Drain collars
  flashing, 248f
  installation, 248f, 249f
Drain fit-out, 249f
Drain flashing, installation/inspection, 248f
Drains, 165–166
Dry soils, particle space, 23–24
Dynamic components, 120, 125, 166

E

Early concepts, 204f
Early planning, 89
Early project phases, 176
Earth mounding, illustrative plan, 76f
Earth mounds, configurations (diagrams), 75f
  combination, 76f
Earthquake-prone areas, green roof system weight (impact), 278
Economic impact analysis, 59–60
Environments
  children exploration, 16f
  degradation, 7
Ethylene propylene diene monomer (EPDM), 146
  membranes, 4
Exchange Square (Bishopsgate)
  concept section, 86f
  construction, 84f
Expanded polystyrene (EP) blocks
  cutting, ease, 154f
  drainage, 123f
    installation, 163f
  lightweight fill, installation, 227f
  placement, 108–109
  usage, 153f
Expected benefits, performance evaluation, 302–304
Expedited review/approval, 45
Extensive, term (usage), 8

F

Fear factor, 221–222
Feasibility design, 53–54
Feasibility phases, 54
Fill conditions plan, development, 94f
Fill types/depths, 180f
Filter fabric/aeration mat, 161f
Filter fabrics, 164–165
Final acceptance, 287–288
Financial institutions, role, 47–48
Finish floor elevations
  establishment, 83–86
  exterior elevations, coordination, 177f
Fire hazard, reduction, 280
Flat living green roof, water storage capacity, 33
Flat roofs
  heat, 4
  living green roof suitability, 128f
  practicality, 4
Flood test, conducting, 145
Fluid-applied membrane, 135, 141
FM Global, green roof systems application, 272
Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL) guidelines, 126
Fountains, 118–119
  paving system integration, detail, 96f
  plantings, combination/completion, 267f

G

Gabions, installation, 238f
Gateway Center (Patsouras Plaza), intermodel transportation hub, 79f–80f
General contractor (GC), 206
Geofoam/geoblock, 152
Geotechnical conditions, 245
Geotechnical investigation, 176
Girder, 98
  structural engineer design loading, 102f
Granite pavers, installation, 256f
Grasses
  layer, usage, 33
  matrix, 22f
Great Lawn (Millennium Park), 173f
  construction sequencing, 172f
Green links/institutions, proposal, 72f
Green roof
  acceptance, 9
  term, usage, 8
Green roof systems, 4
  application, 129
    built-up membranes, 141
    fluid-applied membranes, 141–142
    single-ply membranes, 141
  benefits, 18
  BMP incorporation, 32
  components
    information, determination, 124
    properties/function/performance, 124–125
    submittals, 240f
    understanding, 122
  construction, 8–9
    costs, 46
    issues, 243
    techniques, 143
  design, 8–9, 123
    structural system, selection, 89
  documentation, 123
  early-adoption phase, 46–47
  effectiveness, 75
  envisioning, 40
  inclusion, 51–52
  installation, familiarity, 22
  integration, 80
  maintenance, 289
    requirements, 290
  planning/design considerations, 83
  preconstruction meeting, 238
  prioritization issues, 243–244
  programmatic requirements, 54
  project scale, 63
  scales, 40
  specifications, 276
  structural systems, development considerations, 88
  usage, 9
  water storage capacity, 33
Ground floor, structural grid plan, 93f
Ground snow load, 97
Groundwater infiltration loss, 22t
Growing media, 166, 234–235
  components, weights (usage), 105t
  maintenance, 305

Growing media (*continued*)
performance evaluation, 302
types/depths, 180f
Growing medium, depth, 12
Guaranteed maximum price (GMP), determination, 186
Guarantee period, 292–293

H

Hackney Gate, concept detail, 84f
Healthy cities, maintenance, 15
Heat fluctuation, 156
Hudson Yards
mid-block boulevard
axonometric projection, 74f
plan, 74f
redevelopment, 70
Hybrid membranes, 139
Hydrological cycle, water/atmosphere exchange, 21

I

Illustrative site plan, 56
Impacted streams, 29
Independence National Historical Park
conditions, bird's-eye view, 217f
master plan, rendering, 217f
Inert components, 120, 125, 127
Information, types, 190
Inner park planting, completion, 262f
Insulation, 150–152, 177–178
drainage aggregate, 159f
systems, 232, 246, 253
replacement, 226f
Insulation, placement, 154
Insurance companies, role, 47–48
Integrated site work, complexity, 222
Intensive, term (usage), 8
Interstitial fill, 178
Inverted roofing membrane assemblies (IRMAs)
green roof systems, difference, 146
structural deck insulation, 156f
systems, green roof system differences, 146
Irrigation, 166
control valves, coordination, 171f
line failure, 171f
necessity, 301
supply, 170

