CHAPTER 5
CONSTRUCTION

Figure 1. A log cabin in Norway illustrates the use of bryophytes for chinking between the logs, and more recently for the construction of green roofs. Photo by Michael Lüth.

Construction

One would hardly expect the non-lignified mosses to be useful in construction (Figure 1), but in fact, they can be quite utilitarian, especially in Polar climates and remote areas. In the Antarctic, Granite House at Granite Harbour, Cape Geology, still has remnants of mosses placed there by Scott's last Antarctic Expedition when they built the house in 1911. Stuffed into the cracks in the walls are *Bryum argenteum, B. pseudotriquetrum,* and *Hennediella heimii* (R. Seppelt, Pers. Comm.). The Inuktitut Indians used *Sphagnum* for chinking (Wilson 1978). The Shuswap Indians use the mosses *Aulacomnium* and *Dicranum* for chinking by mixing it with clay (Palmer 1975).

In northern Europe some houses still have chinking of *Homalothecium sericeum*, *Isothecium myosuroides*, and *Pleurozium schreberi* (Richardson 1981) or *Fontinalis antipyretica* as fire insulation between the chimney and walls, hence its name (Thieret 1956). But even in our modern technological times, Philippine construction still uses them as fillers between wooden posts of walls and roof shingles (B. Tan, pers. comm.), Alaskans still use *Hylocomium splendens*, *Racomitrium canescens*, *Rhytidiadelphus loreus*, and *Sphagnum* as chinking (Lewis 1981), and shepherds in the Himalayan highlands use local species for chinking in temporary summer homes (Pant & Tewari 1989). In the more recent habitation of Isle Royale, Michigan, where there are no cars or commercial enterprises, mosses have been used for chinking in a fishery hut (Figure 2).

Figure 2. Moss chinking in a fishery hut on the dock near the Rock Harbor Light House, Isle Royale National Park, Michigan, USA. Photo by Diane Lucas.

For chinking, mosses are pressed between the logs with the fingers or an instrument and left to dry, where they remain compressed and still green. Use of peat for construction will be described in the Uses: Technological & Commercial chapter. In addition to construction, they are used to decorate and insulate buildings. For example, the City Hall in Iceland is decorated with mosses (Figure 3).

Figure 3. Moss wall decorating the Reykjavik City Hall in Iceland. Photos by Steffi Wilberscheid.

Unfortunately, mosses used on the sides of buildings do not always meet the aesthetic goal we would hope for. In Munich, Germany, a huge tufa stone wall of an insurance building was covered with mosses (J.-P. Frahm, personal communication). However, eventually the mosses, so carefully cultivated on the rock (Figure 4), were washed off. The contractor, Michel Chiaffredo, blamed this on the heavy metal pollution and especially the copper that mosses accumulated before dying (Michel Chiaffredo, personal communication 2007). The water used for the irrigation was the water retrieved from roofs, then stored in a tank. The quantity of copper and other heavy metals in these mosses, indicated by the analysis conducted by the Pasteur Institute, killed the *Aloina ambigua* used for the green wall (Figure 5). Unfortunately, nobody wanted to assume the responsibility for the copper sulfate and other metals. *Aloina ambigua* is well adapted to a calcareous tufa, but it is not a copper moss. A new gardener tried to replace the lost mosses with *Brachythecium rutabulum*, installing an expensive system to wet the stone, but this water dissolved the carbonates of the tufa rock, which then crystallized on the mosses and killed them (J.-P. Frahm, personal communication 2007). It appears that the new gardener did not understand the ecology of the moss – or the rock.

Paths

Older walkways around buildings were often constructed of bricks. Mosses eventually filled in the spaces between the bricks, adding a rustic and restful look. Vivian (1996) proclaims the need for such walkways, criticizing the sterile, formal appearance of straight concrete or blacktop. Such mosses seem to be a frequent subject for poets. See the subchapter on Uses: Literature.

Figure 4. These mosses are being cultured on tufa to be used in building construction. Photo by Michel Chiaffredo.

