University of British Columbia

Social Ecological Economic Development Studies (SEEDS) Sustainability Program

Student Research Report

Ecological Connectivity – Soft landscape design proposal for the dead points on the UBC campus

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Prepared for:

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Abstract

Human activities have changed the ecological function and structure of the environment, and the fragmented green space has reduced the ecosystem services. Therefore, it is very necessary to strengthen the connection between green spaces and create new soft landscapes so as to increase fauna habitats and improve the connection among habitats with high species richness and ecological potential. This report will analyze the isolated soft landscapes on the University of British Columbia (UBC) Vancouver campus that cannot connect to surrounding green spaces and then put forward effective soft landscape intervention schemes according to the current conditions of each site. Finally, we will visually present the comparison before and after implementing soft landscape interventions through GIS maps. The presented results of the GIS maps show that after the interventions are added near these isolated soft landscapes, all soft landscapes on campus overlap each other after adding a 10m buffer, which means that the connectivity among soft landscapes has been improved.

Keywords: Ecological connectivity, Soft landscapes, Urban pollinators, Biodiversity, GIS

Acknowledgment

We would like to acknowledge that we are gathered today on the traditional, ancestral, unceded territory of the Musqueam people.

And to express our special thanks and gratitude to the teaching team as well as SEEDs for giving us the opportunity to finish this project and helping us during the semesters.

Introduction

Problem statement

With the development of cities and population density growth, urban green spaces are becoming fragmented (Nor et al., 2017). Fragmentation can reduce ecological connectivity (Nor et al., 2017), degradation of ecosystem functions, and depletion of ecosystem services (Mimet et al., 2013). Connecting fragmented green spaces on campus through soft landscapes can support critical ecological functions such as soil water mitigation, soil enrichment and population dynamics promotion. A previous connectivity analysis by Social Ecological Economic Development Studies (SEEDs) has studied the proximity of one soft landscape to another on the UBC campus, using GIS software to apply a ten-meter buffer zone to existing soft landscapes on the UBC campus. And has identified 'dead points' (Figure 1), which refers to the 'isolated' soft landscapes whose 10-meter buffer does not overlap or is in contact with the buffer zone of the surrounding soft landscape (Mantegna, 2021). We want to understand realistic interventions that can be implemented at dead point locations to improve structural and ultimately functional ecological connectivity.

Figure 1. GIS map completed in a previous project by SEEDs. The red and green dots showing the location of soft landscapes on campus and black lines means their connectivity.

Ecological Connectivity

Enhancing ecological connectivity is crucial for many ecological and evolutionary processes, including dispersal (Newton et al., 2012), gene flow, demographic rescue, and mitigation of negative effects of climate change (McRae et al., 2012).

Ecological connectivity, which is defined as "the extent to which the landscape promotes or hinders the movement between resource patches" (Taylor et al., 1993), is usually described in terms of structural or functional connectivity from low to high (Taylor et al., 2006). Structural connectivity refers to the physical configuration of a landscape and is often measured using metrics such as habitat size and distance to the closest habitat (LaPoint et al., 2015). In contrast, functional connectivity is the behavioral response of an organism as it disperses throughout the surrounding environment (Taylor et al. 2006). However, structural connectivity only describes the physical relationship (e.g., distance) between habitat patches, ignoring the biological and behavioral response to landscape structure (Taylor et al. 2006). Therefore, it is significant to consider both these two aspects of ecological connectivity in our project.

Ecological connectivity could be affected by large areas of pavement, impermeable surfaces of parking and buildings which might increase threats to habitat loss and reduce the biodiversity in cities. Unconnected soft landscapes are potentially harmful to the health of the soil underneath because many ecosystem services, such as water regulation and plant growth support, are mainly provided by urban soils, depending on their physical, chemical, and biological properties (Maréchal et al., 2021).

However, there are also some opportunities affecting the creation of soft landscapes for ecological connectivity. For instance, the site is a potential habitat for animals, especially species with low dispersal ability (Kowarik, 2011), or it has a potential biotic dispersal vector (e.g., birds) (Kimberley et al., 2020); the site has low human activities, and high species richness (Muller et al., 2013); Or the site is close to surrounding soft landscape patches which provide opportunities for establishing corridors to connect two or more habitats (Doerr et al., 2014).

Project Goals

The goals of this paper are to (1) Investigate the potential for soft landscape interventions to improve connectivity through a comparative analysis of the surrounding environments of previously identified 'dead points,' including how they are currently used, what functions they serve, and their ecological features; (2) Identify soft landscape interventions that can benefit ecological connectivity based on a range of factors that are found at these 'dead point' locations through literature and precedent review; (3) Use a cost-benefit (both ecological and monetary) analysis to evaluate the feasibility of these interventions at a selection of 'dead point' sites and use it to recommend strategies to improve connectivity.

Methods

On-site visit

To better understand the characteristics of each site, we went to five dead point sites on February 8th to observe and analyze the existing soft landscape conditions in each site, their surrounding environment, potential animal species, etc.

Literature review

To get the knowledge of factors related to ecological connectivity and provide the UBC campus with more realistic suggestions for soft landscape planning, we have conducted a bunch of literature reviews and precedent studies, engaging the knowledge from the perspective of ecology to landscape architecture. We mainly identify and screen literature from UBC Library and Google Scholar. All searches were conducted in English, covering the publication years from 1993 to November 2021. We also look back on the policies and plans that have structured the ecological environment of the UBC campus to fully understand the context of soft landscape planning.

Production of visual presentation

We used Sketchup and Enscape to build simple 3D models to illustrate how the five sites will appear after implementing our interventions. Also, we downloaded relevant datum from UBC Geodata according to the GIS method mentioned in the previous project of SEED and used QGIS software to analyze the ecological connectivity that could be obtained after implementing our interventions and displayed them on a map (Mantegna, 2021).

Results

Site evaluation

The seven ‘dead points’ of our project are scattered in the south of the campus, but they are basically divided into five groups according to the location and distance (Figure 2).

Based on our on-site observation, we found the ‘dead point’ in site 1 is a small yard planted with two well-grown trees - Southern magnolia (*Magnolia grandiflora*) and Paperbark maple (*Acer griseum*). On site 2, there is a large planting bed cluttered with some Rosa shrubs and Winterberry (*Ilex verticillata*). Site 3 is a large planting area planted with some small Paper Birchs (*Betula papyrifera*) and tangled vines and thorns around them; however, this soft landscape is mostly covered with gravel and pressed by large containers rather than exposed soft soil. The soft landscape in site 4 is a planting strip with shrubs and a small young known tree. And in site 5, the two ‘dead points’ are less-maintained grassy planting beds with no woody plants (Table 1).

Through analyzing the surrounding environment of each site, it can be found that buildings, parking lots, and hard surfaces are the biggest obstacles to structural connectivity of soft landscapes, which caused lacked connectivity of dispersal space for birds, pollinators, and other animals. However, there are also some opportunities; some sites have nearby green patches that can be connected through the new soft landscape design, although they are more than 10m apart. Also, some ‘dead points’ have potential food and nest resource for pollinators and birds since there are flowering shrubs present (Table 2).

