Research at the British Columbia Institute of Technology's Centre for Architectural Ecology
Advancing Living Architecture

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1. The Green Roof Research Facility (Photo: Maureen Connelly, BCIT).

Extensive green (vegetated) roof systems have proven beneficial in addressing climate change and energy efficiency (Eumorfopoulou and Aravantinos 1998; Wong et al. 2003; Takahashi et al. 2004; Connelly et al. 2006), and other key environmental issues such as stormwater mitigation (VanWoert et al. 2005; Mentens et al. 2006), urban noise pollution (Van Renterghem and Botteldooren 2008; Yang et al. 2010), air quality (Yang et al. 2008; Getter et al. 2009), biodiversity (Gedge and Kadas 2005), and habitat and urban ecological restoration (Brenneisen 2006; Calkins 2005). These systems differ from traditional rooftop gardens with a shallower substrate depth, a reduced plant palette, and establishment and maintenance strategies to support what are ideally non-irrigated systems.

This article summarises the incentives for regional research and the research infrastructure at the British Columbia Institute of Technology (BCIT) and its Centre for Architectural Ecology, and highlights industry and community collaborations and curricula to support the advancement of green roofs and walls and student-based research projects.

Incentive for Research

Building sustainable communities presents exciting new opportunities for the widespread use of green roofs. With growing awareness of environmental preservation and sustainable development, Canada's building and construction industries are redefining themselves to address the needs of regional and global sustainability. Within British Columbia, there is a strong interest in green roofs, which is attributed to the favourable climate and the environmental strategies and policy directions of the municipal and regional governments. Vancouver has had an established inventory of successful intensive rooftop gardens, whereas in the early 2000s, extensive green roof systems based on western European guidelines were novel.

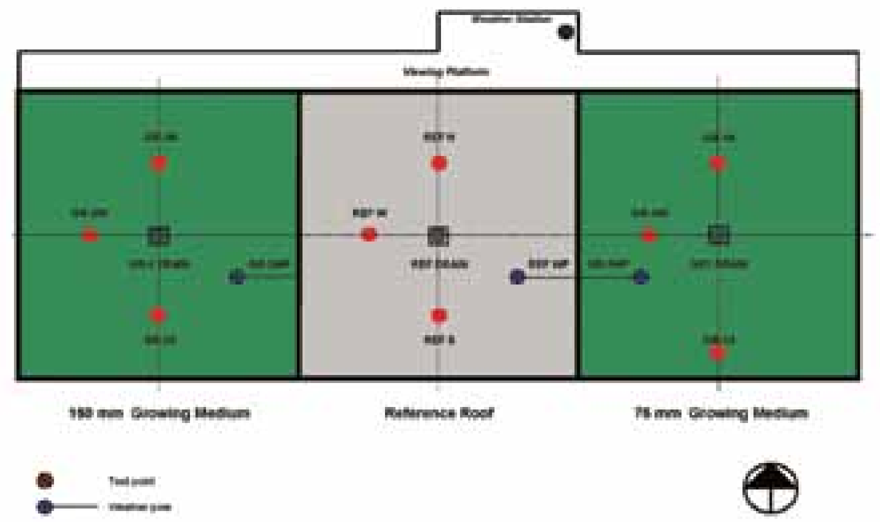
In 2002, Green Roofs for Healthy Cities and a regional industry and inter-governmental consortium held a stakeholder workshop in Vancouver. The participants concluded that although green roofs had been widely adopted elsewhere in Europe, more technical research was required to understand the site-level performance and regional-scale benefits of green roofs specific to Canada's west coast. Further, such research is critical to establishing standards, policies, and programmes to support broader implementation (Green Roof Workshop 2002).