Figure 5. *Aloina ambigua* grows here on tufa rock such as that used for the insurance building in Munich. Photo by Michel Chiaffredo.

Ecocity

Use of mosses to control erosion (Conard 1935; Figure 6), muffle traffic noise, and retain cooling moisture forms the basis of a modern philosophy that may be labelled "ecocity." It follows the premise that mosses form a natural part of the ecosystem and that they have an important role in that ecosystem that can make life more pleasant for the human species, as well as maintaining a healthier ecosystem.

At Ilsong (Ilsong 2004), in Korea, mosses are being touted for their ability to stabilize and beautify the environment in an environmentally friendly way. The Codra system starts with a soil embankment, such as one would find along a highway, and covers it with a layer of concrete formed like a rock outcrop, *i.e.*, not flat, but with undulations like rocks. To this, mosses are added and eventually make a soothing green mat that catches water and helps to stabilize the bank. Presumably, even if the concrete develops cracks, the mosses will be able to fill in and maintain the stability. Mosses such as *Hyophila* (Figure 7) readily grow on such concrete coverings in Japan and presumably elsewhere that this moss occurs naturally. The moss catch system consists of blocks forming vertical walls that are covered with mosses. These systems require early maintenance that assures sufficient water until the moss system becomes established.

Figure 6. Soil bank where mosses such as *Polytrichum* help to maintain stability. Photo by Janice Glime.

Figure 7. The drought-tolerant, calciphilic moss, *Hyophila involuta*, grows easily on concrete. Photo by Michael Lüth.

Green Roofs

I am a little disappointed when my friends risk life or limb on their roof, trying to remove mosses from the shingles. Although mosses have traditionally been considered a nuisance on roofs, with people spending hundreds of dollars to remove them, more recently they have made a new debut in Germany, the United States, and other places. Their new acclaim offers the advantage of cleaning the atmosphere of pollution while buffering the temperature, fireproofing, and creating a sound barrier. For more southern locations where slate roofs are common, they offer a lighter and cheaper alternative (Posth 1993). They are now being produced commercially in Germany (Behrens Systemtechnik) for roofing (Frahm 2004; Figure 8). Interestingly, it is this German company that is installing moss roofs in Michigan, USA. However, most people still consider mosses on roofs a nuisance because they add weight and increase the growth of fungi, and many consider the roof to look dirty.

Figure 8. Jan-Peter Frahm demonstrates a sheet of moss that is ready to be used in "green roof" construction. Photo by Jan-Peter Frahm.

Michel Chiaffredo and Franck-Olivier Denayer (2004) treat the mosses as both aesthetically beautiful and ecologically sound additions to urban roofs (Figure 9; Figure 10). And they are getting customers in the "green roof revolution" who agree with them (Chiaffredo 2004). To quote them, "It is thus possible to set up on roofs, in one go, a combination of all the living elements that nature would introduce spontaneously over a far longer period of time: veil of micro-organisms associated with mosses, and wild seeds of dependent xerophilous plants. The natural environment thus reconstituted will evolve very slowly according to the ecological conditions of the site, requiring neither maintenance nor the introduction of fertilizers. This innovative phytoecological engineering makes it truly possible to maintain biodiversity, unlike all the agronomic or horticultural processes, even within the very heart of towns and cities." (Chiaffredo & Denayer 2004; Figure 11).

Figure 9. This modern building has a green roof. Photo by Michel Chiaffredo.

Figure 10. This green roof has bryophytes with skylights. Photo by Michel Chiaffredo.

Figure 11. This bryophyte plantation prepares bryophytes for green roof construction. Photo by Jan-Peter Frahm.