J

J. Paul Gerry Center
comfort/respite, places, 15f
fountain, 121f
gardens, usage, 10f
institutions, features, 67f
interior galleries, linkage, 66

L

Land, development, 6
Landscape/architecture, merger, 1, 64
illustration, 57f
Landscape social-use diagrams, relationships, 55f
Landscapes over structures, 9
application, 13
completion, 265f
construction, 234–235
coordination, site work, 121f
design/documentation/building, structural principles/considerations, 91
detail section, 14
growing media, 169–174
insulation, 156–157
irrigation, 169–174
maintenance
considerations, 304
requirements, 306f
plant selection, 169–174
protective roofing systems, 122–123
risk, 272
soil layer, 33–34
soil mixes, 169–174
structural system, requirement, 13–14
trees, design load, 107–115
Large-caliper trees
early installation, 256f
protection requirement, 265f
Large-scale planning, proposal, 51f
Lateral force, 98
Lawn panel, early installation (bird's-eye view), 209f
Leaks
source, 275–276
Leaks, impact, 275
LEED certification levels, defining, 273
LEED guidelines/standards, usage, 176
Liability insurance, types, 270
Liability risk, areas, 273
Liberty Bell Pavilion, 218f
site development, 219f
Visitor Center, 218f, 220f
Light standard, visibility, 224f
Lightweight aggregates, components, 167
Lightweight drainage aggregates, 159–160
Lightweight fill, 233, 253
insulation materials, usage, 157–158
Live load, 97
Living bridge, example, 71f
Living green roof, 9–10
application, 10
steeply sloped roof, 128f
areas, marking, 263f
components, think profile, 12–13
construction, 234–235
detail section, 11f
effectiveness, residential scale, 31f
growing media, 167–169
performance evaluation, 302
heat transfer reduction, National Research Council of Canada field study, 35
implementation, barriers, 46
installations, 16f, 291f
success, 130f
insulation, 155–156
irrigation, 167–169
landscape/architecture, merger, 9f
long views, 13f
maintenance requirements, 292
parking structure, relationship, 12f
plants
cover, 295f
diversity, 120f
installation, 264f
performance evaluation, 302
selection, 167–169
primary maintenance, 292
protective roofing systems, 122–123
retrofit, 32f
installations, precautions, 276
soil profile, 22f
stormwater control performance, North Carolina State University study, 20
systems, evaluation, 302t
usage, viewpoint, 66f
vegetation, 168–169
weeds
growth, 294
presence, 297t–300t
Loading information, 102–103
Loads
designing, standards, 279
principles, 97
relative cost, relationship, 104
usage, ranking, 97t
Lobbies, design, 64f
Long-term maintenance/care, 293, 295

M

Maintenance, 274, 276
manuals, 274, 289
period, 287, 292–293
personnel, impact, 290
problems, avoidance, 306f
requirements, 282, 284
responsibility, 284, 288–289
Manual irrigation, ability (irrigation), 169f
Manufacturers, concerns, 277
Mass transit, desirability, 78, 80–81
Master planning, 52–53
process, order-of-magnitude costs (determination), 53
usage, 53
Masterspec, 127
Material
changes, 232
loads, 118–119
weights, 99, 118–119
ranking, 118t
Mature tree green weights, estimation, 111, 113
Meadows, growth, 2f
Membrane. *See* Waterproofing membrane
accessibility, 143
protection ability, 143
reinforcement, application, 140f
MEP, linear relationships, 204f
Metal decking, steel beams/columns support, 208f
Metal framework, early installation (bird's-eye view), 209f
Microclimates, 204f
Millennium Park, 42f

Modified bitumen (Mod-Bit), 138–139
Moisture retention mats, 164
Mold, potential (reduction), 280
Multicolored living green roof, 33f
Municipal leaders/legislators/regulators, role, 44