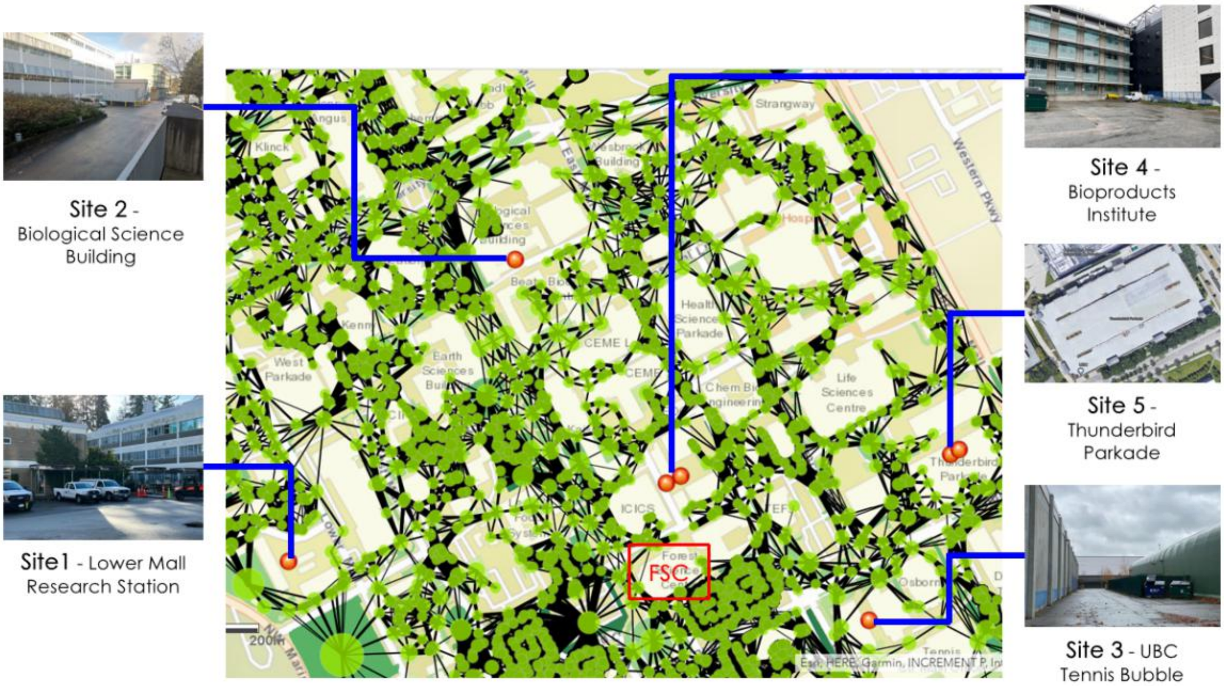


Figure 2. Map shows the location of seven studied ‘dead points’ and five sites.

Site Number	Location	Existing Soft Landscapes	Surrounding Environment	Potential Fauna species
1	East of the lower mall research station	A small yard planted with two well-grown and well-maintained trees	✧ Near a parking lot ✧ Surrounded by dense buildings	**Birds：** ✧ Common Raven ✧ Rufous Hummingbird **Insects：** ✧ Honey Bee ✧ Bumble Bee ✧ Wasp ✧ Butterfly
2	South of the biological science building	A planting bed cluttered with a large number of shrubs	✧ Near a parking lot ✧ Blocked by surrounding buildings	**Birds：** ✧ Rufous Hummingbird ✧ American Robin ✧ Varied Thrush **Insects：** ✧ Honey Bee ✧ Bumble Bee ✧ Wasp ✧ Butterfly
3	Between the UBC tennis bubble and Osborne center	✧ A large planting area planted with some small trees ✧ Tangled vines and thorns around the tree ✧ Most of the surface is covered with gravel and pressed by large containers	Surrounded by hard surfaces	**Birds：** ✧ Common Raven **Others：** ✧ Squirrels
4	North of the bioproducts institute	A planting strip with shrubs and a small young tree	✧ Near a parking lot ✧ Surrounded by buildings	**Birds：** ✧ Common Raven ✧ Rufous Hummingbird ✧ American Robin ✧ Varied Thrush **Others：** ✧ Squirrels **Insects：** ✧ Honey Bee ✧ Bumble Bee ✧ Wasp ✧ Butterfly
5	Roof-top of the thunderbird parkade	Two grassy planting beds but without any woody plants	✧ Surrounded by hard surface ✧ Some nearby grassy planting beds	**Birds：** ✧ Common Raven ✧ Western Gulls **Insects：** ✧ Bumble Bee ✧ Wasp

Table 1. Summarizing table of the location, existing soft landscapes, surrounding environment and potential fauna species of each site.

	Factors		Associated Sites				
			Site 1	Site 2	Site 3	Site 4	Site 5
Challenges	Structural connectivity	Blocked by buildings	☆	☆	☆	☆	
		Near a parking lot that with high vehicle passing frequency	☆	☆		☆	☆
		Impermeable surface	☆	☆	☆	☆	☆
	Functional connectivity	Lack of networks for the dispersal space of pollinators and birds	☆	☆	☆	☆	☆
Opportunities	Structural connectivity	Close to the nearby soft landscapes		☆	☆		☆
		Low frequency of human activity			☆		
	Functional connectivity	Potential food and nest resource for pollinators and birds	☆	☆		☆	
		Potential resilience of the landscape	☆	☆	☆	☆	☆

Table 2. Summarizing table of observable challenges and opportunities for soft landscaping on each site. The '☆' marking the sites that have the relevant challenge or opportunity factors.

Campus Policy and Planning Context

Our project will correspond to the vision and aspirations of UBC for sustainable development raised by the 20-Year Sustainability Strategy for the University of British Columbia Vancouver Campus (2014) and a range of measures to address global climate change proposed by the UBC Climate Emergency Engagement Final Report and Recommendations (2021).
(Please refer to the Appendix A for information on land use on UBC campuses and animals involved in pollination activities)

Interventions

a. Green Parking lot

The green parking lot aims to add vegetation on impermeable gray surfaces and alleviate the obstacle of parking lots to ecological connectivity. Because most of our studied 'dead points' are located near parking lots or large hard surface areas, which are the main factors causing the emergence of 'dead points'.

Silva Cell is a modular suspended pavement system; installing Silva cells under the parking lot can increase soil volumes to support large tree growth and the capacity of planting trees in the parking lot while maintaining the original parking function of the parking (Figure 3) (Tripak et al., 2019). Turf stone is a grid form of permeable pavement that can be filled with grass or topsoil and improve vegetation growth, especially grass and wildflowers (Figure 4) (Zhou et al., 2016).