Chiaffredo and Denayer point out the advantages of using such vegetation on one's roof:

- *Regulate rainwater*: Collection of water by rooftop vegetation, especially bryophytes, will prevent the movement of water from large surfaces onto a small area of ground below and permit the return of water slowly to the atmosphere by evapotranspiration.
- *Increase biodiversity*: Opportunities for diversity in urban areas is limited, and rooftops add an opportunity for additional flora and fauna.
- *Decrease the greenhouse effect*: Bryophytes are heat sinks that will cool by evapotranspiration on the one hand and retain heat by insulation in winter on the other, reducing the heat flux in and out of the building.
- *Improve air quality*: Bryophytes produce oxygen, use CO_2, and trap dust particles, thus helping to clean the atmosphere.
- *Reduce sound pollution*: Roofs can serve as sounding boards to bounce sounds, whereas the rough surface of a bryophyte mat absorbs sound, thus reducing the sound pollution of traffic or noisy equipment.

When the roof is flat, the moss garden can be aesthetically pleasing as well (Figure 12). Mosses for green roof gardening can be grown in plantations (Figure 11) where natural diversity develops (Figure 13).

Figure 12. This completed green roof has a formal design, but many are more casual. Photo by Jan-Peter Frahm.

Figure 13. This mat of mixed mosses is ready for transplantation to make a "green roof." Photo by Jan-Peter Frahm.

In 2004, Bryonetters contributed their ideas to the species of mosses suitable for roofs. John Christy suggested that *Ceratodon purpureus* was a good candidate because of its ability to form sods on concrete, gravel, asphalt, and wood. It tolerates nitrogen, so air pollution and bird droppings would be less of a problem than for some mosses. Use of zinc-plated metal around roof vents, chimneys, skylights, and other objects must be avoided because they will kill the mosses. Spreading mosses by fragments will accelerate their establishment. Other weedy species such as the acrocarpous *Bryum argenteum*, *Tortula*/*Syntrichia*, and *Racomitrium* will colonize the more exposed areas, whereas pleurocarpous taxa such as Mniaceae and *Brachythecium* will colonize shadier sites.

Henk Greven suggested that *Polytrichum formosum* is easily transplanted and he would expect it to do well on roofs. Michel Chiaffredo has shown this to be the case (Figure 14; Figure 15).

Controversies have arisen regarding the best upkeep for the green roof. Ideally, these roofs are low or no maintenance ecosystems. Thus, we would anticipate no need for fertilizers, which generally seem detrimental to bryophytes anyway. However, many of the roof gardens that have been in existence seem to be deteriorating (Koehler 2003), leading the roof gardeners to promoting fertilization. Chiaffredo and Denayer (2004) disagree with this approach, concluding that it is "contrary to the very definition of extensive vegetalization." The International Green Roof Association lists the moss-sedum-herbs and grasses community as a low maintenance, low cost green roof plant community (IGRA).

Figure 14. These large mats of *Polytrichum* are ready for transplantation to a "green roof" site. Photo by Jan-Peter Frahm.

The principle of the green roof for some companies relies on the well-known ability of mosses to colonize such a substrate with no help from us (Figure 16). At this stage, they are pioneers and require no watering or fertilizer (Figure 17). Diversity develops normally, hence providing stability (Figure 18). Their development can be compared to that of the cryptogamic crust that is so important in anchoring and nurturing the soil of prairies and semideserts in the North American Southwest, Israel, and parts of China and Australia. These crusts remove CO_2 from the atmosphere, convert atmospheric N to ammonia and nitrates, and generally improve the quality of the habitat for invading organisms, while improving the air quality for humans.

Using the studies on bryophytes as pioneers in these natural habitats as models, green roof landscapers have conducted studies on the best substrates for the roofs. The most popular and successful roofing material is a mineral one of volcanic origin, having a granulometric variation of 1-16 mm. Fentiman Consulting advocates a thin layer of concrete as a substrate for moss establishment (Grant 2006).

Figure 15. *Polytrichum* displays a marvelous collection of capsules with hairy caps in the background and numerous male splash cups in the foreground. Photo by Jan-Peter Frahm.

Figure 16. Buildings in Norway with natural green roofs. Photo by Michael Lüth.

Figure 17. Seashore damaged by tourists shows damaged bare sand area and restored area beyond the rope. Photo by Michel Chiaffredo.

