COMPARATIVE ANALYSIS OF GREEN ROOF GUIDELINES AND STANDARDS IN EUROPE AND NORTH AMERICA

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ABSTRACT

The German FLL Guidelines for green roofs are designed to inform about state-of-the-art performance expectations for green roofs. North America is experiencing steady growth in the green roof market and has no single-source set of standards or guidelines; therefore there is a need to identify what type of guidance may be lacking. Seven domains of knowledge from the FLL Guidelines are compared to similar areas of content in North American documents. It was found that although there are several North American green roof guidelines in use, compared to the FLL Guidelines there are areas where knowledge is lacking: guidance for compatibility of system components, slope application, filter fabrics, root barriers, surface and subsurface drainage, growth media, and erosion control, as well as standards or postconstruction testing requirements for fabrics, bulk density of growth media, root barrier performance, drainage media, and growth media. A case study of the Chicago City Hall green roof examines its content compliance with FLL performance standards. Recommendations for further advancement of North American guidelines include the need for more collaborative research and development in efforts to advance existing and new guidelines across ecoregions.

KEYWORDS

FLL guidelines, performance guidelines, regulation, ecoregion, vegetated roofs

INTRODUCTION

Green roof technology in North America is beginning to be known for its ecosystem services, potential to beautify rooftops, and capacity to renew planning in urban centers (Cantor 2008; Eisenman 2006; Oberndorfer et al. 2007; Weiler and Scholz-Barth 2009; Werthmann 2007). Mayor Daley in Chicago, Illinois, for example, has been an advocate for green roofs in Chicago beginning in 2001 with completion of the Chicago City Hall green roof pilot project and its green roof initiative. Since then, Chicago has led surveys of new North American green roof construction every year since 2003 (Green Roofs for Healthy Cities 2010), has installed over 2 million square feet of green roofs (Velazquez 2010), and has revitalized its downtown with one of North America's grandest roof gardens, Millennium Park. In New York City, the

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High Line project brings to life an abandoned elevated rail line that connects 25 city blocks with a continuous thread of elevated parkway. There are also plans to further expand urban greening in New York to connect a broad network of elevated parks, rooftop plazas, green roofs, and bridges with the Hudson Yards project (Weiler and Scholz-Barth 2009).

Such planning transcends traditional thinking for green roof technology from the site to regional scale (Weiler and Scholz-Barth 2009) and entails a certain degree of risk as green roofs are still an emerging technology in North America. As green roofs continue to populate grand plans such as those in Chicago and New York and many municipal, state, and federal buildings across the U.S. and Canada, assurances for long-term performance expectations for green roofs must be in place, especially where they are being incentivized, are required in city codes and ordinances (Peck 2009), or need to be defended in the courts of law. There is and has been for quite some time a clarion call across North America for more technical knowledge and better guidance for safe and reliable performance of green roof construction (Factory Mutual 2007; Federal Energy Management Program 2004; Graham 2009; Loveland 2010; Miller and Narejo 2005; Ngan 2004; Philippi 2005).

Europe has several decades of experience with green roofs and has a well-established set of green roof standards and guidelines. This state-of-the-art knowledge is found in one of the first published green roof guidelines known as the "Guidelines for the Planning, Construction and Maintenance of Green Roofing," commonly referred to as the German FLL Guidelines for green roofs (FLL 2008). It is published by the "Green Roofing" subgroup of the not-for-profit German organization Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e. V. (FLL) [Landscape Development and Landscaping Research Society]. It is a regulatory commission, comprised of a consortium of voluntary industry experts, university researchers, and seasoned professionals (FLL 2008). Founded in 1978, the committee has over four decades of experience, performance, and materials trial-and-error research that have resulted in the development of the FLL Guidelines (Ngan 2004). Their stated purpose is for the FLL green roof guidelines to be a "recognized code of practice," often used for legal standing (FLL 2008, p. 1). While the guidelines provide guidance, they "do not reduce the user's responsibility for their own behavior" (FLL 2008, p. 1). Thus, while the guidelines are a measure for regulated professionals, suppliers, installers, and municipal or state regulators to use in the pursuit of precise and faultless technical application of green roof technology, it is recognized that application of the guidelines is not guaranteed to ensure fault-free results as the user needs to apply common sense and common knowledge (FLL 2008). As an emerging and sometimes loosely regulated technology across North America, the FLL Guidelines can be used to recognize minimal performance expectations and thus reduce the potential for failure (Philippi 2005).

Although there have been many successful applications of green roof technology in North America, not all green roofs have remained green (Shackford 2008) or performed equally (Simmons et al. 2008). Table 1 identifies several types of failings found on green roofs including poor drainage and inadequate growth media design, exceedance of structural designs, and plant failures and difficulties with maintenance. I am also aware of several unpublished failings, including structural collapses, slope failures, failed plantings, and damage to interiors of buildings from clogged drainage systems. For each type of failure, the FLL guidelines provide guidance as well as requirements for materials suitability or performance testing to aid in preventing future occurrences. Although these assurance measures can be accomplished with private performance guidelines such as *Factory Mutual* or a private green roof system provider's

TABLE 1. Chronological list of a few green roof failures.

Technical Failure	Design	Reference
Growth media slumping (pp. 171-175), drainage (p. 164) and plant failures	Custom	Osmundson, 1999
Structural cracking of concrete roof deck due to excessive green roof substrate loads	Unknown	Personal communication with anonymous green roof owner in Chicago (B. Dvorak, 2003).
Plant failures of four projects cited due to inadequate growth media blends, drainage, and sick plant syndrome	Vendor and custom	Carey, 2005
Plant failures in three projects due to plant selection, clogged drainage systems, and inadequate growth media blends	Custom	Paladino, 2006, pp. 9, 15, 19
Plant failures due to media, irrigation, and maintenance problems. Five of six evaluated projects had serious problems in the first two years.	Vendor	Shackford, 2008

warranty, for municipal, state, or federal projects where performance standards, guidelines, and testing are required, this knowledge serves as the foundation for legal agreements among builders, planners, designers, and contractors and serves to protect public green roof investments (Factory Mutual 2007; FLL 2008; Graham 2009; Mishra 2004).

At the turn of the 21st century, North American standard and guideline organizations began working to articulate guidelines and standards for green roofs. The American Society of Testing and Materials International (ASTM) and several other organizations have made much use of the content found in the FLL guidelines in developing its current set of published guidelines. This paper seeks to make known North American green roof standards and guidelines compared with technical knowledge areas communicated in the FLL green roof guidelines.

METHODOLOGY

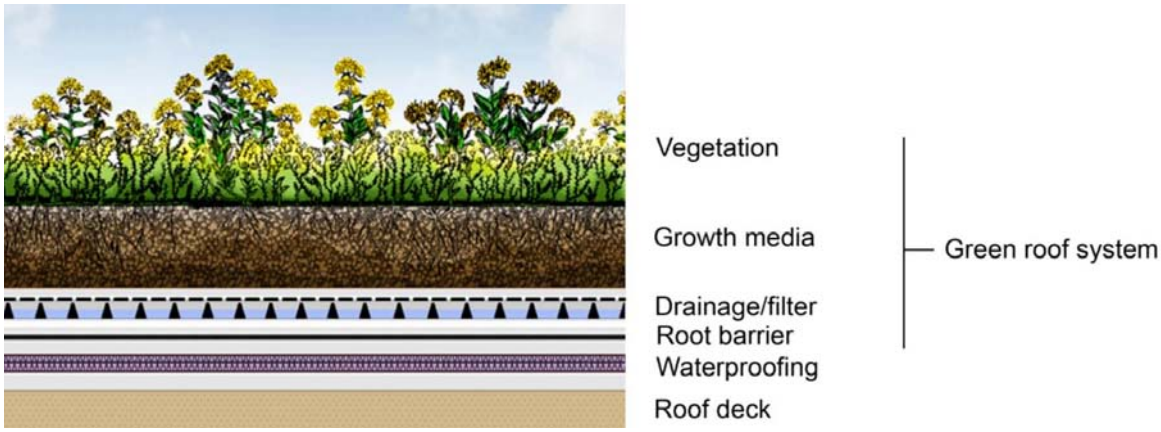
The research methods employed in this investigation were to first examine content in the FLL guidelines and sort it into distinct domains of knowledge (Table 2). Next, a review of North American guidelines and standards was conducted for a gap analysis of these same FLL areas of knowledge. Content of each attribute was sorted into tables for comparison and discussion. Finally, a case study of the Chicago City Hall green roof is provided as an example of how content in the FLL guidelines was effectively applied.