One of the precedent cases for installing Silva cells is the parking lot reconstruction project of Lidl superstore, New Milton, UK, in 2010, which meets the purposes of tree planting and rainwater management at the same time (Deep root, 2010). Besides, Heritage Farm, Vancouver, WA, paved a turf stone structure on the parking space to increase the lush appearance of the green space and reduce runoff naturally (Figure 4) (Vogt, 2016).

Figure 3. A schematic diagram of a section showing the Silva cells installed underground of the parking lot.

Figure 4. The lush appearance after the completion of paving turf stone pavement in the parking lot of Heritage Farm, Vancouver, WA.

b. Urban Green Swale Cells

Urban green swale cells can replace impervious surfaces in cities with continuous or spaced sunken swale cells, improve ecological connectivity by planting pollinator-friendly plants, and provide planting beds (Figure 5) (Susdrain, 2018). Meanwhile, urban green swale cells, as a kind of urban green infrastructure, can help the city's Sustainable Drainage System (SuDS), and it has been applied in the previous study 'Grey to Green – Sheffield' and has been successful (Figure 5) (Dunnett, 2022).

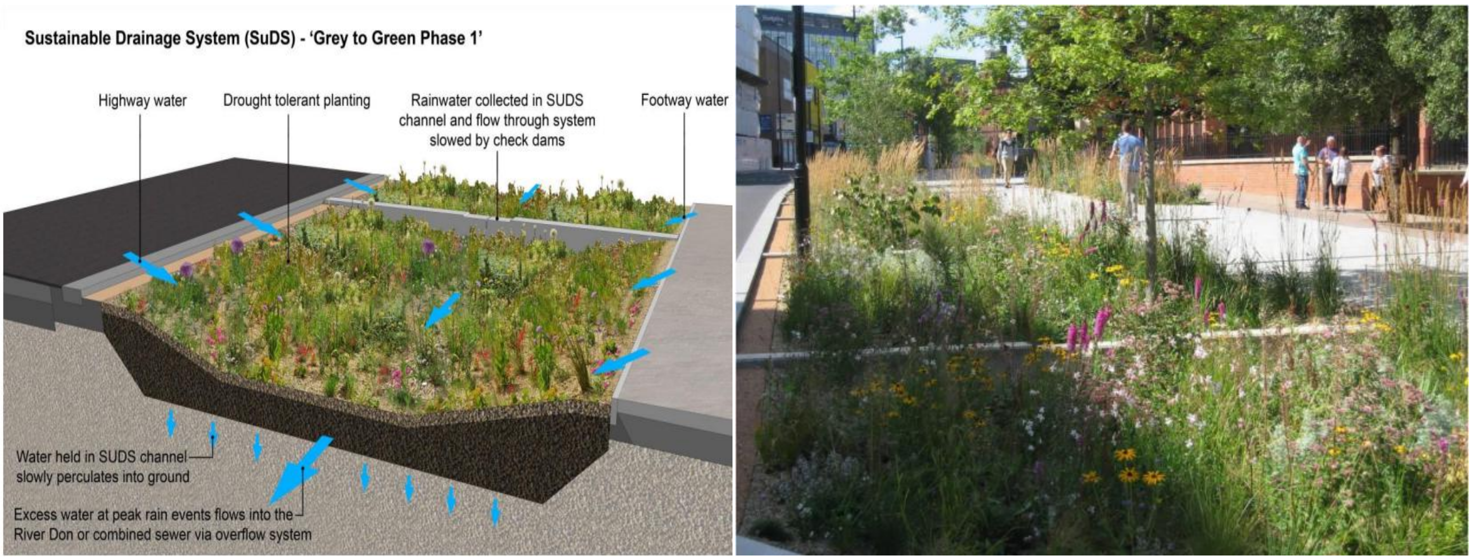


Figure 5. The left one shows the structure diagram of Sustainable Drainage System and the right one shows the 'Grey to Green' project by placing urban swale cells in Sheffield, UK.

c. Pollinator Pathway

The road edge contains a large area of the city, which can assume the function of ecologically important network elements and is a refuge for pollinators in densely populated urban areas. Therefore, effective road edge planning is likely to increase the robustness of urban plant-pollinator communities (Baldock et al., 2019). Therefore, we propose to establish pollinator pathways on the roadside, which is an intervention to connect green spaces with potential pollination value along the path by replacing the existing boulevard grass belt with pollinator-friendly flowering herbs or shrubs.

The first pollination pathway, founded by artist Sarah Bergmann, is located on Columbia Road in Seattle (Figure 6), connecting the University of Seattle and the woods in Nora, a native plant garden (Figure 7) (Pollinator Pathway, 2021). This kind of project is also being carried out in London, Ontario, Putnam County, Cornell, and other places.

It is essential to consider the species selection of this intervention. Besides paying attention to the diversity and richness of flower resources, the selection of native species is necessary. If invasive species are introduced into native plants, gene swamping or direct interaction with escapees may happen(Johnson et al., 2017). Moreover, the spatial and temporal continuity of resources should both be considered (Bennett & Lovell, 2019). The gap in flower availability will limit the foraging, offspring production, and colony size of pollinators (Nicholson et al., 2021). Based on these factors, we propose a recommendation list (Figure 8 & Appendix B).

Figure 6. Location of the pollinator pathways in Seattle. The green line indicates the first designed pathway which is located on Columbia Road, and the orange line shows the planned expansion pathway which will connect to the volunteer park to the north.

Figure 7. Comparison of Columbia street before and after the implementation of pollinator pathway.

Figure 8. Recommended native flowering forbs and their starting flowering time.

d. Green corridor

Green corridors can physically connect isolated soft landscapes to the nearest soft landscape (Figure 9). If physically connecting two soft landscapes is logically impossible, green corridors can act as stepping stones to connect isolated soft landscape polygons to a network of green infrastructure. Green corridors can also help encourage environmental conditions suitable for the growth of mycorrhizal fungi because if UBC creates more green corridors on campus, there will be more underground space for mycorrhizal fungi to connect to existing green spaces within green infrastructure network. Green corridors are the easiest biophilic design element to implement on campus because the shape and size of green corridors can be manipulated to fit a given area without having too much impact on the surrounding gray infrastructure (Zhang et al., 2019).

