3 TECHNICAL MEASURES TO MITIGATE SOIL SEALING

The following section describes two construction methods which have the one property in common; they improve the local water capacity.

- Permeable surfaces
- Green roofs

Permeable surfaces can be considered as a method to reduce soil sealing along construction projects. Green roofs can not necessarily be classified as instruments to reduce soil sealing, however they generate new green space and create an added value to the quality of living in particular in very densely built areas.

3.1 Permeable surfaces

Permeable surfaces reduce soil sealing and increase the water drainage capacity of surfaces. However, permeable surfaces cannot be considered as a soil protection measure, since all techniques require removal of the upper soil layer of at least 30 cm. In some cases the original soil can be replaced to some extent, as in the case of gravel turf.

A variety of construction materials and techniques for permeable surfaces exist, they differ in their properties in particular in their frequency of use, allowable mechanical load, subsurface, environmental benefits, permeability, maintenance and of course in their costs. The current chapter is divided in four subsections:

- The principle of permeable surfaces, in particular in comparison with conventional impermeable surfaces,
- Overview of most common permeable surfaces. A brief description, including their benefits and most common applications.
- Detailed technical description of selected techniques. Three techniques were selected, due to their broad application potential, their low costs and maintenance.
- Legal requirements and incentives. In some European regions and cities financial incentives support the application of permeable surfaces or are even stipulated by the planning legislation. Identified examples are described and explained.
- Best practice. A few examples of exceptional applications are given.

3.1.1 The principle of permeable surfaces

Permeable surfaces aim to increase the water drainage capacity of surfaces and are in many cases a visual improvement to conventional asphalt layers. Key benefits usually are:

- flood prevention
- a relief of the local sewage water system,
- a contribution to the formation of natural groundwater,
- an improvement of the micro climate\(^1\), due to increased water evaporation,

\(^1\) Recent surface temperature surveys from the cities Budapest (Hungary) and Zaragoza (Spain) revealed that temperatures in highly sealed areas can be up to 20 °C higher compared to green shaded surfaces, see also reference [5].
the use of regional material - in some cases also recycling material (i.e. compost, building rubble),

- in some cases vegetation layers are possible, and

- in most cases a visual improvement.

Permeable surfaces play an important role in flood prevention since they can reduce the velocity and quantity of run-off water. In order to understand the full range of benefits and limitations of permeable surfaces their function is explained and compared to conventional asphalt surfaces (see also Fig. 66).

Conventional impermeable surfaces normally fulfil only one function e.g. prevention of the infiltration of pollutants, namely the support of vehicles and pedestrians. Rainwater flows over the surface to a gully and then to a drainage system. In urban areas this is usually the municipal sewage system. In the event of heavy rainfall sewage systems in urban areas tend to be overloaded.

- **Layers.** The impermeable layer consists of asphalt or concrete bricks and usually has a depth of up to 15 cm. For heavily trafficked surfaces two layers of asphalt are applied. The subbase consists of compacted loose material with fine particles. The thickness of this layer depends on the use intensity of the surface and ranges between 15 and 30 cm.

- **Life time.** A conventional asphalt layer is expected to last 20 years, the life time is longer if the use intensity is low.

- **Costs.** The costs of a conventional asphalt surface depend on the crude oil price and the local personnel costs. In 2010 the crude oil price was at 70 to 90 U$/barrel and the price for conventional asphalt layers amounted to approximately 35 to 40€/m² (without VAT) in Central European countries.

- **Maintenance.** After 10 years the surface may need “resurfacing”, meaning that an upper layer of about 4 cm is removed and replaced by a new asphalt layer.

- **End of life time.** Recycling of asphalt is to some extent possible but is very energy intensive.