As a means to organize materials into a useful framework for content analysis, seven domains of green roof knowledge were identified in the FLL Guidelines: *systems design, structural, waterproofing/root barriers, drainage, growing media, vegetation,* and *maintenance* (Figure 1 and Table 2). These seven domains address critical content outlined in the FLL Guidelines. Systems design (1) is presented first, as it covers knowledge of comprehensive and interdependent issues such as compatibility of materials, materials application, wind, fire, and application of filter fabrics. The remaining knowledge areas follow typical considerations for green roof design, construction, and maintenance from the roof deck upward: (2) structural, (3) waterproofing and root barriers, (4) drainage, (5) growth media, (6) green roof vegetation, and (7) maintenance.

TABLE 2. Domains of Green Roof Knowledge Covered in the FLL Green Roofing Guidelines.

Knowledge Domain	Content	Location
1. Systems design	Application, interactions of and compatibility of components	Chapters 1, 2, 5, 6, 7, 16
2. Structural	Dead and live load considerations	Chapters 1, 2, 5, 16, App. 1
3. Waterproofing/root barriers	Membrane standards, application and testing	Chapters 2, 5, 6, 7, App. 3
4. Drainage	Materials, properties, application and testing	Chapters 7, 8, 16, App. 2
5. Growth media	Materials, properties application and testing	Chapters 2, 7, 10, 16, App. 2
6. Vegetation	Forms of, application and installation	Chapters 2, 3, 7, 11, 12
7. Maintenance	Types of and required activities	Chapters 7, 11, 12, 13, 16

FIGURE 1. Example of a multilayered green roof system with components similar to those covered in the FLL Green Roofing Guidelines.



FINDINGS AND DISCUSSION

The review of North American standards and guidelines was completed during fall 2009 through December 2010 and yielded several categories of documents, including *standards, guidelines, codes* as well as *design manuals, specifications, reports,* and *books.* Books and proprietary guidelines are not included in the formal review content, but there are several citations to books made to provide further direction of guidance.

The following North American organizations were found to support guidance for green roofs: ASTM, the National Roofing Contractors Association (NRCA), the *Whole Building Design Guide* (WBDG) for federal building projects, the International Building Code (IBC), and the American National Standards Institute (ANSI). Since 2004, the ASTM Green Roof Subgroup has published five green roof documents. There is one standard guide for the selection, installation and maintenance of green roof vegetation (ASTM E 2400 2006), one standard practice for determining structural loads of green roof systems under dry and saturated conditions (ASTM E 2397 2005), one document for determining the saturated and dry

weights of growth media (ASTM E 2399 2005), and two documents that cover methods for testing water permeability rates through drainage materials (ASTM E 2396 2005; ASTM E 2398 2005). The NRCA issued *The NRCA Green Roof Systems Manual* to better provide for the roofing industry's need to understand green roofs (NRCA 2007). The U.S. government has issued the WBDG which includes specifications for green roofs on federal projects. The IBC has developed language regarding fire and wind requirements to allow the use of green roofs, but only limited detail is provided. The ANSI has issued a standard to address fire and wind concerns with vegetated roofs (ANSI/SPRI VF-1 2010).

Systems Design

Systems design is knowledge of how individual components of green roof systems work together for the long-term sustainment of the green roof (Snodgrass and Snodgrass 2006; Weiler and Scholz-Barth 2009). Some of the green roof failures cited in Table 1 were due to either faulty application of individual components or poor selection of or lack of knowledge of materials (Carey 2005; Osmundson 1999; Palandino & Company 2006; Shackford 2008). For example, if an FLL compliant growth media is specified but it is coupled with an inappropriate drainage layer (too fast or too slow draining), then anaerobic or excessively dry conditions could prevail and result in serious decline of vegetative growth (Beattie and Berghage 2008). Knowledge of how all of the components can come together is discussed in the FLL Guidelines, but it is not prescriptively articulated. In the FLL there are general statements about the importance of cross-checking the compatibility of materials, but in Germany, knowledge of how complex system components come together is left to technical training (Seeger and Ansel 2004) or acquired through experience. Since green roofs are still an emerging market in North America, there is also need for elaboration of systems knowledge. Green Roofs for Healthy Cities organizes regionally based green roof training and has a green roof accreditation program. There remains, however, a need for more knowledge regarding the application of green roofs across different ecoregions (Dvorak and Volder 2010).

FLL (Chapter 5) covers general knowledge for many aspects of green roof design such as cross-compatibility of materials and slope application. Roof decks with slopes less than 2% (1.1°) may not adequately drain and therefore require special measures to remove excess water. Slopes greater than 26.8% (15°) may require special consideration to retain the substrate in place with slope revetment provisions. Application of extensive green roofs to slopes greater than 100% (45°) is not recommended (Chapter 5.3). Chapter 6 covers general and some specific systems and construction issues including wind loads (section 6.8) and fire (section 6.9) as these issues are often context related. Section 6.8 covers terms and concepts for protecting green roofs from wind damage, where section 6.9 provides discussion of design-related considerations regarding fire resistance for extensive green roofs and further directs detailed discussions of fire to federal orders for buildings.

North American references yield some guidance on green roof systems design; however, several green roof books provide better coverage on systems-related concepts and technical knowledge (Cantor 2008; Weiler and Scholz-Barth 2009). There are, nevertheless, several new standards that address systems-related issues. Wind and fire concerns are addressed in the new ANSI/SPRI document VF-1. In this eight-page document, a number of terms, definitions, and system requirements are identified for vegetated roofs. A great level of guidance and detail is provided in this standard, and it should help accelerate the acceptance of green roofs with

TABLE 3. Analysis of the systems design knowledge domain.

Attribute	FLL Standard or Guideline	North American References	FLL Standard Test/Practice	North American References
• System and Compatibility	Chapters 1, 5, and 6 cover use and cross-compatibility of materials, also in their context to the environment. Chapter 7 covers interdependence and differentiation of working layers.	NRCA has terse coverage of green roof systems and components in Chapter 6, and WBDG includes a description of a green roof system in section 1.3. ANSI/SPRI VF-1, in section 3, discusses the need for systems knowledge.	Chapter 16 covers suitability and postconstruction testing for compatibility of drainage materials.	IBC 104.11.2 2009 makes provision for green roofs through testing; however, no performance characteristics are provided. WBDG 1.7 D requires warranty of green roof system for 15 years.
• Application	Roof slopes <2% (1.1°) and >26.8% (15°) require special consideration (Chapters 5.3 and 6.10.1-2). Roof slopes >100% (45°) are not recommended (Chapter 5.3). Chapters 7.2 to 7.2.1 and Table 2 cover substrate depth guidelines for different types of green roofs.	ANSI/SPRI VF-1 fire and wind standard is for roof slopes up to 2:12. No guidance on slopes.	…	…
• Wind	Chapter 2 covers wind design load references to DIN 1055-4/7 for load and planning. Positive and negative loads pressures must be considered particularly at edges and corners. Chapter 6.8 covers pre and postconstruction wind related issues and cites DIN 1055-4 for wind load classes.	ANSI/SPRI VF-1 sections 3.7 and C 3.6 cover wind requirements for green roofs where basic wind speed is determined to be less than 140 mph (225 kph).	Chapter 6.8 cites DIN 1055-4 for calculation of wind loads.	ANSI/SPRI VF-1 cites ASTM E-108 and UL 790, which can be used to test materials.