The performance of extensive green roofs was expected to be unique in coastal British Columbia compared to other parts of Canada and the rest of the world because of its unique rainforest climate. Environment Canada Climate Normals for Vancouver (harbour) record the daily mean temperature as 11 degrees Celsius and annual precipitation as 1589 millimetres, with annual snowfall at only 44 millimetres. The stakeholders identified the major barriers to the implementation of extensive green roofs in the region as the following: the lack of climate specific performance data; the absence of third-party testing and verification of green roof systems; and a lack of demonstrated feasibility. The conclusion of the 2002 workshop was the impetus for the BCIT Green Roof Research Program, which led to the establishment of the Centre for Architectural Ecology (hereafter referred to as "the Centre") and the Green Roof Research Facility (hereafter referred to as the "Research Facility").

Research Infrastructure

The Research Facility (Fig. 1) was constructed and commissioned in 2003 as a field test site to provide demonstration and performance data on green roofs and living walls for the greater Vancouver region, and became the hub for the green roof industry and research in Western Canada. The Research Facility is a 100-square-metre building with three independent roof surfaces (one reference roof and two green roofs) that has produced over 10 years of research, in particular on stormwater source control and thermal performance (Fig. 2). Additional research has provided data on acoustics (sound transmission, absorption, and impact isolation), plant viability, maintenance of green roofs, and the rainwater interception capacity of green façades. A regional infrastructure network was also established to evaluate the performance of green roofs and walls in other parts of the province. This network was facilitated by municipal and regional governments and includes the White Rock Operations Centre, the Electronic Arts Motion Capture Studio in Burnaby, and the Capital Region District Headquarters in Victoria (Fig. 3, 5 and 7). At the Research Facility, the roofing evaluation modules (REMs) (Fig. 4) simulate a consistent indoor environment and gather real-time climate-specific performance data; one REM serves as a reference. Some of the REMs have been moved to alternative locations, such as northern Alberta, to investigate the performance of green roof systems in colder climates. There is also a sound transmission facility (Fig. 8) that was built to quantify the transmission loss of green roofs.

In addition to the Research Facility, a 1,300-square-metre Elevated Lab (Fig. 6 and 9) was built in 2007 at BCIT's main campus in Burnaby and has also been used for research purposes, specifically looking at the acoustical characteristics and viability, establishment, and maintenance of green roof plants. The Centre is currently developing the Elevated Lab to expand the functionality of the original Research Facility and to expand the Centre's activity to the BCIT community on the main campus. The Elevated Lab will be used for educational tours and to coordinate knowledge transfer activities, ultimately giving students the opportunity to engage in innovative research while providing a link between the classroom and the industry. In addition, the Elevated Lab will highlight and present all of the research that the Centre has done over many years and will act as a solid base to start new research projects to continue building knowledge regarding living architecture technologies that are urgently needed in our cities. Students will

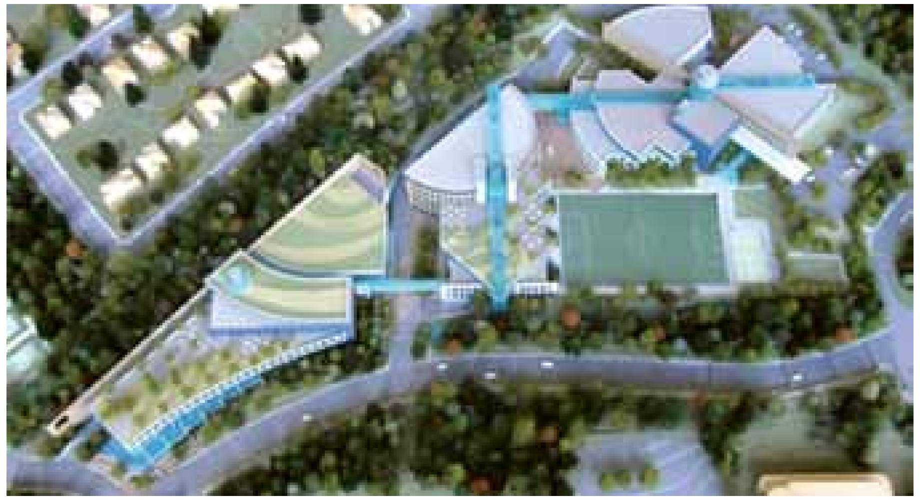


2. Schematic roof plan of the Research Facility showing the location of the green roofs (GR-1 and GR-2), instrumentation, weather poles (WP), and weather station

be able to learn in a unique "out of-class" environment and take the knowledge they gain and apply it worldwide.