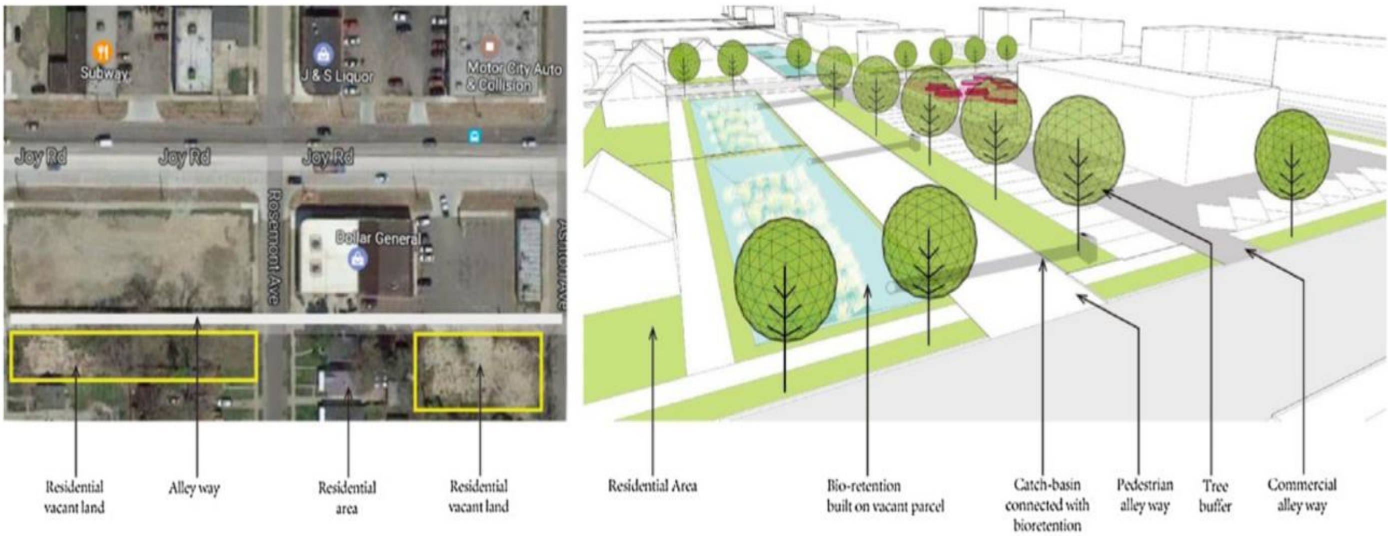


Figure 9. The corridor design for alleys between commercial and residential land in the city of Detroit.

e. Vertical green systems (VGS)

By offering additional opportunities to enhance biodiversity in cities, green roofs and green walls have emerged as conservation tools (Mayrand & Clergeau., 2018) (Figure 11). Based on the literature review, there are 13 construction types of VGS, such as living wall and green facade (Figure 10). The benefits of VGS could be observed on two levels - on an urban scale and a building scale (Radić et al., 2019).

Yang and his co-workers have conducted research to evaluate the thermal and energy performance of a double-skin green facade in the summertime. The result reveals a positive effect to reduce temperature both exterior and interior during the day, while the temperature of the green wall would be higher than the original wall at night with the absence of solar radiation(Yang et al., 2018).

Figure 10. VGS contribute to ecological connectivity in urban context

Figure 11. The exterior living wall on the UoL teaching and living center, Leicester, UK.

Cost and Benefits Analysis

Increasing the coverage of soft landscape through various interventions can first physically shorten the distance between patches and the range of gaps (Beaujean et al., 2021), so as to improve structural ecological connectivity. Secondly, through the integration of diverse plants, some species (such as birds and pollinators) may benefit from soft landscapes that provide or physically connect suitable habitats and resource patches (Taylor et al. 2006). This improvement promotes the dispersal of organisms between natural areas and also means the improvement of functional connectivity. As shown in Table 3, most interventions can provide nutrition resources and habitat for birds and pollinators (Table 3), which represent a large part of the habitat connector (Hackett et al, 2019). When they can easily move between urban green spaces, landscape facilitation of flows occurs (Egerer et al, 2020) and different patches are more closely linked through these service providers. Moreover, those interventions could provide other benefits like recreational opportunities and enhancing the quality and aesthetic value of the environment (Table 3).

Intervention	Benefits to Ecological connectivity	Other benefits
Green Parking lots	• Improve vegetation growth thereby creating more nesting habitats for pollinators and increasing their richness and abundance (Choate et al., 2018). • Benefit to tree growth/health and provide greater stability (Tripa et al., 2019). • Plant-covered soils would maintain a healthy soil microbial community (Piotrowska-Długosz et al., 2014)	• Benefit to retain water runoff and reduce the concentration of sediments and heavy metals in soil (Page et al., 2015). • Retain more nitrogen and phosphorus in soil compared to asphalt and concrete parking lots (Zhou et al., 2016).
	• The combination of bioswales and dry beds allowed for a biodiversity enhancement and	

Urban Green Swale Cells	provide functional networks of habitats and ecosystems (Bolliger & Silbernagel, 2022) ● Acts as a habitat corridor, connecting with the surrounding soft landscape cover and creating observable new habitat for pollinators through the diversity and length of flowering time (Scanlon, 2020) ● Increased habitat connectivity helps protect and restore species interactions and improves site resiliency (Thompson & Gonzalez, 2017; Zhang et al., 2019)	● Optimizing landscape, ecosystem functions and services to meet human needs, enhance human well-being (Bolliger & Silbernagel, 2022) ● As a solution to reduce surface runoff for sustainable urban drainage systems (Ebrahimian et al., 2019)
Pollinator Pathway	● Provide nutrition and habitat (nesting and food resources) for pollinators. ● Increase the abundance and diversity of pollinators (Johnson et al., 2017; Menz et al., 2011) ● Promotes the pollination services (Abrol, 2011) ● Improve the pollen-mediated gene flow (Johnson et al., 2017) between different patches	● Aesthetic value and educational significance. ● Maintain the pollination process, growth, and reproduction of edible plants in the surrounding nurseries and community gardens.
Green corridor	● Green corridors help the fragmentation of wildlife habitats. ● Respond to weather conditions, have greater storage capacity, and better protect water quality(Zhang et al., 2019). ● Green corridors could help conserve soil on campus and also may create more room for tree roots and mycorrhizal fungi to grow.	● Provide recreational opportunities and enhance the beauty and environmental quality of neighborhoods (Zhang et al., 2019). ● Green corridors help disperse animal populations throughout campus and allow for a diversified gene pool. ● Green corridors allow animals and amphibians to breed, but they also give them a safe way to cross otherwise dangerous roadways.
VGS (Vertical green systems)	● With more than 300 species recorded on the vertical wall, VGSs could be habitats that support biodiversity (Mayrand & Clergeau, 2018). ● Many vertical plants are good for nesting birds and other urban wildlife (Timur & Karaca, 2013)	● Reducing the urban heat island effect (El Menshawy et al., 2021). ● Absorbing fine dust particles (El Menshawy et al., 2021). ● Positive effects on hydrology (Radić et al., 2019). ● Reducing noise reflection from hard surfaces (Radić et al., 2019)

Table 3. The table listed the benefits of each intervention.

The potential cost has been divided into 2 parts: implementation and maintenance cost (Table 4). Implementation costs include material, seedling, and labor. Besides, maintenance costs include irrigation, trimming, nutrient supply, repair,and replacing or replanting. We made our decisions on intervention selection by comparing their potential cost and trying to minimize the cost. For instance, if the site already has the plant bed we would most likely choose a green corridor and pollinator pathway to reduce unnecessary expenses on the construction. The costs of green parking lot, urban green swale cells and

VGS may be relatively high because they have additional materials and construction expenses. In case of sufficient funds, one or more of them can be selected for installation.