Permeable surfaces provide support and drainage at the same time. They have to be considered as filter and storage units and cannot exist alone, since they need to be complemented with either a drainage system or an infiltration basin. Only in the case of gravel turf is a “stand alone” solution without drainage system possible. Permeable surfaces allow rainwater to soak through the surface into the underlying sub-base where the water is temporarily stored before it either percolates into the ground or flows to a drainage system. Fig. shows the key differences of the two systems. The following section provides an overview of the most common permeable surfaces, their subsoil layers, recycling options, maintenance and costs.
The water run-off co-efficient is used to define how much water can actually percolate through the surface. Totally sealed surfaces have a coefficient of 1, meaning that no surface water seeps through the surface. Completely permeable surfaces have a coefficient of zero which means that no surface water is left. The subsequent section provides an overview of the most common surfaces (see also Fig. 67) and includes short technical descriptions for each of them.

3.1.2 Overview of most common permeable surfaces

The current section provides an overview of the most common permeable surfaces. Information on costs is related to conventional impermeable asphalt surfaces and is indicative, because labour costs are highly differential among the EU Member States.

In Fig. the most common surfaces for “artificial” open areas are shown. The surfaces are presented according to their permeability; i.e. the first picture shows conventional lawn which can be considered as 100 % unsealed, pictures 2 to 7 refer to various permeable surfaces, and the last picture shows asphalt, being 100 % sealed.
Fig. 67 Overview of most common surfaces
Sources: [116], [117], [118]

Tab. 7 Comparison of benefits and limitations of most common permeable surfaces (in relation to asphalt)
Sources: [116], [117], [118]

<table>
<thead>
<tr>
<th>Surface Type</th>
<th>Application range</th>
<th>Benefits</th>
<th>Limitations</th>
<th>Cost (asphalt)</th>
<th>Run-off coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lawn, sandy soil</td>
<td>+++</td>
<td>+++</td>
<td>+++ 100%</td>
<td>&lt;0.1</td>
<td>&lt; 2%</td>
</tr>
<tr>
<td>Gravel Turf</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>100%</td>
<td>0.1 - 0.3</td>
</tr>
<tr>
<td>Grass grids (plastic)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>90%</td>
<td>0.3 - 0.5</td>
</tr>
<tr>
<td>Grass grids (concrete)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>40%</td>
<td>0.6 - 0.7</td>
</tr>
<tr>
<td>Water bound surfaces</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>50%</td>
<td>0.5</td>
</tr>
<tr>
<td>Permeable pavements</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>20%</td>
<td>0.5 - 0.6</td>
</tr>
<tr>
<td>Porous asphalt</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>0%</td>
<td>0.5 - 0.7</td>
</tr>
<tr>
<td>Asphalt</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>0%</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Costs*: Asphalt = 100%

* Indicative costs in relation to asphalt are provided, in 2010 average costs for conventional asphalt layers amounted to approximately 40 €/m² (without VAT), including construction costs. For each surface type material costs and labour costs were considered.

3.1.3 Gravel Turf

Gravel turf looks like conventional lawn and can absorb rain water up to 100%. Gravel turf is also known as “reinforced grass with gravel” is currently the most promising technique for parking areas and low frequented roads. The building costs are currently less than half compared to conventional asphalt layers and maintenance is very low. However, their construction needs qualified “building competence”. In the past bad practice has led to plugged in surfaces and loss of water drainage capacity. The technique was remarkably improved in recent years, and gravel turf is today a promising ecological surface for public parking areas. Key barriers are currently lack of experience of builders and restrictions from the water authorities, who in many cases demand that rain water of large surfaces is directed to a sewage system.
Gravel turf can be built with material, which is regionally available in all European countries. Two major components are used: 1/ natural gravel or recycling material like building rubble, 2/ organic supplements which can be compost or the original soil. For the vegetation layer grass seeds are used.

Subsoil
Gravel turf needs subsoil preparation to increase the stability. 1-layer gravel turf needs a subsoil layer of 30 cm, usually a mixture of gravel and compost. 2-layer gravel turf needs to be applied when subsoil stability is not sufficient, an additional 20 cm layer needs to be applied.
Run-off coefficient 0.1 - 0.3

Drainage
Gravel turf is one of the very few permeable surfaces which can be constructed without an additional drainage system.