The green roof research and resource demonstration programmes at BCIT were designed to better understand and communicate the many public and private benefits of green roofs. Findings from the Research Facility have provided data on the beneficial effects of reduced substrate depths for stormwater mitigation and thermal performance (Connelly et al. 2006). The data obtained is useful in determining the cost benefits of green roofs based on reduced energy consumption. The research findings are directly applicable to the future densification of the Lower Mainland, and could be applied to other metropolitan areas. In addition, the research findings contribute to the calibration of a development-scenario modelling tool, which was developed for the restoration and protection of the regional watersheds. This important research initiative has provided industry and educational resources for the design, building, and maintenance of green roofs.

The findings from novel research projects propose a framework to embed the new qualitative and quantitative knowledge of the acoustical characteristics of vegetative roofs into the architectural design process. The research findings quantitatively define green roofs as an acoustical solution for the control of noise and inform the architectural design process about the capacity of green roofs to increase the sustainable and liveable use of rooftops (Connelly 2011) (Fig. 11 and 12). Vegetative roofs simultaneously embrace and contribute to the contextual soundscape, allowing designers and users to realise an increase in the aural quality of place, both inside buildings and up on the rooftops. Research on plant viability has shown which are the plant communities that provide the best options for a low-maintenance, healthy, viable community in the Pacific Northwest region (Connelly and Rousseau 2013). Findings from a study on the rainwater interception capacity of green façades inform designers of appropriate details of green façades in coastal rainforest regions that receive large amounts of rainfall (unpublished results).



3. Extensive green roof on the Electronic Arts Motion Capture Studio (Photo: Electronic Arts).

4. Roofing evaluation modules (Photo: BCIT).

5. Extensive green roof on the White Rock Operations Centre (Photo: Kerly Acosta, BCIT).

Industry and Community Connection Projects

Industry partnerships have helped to advance green roof research at BCIT and to increase the adoption of green roof and living wall technology in western Canada. There have been several successful industry partnerships that have helped with BCIT's educational mandate, provided demonstration resources, enabled third-party product testing, and supported academic student scholarships. BCIT has benefited from industry and government involvement and relationships; other cities would benefit from a tri-party (public and private) mandate to encourage and expand the adoption of green roof and wall research. A dedicated research facility in association with a regional infrastructure network would also help to increase demonstrations and research, academic rigour, and the uptake of green roof and wall technologies. It is also important to be responsive and adaptable to the evolving needs of the specific region in which the research is being conducted.

BCIT has provided support to other academic institutions and municipalities for the development of specific green roof research programmes and has participated in a number of green roof industry events, including the United Nations World Urban Forum in 2008. BCIT co-hosted the Cities Alive Green Roof and Wall Conference in 2010, and hosted three trade workshops with the industry on research, policy, and education. The Centre recognises that, in order to advance sustainable construction technologies, a multi-tiered approach that incorporates ongoing industry collaborations and educational programmes is needed.

Industry partners have provided different green roof systems and products for the REMs to evaluate stormwater mitigation, thermal performance, and plant viability; these systems and products include vegetation, drainage mats, growing medium, water retention systems, and maintenance programmes. The REMs provide useful information about the effects of a specific green roof system on the building and surrounding area to manufacturers, architects, landscape architects, developers, and community planners. Benefits from the testing and verification of these different systems and products include comparative performance data, quantitative third-party verification, increased market confidence, and an optimised return on investment.