Interventions	Cost		Notes
	Implementation cost	**Maintenance cost**	
Green Parking Lot	● Silva cell technology 14-15$/ft^2 (Smart Truco et al., 2018). ● Turfstone pavers for parking lot: 5–10$/ft^2 (Zhou et al., 2016). ● Seedlings of the trees	● Damage replacement fee ● Turfstone patch: filling in Cracks $5 - $150 per project ● Tree maintenance	/
Urban Green Swale Cell	/	/	Grey to Green - Sheffield is a government-led project with a total cost of 6.3 million pounds over two phases (Susdrain, 2018)
Pollinator Pathway	● Seedlings - Native, pollinator-friendly flowering forbs - Flowing shrubs (woody species) as the physical structure ● Signs ● Artificial nest for pollinators (if possible)	● Irrigation system ● Labor Cost (Hand-weeding, tidy edge) ● Replanting plan ● Trimming ● Organic material (compost, organic fertilizer)	/
Green Corridor	● Replacement fee ● Seedlings	● Tree maintenance cost ● Irrigation system ● Nutrition supply (organic matter)	/
VGS	● Living wall system based on planter boxes HDPE: 480-720US$/m2 (Radić et al., 2019) ● Cable wire system: 50US$/m2 (Radić et al., 2019)	● Irrigation system ● Thermal control system	/

Table 4. This table listed potential cost of implementation and subsequent maintenance of different interventions. Some are monetary, while most are just enumeration.

Recommendations

Based on the description of the five sites and proposed interventions above, a decision-making map was made as a guideline to assist in deciding how and why to implement the interventions in each site (Appendix C).

Site 1 can be briefly described as a yard planted with two well-grown trees, blocked by a parking lot and dense buildings (Figure 12). So the very first plan is to deal with those impermeable surfaces brought by traditional parking lots. Without influencing the functions of this site, we propose to implement silva cells underground and use the concept of urban green swale cells to provide a better growing environment for trees. In order to make sure space utilization, the concepts of silva cells, swale cells, and turf stones could be integrated (Figure 13). Both the green parking lot and urban green swales cells can transform otherwise impervious surfaces into permeable areas, reducing surface runoff and providing habitat to fauna, especially pollinators, and improving ecosystem connectivity (Ali et al., 2019; Aronson et al., 2017; Kendra, 2020; Page et al., 2015).

If the budgets are adequate, we highly recommend using VGS on the Lower mall research station to get through those dense buildings (Figure 13). A support system would be a good choice with the lowest implementation cost of $210/m2, less influence on the building's structure, and more energy-saving for buildings (Huang et al., 2019). There are also some drawbacks to the support system. With a higher salary for maintenance workers and a higher rate of replacement, there will be higher maintenance costs. So we suggest using locally purchased plants and appropriate plant species that fit the VGS location to reduce the cost.

Both pollinator pathways and green corridors are recommended to be established along the Lower Mall (Figure 13). There are various soft landscapes and larger natural patches such as woodland and meadow along the Lower Mall, which are all potential pollinator habitats. Through the planting of more pollinator-friendly plants, we can ensure connectivity between patches of similar pollinator habitat types to a certain extent, and avoid interruption of the supply of resources such as food and nesting (Hackett et al., 2019), so as to facilitate the dispersal of pollinators across different soft landscapes (Bennett & Lovell, 2019), enhance both functional and structural connectivity.

Figure 12. Top view of site 1. The red rectangle highlights the dead point within this site, and the annotations briefly describe where and how we plan to implement interventions.

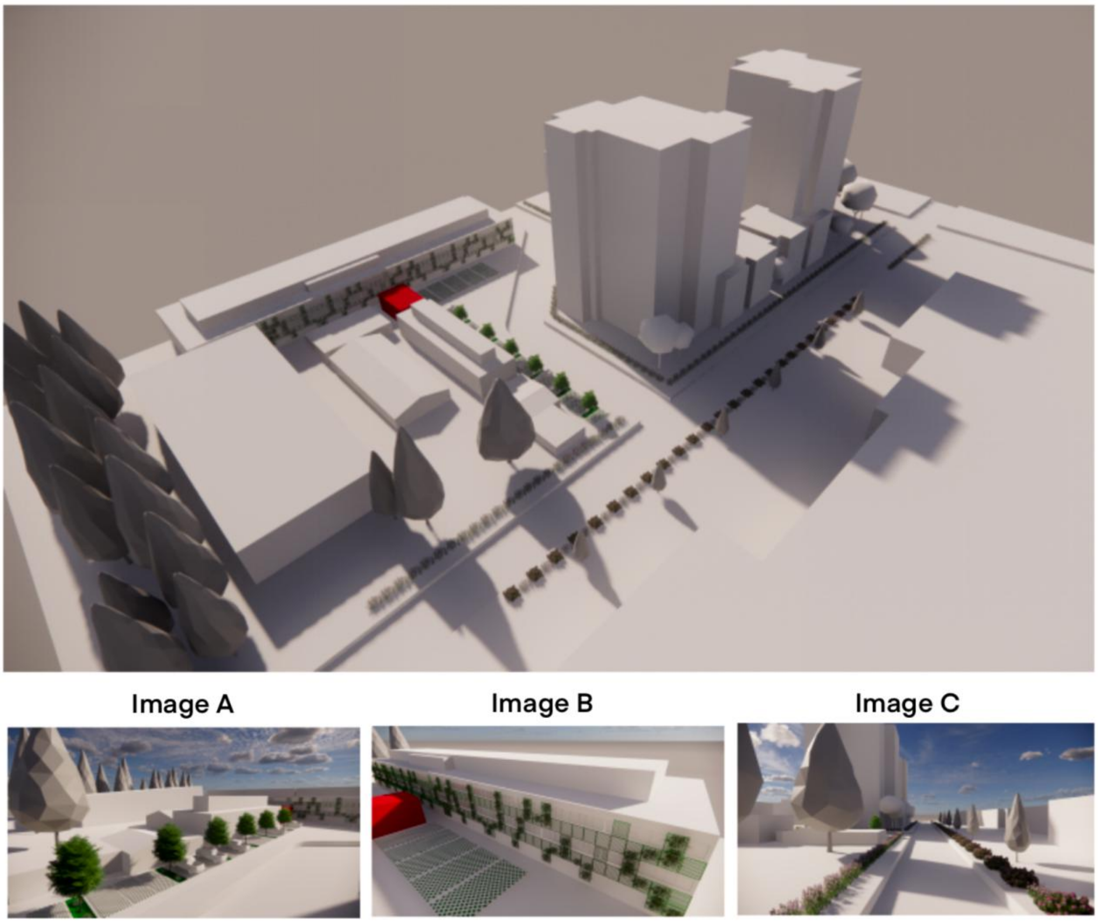


Figure 13. The 3D models for site 1 created by Pinyi Fu, 2022. The red box is the location of 'dead point', white models are representing existing structures, while colored models representing proposed settings.