Application range
Gravel turf is most suitable for parking areas with low or intermittent congestion. It may also be used for emergency access e.g. in parks or to residential buildings and for infrequently used roads. Gravel turf is also a suitable technology for tramway tracks, which are not or rarely frequented by car traffic (see also Best Practice).

Maintenance
The surface is maintained like a normal lawn and needs about 2 to 3 grass cuttings per year. In winter snow removal needs to be carried out with a highly elevated snow plug (3 cm above surface) and without road salt.

Benefits
1/ High water drainage capacity saves waste water costs, 2/ Landscape protection: gravel turf is not an optical intrusion like asphalt sealing, 3/ Regional materials: the required materials are easily available and don’t need long distance transport, 4/ Reuse of recycling material is possible for the subsoil layer, in particular recycling material from the building industry

Limitations
1/ Permanent parking, 2/ highly frequented parking lots, 3/ barrier-free parking, 4/ winter maintenance, requires snow removal without road salt (which is common in many countries)

Costs
Simple and inexpensive construction, indicative costs are 15 to 2 € per m² (excl. VAT) Conventional asphalt layers amount to approximately 35 – 40 €/m² in Germany, Austria, Italy (exc. VAT) No seepage water collection system needed.

Conclusions
Gravel turf is a long lasting ecological surface and is ideal for large parking areas which are not permanently frequented. The surface can also be used for day parking. The potential applications are by far not exploited; good examples are for instance the “green tramway tracks” (see also Fig. ). Another benefit is the fact that the surface does not require an additional drainage system. The surface is maintained like a normal lawn and needs about 2 to 3 grass cuttings per year. Key barriers are currently lack of experience of builders and restrictions from the water authorities, who in many cases demand that drainage of large surfaces is directed to a sewage system.
3.1.4 Plastic grass grids

Plastic grass grids look like conventional lawns, they are simple to install and low cost.

<table>
<thead>
<tr>
<th>Description</th>
<th>Plastic grass grids can be either filled with soil and grass seeds or with gravel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Polyethylene (recycled versions available), grass seeds, original soil, sand, crushed rock and gravel</td>
</tr>
<tr>
<td>Subsoil</td>
<td>Plastic grass grids are installed on a crushed stone bed similar to gravel turf. For additional stability and frost protection a second layer of crushed stone is required (see Tab. 8).</td>
</tr>
<tr>
<td>Run-off coefficient</td>
<td>0.3 (90 % unsealed surface)</td>
</tr>
<tr>
<td>Drainage</td>
<td>Plastic grass grids can be installed without additional drainage systems.</td>
</tr>
<tr>
<td>Application range</td>
<td>Low frequented parking areas and gate ways</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Regular maintenance by mowing and special snow removal (no road salts) necessary.</td>
</tr>
<tr>
<td>Benefits</td>
<td>Low cost, no run-off water management necessary, landscape protection, re-use of upper soil layer possible, use recycling material possible (recycled polyethylene)</td>
</tr>
<tr>
<td>Limitations</td>
<td>Not for permanent parking, not for regularly frequented parking, not for disabled persons parking (bad accessibility by wheelchair or crutches), requires regular maintenance (mowing) and special snow removal (no road salts), the material is sensitive to UV radiation and gets fragile.</td>
</tr>
<tr>
<td>Costs</td>
<td>Total costs per square meter are estimated to range between gravel turf and conventional asphalt layers; i.e. about 30 €/m². The plastic grid alone costs about 11 – 16 €/m² (excl. VAT) without sub-base and labour costs.</td>
</tr>
</tbody>
</table>

Fig. 6 Grass grids – examples
Source: The Construction Centre [124]
Conclusions

Plastic grass grids improve the water drainage and storage capacity of surfaces and have a landscaping function. However, this solution is preferable for low frequented parking areas. The life span of the plastic grid is lower compared to concrete or gravel based systems.

3.1.5 Concrete grass grids

Concrete grass grids have a higher stability as plastic grids and last longer, but their installation costs are considerably higher.

![Concrete grass grids](image)

**Fig. 70 Concrete grass grids – examples**

Source: Producer website

### Material

Concrete grass grids, grass seeds, original soil, sand, crushed rock and gravel.