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regulators and design insurance providers regarding wind and fire codes on green roofs. The ANSI/SPRI VF-1 and FLL documents share similar conclusions on wind and fire—that properly designed and maintained green roofs can meet wind fire-resistant code requirements. The 2009 version of IBC now makes accommodation for green roofs but provides no guidance. Chapter 9 covers filter layer or geotextile use and requirements including density, materials, strength, aperture opening, and cross-references to growth media requirements for fabric to effectively maintain 90 percent of the media.

TABLE 3. *(continued)*

Attribute	FLL Standard or Guideline	North American References	FLL Standard Test/Practice	North American References
• Fire	Chapter 2 cites federal fire code DIN 4102-4/7, which makes no claim for green roofs, Chapter 6.9, however, covers FLL provisions for fire. Green roofs are deemed fire-resistant if they are over 3 cm deep, have fire-resistant vegetation, have 50-cm-wide gravel boarders at edges, and have a firewall/ barriers every 40 m. Other federal or state documents cited.	ANSI/SPRI VF-1 sections 4 and 5 cover terms and explicit detail for fire-resistant green roofs including vegetation type, fire breaks, border zones, hydrants, and maintenance. Growth media desired organic content ≤20%.	Chapter 16 covers suitability testing requirements for growth media and drainage materials behavior under fire.	The ANSI/SPRI VF-1 document cites ASTM E-108 and UL 790 can be used for testing materials.
• Filtration	Chapter 2 cites DIN EN 12225 Geo-Textiles and Geo-Textile-related Products. Chapter 9 covers filter layer requirements including density, materials, strength, aperture opening, and growth media requirements for fabric to effectively retain 90% of media.	…	Appendix 2 cites ISO 12958 as part of postconstruction testing for horizontal water permeability.	…

Structural

Perhaps one of the most critical domains of knowledge for establishing long-term design and construction of green roofs involves structural considerations. Exceeding the weight limits of a structural deck can nullify all good intentions with an immediate collapse of the deck or the longer-term development of cracks or fissures after the green roof system has been installed. The FLL Guidelines address structural and weight issues in several locations, and they provide guidance for design load and surface load considerations (Table 4). FLL (Chapter 2) provides lists of DIN (DIN is a European guideline system similar to ASTM) cross-references to structural load considerations such as live loads, dead loads, wind loads, and snow and ice loads. FLL (Chapter 5.6) gives guidance regarding construction and materials. In addition, the FLL (Appendix 1) provides a reference to estimate the density of substrate materials at maximum water holding capacity in FLL Tables 13 to 16. There are no standard tests or practices regarding structural issues in the FLL Guidelines.

North American guidelines and standards regarding structural issues are found in several documents including IBC 2009, Chapter 16, sections 1607.11.2.2 and 16.11.3. The code identifies that accessible roof gardens must have minimal capacity to support 4.79 kN/m^2 (100 lb/s.f.), whereas nonoccupied vegetated roof decks shall be designed for live loads of 0.958 kN/m^2 (20 lb/s.f.) under saturated conditions (Graham 2009). If testing of materials is needed, IBC 104.11.2 provides a section for testing of alternative materials including landscaping. ASTM has significant coverage for green roofs in documents E 2397 and E 2399, and the WBDG covers structural issues in (WBDG 07 33 63 (Section 02930) 2007). ASTM E 2397 is a standard practice for estimating total system weights, and ASTM E 2399 guides the calculation of bulk density or weight of growth media in its dry and saturated states prior to construction. The FLL Guidelines do not provide a similar practice for estimation of the weight of the total system, just for individual component parts. The WBDG 073363 (section 02930) document provides a weight limitation for green roof systems to 8.1 kg per 0.09 m^2 (18 lb/s.f.) for extensive green roof systems. This general guide also cross-references ASTM E 2399 as a method for contractors to meet growth media bulk density requirements.

Typical structural loads for common materials used on green roofs and roof gardens were found in the FLL Guidelines in Appendix 1, Tables 13 to 16. The tables cover a range of weight values for a variety of materials commonly used on green roofs such as drainage materials, growth media, protection layers, and different forms of vegetation. North American guidelines currently provide no similar table for reference, but ASTM E 2397 requires submittal of material samples for testing as part of the standard practice.

TABLE 4. Analysis of the structural knowledge domain.

Attribute	FLL Standard or Guideline	North American References	FLL Standard Test/Practice	North American References
• Design loads	Chapters 1, 5, and 6, and Appendix 1 cover live and dead loads, staging, and common material loads. Chapter 2 has references to DIN 1055-4 wind loads and 1055-100 planning/safety	IBC 1607.11.22 sets minimum roof live loads for roof gardens at 100 psf (4.79 kN/m^2) and IBC 1607.11.3 guides that extensive green roofs shall have live loads of 20 psf (0.958 kN/m^2). WBDG section 1.3 A.2 limits extensive green roofs to 8.1 kg per 0.09 m^2 (18 lb/s.f.). NRCA offers terse structural guidance on p. 16.	…	ASTM E 2399 provides a method for determining saturated weight of growth media.
• Surface loads and material properties	Appendix 1, Tables 13 to 16, list densities of common materials used on green roofs.	…	Postconstruction testing is required for bulk density (Table 7) and a 4-year structural warranty is required (p. 76).	ASTM E 2397 provides a method for determining dead and live loads of green roof systems. Postconstruction evaluations are not required.

Waterproofing/Root Barriers

Protection of roof decks from intrusion of water and root penetration is another critical consideration for green roofs. Some post–World War II roof gardens were known for leaking because of a lack of provision for the green roof system placed on top of the bituminous waterproofing systems (Osmundson, 1999, p. 158). Today's waterproofing systems are greatly improved and there is much guidance on their application to roof gardens and green roofs. Waterproofing guidelines and standards exist for developed countries across the world; however, the application of green roofs on top of waterproof membranes introduces new criteria to be considered. The FLL Guidelines provide much detail regarding waterproofing and root barriers. Table 5 (later) refers to several locations within FLL including Chapter 2 for materials and detailing and Chapter 5, sections 5.4 through 5.5, for compatibility and load-bearing applications. Chapter 2 has many cross references to DIN for indentifying roofing membrane materials, their installation and construction. Chapter 5 discusses general suitability of different roof conditions for green roofs. The FLL has some guidance on application of green roofs with different types of roof configurations but provides no standard test or practice regarding application of green roofs to waterproofing systems.

The North American review of standards reveals that the ASTM currently has no specific guidance in selecting waterproofing materials for green roofs. The NRCA manual (Chapter 5), however, provides guidance. There is much detail in this guide regarding waterproofing types, materials, construction details, and recommendations for their application on green roofs. Document WBDG 07 55 63 (section 07530) specifically addresses the application of

TABLE 5. Analyses of waterproofing and root barrier knowledge domains.

Attribute	FLL Standard or Guideline	North American References	FLL Standard Test/Practice	North American References
• Waterproofing	Chapter 2 cites DIN 18195-1/2/5/8/9/10 and 18531-1/2/3 all cover materials and detailing. Chapter 5.4-5.5 covers compatibility and load-bearing application.	NRCA covers temporary (p. 15) and permanent waterproofing considerations in Chapter 5 and details in the appendix. WBDG section 07 55 63 (section 07530) covers application of green roofs over waterproofing. IBC Chapter 15, section 1507 makes provision for green roofs.	…	…
• Root barriers	Chapters 6.2 and 7.2.5 cite requirements for permanent protection of waterproofing. Proof of material performance per Appendix 3 testing required.	NRCA Chapter 6.2 covers recommended materials for use as root barriers. No testing is required.	Postconstruction testing required for root barriers up to 15 years beyond installation (p. 77). Appendix 3 covers standard test methods for root barriers.	…

green roof technology to waterproofing and provides quality assurance measures and provisions for material selection, installation, and maintenance (WBDG 07 55 63 (Section 07530) 2007). This document also cross-references other WBDG documents for guidance on waterproofing and moisture control. The 2009 version of IBC, Chapter 15, section 1507.16, makes provisions for the first time for vegetated roofs as a viable roof covering (Graham 2009).