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The Research Facility and Elevated Lab were developed in collaboration with government funding (Natural Sciences and Engineering Research Council of Canada, Western Economic Diversification Canada, and the National Research Council of Canada), provincial institutions and associations (Investment Agriculture Foundation of British Columbia and the British Columbia Landscape and Nursery Association), and industry partners (GreenScreen, ModuloGreen, Soprema, Architek, and Zinco), as well as collaborations with other Canadian academic institutions.

Curriculum

As Canada's premier polytechnic institution, BCIT supports the green roof industry in western Canada through leading-edge curriculum developed by the Centre. BCIT embraces innovative teaching practices to enhance students' experiences and provide unique learning environments. The Centre is dedicated to improving local and global awareness and knowledge of green roof and living wall systems through education and demonstrations. Research and technology transfer are integrated through the diploma and degree programmes, as well as through academic collaborations and professional development.

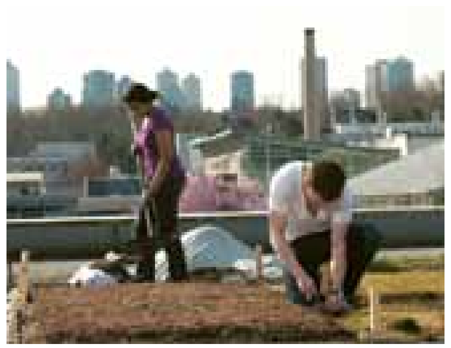
Students in undergraduate programmes, such as Architectural and Building Engineering Technology (ABET), make use of the Centre for research projects and hands-on experiences and workshops. Faculty members from the Centre deliver lectures across a multitude of disciplines, such as ABET, civil engineering, sustainable resource management, building science, and interior design, as well as for the Centre for Interactive Research on Sustainability and the School of Architecture and Landscape Architecture at the University of British Columbia.

The courses focused on green roof and wall education at BCIT include Green Roofs and Walls (GROW) 0001 (Green Roofs – Concepts, Systems, and Incentives), GROW 1000 (Green Roofs – Details, Installation,

6. Landscaping on the Elevated Lab (Photo: Nicolas Rousseau, BCIT).

7. Living wall on the Capital Region District Headquarters in Victoria (Photo: Maureen Connelly, BCIT).

8. Sound transmission facility (Photo: Maureen Connelly, BCIT).



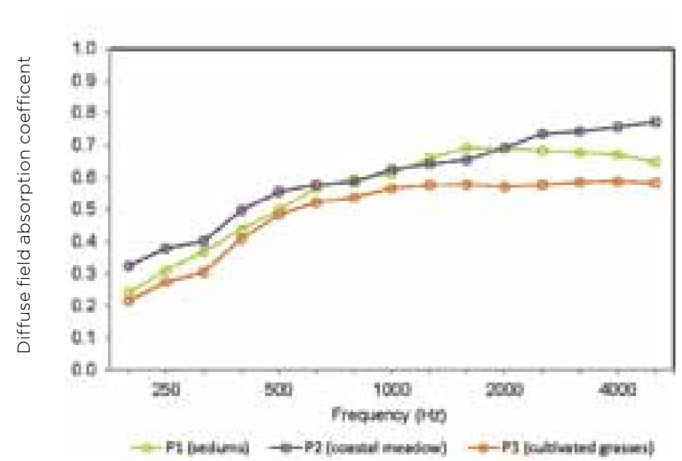
9. Landscaping on the Elevated Lab (Photo: Scott McAlpine, BCIT).