### Subsoil

Concrete grass grids are installed on a crushed stone bed, for additional stability and frost protection a second layer of crushed stone is required. The grids are either refilled with original soil, humus and grass seeds or with gravel. The construction of the sub-base is similar to concrete pavers (see also Tab. 10). Specific installing machines are available for larger surfaces.

### Run-off coefficient

0.6 with gravel filling, 0.7 with humus and grass seeds

40% unsealed surface

### Drainage

Run-off water need is usually directed to nearby drainage ditches.

### Application range

Car and caravan parks, fire access routes, footpaths, temporary car parks, and street verges.

### Maintenance

Requires regular maintenance (mowing) and special snow removal.
Benefits

Run-off water management necessary in regions with heavy rainfalls (typically nearby drainage ditches).
Reuse of upper soil layer possible
Can be easily repaired
Green vegetation layer possible

Limitations

Not for barrier free parking, requires regular maintenance (mowing) and special snow removal (no road salts). The surface is very bumpy and not suitable for shopping trolleys.

Costs

Costs are about equal to concrete pavers and are approximately at 40 €/m² (excl. VAT).

Conclusions

Concrete grass grids are a long lasting solution and are also suitable for higher frequented parking areas. They have a landscaping function and increase the local water and storage capacity by at least 60% percent compared to conventional asphalt layers. Major drawbacks are regular maintenance and the bumpy surface. They are ideal for highly frequented parking grounds at recreational sites.

3.1.6 Water bound surfaces (macadam)

Water bound surfaces are the most traditional type of semi-sealed surfaces. They are also known as gravel walks and dirt roads. Their application range reaches from walk ways to roads with low frequency, depending on subsoil layers. Compared to conventional asphalt surfaces water bound surfaces have considerably lower building costs but require higher maintenance.

Water bound surfaces are supposed to be vegetation free. There a different design options possible with regard to the gravel colour of the surface layer and the boarder design.

Fig. 71 Water bound surfaces - examples
Overview of best practices for limiting soil sealing or mitigating its effects in EU-27

Tab. 9 Water bound macadam – technical description of layers and building material

Source: Green Concrete [119], City Planning Department Vienna [121]

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
<th>Frequency</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>L = low frequency</td>
<td>only pedestrians</td>
<td>1 cm</td>
<td>0/2 crushed sand, 0/4 landscaping</td>
</tr>
<tr>
<td>M = medium frequency</td>
<td>small vehicles</td>
<td>2 cm</td>
<td>0/2 crushed sand, 0/4 landscaping</td>
</tr>
<tr>
<td>S = strong frequency</td>
<td>heavy vehicles (fire engines)</td>
<td>2 cm</td>
<td>0/2 crushed sand, 0/4 landscaping</td>
</tr>
<tr>
<td>1</td>
<td>cover layer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>compensation layer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>supporting layer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>frost protection</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Material
Water bound macadam can be built with material, which is regionally available in all European countries. Major components are 1/ sand, and 2/ crushed rock in different in grain sizes.

Subsoil
Water bound surfaces are based on a very traditional technique. Different layers of gravel and crushed rock are applied. The grain size increases with the depth. Frost protection as bottom layer is applied.

Application range
Walk ways and low frequented roads with a slope gradient of max 2%

Maintenance
Frequent repair of the upper layer (filling the holes)

Benefits
1/ High water drainage capacity saves waste water costs, 2/ Building effort and costs are low, 3/ Regional materials can be used, since gravel and crushed rock are available in most European countries, 4/ good walking comfort

Limitations
1/ Dust formation, the surface is not recommendable in highly wind exposed areas, 2/ Mud accumulation if water run-off is not managed properly, 3/ The upper layer needs regular repair, 4/ Unsatisfactory snow removal: because of the rough surface snow plugs have to be adjusted 3 cm above the surface. Residual snow remains on the street and either freezes or melts.