Image A: Green parking lot and urban green swale cells.
Image B: Green parking lot and vertical green system.
Image C: Green corridor and pollinator pathway.

After having the 3D models to visualize our interventions, we used QGIS software to demonstrate that ecological connectivity can be improved (Figure 14). The existing soft landscapes on the UBC campus are shown as the yellow shaded area, and the blue layers are their 10m buffer zones, most of the blue layers are interconnected and overlapped. However, there is an isolated blue layer in the middle of the map, which is the 'dead point'. Then, we used a red shaded area to express the location and area of the proposed intervention and made a green layer to display their 10m buffer. The Green layer successfully connects the isolated blue layer. Therefore, by implementing our interventions, the existing isolated soft landscape in Site 1 can be connected with the surrounding green spaces which directly improving the structural connectivity and providing potential functional connectivity.
(Please refer to Appendix D for 3D models and QGIS maps of the other four sites)

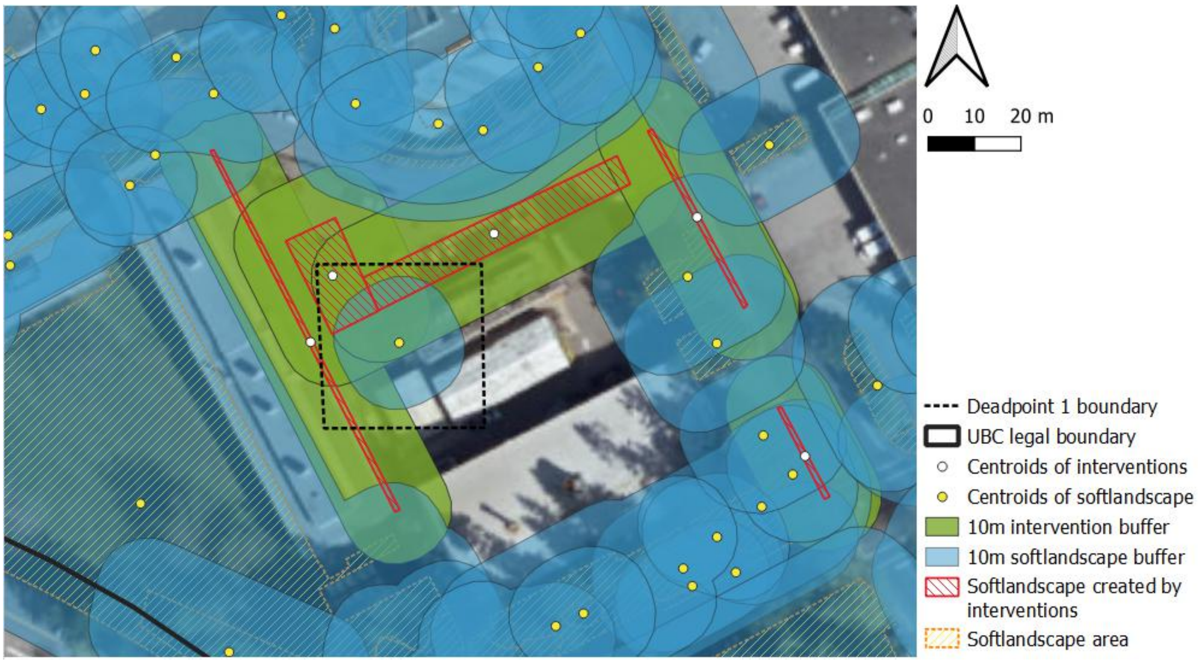


Figure 14. The GIS map at Site 1 shows ecological connectivity can be increased and dead points eliminated after the adding of interventions.

Conclusion

This report is aiming to use proposed interventions to create connections between 'dead points' and other connected soft landscapes. By using evidence from literature, site evaluation and GIS maps, we have proved that 'dead points' could be connected to the surrounding soft landscape after the intervention was applied. We also are trying to make detailed and feasible plans. But we still need more expertise and knowledge before the plans can be implemented in reality.

Implementing soft landscapes can only be the first step to enhance the ecological connectivity within the urban context. More efforts should be given to the maintenance process to create regenerative soft landscapes. Therefore, more implementations of soft landscape interventions can be acknowledged on the UBC campus or even in Vancouver. Concrete buildings and streets have been obstacles to ecological connectivity in the past. We believe that after successfully implementing proposed interventions, the public would give more attention to ecological connectivity. In the future, city planners would consider ecological connectivity when they are expanding urban areas.

Appendix A - Policy and Plan Summarization

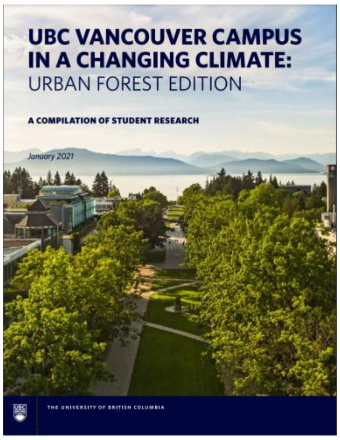
UBC Vancouver Campus in a Changing Climate: Urban Forest Edition (2021) (Figureb 15) indicated that the land cover types at UBC:

Artificial surface: 44.6%;
Tree canopy: 30.4%;
Soft landscape: 25%,

While in the academic land:

Artificial surface: 61.4%;
Tree canopy: 22.2%;
Soft landscape: 16.4%.

The proportion of soft landscape is the lowest in both UBC and academic areas, and it is still decreasing.



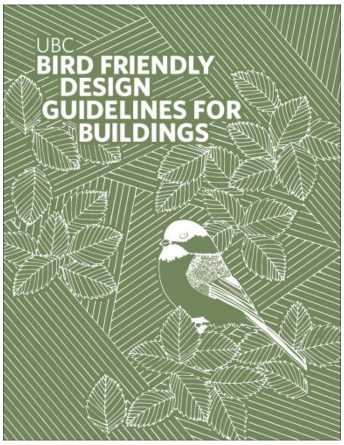


Figure 15. The cover page of two relevant guidelines.

UBC Bird Friendly Design Guidelines for Buildings (2019) (Figure 15) provided some bird species, such as Varied Thrush, Fox Sparrow, American Robin, and Gold Crowned Kinglet that can contribute to seed dispersal on the UBC campus. Three major ground-dwelling bee species may exist in the UBC area to provide wildflower and crop pollination, and they are Mining Bee Andrena, Sweat Bee Halictus, and Sweat Bee Lagioglossum. They create their habitat by burrowing into dry, sandy soil (Robertson-Mercer et al., 2017).