In London, England, the CUE Building of the Morniman Museum did not begin with bryophytes on its green roof (Grant 2006). However, successful establishment of tracheophytes led to natural succession and invasion of native species, including bryophytes. Mosses became frequent in the more open areas, including *Bryum capillare*, *Ceratodon purpureus*, *Hypnum cupressiforme*, *Pseudoscleropodium purum*, and *Brachythecium rutabulum*. The wetter north-facing section sported, in addition to a number of grasses, a luxuriant growth of mosses made up of *Rhytidiadelphus squarrosus*, *Brachythecium rutabulum*, *B. albicans*, *Kindbergia praelonga*, and *Calliergonella cuspidata*.

Figure 18. This restored area shows colonization by pioneer plants, including the bryophytes. Photos by Michel Chiaffredo.

Sadly, it seems that using mosses for green roof construction has not become a common practice in the USA. Rather, xerophytic tracheophytes dominate greenroof landscaping there. But the idea has been planted, and ecologically minded green-roofers are considering the advantages in heat control vs. the disadvantages in introduction of pests, added weight, and moisture damage to roofing shingles.

Grant (2006) sums up the green roof concept, stating "Green roofs are arguably the best example of multifunctional urban design, whereby elements on, in, and around the built environment serve several purposes. A roof (or external wall) can and should be more than just a weather-proof surface or structural element—it can be part of a living, cooling, cleansing skin that not only helps reduce flooding, urban heat-island effects, and air and noise pollution, but also provides wildlife habitat and tranquility." As proof of this utility, w have learned that at the Michigan Ford Rouge auto manufacturing plant, the green roof reduces power needs (Cesere 2006) through its function as a heat sink and evaporative cooling ability (Roofscapes 2004)!

Eliminating Moss

Unfortunately, not everyone shares the perception of the aesthetic appeal of mosses and liverworts. When they occur on roofs, and even in the cracks in the sidewalks, some people will declare war. I have been asked how to eliminate them on a roof, and my answer is "Why do you want to?" Of course on roofs they add weight, especially when wet, and can get in the way when shovelling heavy snow off during six months of winter, but still!

Several bryocides seem to be successful. The one most familiar to me is lime ($CaCO_3$), partly because most bryophytes prefer more acid conditions, but perhaps even more important are the desiccating properties of lime. Bogdanov (1963) describes liming to eliminate mosses in forest stands (!) of drained swamps. A recent ad on the internet, however, seems to me a slightly better solution, if you must. This is a product called Moss Aside™, an herbicidal soap (Gardens Alive). It will let you grow thicker lawns!

Others advocate zinc or copper strips placed near the peak of the roof. Rainwater dissolves enough zinc to form zinc carbonate, which washes down the roof, killing the mosses. Of course, it accumulates on the ground below and will ultimately get into the water supply, so the solution can be a deadly one if many people begin this practice.

One web site advocates using a standard scrub brush on a long handle to remove the moss. I cannot help but wonder if the brush doesn't do more damage to the asphalt than the moss does. And how practical is it for a roof like the one in Figure 20?

Golf Courses

In September 2006, Bryonet subscribers were asked to recommend the ideal moss for a golf course. Susan Moyle-Studlar (Bryonet, 14 September 2006) contributed several suggestions. She suggested *Polytrichum* species because they tolerate the high light levels of a golf course and are trampling resistant, being firmly anchored to the substrate. In fact, the trampling can help to propagate them by creating fragments that can produce new plants. They are common plants along trails and railroad tracks. However, she cautioned that they are a bit tall and will require frequent watering.

A shorter and softer turf, relatively trampling resistant, is formed by *Dicranella heteromalla* (Figure 19) along forest trails, but she cautions that it is not well-anchored, possibly leading to a "choppy turf" following the activity of golfers. But, like *Polytrichum* species, these would also need watering and additionally would need shade.

Figure 19. *Dicranella heteromalla*, known as green thread moss, grows here on a vertical bank. Photo by Michael Lüth.