---

2 0/2 refers to particle size from 0 mm to 2 mm
**Costs**

Investment costs are about one third lower than conventional asphalt layers, and depend mainly on regional labour costs. Indicative costs for waterbound surfaces are 20. €/m² (excl. VAT) referring to Germany in 2010.

**Run-off coefficient**

0.5

**Drainage system**

Roads with a water bound macadam surface are usually built with side ditches for water drainage.

**Conclusions**

Major drawbacks of water bound surfaces are dust formation and unsatisfactory snow removal. This type of surface is only applicable for extremely low frequented roads and parking areas.

### 3.1.7 Permeable concrete pavements

In this section the two most common types are described, namely concrete blocks with voids, and permeable blocks without voids. The water seeps either through the voids between the blocks or through the porous blocks themselves.

**Concrete blocks with voids** are typically used in urban areas for highly frequented parking lots, gate-ways and courtyards. Concrete blocks are installed on a permeable, open-graded crushed stone bedding layer. The joints are filled with either with humus and grass seeds or crushed stones. Gravel fillings make the surface smoother and are preferable for parking areas where shopping carts are used. A joint width of 3 cm is ideal for infiltration. In low infiltration soils some or all drainage is directed to an outlet via perforated drain pipes in the sub-base.

**Permeable concrete blocks** consist of concrete made from tiny compacted pellets. This solid structure is porous i.e. water drains directly through the surface of the block. They are installed without open voids. The lower sub base consists of compacted gravel of 15-30 cm thickness, depending on use intensity and frost stability.
Fig. 73  **Left: principle of permeable concrete blocks, right: parking area with permeable concrete blocks**
Source: [123], [122]

### Tab. 10  Permeable concrete pavers – technical description of layers and building material
Sources: [117], [120]

<table>
<thead>
<tr>
<th>Layer</th>
<th>L - low frequency</th>
<th>M - medium frequency</th>
<th>S - strong frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6 – 8 cm concrete blocks joints: humus and sand</td>
<td>6 – 8 cm concrete blocks joints: humus and sand</td>
<td>6 – 8 cm concrete blocks joints: humus and sand</td>
</tr>
<tr>
<td>2</td>
<td>4 – 2 cm compensation layer in compacted form, crushed rock 0/8</td>
<td>4 – 2 cm compensation layer in compacted form, crushed rock 0/8</td>
<td>4 – 2 cm compensation layer in compacted form, crushed rock 0/8</td>
</tr>
<tr>
<td>3</td>
<td>10 cm supporting layer in compacted form crushed rock 0/32</td>
<td>20 cm supporting layer in compacted form crushed rock 0/32</td>
<td>20 cm supporting layer in compacted form crushed rock 0/32</td>
</tr>
<tr>
<td>4</td>
<td>not necessary</td>
<td>10 cm frost protection compacted form crushed rock 0/32</td>
<td>10 cm frost protection compacted form crushed rock 0/32</td>
</tr>
</tbody>
</table>

L = only pedestrians  M = small vehicles  S = fire engines

### Material
Both systems are made of concrete blocks and gravel. In the case of concrete blocks with voids humus, sand and grass seed are additionally used. All materials are regionally available in all European countries.

### Subsoil
There are various shapes of concrete pavers available. In order to increase the drainage capacity there are also special blocks of porous concrete available. In such cases the run-off water can seep through the joints but can also to some extent drain through the bricks.

### Application range
Parking lots, pedestrian paths, surfaces at industrial sites
Maintenance of the joints is required, in order to avoid plugging and loss of drainage capacity. The voids are cleaned with specific gravel exhausters and refilled with new gravel every 5 – 10 years.

Benefits
1/ Disruptions due to frost can be excluded, 2/ Partly permeable, 3/ Vegetation in the joints, 4/ Low maintenance, 5/ Low slip hazard when glazed frost, 6/ Visual appeal better than asphalt, great variety of design options (patterns and colours)
Voids filled with gravel have a higher and longer lasting permeability.