Appendix B - Recommended species selection list

	Botanical Name	Common Name	Flowering Season	Sun	Soil	Pollinators
Shrubs	*Rubus spectabilis*	Salmonberry	March - June	Sun, partial shade to shade	Moist	Bees, butterflies
	Arctostaphylos uva-ursi	Kinnikinnick	April - June	Sun to shade	Dry to moist	Bees, beetles
	Rhododendron albiflorum	Cascade azalea	June - August	Sun, partial shade to shade	Dry, well drained, moist to wet	Bees, flies
	Rosa acicularis	Prickly rose	June - July	Sun to partial shade	Dry to wet	Bees, flies, beetles
Forbs	*Delphinium nuttallianum*	Twolobe larkspur	March - July	Sun	Dry to well drained	Bees, moths, hummingbirds
	Erigeron strigosus	Prairie fleabane	April - May	Sun	Well drained	Bees, butterflies, flies
	Achillea millefolium var. *Occidentalis*	Western yarrow	April - October	Sun to partial shade	Dry	Bees, flies, moths
	Fragaria virginiana	Virginia Strawberry	May - August	Sun to partial shade	Dry	Bees, flies, butterflies
	Lupinus sericeus	Silky lupine	June - August	Sun to partial Shade	Dry to moist	Bees, hummingbirds
	Euthamia graminifolia	Flat-top goldentop	July - September	Sun	Moist	Bees, beetles

Table 5. This table lists plants that attract pollinators. It is not exhaustive, but provides some plant species (City of Vancouver, 2022) to choose from, and their flowering seasons and growth conditions.

Appendix C - Decision-Making Map

This decision-making map helps us decide which intervention to be implemented under certain conditions (Figure 16).
Firstly, we would consider both the budget and surrounding settings. If the budget is adequate and there are very dense buildings or vertical walls surrounding, we highly recommend implementing VGS to get both aesthetic and ecological values. Then we would introduce the green parking lot and green swale cells to replace impermeable surfaces with soft landscapes. Finally, a pollinator pathway would be established on the streets or paths with green infrastructures existing in good condition while green corridors could be added on paths with fewer green elements.

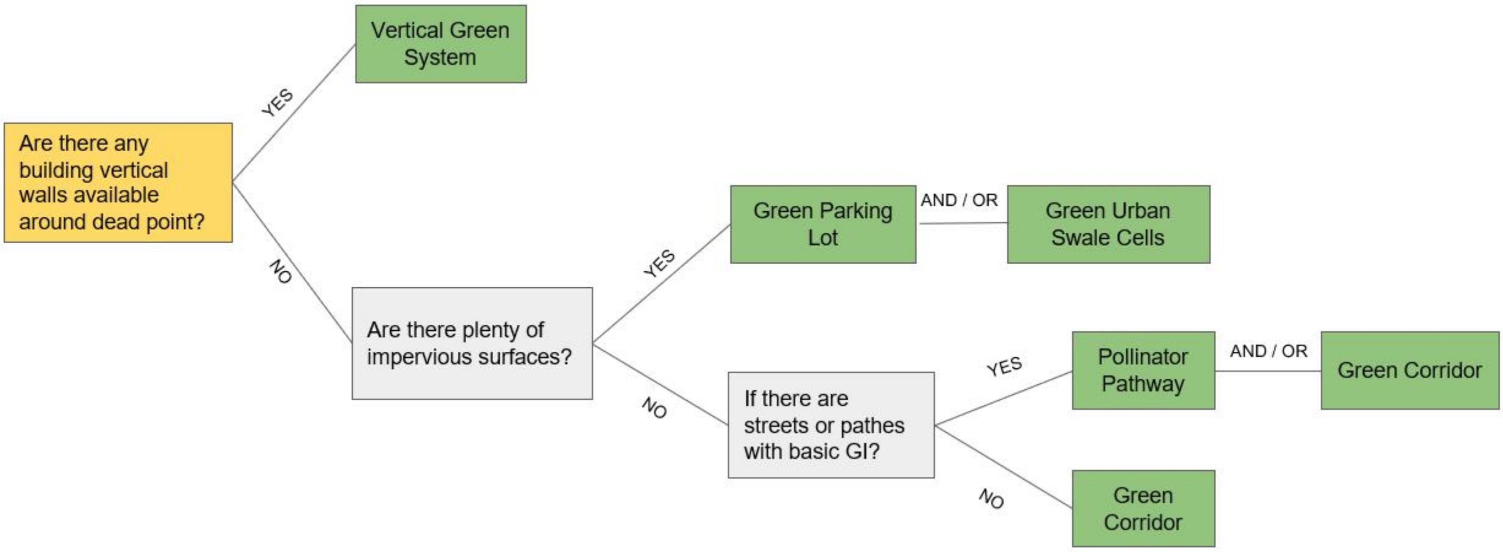
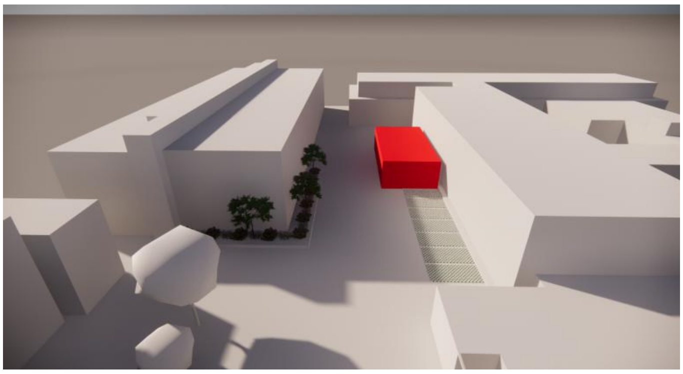
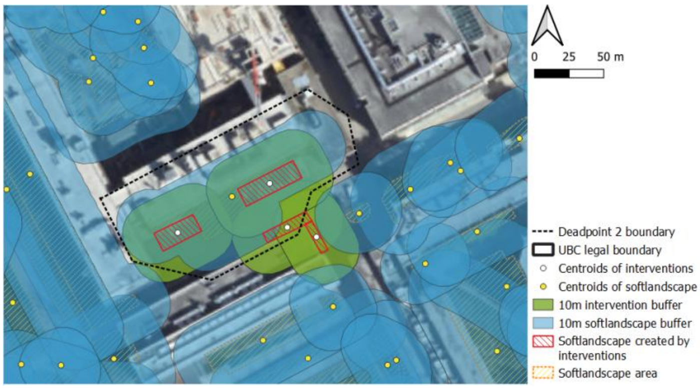


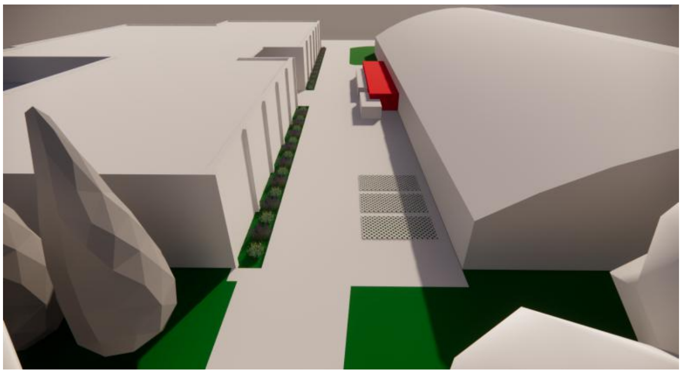
Figure 16. Decision making map of how and why interventions can apply to the site.