Protection of waterproof membranes from plant root penetration is an important recent development that has allowed vegetated roofs to be considered long-term investments. The FLL Guidelines have very detailed descriptions of testing methods and procedures (Appendix 3, pp. 103-119; (FLL 2008). The detail found in the FLL root barrier test procedures has yet to be replicated elsewhere. ASTM currently has no standard or guidance regarding root barriers. The NRCA manual (Chapter 6.2), however, provides some detail about material choices for different waterproofing systems. It remains one of the best documents to use regarding root barriers, beyond the FLL Guidelines. There are some other sources of information about this topic; they are not standards or guidelines but can be used during the design process. They include two books—*Green Roofs in Sustainable Landscape Design,* which has a generic specification in the appendix that covers some detail on root barriers, and *Green Roof Systems,* which has an entire chapter with much detail on waterproofing and protection from root intrusions (Cantor 2008; Weiler and Scholz-Barth 2009).

Drainage

There are three main considerations regarding the drainage of green roofs covered in the FLL Guidelines: materials selection and the management of surface and subsurface water (Table 6). Drainage materials appropriate for use on green roofs are covered in detail in FLL Chapters 7 and 8. Standard tests for material properties are covered in Chapter 16, Tables 7 and 9. Surface drainage refers to water that may flow along the surface of a green roof if the substrate becomes saturated and the rate of rainfall exceeds the drainage capacity of the substrate. For an understanding of how to manage water under these conditions, FLL Chapters 7 and 8 give much detail and guidance for sizing and managing surface water flow on green roofs. Options for managing subsurface flows are described in Chapter 8 as well as the Appendix. Considerable performance detail is provided regarding recommended flow rates for different materials typically used on green roofs matched to different forms of roof greening such as extensive, intensive, and simple intensive green roofs.

Compared to the content and level of detail found in the FLL Guidelines, North American documents regarding drainage are significantly lacking. The NRCA Manual provides some guidance, description of materials, and recommendations for selection of different materials. The WBDG document 073363 section 02930 provides some detail with guidance on recommended surface and subsurface flow rates. The ASTM documents E 2396 and E 2398, however, offer much guidance for testing of materials for two common types of drainage systems: granular media (E 2396) and geocomposite drainage layers (E 2398). Although the ASTM documents provide procedures for testing of drainage materials for green roofs, they do not provide guidance for the selection of materials or application. The FLL Guidelines remain the best resource for these purposes. Again, *Green Roofs in Sustainable Landscape Design* has a specification in the appendix that covers some performance details for drainage media, and *Green Roof Systems* has an entire chapter with descriptive detail on drainage design features typically used on green roofs. As a side note, some of the references to FLL in these books are to the previous English version of FLL from 2004. The 2008 version of FLL has significantly reorganized chapters and tables.

TABLE 6. Analysis of the drainage knowledge domain.

Attribute	FLL Standard or Guideline	North American References	FLL Standard Test/Practice	North American References
• Drainage materials and construction	Chapter 8.1-2 lists suitable drainage materials and their performance requirements. Grain size distribution is in Chapter 8.2.1; stability, chemical, and permeability properties are discussed in Chapters 8.2.5 to 8.2.9; and Chapter 8.3 covers construction requirements.	NRCA covers some guidance for deck drainage (p. 17) and for drain sheets and reservoir layers (6.3) and surface drainage (7.4). Multiple drainage details are located in the appendix. WBDG 073363 (section 02930) provides terse coverage of drainage materials.	Chapter 16, Tables 7 and 9, discusses suitability and postconstruction performance testing; Appendix 2 covers methods for drainage tests (14 pp.)	…
• Management of surface flows	Chapter 7.3.4-5 covers water retention, discharge, coefficient planning, and calculation. Chapter 8.2.5 covers drainage calculations for runoff rate.	…	Appendix 2 covers methods for drainage runoff tests.	…
• Management of subsurface flows	Chapter 8.2.5 covers permeability rates ≥0.3 cm/s (180 mm/min) per 400 m^2 area draining 15 m at 2%. Appendix 2 covers permeability calculation for field testing.	WBDG 073363 in section 2.1 A cites minimum value of ≥20 gal/min/ft for synthetic drain layers placed under growth media.	Appendix 2 covers methods for testing of permeability of drainage materials (14 pp.).	ASTM E 2396 provides methods for testing flow rates of granular media, where ASTM E 2398 covers synthetic drain sheets. No guidance on performance.

Growing Media

One of the significant developments of the FLL Guidelines emerged from the need for guidance on the composition and application of media to grow green roof vegetation (Köehler and Keeley 2005). Growing media is perhaps one of the most critical components considering the success or failure of plants (Beattie and Berghage 2004). The FLL Guidelines contain considerable detail regarding the components and performance expectations of growing media and its drainage, moisture, nutrients, organic content, and structural stability over time. Table 7 defines content regarding growing media found in the FLL Guidelines.

Chapter 7 of FLL provides critical information regarding the application of growth media for green roofs. For example, in Chapter 7, Table 2 (p. 43) provides limits and ranges of depths of growth media for different forms of plants and green roofs. Chapter 10 provides detailed performance descriptions of materials; granulometric distribution ranges for extensive, intensive, and simple intensive green roofs; and recommended densities of media in Figures 1 though 3 and Table 5. Chapter 16 and Appendix 2 provide tables for required test

TABLE 7. Analysis of the growth media knowledge domain.

Attribute	FLL Standard or Guideline	North American References	FLL Standard Test/Practice	North American References
• Growth media depth, material/ composition	Chapter 2 cites DIN 18123 (grain size) and DIN 18127 (proctor test). Chapter 7 covers terms, course depths (Table 2), water retention, capacity, permeability, runoff, storage, and additional watering needs. Chapter 10 covers materials, grain size distribution, organic content ≤40-90 g/L (≈3-12%), air ≥10% vol., pH (6.0-8.5), salt 2.5-3.5 g/L, nutrient values for N, P_2O_5, K_2O, Mg (varies), and more.	WBDG 073363 (sec. 02930) 2.1 B covers a much abbreviated form of FLL contents in material, chemical, nutrient, and grain-size performance characteristics. Organic content at 4-8% (dry wt.), no media depth guidance for different forms of plants.	Chapter 16 covers postconstruction testing requirements for media Tables 7, and 8, and 10-12 for 3 to 5 years beyond installation. See below for additional testing requirements in Appendix 2.	ASTM E 2399 covers maximum media bulk density test methods. No postconstruction evaluations required.
• Managing growth media, permeability, and erosion control	Chapter 10 covers permeability and water storage. Intensive greening should convey 0.3 mm/m and hold ≥45% water volume. Extensive greening should convey 0.06 mm/ min and maintain ≥35% water volume but varies for different forms and conditions of green roofs. Chapter 14 covers erosion control. Guidance in Appendix 2 covers terms for testing.	WBDG 073363 (section 02930) 2.1 B covers hydraulic conductivity for extensive greening (0.05 in/min) and maximum water (≥35%) and air (15%) content by volume. No erosion control coverage.	Appendix 2 covers sample requirements, reference values, properties, methods, notes for testing media granulomeric distribution, apparent density, water movement, air, pH, salt, organic content, nutrients, runoff C values.	…

procedures for material suitability and their requirements for testing two years after installation. The level of detail provided in FLL regarding growth media performance has not yet been reproduced for applications in North America.