N

National Constitutional Center, 220f
National Fire Protection Association (NFPA) 5000 Building Construction and Safety Code, 280
National Research Council of Canada, 23, 35
Natural resources, depletion, 7
Nature, designing (relationship), 5
Netherlands, negative impacts (amelioration), 3f
90 percent rule, 32
Nonpoint-source pollution, origin (identification difficulty), 35
Nonsupportive streams, 29–30
North Carolina State University, stormwater control performance study, 20
Not-to-exceed amount, 276

O

Open-joint paving system, usage, 257
Open space
  completion, 69f
  ecosystem services, providing, 7
  pedestrian linkages, concept drawing, 73f
  physical/visual continuity, linkage, 65–66
  value, assignation, 5–6
Outside, visual access (design goal), 65
Overbidding, 221–222. *See also* Subcontractors
Owners, impact, 45–47

P

Palm grove, installation/completion, 266f
Palms, installation, 258f
Parapet walls
  leaks, contribution, 275
  waterproofing, 209f
Parking
  construction costs, example, 46
  structure, integration (construction detail), 223f
Paver thickness, decrease, 234
Paving, 178, 253, 257
  detail, 77f
  insulation/drainage, 158
  schematic design, 99f
  system
    detail, 117f
    fountain integration, detail, 96f
  types, mockup (in situ), 242f
Pedestals
  pavers, usage, 257f
  system, granite pavers (installation), 256f
Pedestrian
  circulation, segregation, 211f
  entrance ease, perspective, 212f
  open space, links, 71f
Performance evaluation, 282
Pershing Square floor, 129f
Pervious surfaces, 21–22
Phasing, complication, 285f
Planners, roles, 48
Planning process, 49
Planted areas, optimal water retention, 133
Planters
  depth, 212f
    variation, 215f
  detail, 117f
  drainage systems, water accommodation, 250f
  eye-level view, 210f
  sides, waterproofing, 209f
  soil mix, usage, 252f
Planting, 178
  beds, usage, 204f
  completion, 229f, 287
  detail, 77f
  final acceptance, 287–288
  irrigation, relationship, 257, 259
  issues, 86
  maintenance, 289–290
  maintenance/guarantee period, 287
  palette (understanding), drawings (usage), 106f
  proposal, illustrative plan, 76f
  requirements, 122
  schematic design, 99f
  soil, drainage/aeration, 161f
  systems, 234–235
    determination, 181f
    fill conditions, detail, 94f
    indication, 108f
    type 1, 182f
    type 2, 182f
Plant mixes, maintenance, 12
Plants
  damage, 296
  deletion, 235
  dynamic components, 166
  early installation, bird's-eye view, 209f
  health, inspection/monitoring, 296
  identification, 263f
  inspection, 231f
  maintenance, 305
    period/guarantee, length, 236
  performance evaluation, 302
  prepurchase
    requirement, 231f
    usefulness, 229f
  quality/quantity/size, 235
Polymer-Modified Bitumens, 138–139
Polystyrene, types/material composition/fabrication, 152, 154
Polyvinyl chloride (PVC), 137, 146
Positive drainage, ensuring, 259
Positive slope, accomplishment, 133–134
Postcompletion, 268
Pounds per cubic foot (PCF), 98
Pounds per lineal foot, 98
Pounds per square foot (PSF), 98
Pre-bid conferences, 216–217
Precast paving modules, samples (comparison), 240f
Pre-concept design, 53–54
Pre-concept phases, 54
Preconstruction meeting, 237–238
Premixed growing media, availability, 234
Primary root barriers, 146–147
Process sketches, 58f
Product data, 126
Product selection, 276
Professional liability insurers, risk perception, 272
Programming design, 53–54
Project
  care/protection, impact, 286f
  conditions, 284
  construction sequencing, large-caliper trees (early installation), 256f
  costs, estimation, 221
  design/construction, management, 206
  layout control, 244
  phases, 176
Proprietary green roof systems, 184
  availability, 185f
Protection board, 148, 150
  installation, 149f
  setting bed, installation, 214
Prudent risks, 272
Puncture/deformation, potential, 168

Q

Quality assurance, 214

R

Rainfall intensity, 24
Rain runoff, revised utility fee structures, 45
Ray and Marie Stata Center, stormwater management system, 42f
References, 189f
Reservoir panels, 163f
  cones/cups, design, 162f
Residence time, stormwater treatment efficiency function, 33
Resources, conservation, 40, 43
Risk
  assessment/spread, 271
  evaluation, 271
  management, 269, 275
  minimization/insuring, 269
Roof
  defining/redefining, 4
  drain access pit, 166f
  floor
    equivalence, 8
    function, 129f
  heat flow, 37t
  leaks, cause, 275
  slope, 127–131
    variation, 34
  temperature, 36t
  utilization, 12f
Roof snow load, 97–98
Root ball
  depth, estimation, 110, 113
  diameter, estimation, 110, 113
  size, 110, 113
    ASNS minimum, 110t