Leucobryum can tolerate trampling, as exhibited by its proliferation near a picnic shelter in West Virginia, USA. Moyle-Studlar considers this a possible candidate because of its tolerance of greater aridity than the former two, its retention of its attractiveness when dry, and its ability to reproduce from broken leaves. Nevertheless, the chopping effect of golf clubs would most likely be quite destructive; hopefully winter would give it a chance to recover.

Pleurocarpous mosses such as *Hypnum imponens* (Figure 21) and *Thuidium delicatulum* likewise seem to return from trampling damage, but they also pose the same problems of the above mosses and lack a secure anchoring system.

Figure 20. This house in Bretagne has mosses invading the roof. Photo by Michael Lüth.

Figure 21. *Hypnum imponens* appears here with *H. jutlandica* in the background. Photo by Michael Lüth).

John Christy (Bryonet, 15 September 2006) reported seeing *Bryum argenteum* forming tightly-packed, extensive turfs growing among the closely clipped grass on golf greens on the west coast of North America. The moss seemed to grow well on the hard but well-drained surface. Diana Horton (Bryonet, 15 September 2006) reported the same species from a golf course in Arizona, where it formed a "beautiful, short and dense sod." Only this time the manager wanted advice on how to eliminate it!

In ruins near Abingdon, Great Britain, mosses were tucked between and behind the stones of a Roman well. Dickson (1981) concluded that the mosses were placed there deliberately because they were not the ones that one would expect there naturally. Hence, he suggested they might have been used to filter the water. One might expect them to help hold the rocks together as well.

Building Construction

In the Philippines, one of the tallest mosses known, *Spiridens reinwardtii*, is used as a binding material (B. C. Tan, pers. comm.). It also serves as a filler between wooden posts and shingles in building the local huts.

In Japan, mosses are used on walls, embankments, and roofs for both aesthetic purposes and practical ones (Deguchi, personal communication 2005). Deguchi has actually published in the Green Architecture Tribune 22: 8, a newsletter among the building industries in Japan, encouraging the use of bryophytes. Mosses not only give the building an "old" and quiet appearance, but they also reduce heat loss in winter and air conditioning needs in summer. Typical mosses for these purposes are *Hypnum plumaeforme* (Figure 22) and *Racomitrium japonicum.*

Custom Stone Handlers, Squirrel Mountain Stone, in Tennessee, will provide choices of boulders with intact moss. It appears that most of these are intended for gardens, but they could be used in construction as well. A die-hard bryologist might even choose them for fireplace construction.

Travertine Rock

In calcareous waters, certain mosses are tufa formers (Crum 1973). The species *Didymodon tophaceous* makes such deposits, forming **didymodontoliths**! The tufa is formed by $CaCO_3$ deposits on the moss surface as photosynthesis removes the CO_2 from the water. These deposits result in a soft limestone that hardens into a porous brownish stone known as **travertine**. This elegant-appearing travertine was once a common flooring material in many public buildings, especially banks. But its use was not just modern; the Roman Coliseum was built of travertine. This travertine rock, formed by the mosses, is not to be confused with the volcanic tufa that was a fragile rock also used by the Romans (Michel Chiaffredo, personal communication 2007).

Problems in Construction

But mosses are not always welcome in construction. Not only are they considered a problem on roofs, but their moisture and organic acids contribute to the degradation of statues, tombstones, and walls (Perry 1987). On my own campus, student workers were instructed to spray them with herbicides in the cracks in the sidewalks because they made the walks look "unsightly." Fortunately, from my biased point of view, the mosses usually survive the herbicide treatments. And to my eyes, the mosses looked much better than the anthills that appeared in their absence! But, alas, this year they are being dug out. Obviously, our maintenance folks do not agree with Vivian (1996), or me!