The ASTM E 2399 is a standard test method used to determine bulk density of growth media. The NRCA Manual refers to FLL and/or qualified vender specifications. The WBDG 073363 (section 02930) 2.1 B provides some detail regarding material performance and recommendations on organic content, granulometric particle distribution, pH, salt and mineral content, hydraulic conductivity, pore space, and more. This guidance is in line with FLL Guidelines and could be used as a beginning point for the custom design and specification of projects for some North American ecoregions. Some regions, however, may need a greater capacity of the media to drain more freely, where annual precipitation is above 127 cm (50 in) (Beattie and Berghage 2008).

Vegetation

The FLL Guidelines represent a comprehensive and interconnected system of knowledge that assumes accomplished performance expectations from one characteristic to the next. For example, FLL assumes that plant materials considered appropriate to a green roof are installed with an FLL-compliant growth media and drainage system design. Regardless, the green roof design process is as much an art as a science in that it involves more than the calculated sum of individual components. The FLL guidelines provide general advice on application of plants (see Table 8 here), such as depths of media and selection of media for plant types, but the guidelines provide no recommended species. FLL assumes an experienced designer is involved, and it is not meant to provide a complete recipe in cookbook fashion. It assumes

TABLE 8. Analysis of the vegetation knowledge domain.

Attribute	FLL Standard or Guideline	North American References	FLL Standard Test/Practice	North American References
• Vegetation selection	Chapter 3 covers considerations for different forms of green roofs (3.1 to 3.2.4) and vegetation (3.3.4), environmental factors (3.3.2), and site- (3.3.1) and building-related considerations (3.3.3). Aesthetic considerations are not emphasized.	ASTM E 2400 covers criteria for plant selection including: design intent, aesthetics, climate, microclimate, plant characteristics, and media qualities. WBDG 2.2 cites ASTM E 2400 and additionally requires a minimum of 5 proven plant species that are less than 18 in (0.45 m) tall at maturity.	60% of specified seed species must be present after 24 months (p. 71).	…
• Depth of growth media	Chapter 7 (Table 2, p. 43) covers typical depths of media per different forms of vegetation.	ASTM E 2400 mentions growth media depth is important but makes no articulation of what this means.	…	…
• Vegetation installation	Chapter 2 references DIN 18915-18 for soil attributes. Watering, plant propagation, and installation are covered in Chapters 7 and 11. Chapter 12 covers establishment and acceptance criteria. Typically 80% coverage of planted area with specified plant material is required after 12 to 15 months. Multiple cross-references to DIN for landscape industry standards.	ASTM E 2400 covers installation methods for different forms of plants: precultivation, direct planting on roof via plugs, cuttings, and seed. Discusses seasonal considerations. No requirements for plant establishment. WBDG 073363 (section 02930) 1.8 requires warranty of plants for 24 months.	Typically 80% coverage of planted area with specified plant material is required after 12 to 15 months. Warranty plants 2 years. No gaps in vegetation over 2.5 m^2 allowed.	WBDG 073363 (section 02930) 1.7 B. requires plant infill after 12 months if there is ≤60% plant coverage and 80% after two years. Section 3.4 cites water requirements and seeding rates.

that its users have experience and knowledge of the application of plants on green roofs. For this reason, FLL provides general guidance for plants and allows much freedom, as green roof design in Germany is not so much a one-design-fits-all application—the consideration of unique conditions is always necessary. General and detailed categorization for plants is given in FLL Chapters 3, 7 (Table 2), 11, and 12.

ASTM has published a guide on the selection of green roof plants and their maintenance in ASTM E 2400. General characteristics for the selection of plants suitable to rooftop environments as green roof design are provided as plant selection is greatly influenced by microclimate, roof environment, and regional climatic influences. Although it covers important considerations such as design intent, aesthetics, climate, microclimate, plant characteristics, and a terse discussion of desired media qualities, there is currently a void of knowledge concerning green roof plants at the ecoregion level for North America (Dvorak and Volder 2010). There are, however, in ASTM 2400 some helpful descriptions of different methods for the establishment of green roof plants with recommendations regarding timing. In WBDG 073363 (section 02930) 1.7 B, there are recommended seed application rates for extensive green roofs. The NRCA provides no new information regarding green roof vegetation. There are several books with good instruction on green roof vegetation, including Green Roof Plants by Snodgrass and Snodgrass (2006), *Planting Green Roofs and Living Walls* by Nigel Dunnett and Nöel Kingsbury (2004), and the previously cited *Green Roofs in Sustainable Landscape Design* and *Green Roof Systems.*

Maintenance

The FLL Guidelines cover different aspects of green roof maintenance in several locations. Chapter 7 (section 7.4) discusses maintaining appropriate moisture levels in the media through proper design of the substrate such as reservoir sheets or drainage retention fabrics. It also discusses different options for irrigation and requirements for maintaining water during drought or temporary watering for plant establishment. Chapter 11 (sections 11.4 through 11.7.3) covers a general but diverse range of maintenance recommendations, and section 11.8 covers warranty expectations. Chapter 16 (Tables 8 and 10-12) provides lists of testing activities regarding inspection of the green roof system components after the green roof has been installed. The testing properties listed in these tables are concerned with the health of the growing medium and evidence that maintaining a green roof has as much to do with monitoring substrate properties as with regulating surficial elements.

The ASTM E 2400 document gives some general guidance to watering, plant establishment, and sustainment. There is some detail about requirements of necessary activities such as checking soil nutrient levels and instilling the attitude that long-term care is needed. The WBDG document 073363 (section 02930) part 1.8 gives terse but specific detail regarding maintenance activities, a maintenance schedule, and requirement for reports and defines an establishment period of two growing seasons. The NRCA manual outlines maintenance activities required for waterproofing and protection by the green roof system contractor (section 10) and landscaping contractor (section 11). In *Green Roofs in Sustainable Landscape Design,* specific detail regarding maintenance for case study projects provides much insight into what is required of several well-known green roofs across North America. "Green Roof Systems" devotes an entire chapter with great detail on maintaining green roofs, including lists (and photographs) of common weeds found on green roofs.

TABLE 9. Analysis of the maintenance knowledge domain.

Attribute	FLL Standard or Guideline	North American References	FLL Standard Test/Practice	North American References
• Watering	Chapter 7.4 covers temporary and permanent substrate water retention and supplemental watering considerations.	ASTM E 2400 has some guidance on passive and active irrigation.	Chapter 16, Tables 8-11, covers water storage testing requirements.	…
• Weeding, general care, warranty	Chapter 11 covers maintenance considerations for different groups of plants and has multiple cross-references to DIN. Chapter 12.5-6 covers establishment and acceptance activities. Chapter 13 covers long-term care of plants and media.	ASTM E 2400 covers recommended plant maintenance activities for two years. NRCA Guide section10-11 covers inspection of drains, plants, and media.	Chapter 16, Table 8, covers suitability and evidence test requirements for substrates, seed establishment, and plant compatibility. Tables 10-12 cover plant nutrient testing.	WBDG 073363 (section 02930) 1.8 covers basic maintenance activities, 24-month establishment, and warranty.

Discussion

Based on the findings of this study, it was found that compared to the content of the FLL guidelines, North American green roof guidelines and standards are lacking in the areas of testing of system compatibility, guidance on slope application, guidance on filter fabrics, testing of postconstruction performance of fabrics, guidance on common material loads, postconstruction testing of bulk density, guidance and testing of root barriers, postconstruction testing of drainage materials and performance, guidance and testing of growth media, guidance for erosion control, and testing for plant establishment and general maintenance. Considering the content of the principal sources of guidance identified for North America, including ASTM, NRCA, ANSI/SPRI VF-1, and the WDGB documents, they begin to address most of the critical domains of knowledge for green roof design but lack the interconnectivity, comprehensive coverage, and detail on performance and testing requirements found in FLL Guidelines for the established purposes of this investigation.