Root barriers, 146–147
location, 147
manufacture, 147
photograph, 147f
Rubberized asphalt membrane, hot-mopping, 139f
Rubberized bitumens, 138–139
Runoff. *See* Stormwater runoff; Surface
R-value, 151

S

Saarbrücken, stormwater runoff reduction subsidies, 44
Safety cord housing, roof deck anchor, 293
Safety devices, 301
Saturated soils, water (comparison), 216f
Schematic design, 60–61
phase, 179f
components, considerations, 181f
Schematic phase section, 60f
Scope of work, bidding, 217, 219
Sculptured earth mounds, design proposal (perspective), 77f
Sculpture garden, illustrative site plan, 91f
Sculpture locations (flexibility accommodation), structural system (requirement), 95f
Seasonal constraints, 222, 224–225
Seasonality, 264
Seattle, urban design guidelines, 43–44
Sedum (genus), usage, 11f
Sedum layer, usage, 33
SEI/ASCE 7–02, development/publication, 279
Setting bed, installation, 214f
Sewer outfall, combination, 29f
Sewer systems discharge, combination, 34f
Shade tree, total tree load (calculation), 115–116
Shear wall, 98
Single-ply membrane, 135, 137–140
installation techniques, 139–140
loose-laid applications, 140
partially adhered applications, 140
Sites
access, impact, 285f
benches, integration, 212f
conditions, 204f
building footprint, 92f
considerations, 63
constriction, impact, 285f
control, 239
demolition, early packages, 238
development, 219f
elements
coordination, consideration, 86
material loads, 119
infrastructure, large-scale concrete installation, 244f
observation reports, 242–243
plan, proposal, 56f
section, interrelationships, 57f
utilities, discovery, 245
walls/stairs/planters, 258f
work, 290
completion, 229f, 287
complexity, 222
finishing touches, 222
Sitework, final acceptance, 287–288
Slabs, tops (establishment), 83–86
Sloped roofs, 128
heat, 4
Sloping, waterproofing, 247f
Slow-release-fertilizer, application, 296
Soil mixes, 147, 166, 178, 234–235
maintenance, 305
placement, 249f
Soils, 23–24
composition, 23
composition, analysis, 241f
densities, loads (relationship), 105
dynamic components, 166
fabrication, 260f
installation, 259f
failure, 130f
profile plan, sketch, 183f
testing, submittals, 241f
weight, calculation, 113
Specifications, 214
Specific gravity, 98
Standards, availability/usage, 126–127
Stepped structural slab, waterproofing, 247f
Stone copings, protection (absence), 253f
Stone drainage aggregates, 159
Storm
characteristics, 24–25
concentration, time, 24
duration, 24
frequency, 24
ranking, 25t
intensity, 24
Stormwater
drainage systems, water accommodation, 250f
effects, mitigation, 29
hydrological cycle, relationship, 21
vegetation/soils
impact, 22–23
interception, 22f
Stormwater management
practices, goal, 21
requirements, living green roof satisfaction, 11–12
roofs, utilization, 12f
Stormwater runoff
calculation, 26
coefficient, 26t
erosive power, increase, 29–30
impact, 19f
revised utility fee structures, 45
sediment, carry, 27f
volume/flow rates, monitoring, 23
Street leaf mulch, sterilization/containment (absence), 294f
Streets, avenues (building relationship), 70f
Structural considerations/components, defining, 97
Structural deck
fill section, detail, 78f
finished grade, depth (limitation), 96f
flood testing, 246f
insulation, 155f, 156f
slope, 90f
achievement, 132f
Structural decking
drainage, 90f
waterproofing, 255f
Structural design, insurer concern, 277–279
Structural framing
concrete formwork/pouring, 225f
plan, construction detail, 225
Structural grid, structural engineer proposal, 100f
Structural principles, 97
Structural properties, consideration, 97
Structural slab, 131–134
Structural system
requirements, development, 62f
selection, 97–98
Structured parking, 81, 82
cost, 80
Structures
horizontal forces, 117–118
vertical forces, 116–117
Study models, 205f
Stuttgart, municipal green roof requirements/incentives, 66f
Subcontractors, 214
overbidding, issues/areas, 221
scope of work, 216
Submittals, review, 239
Substantial completion, 287
maintenance, 292
Subsurface runoff, 21
Subsurface stormwater holding basin, installation, 254f
Subsurface water/drainage, 245
Suburbanization, effects, 25
Surface
albedo value, 35t
characteristics, 21–23
drains, stormwater movement, 252f
runoff, 21
Surface parking, 81–83
Survey data, 244
Synthetic drainage components, 160–161
Systems, protection/maintenance, 284