Log Dams

Bryophytes can have advantages in emergencies because of their absorptive ability and small size. For example, when a temporary log dam developed a leak during a timber harvest in Japan, the resourceful workers used *Hypnum plumaeforme* (Figure 22), *Loeskeobryum brevirostre, Rhytidiadelphus japonicus,* and *Thuidium kanedae* to stop the leak (Ando 1957). And forest workers in Pennsylvania, USA, deliberately use rocks with *Fontinalis* on them to help stabilize newly constructed weirs. The mosses quickly spread to other rocks, effectively gluing them together.

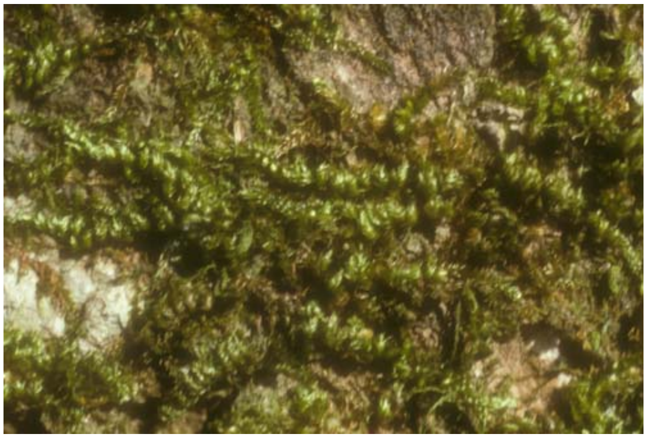

Figure 22. An epiphytic *Hypnum plumaeforme* is a moss among those used to repair a log dam in Japan and is also used on walls to give a cooling effect. Photo by Janice Glime.

Boat Construction

Use of mosses in boat construction is well documented. In the Scottish Highlands, mosses were prepared by steeping in tar, then used for caulk (Crum 1973; Figure 23). As in those used for houses, they were usually relatively large, pleurocarpous mosses such as *Eurhynchium striatum* and *Neckera complanata* (Pant & Tewari 1990). Mosses were even imported into Holland from Belgium after the 16th Century for caulking the carvel-built boats (Dickson 1973). And *Polytrichum commune* served for making the ropes (Figure 24). The online Deutsches Schiffahrtsmuseum (accessed on 20 March at www.dsm.de/ MA/schlachte.htm) displays a rope made of this moss and carbon-dated to 1770.

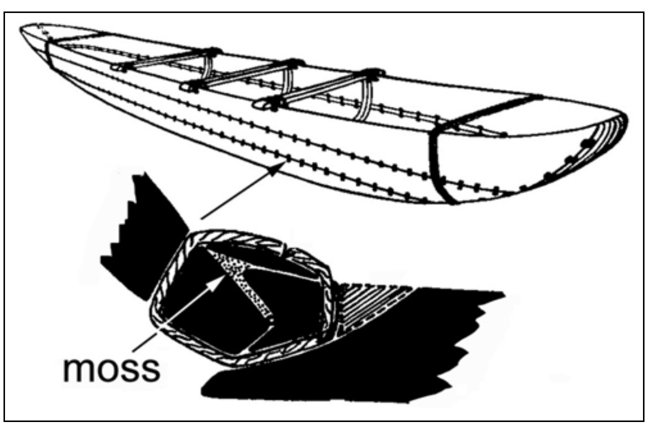

Figure 23. In this boat, mosses were used as rope caulk. Redrawn from Dickson (1973) by Janice Glime.

The native Yaghan people in Chile used mosses to build their canoes in quite a different way (Metzner Productions 2006). They buried tree bark in peat for a season, allowing the acidity to preserve the bark while the moisture made it flexible. They could then form it into a canoe.

Figure 24. *Polytrichum* was used as rope caulk. Photo by Per Hoffmann.

Summary

In construction, mosses can provide chinking and even building material, as well as ameliorating the climate. Green Roof technology uses the process of natural succession to vegetate roofs and disturbed areas. Caution must be exercised in choosing bryophytes that are adapted to the type of substrate being used. On golf courses, bryophytes require no mowing and withstand at least some trampling. Bryophyte ropes have been used to construct boats.

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