There was found some general guidance for systems design but, in terms of adequately defining possible arrangements of green roof components, practitioners who venture off the path of FLL guidelines or vender-provided and -warranted systems have little guidance to work from and *assume liability for the success or failure of the green roof system.* This brings to light the need for advancement of systems design guidance. Perhaps this is one of the most difficult areas to advance given the complexity of interrelated components and adaptability across ecoregions. In the near future individual components of green roofs may become better understood and represented by guidelines and standards, but the understanding of how components work together as a sustainable system across North America's different ecological regions may not take place for a while.

The structural guidance for green roofs is probably the most advanced of the seven knowledge domains. The ASTM standard practice E 2397 requires material submittals that project weights of the entire green roof system in their dry and saturated states. The FLL Guidelines have no equivalent practice. The FLL, however, has some good guidance concerning design loads and provides common material loadings for green roofs. One consideration missing from all reviewed documents is the staging of materials on rooftops. A licensed structural engineer should guide the staging of materials during the green roof construction process. Construction of some green roof projects can become complex and precise staging of materials on roof decks is critical. Articulation of these considerations is currently missing from ASTM and FLL guidelines.

North American guidance on waterproofing for roof decks is well advanced, but guidance specific to green roof applications is limited. The NRCA manual provides some guidance for waterproofing and root barrier protection alternatives, but as a manual, it is difficult to make use of in municipal regulation. The WBDG specification provides some guidance on waterproofing and root protection with green roof systems as well, but there is no standard test for investigating materials that can be effectively used as root barriers for different types of plants. Many of the green roof system vendors on the market emerged out of the roofing industry and therefore knowledge of waterproofing for green roof systems is advanced and is beginning to be communicated but has yet to become specifically covered in guidelines and standards.

The remaining knowledge domains—drainage, growth media, vegetation, and maintenance—were found to have some support and guidance; however, much work is still needed. One aspect of drainage, for example, is covered in standard testing methods (E ASTM 2396 and 2398) for flow rates of water moving through drainage layers, but no guidelines exist to recommend specific ranges of permeability for different types of green roof systems. Drainage was identified as one of the problematic issues for many of the projects identified in Table 1. More research is needed to better understand the favorable conditions required for the different forms of green roofs such as succulent roofs, meadow roofs, and roof gardens across difference ecoregions. Drainage characteristics are also manifested in the qualities of growth media. Again, the North American documents lack communication regarding growth media composition and performance. The WBGD specifications provide some detail concerning composition and performance requirements for growth media; however, they only begin to outline some of the critical information that is found in the FLL Guidelines.

Although in the FLL Guidelines there is much useful direction for the design and construction of green roofs and roof gardens, its primary application is across Germany's generally homogeneous climate. North America is a large continent with a great diversity of ecological regions. A uniform standard or guideline may require understanding of local green roof research to be effectively applied across ecoregions. When considering succulent vegetation for extensive green roofs, for example, although the *Sedum* species is proving useful in many northern North American ecoregions, research in Florida at one research site (Livingston et al. 2004) demonstrated that some *Sedum* sp. may not be reliable in central Florida due to high nighttime temperatures and humidity (Livingston et al. 2004). To address these conditions, ecoregion-specific plant pallets and growth and drainage media will likely need to be developed for diverse ecological regions, as well as the growth media and drainage system requirements to support those plants. In light of these differences, regionally based green roof standards should be developed to address these differences. Much more research is needed to support the development of regionally based guidelines or standards. To further advance this

goal, North American green roof research should make reference to existing North American guidelines and standards as well as the FLL Guidelines as a way to provide a base reference or context to better understand the application of the research findings.

There are also new uses for green roof technology where the FLL Guidelines may provide little guidance, and therefore new guidance is needed. Emerging trends suggest that green roofs are being used to grow food, treat waste water, and provide other industrial uses (Banting et al. 2005; Brenneisen 2004; Cantor 2008; Chrisman 2005; Kortright 2001; Peck et al. 1999), but little is known about plants and substrate requirements for these uses. Modular and other types of unique green roof systems were not covered in FLL or North American guidelines. There is so little research regarding modular systems that performance is relatively unknown. These new directions highlight opportunities for green roof technology, but since guidance is lacking in these areas, their application should be considered experimental.

Evidence of the Successful Use of FLL Guidelines in North America

Several municipalities have embraced the FLL Guidelines. The city of Toronto, Ontario, has passed an ordinance for new flat roof construction to include green roof technology (Peck 2009). The FLL guidelines are cited and used throughout the Toronto guidelines for green roofs (Toronto 2010). The city of Chicago, Illinois, requires vender certification on public projects, where city guidelines are based upon the FLL Guidelines (Weston Solutions 1999). The Chicago City Hall Green Roof Urban Heat Island Pilot Project was designed to investigate urban heat island benefits of green roofs in Chicago and serve as testing grounds for green roof vegetation. During the project's planning phases, the city of Chicago produced a set of compliance guidelines for green roof system providers (Laberge 2003; Weston Solutions 1999). The green roof system installed on Chicago City Hall represents a German-based provider Optigrün system adapted to Chicago City Hall by Roofscapes, Inc.

FLL compliance was a fundamental requirement for system and component characteristics of the green roof (p. 17, Weston Solutions, 1999) including forms of and application of vegetation, growth media, drainage media, waterproofing, root barriers, maintenance, and fabrics. FLL Guidelines were found identified in multiple locations in the Weston report, "Urban Heat Island Initiative Pilot Project Final Report," and the Chicago Department of Environment's "Chicago Urban Heat Island Initiative City Hall Pilot Project Green Roof Installation, Part 2: Detailed Specifications (Feb. 2000)." There are other locations where FLL was not mentioned specifically, but elements were found to be in compliance or similar. Table 10 describes the green roof system components specified in the Weston report and is discussed next.

Vegetation

Plants used on the Chicago City hall green roof meet FLL guidance in several areas—first, by meeting recommendations for use of local or regionally adaptive plant material that is considered appropriate to the roof conditions, and, second, by acknowledging FLL growth media depths for different forms of green roofs. Since there are many species of prairie plants that are tolerant of drought and nutrient deprived soils, the native tall and short grass prairie ecosystems were inspiration for plant selection (Figure 2). More than 156 species of native and locally adaptive introduced plants were originally specified (Laberge 2003). Because there was little to no record of vegetation for extensive green roofs in Chicago at the time, the plant palette was considered experimental.

TABLE 10. Chicago City Hall Design Comparison with Content of the FLL Guidelines.

Attribute	**FLL Guidance** (References below are from the 2008 edition, and are carried over from the 1995 edition).	**Chicago City Hall** (references below are from *Weston Solutions,* 1999. The report made use of FLL 1995 edition)
• Vegetation	"Stock shall be well suited to conditions encountered, capable of self-propagation and should be of local or regional flora" (p. 15).	Plant list consisted of native and introduced species likely considered adaptable to the rooftop conditions (p. 19 and Tables 8-1a to 1d). Self-propagating native and introduced vegetation has thrived for one decade (Dvorak and Carroll 2008).
• Depth of growth media for vegetation	Extensive green roof systems: 10 to 15 cm for *sedum,* herbaceous-grass plants (Table 2, p. 43). Intensive (simple) green roof systems: 12- to 35-cm depth (Table 2, p. 43).	Extensive 9.6 cm depth for stonecrop, short grasses, and forbs (Table 5-1). Intensive (simple) 16.51-cm depth for medium grasses and forbs (Table 5-2). Most species also planted outside of their ranges to test adaptability. Big bluestem was found growing in 9.6-cm depths, well outside its expected range (Dvorak and Carroll 2008).
• Growth media	Chapters 7, 10, and 16 and Appendix 2 provide general and detailed characteristics for growth media.	"The physical and chemical properties of the growing medium must satisfy relevant FLL guidelines: bulk density, grain-size distribution, moisture capacity, permeability, and mineral and organic requirements" (p. 18).
• Drainage media	Chapters 7 and 8 and Appendix 2 provide detailed coverage of green roof drainage.	Generally described on p. 17 and Tables 5-7 where grain size and weight ranges are provided per FLL Guidelines.
• Waterproofing/ root barriers	Chapters 2, 5.4-5.5. Warrantees are generally not required in FLL.	15-year warranty for entire green roof system including prevention of water and root penetration of membranes.
• Fabrics	Chapter 9, Filter Course, describes various technical requirements.	"A thin filter layer is necessary to prevent growing medium from leaching into the drain layer… (p. 18 *Weston Report*), and provisions for erosion control (Standard Spec. ibid, p. 6).
• Maintenance	Requirements are covered in Chapters 12 and 13. Annual evaluation requires 80% plant coverage.	Report includes many activities included in FLL plus plant coverage at 80% survival by end of each 12-month period for 2 years.