T

Terrace framing plan, 93f
Testing, costs/timing, 228
Thermal resistance, R-value, 151
Thermoplastic membranes, 137
thermosetting characteristics, 138
Thermoplastic olefins (TPOs), 137, 146
Thermoplastic PVC/TPOs, 146
Thermosetting membranes, 137
Topping slab
composite steel/concrete structural deck, positive drainage, 122f
concrete, pumping, 133f
reinforcement, installation, 132f
usage, 90f, 134
Total maximum daily load (TMDL) criteria, 30
Total tree design load, calculation, 115
Total tree load, calculation/conversion, 115
Traditional roofs, 4
Transient load, 97

Transit/parking, integration (enhancement), 78
Trees
aerial hedge, usage, 230f
care/production, contractor responsibility, 286f
delivery weight, 109
design load, 114t
green weights, 112t
installation weight, 109–110
load, calculation, 113, 115–116
location
detail, 108f
perspective, 77f
on-site storage, 288f
outer double row, planting (completion), 262f
pit soil weight, calculation, 115
pit width/depth, determination, 113
planting, 215f
pruning, diagram, 230f
selection, 229f
size, study, 106f
watering system, requirement, 288f
Trunk caliper, measurement, 110
Tuscany vineyard, lawn coverage, 65f

U

Uncommon Ground (Cronon), 19
Underbidding, 221
Underdrainage pipes, usage, 253
Underground parking, 81–83
cost, 80
green roof systems, inclusion, 82
United Nations, gardens, 2f
Unplanned development, result, 6
Upset amount, 276
Urban conditions, tree growth (expectation), 106f
Urban design, usage, 50–52
Urban growth/development, living green roofs/landscapes over structures (impact mitigation), 15
Urban heat island effect, 37
Urbanization
cumulative effects, 28
effects, 19, 25
process, 27–28
Urban microclimates, enhancement, 68
Urban space, underutilization, 211f
Urban sprawl, cumulative environmental impacts, 6–8
Urban stormwater
management, BMPs, 32
runoff, concentrated pollutants, 35
Use areas, illustrative plan, 211f
Utilities
damage, potential, 305, 307
fee structures, revision, 45
location, 245
systems, extensiveness, 251f

V

Value engineering, 232
Vegetated roofs, insulation, 13f
Vegetation
protection, thermal fluctuation (insulation), 155
weights/loads, 107
wind load, 116–118
Vehicular/garden circulation, relationships (conceptualization), 92f
Very-large-caliper trees, installation, 69f
Viewshed diagrams, 56f
Vila Olimpica
architecture/landscape, merger, 14f
concept section, 85f

W

Wall
completion, 224f
detail, 117f
mockup, 228f
Wall/tree locations, construction photo, 77f
Warranties, 276
terms, negotiation, 277
Water, 118–119
heaviness, 216f
quality, 34–35
quantity, 28–30
Waterproofing, 134–146, 177–178
consultant, usage, 146
damage, potential, 305, 307
insulation location, relationship, 154–155
materials, impact, 131
replacement, 226f
specification section, 187f–188f
system, selection, 141–142
considerations, 142–145
systems, 232
types, 134–141
warranties, understanding, 276–277
Waterproofing membrane
damage, 145f
Europe/U.S. comparison, 142
flood testing, 144f
heat-welding seams, 138f
installation/protection, 246
insulation, 156f
systems, 136t–137t
impact, 275
Watersheds
property lines, independence, 27–28
urbanization, 29
Weeds
growth, 293, 295
types, 297t–300t
Weed seed bank, 295
West Ferry Circus, open spaces, 3f
Windborne debris, FM Global concern, 278
Wind load, 116–118
Wind mitigation, linear relationships, 204f
Windscreens
eye-level view, 210f
usage, 204f
Work
performing, qualifications, 226, 228
scope, bidding, 217, 219
Working slab, slope (provision), 148

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