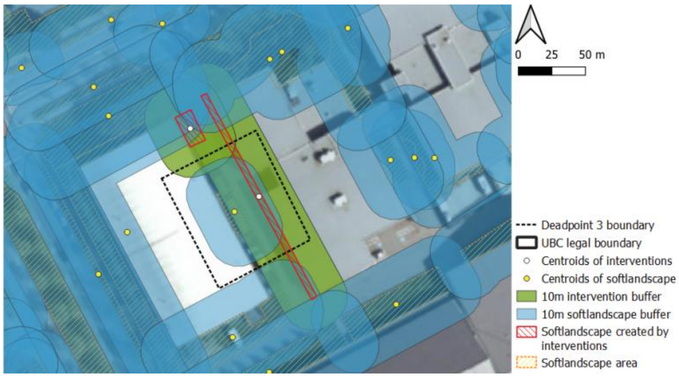
Appendix D - 3 models and GIS maps of rest four sites



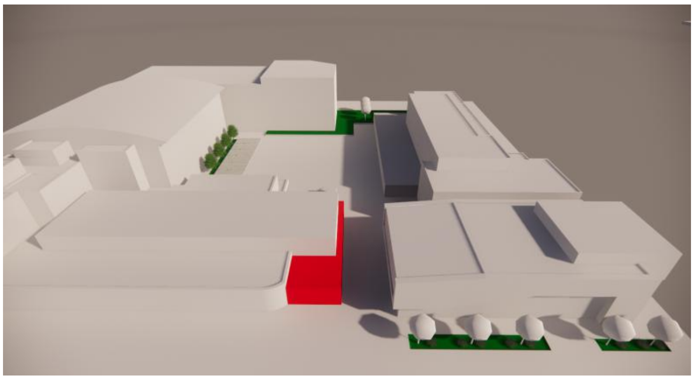


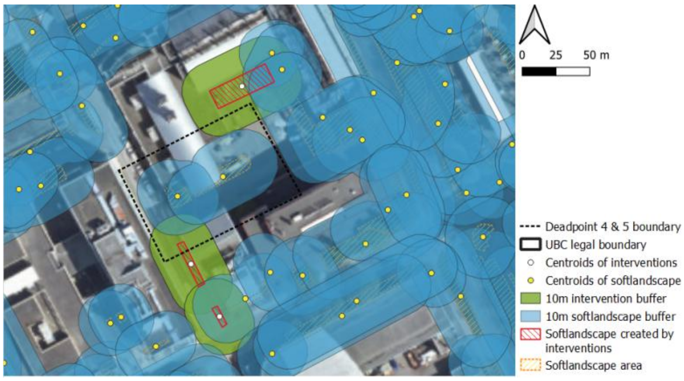
The ‘dead point’ of site 2 is a planting bed cluttered with a large number of shrubs, which is blocked by surrounding buildings and parking lots. First, we implement turf stone to transform impervious surfaces into permeable areas. Second, we found that the planting bed has a high pollination value because there are a large number of flowering shrubs in it. Therefore, we chose to build a green corridor to help the organisms in the site disperse into the surrounding environment.





In site 3, in order to create connectivity from the blocked large planting area covered with gravel and pressed by large containers to its nearby green spaces. We first plan to pave turf stone in the parking areas. Secondly, we choose to implement green swale cells on the other side of the road. These two interventions are aiming to improve the structural connectivity thereby promote the dispersion of low dispersal species.





The ‘dead point’ of site 4 is also blocked by surrounding buildings and a parking lot. Therefore, we choose to create more soft landscapes in the parking lot by installing silva cells and turf stones. Secondly, we noticed that although the engineering Rd on the west side of the site was planted with trees, they were planted in

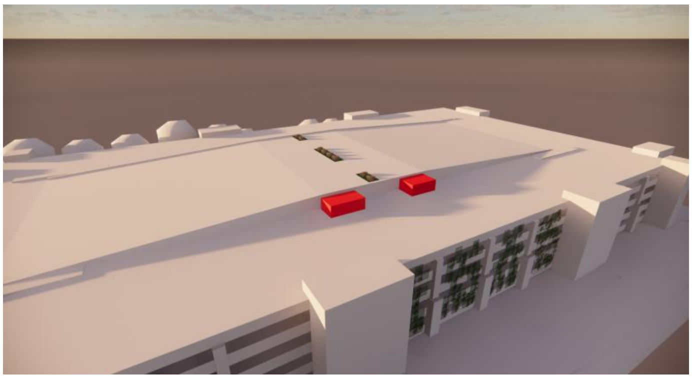
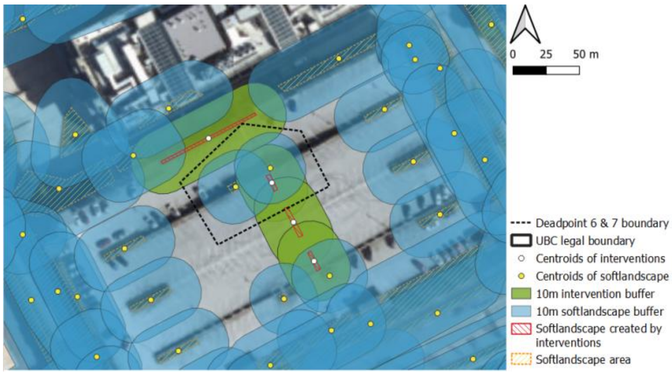
<table>
<tr><td colspan="2">limited planting pits, and the tree pits were lower than the surrounding hard landscape and covered by iron mesh. Therefore, we chose to establish a green corridor to allow more soft landscapes to be exposed.</td></tr>
<tr><td></td><td>
</td></tr>
<tr><td colspan="2">The ‘dead points’ on Site 5 are located on the Thunderbird Rooftop Parking Lot. In order not to occupy the existing parking space, we chose to add green swale cells in the vacant location and increase the vertical ecological connectivity through the construction of VGS. Finally, we propose to add a pollinator pathway on Thunderbird Blvd to improve the functional connectivity between a large number of soft landscapes along the road.</td></tr>
</table>

Table 6. This table shows the 3D models of the remaining four sites, the GIS map, and the explanation of why the corresponding interventions are set in these sites. It can be seen from GIS maps that after the addition of intervention in each site, the originally isolated soft landscapes have been successfully connected with the surrounding green space structurally.

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