Another critical FLL characteristic for vegetation includes recommended depths of growth media with general forms of greening (Figure 3). Plants were selected according to depth of media by plant physiology and were indentified in multiple tables in the report. Figure 3 here identifies the depth of green roof substrates. Shallow extensive (9.6 cm) and semi-intensive systems (16.51 cm) prevail, where only very small portions of intensive systems were possible (Dvorak 2009; Laberge 2003). Succulent green roofs in the FLL Guidelines for example, require shallow soils up to 10 cm, where grasses and forbs require deeper media depths over 12 cm. Chicago City Hall has 9.6-cm-deep extensive green roof systems, whereas the simple intensive systems are 16.51 cm deep (Figure 3). Experimental measures regarding growth media depth and plant form were also investigated. The same species selected for the simple intensive systems were extended across the extensive systems as a way to identify potential

species that may grow in shallow substrates. Over time most of the forbs and grasses that thrive in the simple intensive systems have a significantly reduced presence in the extensive systems. Although there are a few species lingering in protected areas where moisture is more consistently present, most of the forbs and grasses may become outcompeted by succulents. One anomaly is the persistence of *Andropogon gerardii* (Big bluestem) planted on two nonirrigated slow draining extensive roofs (Dvorak and Carroll 2008).

FIGURE 2. Simple intensive green roof system with prairie vegetation on Chicago City Hall Green Roof (photograph B. Dvorak, July 2004).

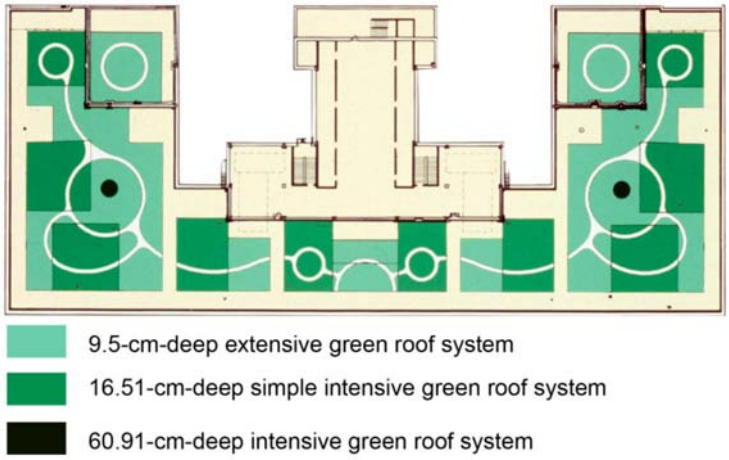
Growth and Drainage Media

Growth and drainage media properties are described in detail in several chapters of the FLL Guidelines as identified in Tables 6 and 7 (earlier). The Weston Report identified that growth media and drainage characteristics are to meet the FLL Guidelines and were specified in multiple tables with detailed ranges for performance. The drainage system characteristics that are detailed at length in FLL make reference to granular drainage systems used by Roofscapes, Inc. The growth media installed on Chicago City Hall was a proprietary media that met FLL specifications for permeability, granular distribution, chemical, and organic composition, as these qualities were required in the design (Weston Solutions 1999, p. 38).

Waterproofing/Root Barriers/Fabrics

Waterproofing in the FLL Guidelines is primarily redirected to DIN documents. Waterproofing membrane protection from root intrusion in FLL is defined in the appendix, but in the Weston Report a sample specification was included and requires green roof system providers to warranty green roof system and all waterproofing and root barrier systems for 15 years. FLL discusses green roof fabrics and geotextiles in Chapter 9. The Weston Report mentions fabrics as a functional component of the green roof system but does not make specific value reference to FLL or its content.

FIGURE 3. Chicago City Hall Green Roof Systems Plan (Weston Solutions Final Report, 1999).



Maintenance

Green roof maintenance requirements vary by project and are discussed in the FLL Guidelines in Chapters 13 and 16 and Appendix 2. The Weston report defines similar maintenance activities for plant and moisture maintenance. The Weston report requires 80% plant coverage by the end of 12 months, and FLL requires 80% coverage by 12 to 15 months. A survey of plant vegetation was conducted at the end of the first growing season on Chicago City Hall and estimated plant cover met the 80% coverage requirements (Dvorak and Carroll 2008).

Although the Chicago City Hall roof garden is an example of the successful application of FLL Guidelines to North America, its plant systems were damaged by heat and drought stress in the second growing season as drought affected Chicago prior to the completion of the irrigation system. A new city-led maintenance team resolved several complex maintenance issues only after several years of experimental work (Dvorak and Carroll 2008). The garden now receives fulltime maintenance and is managed as a prairie garden with annual removal of previous year's growth, eradication of invasive species, in-fill and interplanting of new species, and periodic irrigation (Dvorak and Carroll 2008).

CONCLUSIONS

Based upon the findings of this study, it is was found that compared to the FLL Guidelines, North American green roof guidelines and standards are lacking in areas of *compatibility of system components, slope application, filter fabrics, root barriers, surface and subsurface drainage, growth media, and erosion control, as well as standards or postconstruction testing requirements for fabrics, bulk density of growth media, root barrier performance, drainage media, and growth media.* As green roofs are becoming known for their multiple benefits such as building life-cycle efficiencies, stormwater, urban heat island, energy, and wildlife habitat mitigation (Oberndorfer et al. 2007) and incentivized or required, municipalities may need comprehensive coverage of green roof performance expectations for effective application and regulation. What are the growth media, drainage, and irrigation performance requirements for different forms of green roofs most suited across different ecoregions? Without detailed guidance in these areas, the FLL Guidelines may need to play a larger role in the design, construction, and maintenance of green roofs in North America until more local evidence can be developed to support such guidelines.

Interdisciplinary research and development are needed from the green roof industry and government agencies to help accelerate these goals, not just for the development of guidelines and standards but also for the long-term realization of green roof benefits in urban centers. The potential gains from the application of green roof technology across North America look bright, but there is a current void in performance guidelines and standards that are needed to support its regulation and governance.

REFERENCES

ANSI/SPRI VF-1. (2010). "External Fire Design Standard for Vegetative Roofs." American National Standards Institute, Waltham, MA, 8.

ASTM E 2396. (2005). "Standard Test Method for Saturated Water Permeability of Granular Drainage Media [Falling-Head Method] for Green Roof Systems." ASTM International, West Conshohocken, PA, 4.

ASTM E 2397. (2005). "Standard Practice for Determination of Dead Loads and Live Loads Associated with Green Roof Systems." ASTM International, West Conshohochen, PA, 4.