Limitations
1/ Litter in the joints can lead to decreasing run-off capacity, 2/ Walking comfort is lower compared to asphalt, 3/ In low infiltration soils some or all drainage needs to be directed to an outlet via perforated drain pipes in the sub-base or to drainage ditches.

Costs.
Indicative costs for standard quality pavers are currently at 40 €/m² (without VAT, Austria, Italy, Germany). Premium quality pavers cost up to 60 €/m². Maintenance costs of concrete pavers are clearly lower. In the case of construction works brick pavers can always be recycled, whereas asphalt needs to be disposed of.

Run-off coefficient
0.5 - the joints amount to 20 % of the surface.

Drainage
Run-off water is typically directed to nearby drainage ditches.

Conclusions
Over their lifetime concrete pavers are more sustainable and cost less than conventional asphalt layers. In the case of road works the material can be entirely reused.

3.1.8 Porous asphalt
Porous asphalt requires the same building technique as normal asphalt. Porous asphalt consists of standard bituminous asphalt in which the fines have been screened and reduced, creating void space to make it highly permeable to water. The void space of porous asphalt is approximately 15 - 20%, as opposed to two to three percent for conventional asphalt.

(1) = conventional asphalt, (2) = porous asphalt with rough grain size, (3) porous asphalt with fine grain size.

Fig. 74 Porous asphalt – examples
Source: [118]
Final Report
Overview of best practices for limiting soil sealing or mitigating its effects in EU-27

Material
Bituminous material, gravel

Subsoil
four layers:
(1) 5 – 10 cm layer of asphalt,
(2) 2 – 5 cm crushed aggregate,
(3) 30 cm supporting layer of crushed rock
(4) layer of geo-textile material.

Run-off-coefficient
0.6 - 0.7

Drainage
The requirements to drainage are the same as for conventional asphalt.

Application range
Roads, parking areas, large public surfaces and recreational surfaces

Maintenance
No regular maintenance required, renewal of the surface is more often necessary compared to conventional asphalt; approximately every 12 years compared 25 years.

Benefits
Dry surfaces result in higher road safety, no run-off water management necessary except in regions with extreme rainfalls, noise reduction/absorption

Limitations
Lower life span than normal asphalt, plugging of pores and reduction of drainage capacity

Costs
Costs are about equal to conventional asphalt surfaces, i.e. approximately at 40 – 50 €/m² (excl. VAT) but the life span and optimal functioning of the material is only half compared to conventional asphalt.

Conclusions
Porous asphalt has no landscaping function but can increase the local water storage and drainage capacity by at least 20 % compared to conventional asphalt.

3.2 Green Roofs
A green roof is a roof on a building that is partially or completely covered with a growing medium and vegetation, planted over a waterproof membrane. It may also include additional layers such as a root barrier and drainage and irrigation systems. The earliest known green roofs were turf roofs, a Nordic tradition still practiced today in many parts of Norway and Iceland. Turf was a durable and readily available building material known to have an insulating effect. Fig. shows the principal components of green roofs.
Green roofs can help to address the lack of green space in many urban areas. They are relevant for minimising some of the negative effects of soil sealing by moderating the urban heat island effect, improving the air quality by filtration of airborne particulates, providing an oxygen supply for humans and animals, creating a refuge for wildlife and retaining storm water hence reducing the load on the urban sewage system.

Depending on the depth of planting medium and the amount of maintenance they need green roofs can be categorized as intensive, semi-intensive, or extensive. Examples are given in Fig. 76. Intensive roofs are thicker and can support a wider variety of plants but are heavier and require more maintenance than extensive roofs which are covered in a light layer of vegetation and are lighter.