10. Berm Project, a 30-square-metre green roof plot on the Elevated Lab (Photo: Maureen Connelly, BCIT).

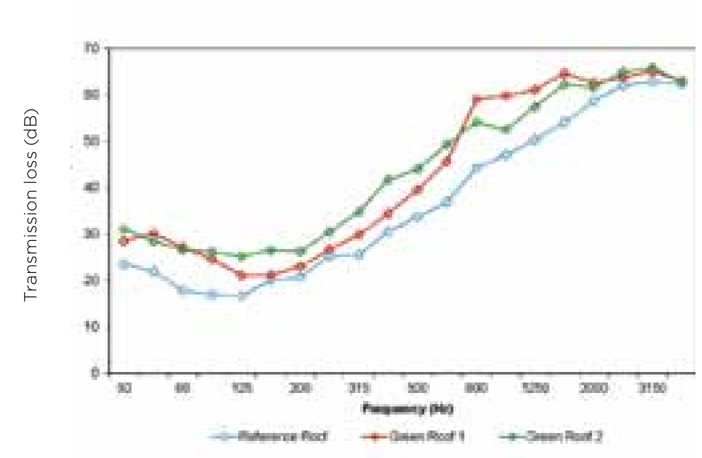
and Maintenance), GROW 1500 (Green Walls), GROW 2000 (Green Roofs – Planting in the Pacific Northwest), and GROW 3000 / ARSC 8210 (Green Roofs and Living Walls for Environmental Solutions). In GROW 0001, students learn about the basics of green roofs and walls, the different types of green roof and wall systems and materials, and appropriate vegetation. GROW 1000 and GROW 1500 provide students who already have a basic understanding of green roofs with the knowledge to determine the appropriate green roof and wall system, design performance criteria, and installation and maintenance methods. In GROW 2000, students learn the role of green roofs in the conservation of biodiversity in urban environments and explore an ecological approach to plant selection and design. GROW 3000 / ARSC 8210 involves a course project in which the construction and implementation of green roof technology are applied and evaluation of the cost and contribution to sustainable development is facilitated. As part of the GROW courses, students tour the Research Facility and integrate the lectures with practical hands-on activities. The GROW courses are of interest to a diverse group, including planners, design professionals, contractors, and the building industry. Approximately 770 students have completed the GROW courses since their conception in 2006.

Opportunities exist for undergraduate students in the interdisciplinary research area of architectural ecology through the Cornelia Hahn Oberlander scholarship and research grant. Research projects are defined by a primary investigator at the Centre and aligned with current and future research. One student's project focused on the connectivity of a publicly inaccessible green roof at a public library in downtown Vancouver, specifically regarding the introduction of elevated planes to the public realm to increase liveability in dense urban centres and skypark corridors to connect rooftops. The library's rooftop has the potential to facilitate connectivity with nature and surrounding buildings. The Berm Project, a three dimensional 30-square-metre green roof plot located on the Elevated Lab (Fig. 10), explores numerous slopes and both the technological and connective implications through hands-on, industry-relevant experience. Using lessons learned from the Berm Project, redevelopment of the library rooftop was proposed to create an occupied space or habitat on the rooftop and to enhance urban connectivity through physical and sensory relationships (Green Roof and Walls Virtual Summit 2013; Bergen 2012).

Opportunities exist for Master's level graduate students in the Master of Applied Science or Master of Building Engineering programmes. Examples of such opportunities include the *Sound Living in Vancouver's Laneway Housing* and *Indoor Environmental Quality of Living Walls* projects. The Sound Living project addresses a research gap connecting building acoustics to health science in Canada. The goal of this project is to ensure that the frameworks for laneway housing and sound living are compatible, reinforce each other, and support Vancouver's Ecodensity Initiative. In collaboration with University of British Columbia, the Indoor Living Wall project addresses the effects of three diverse living wall systems on indoor environmental quality, including effects on levels of volatile organic compounds, carbon dioxide, endotoxins, sound absorption, and noise reduction, and on room-level relative humidity, as it may affect building materials. CG



11. Measured absorption coefficients of three plant communities (in substrate depths of 125 to 200 mm) after two seasons of establishment



12. Measured transmission loss of three roofs at the Research Facility

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