ASTM E 2398. (2005). "Standard Test Method for Water Capture and Media Retention of Geo composite Drain Layers for Green Roof Systems." ASTM International, West Conshohochen, PA, 4.
ASTM E 2399. (2005). "Standard Test Method for Maximum Media Density for Dead Load Analysis of Green Roof Systems." ASTM International, West Conshohochen, PA, 4.
ASTM E 2400. (2006). "Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roof Systems." ASTM International, West Conshohochen, PA, 4.
Banting, D., Doshi, H., Li, J., Missios, P., Au, A., Currie, B. A., and Verrati, M. (2005). "Report on the Environmental Benefits and Costs of Green Roof Technology for the City of Toronto." City of Toronto and Ontario Centers of Excellence--Earth and Environmental Technologies, Toronto.
Beattie, D., and Berghage, R. (2004). "Green Roof Media Characteristics: The Basics." The Second Annual Greening Rooftops for Sustainable Communities Conference, The Cardinal Group, Portland, OR, 411-416.
Beattie, D., and Berghage, R. D. (2008). "Designing Green Roof Growing Medium." *ASTM & FLL Standards Workshop at the Sixth Annual International Greening Rooftops for Sustainable Communites Conference, Awards and Trade Show,* Baltimore, MD, 13-20.
Brenneisen, S. (2004). "From Biodiversity Strategies to Agricultural Productivity." The Second Annual Greening Rooftops for Sustainable Communities Conference, The Cardinal Group, Portland, OR, 10.
Cantor, S. (2008). Green Roofs in Sustainable Landscape Design, Norton, New York, NY.
Carey, P. (2005). "If the Only Tool You Have Is a Hammer, Every Problem Looks Like a Nail or Every Tool Is a Hammer." www.greenroofs.com.
Chrisman, S. (2005). "Green Roofs Ecological Design and Construction." Schiffer, Atglen, PA, 158.
Dvorak, B. (2009). "The Chicago City Hall Green Roof Pilot Project: A Case Study." Paper presented at the Third International Conference on Smart and Sustainable Built Environments. From Building to Promise Building Smartly in a Changing Climate, CIB-International Council for Research and Innovation in Building and Construction, ed., Delft Technical University, Delft, Netherlands, 8.
Dvorak, B., and Carroll, K. (2008). "Chicago City Hall Green Roof: Its Evolving Form and Care." The Sixth Annual International Rooftops for sustainable Communities Conference, Cardinal Group, Toronto, Baltimore, MD, 10.
Dvorak, B., and Volder, A. (2010). "Green roof vegetation for North American ecoregions: A literature review." *Landscape and Urban Planning,* 96(4), 197-213.
Eisenman, T. (2006). "Raising the Bar on Green Roof Design." Landscape Architecture, American Society of Landscape Architects, Washington D. C., 6.
Factory Mutual. (2007). "FM Global Property Loss Pervention Data Sheets: Green Roof Systems."
Federal Energy Management Program. (2004). "Federal Technology Report: Green Roof Systems."
FLL. (2008). "Guidelines for the Planning, Construction and Maintenance of Green Roofing." Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e. V., Bonn, Germany, 119.
Graham, M., S. (2009). "Building Code Compliance for Green Roof Systems." Greening Rooftops for Sustainable Communities Conference , Awards, and Trade show, The Cardinal Group, Atlanta, GA, 10.
Green Roofs for Healthy Cities. (2010). "Green Roof Industry Grows 16.1 per cent in 2009 Despite Economic Downturn." Green Roofs for Healthy Cities.
Köehler, M., and Keeley, M. (2005). "Berlin, Green Roof Technology and Policy Devleopment." Green Roofs: Ecological Design and Construction, Schiffer Publishing, Atglen, PA, 108.
Kortright, R. (2001). "Evaluating the Potential of Green Roof Agriculture." City Farmer, Toronto, pp. 17.
Laberge, K. (2003). "Urban Oasis: Chicago's City Hall Green Roof." The First North American Green Roof Infrastructure Conference: Greening Rooftops for Sustainable Communities, Green Roofs for Healthy Cities, Chicago, IL, 10.
Livingston, E. H., Miller, C., and Lohr, M. (2004). "Green Roof Design and Implementation in Florida." The Second Annual Greening Rooftops for Sustainable Communities Conference, The Cardinal Group, Portland, OR, 11.
Loveland, S. (2010). "Green Roof Incentives + Partnerships -The 2010 Resource Guide." EPA Webcast: Implementing Green Roofs at the Local Level, US EPA, Washington, D.C.
Miller, C., and Narejo, D. (2005). "State of the Green Roof Industry in the United States." *Geosynthetics Research and Development in Progress (GRI 18),* Austin, TX, 22-22.
Mishra, A. (2004). "Canadian Public Policy and Green Roofs: Moving from Policy to Practice." The Second Annual Greening Rooftops for Sustainable Communities Conference, The Cardinal Group, Portland, OR, 17.

Ngan, G. (2004). "Green Roof Policies: Tools for Encouraging Sustainable Design." Support from Landscaep Architecture Canada Foundation.
NRCA. (2007). *The NRCA Green Roof Systems Manual—2007 Edition,* National Roofing Contractors Association, Rosemont, IL.
Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R., Doshi, H., Dunnett, N., Gaffin, S., Köhler, M., Lui, K., and Rowe, B. (2007). "Green Roofs as Urban Ecosystems: Ecological Structures, Functions, and Services." *Bioscience* 57(10), 823-833.
Osmundson, T. (1999). *Roof Gardens – History, Design and Construction,* W.W. Norton & Company, Inc., New York, NY.
Palandino & Company. (2006). "King County Green Roof Case Study Report." King County Department of Natural Resources & Parks, Seattle, WA.
Peck, S. (2009). "Toronto City Council Adopts Mandatory Green Roof Requirements." Green Roofs for Healthy Cities,, Toronto, 1.
Peck, S. W., Callaghan, C., Kuhn, M. E., and Grass, B. (1999). "Greenbacks From green roofs: forging a new industry in Canada." Peck & Associates, Toronto, ON.
Philippi, P. M. (2005). "Introduction to the German FLL-Guildeline for the Planning, Execution, and Upkeep of Green-Roof Sites." The Third Annual Greening Rooftops for Sustainable Communities Conference, The Cardinal Group, Washington, D. C., 7.
Seeger, H., and Ansel, W. (2004). "Key Factors in Successful Green Roof Training." Green Roofs in Puerto Rico and the Caribbean.
Shackford, K. (2008). "Not All Green Roofs are Green: Green Roof Lessons Learned in the Bronx (poster)." *The Sixth Annual International Rooftops for sustainable Communities Conference,* Baltimore, MD, 1.
Simmons, M., Gardiner, B., Windhager, S., and Tinsley, J. (2008). "Green roofs are not created equal: the hydrologic and thermal performance of six different extensive green roofs and reflective and non-reflective roofs in a sub-tropical climate" *Urban Ecosystems,* 11(4), 339-348.
Snodgrass, E., and Snodgrass, L. (2006). *Green Roof Plants,* Timber Press, Portland, Oregon.
Toronto, C. o. (2010). "Toronto Green Roof Construction Standard Supplementary Guidelines." Office of the Chief Building Official, Toronto Building, City of Toronto, Toronto, Ontario, 26.
Velazquez, L. (2010). "Green Roofs Database-City of Chicago-December 23, 2010." Greenroofs.com.
WBDG 07 33 63 (Section 02930). (2007). "Whole Building Design Guide Federal Green Construction Guide for Specifiers." Vegetated Roof Covering Section 07 33 63 (Section 02930), National Institute of Building Sciences, Washington, D.C., 10.
WBDG 07 55 63 (Section 07530). (2007). "Whole Building Design Guide Federal Green Construction Guide for Specifiers." Vegetated Protected Membrane Roofing Section 075563 (Section 07530), National Institute of Building Sciences, Washington, D.C., 5.
Weiler, S. K., and Scholz-Barth, K. (2009). *Green Roof Systems: A Guide to the Planning, Design, and Construction of Landscapes over Structure,* John Wiley & Sons, Inc., Hoboken, New Jersey.
Werthmann, C. (2007). *Green Roof: A Case Study: Michael Van Valkenburgh Associates' Design For the Headquarters of the American Society of Landscape Architects,* Princeton Architectural Press, New York, NY.
Weston Solutions. (1999). "Final Report Urban Heat Island Initiative Pilot Project." Weston Solutions.