Tab. Tab. 11 summarizes general features of green roof types.
Tab. 11 General features of green roof types

<table>
<thead>
<tr>
<th></th>
<th>Extensive</th>
<th>Semi intensive</th>
<th>Intensive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use</td>
<td>Ecological landscape</td>
<td>Garden, ecological landscape</td>
<td>Garden, Park</td>
</tr>
<tr>
<td>Type of vegetation</td>
<td>Moss, Herbs, Grasses</td>
<td>Grass, Herbs, Shrubs</td>
<td>Lawn, Perennials, Shrubs, Trees</td>
</tr>
<tr>
<td>Depth of substrate</td>
<td>60-200mm</td>
<td>120-250mm</td>
<td>150-400mm</td>
</tr>
<tr>
<td>Weight</td>
<td>60-150 kg/m²</td>
<td>120-200 kg/m²</td>
<td>180-500kg/m²</td>
</tr>
<tr>
<td>Cost</td>
<td>low</td>
<td>periodic</td>
<td>high</td>
</tr>
</tbody>
</table>

**Ecological benefits**
1/ Water retention: depending on their design green roofs retain 50-90% of rain water
2/ Binding dust and toxic particles: 10-20% of the dust from the air are filtered
3/ Improved noise protection: reduction of sound reflection by up to 3 dB, improve the sound proofing by up to 8 dB
4/ Improved building thermal performance (insulation): A study conducted by Environment Canada found a 26% reduction in summer cooling needs and a 26% reduction in winter heat losses when a green roof is used. This reduced demand for energy would also mean a massive reduction of carbon dioxide production.
5/ Reduction of the urban heat island effect: Information from thermal studies, carried out at Trent University in the UK, found that on a typical day where ambient temperature was 18.4°C, a bare membrane roof had a surface temperature of 32°C. An identical roof covered with a thin layer plant system had a surface temperature of approximately 15°C.
6/ Biodiversity: refuge for wildlife in urban areas
7/ A larger living space: compensation for green spaces

**Economic benefits**
1/ Increased water retention: reduction of drainage costs
2/ Reduced renovation costs
3/ Reduced energy costs
4/ Substitute for lost areas of landscape
5/ Additional space

**Disadvantages**
1/ Higher initial cost
2/ Higher maintenance costs (however some types of green roof have little or no ongoing cost).
3/ Restrictions involving climate and weather conditions (e.g.: rooftop gardens are inappropriate in very windy places; plants are fragile and can be blown away).
4/ Eventually, stronger roof beams are needed in order to support the several green roof layers (some existing buildings cannot be retrofitted with certain kinds of green roof because of the weight load of the substrate and vegetation exceeds permitted static loading).
5/ More costly repairs and fixings (finding and repairing eventual leaks is more expensive and difficult).
Costs

Costs for green roofs vary very much between different countries, and are generally higher in countries where there are few entrepreneurs that install green roofs. An extensive green roof is normally less expensive than an intensive one. Site-built green roofs are often cheaper than prefabricated mats. The following factors are affecting the price per meter:
1/ Size of roof – the larger the area the cheaper per square meter the roof will be
2/ Height of the roof. This will affect the price in terms of the cost of raising the elements to roof level
3/ Type of green roof
4/ Initial maintenance and establishment costs
5/ Type of waterproofing and insulation used (difference in labor costs)
6/ Other factors (Roof elements that intrude above the roof such as outlets, roof lights and industrial plant and other additions such as access hatches, safety lines can lead to increase in price per meter squared.)
7/ Involvement of manufacturers and contractors
8/ Installation methods

Indicative costs for extensive sedum matted green roofs are 50 – 100 €/m² [126]

3.3 Legal requirements and incentives

Binding requirements to use permeable surfaces along construction are rare. The authors identified three legally binding systems and one system, which is based on monetary incentives.

3.3.1 Binding sealing limit in the City Dresden (DE)

The city of Dresden uses three legally binding instruments to reduce sealing along new construction activities [127].

- The Building Code³ prescribes minimum criteria for the protection of landscape, nature and soils. In this context permeable surfaces for gateways, walk ways, and parking areas are prescribed and a clear reference to the use of permeable concrete pavers, gravel turf, plastic and concrete grass grids is made.
- Specific Construction Permits clearly prescribe a sealing limit for gateways, walk ways, and parking areas.
- The municipal Parking Space Ordinance⁴ limits soil sealing along the construction of new parking areas, the use of permeable surfaces is compulsory.

3.3.2 Sealing Index in the Province Alto Adige (IT)

In the province Alto Adige the limitation of soil sealing is prescribed in the municipal zoning plan and the corresponding municipal construction ordinances⁵. In 2002 the provincial law

³ Grünordnung § 9 Abs. 1 Nr. 20 Baugesetzbuch (BauGB)
⁴ Satzung der Landeshauptstadt Dresden über Stellplätze und Garagen, February 2001
⁵ Norme di attuazione al piano urbanistico / Durchführungsbestimmungen zum Bauleitplan
3.3.3 Permeable surfaces without planning permission (UK)

Policy promoting the use of Sustainable Urban Drainage (SUD) systems in the UK is relatively advanced; at a high level SUDs are explicitly promoted in Planning Policy Guidance 25 to prevent urban flooding [129]. Moreover, this is promoted at the development plan level and by local authorities especially within the London Boroughs i.e. Islington and Ealing. In addition, in England the permitted development requirements for households have recently changed meaning that surfacing of front gardens with permeable surfaces (refer to section on permeable driveways) does not require planning permission, while the use of impermeable surfaces requires planning permission. There are therefore tools in place to promote SUD use generally and specifically address the consequences of local, small scale sealing.

3.3.4 Binding sealing limit in the City Vienna (AT)

For new development areas Specific Construction Permits are issued by the city planning authorities, which prescribe permeable surfaces for gateways, walk ways, and parking areas [130].

3.3.5 Tax incentives in several German municipalities

German municipalities are in charge of collecting the Rain Water Tax from real estate owners. The tax refers to rain water that is being directed to the municipal sewage system. The calculation of the tax is usually based on the size of the sealed surface. Some municipalities provide tax reductions for the installation of rain water collection systems or the use of permeable surfaces instead of asphalt layers. However, the tax as such is not very high and resulting reductions are too small to influence building techniques. To give an example, in the case of the municipality Wuppertal the tax incentive would result in 3 € per parking space and year if adequate permeable paving is installed\(^7\) [131]. From an economic point of view the construction of a rain water collection system makes more sense to house owners. Rain water can be stored in a reservoir and used for irrigation, which saves water costs.

3.3.6 Green roof subsidies

In Austria green roof policies were introduced in Linz in 1985 as part of legally binding and compulsory building plans. It was one of the first cities in the world to have a compulsory

---

\(^6\) B.V.F. - Verfahren (Bесhрänkungen der versiegelten Flächen)

\(^7\) The municipality Wuppertal charges 1.9 € per m\(^2\) sealed surface and year. Tax reductions of 30 % are granted for permeable pavers, 50 % for green roofs, and also 50 % for the installation of rain water collection systems. A large supermarket with 100 parking spaces (approx. 1.000 m\(^2\)) would save 570 € per year.
green roof policy. In 1989 the City of Linz started with a generous financial incentive for building owners, by sponsoring green roofs up to 30% of total investment costs. This subsidy was later reduced in 2005 to 5%. The total area prior to 2007 was 400,000 m² (equivalent to 40 soccer-pitches). About 90% of this area are extensive green roofs and 10% intensive green roofs [126].

In Germany policies to encourage green roof construction exist at all levels of jurisdiction; at the national, federal, and the municipal level. German green roof policies, many of which have been in place for over a decade, fall into four general categories [132]:

- direct financial incentives (subsidies)
- indirect financial incentives (split wastewater fees)
- ecological compensation measure; and
- integration into development regulations.

In 2003 green roofs made up 14% of total roof area in Germany. In the 1990ies several German cities started to levy commercial buildings related to the amount of sealed ground space they occupy. For example in Berlin this tax amounted to 2 € per m² per annum. A reduction of 50% of this tax rate is applicable for buildings that have planted roofs. Similar taxation and incentive schemes operate in Bonn, Munich and Stuttgart. For these reasons the roof space covered by greenery in German cities has increased at an astonishing rate. In 1995, 10,000,000 m² of roof space had been greened. By 1999 this figure had risen to 84,000,000 m². Nearly one third of all cities have regulations to support green roof and rain water technology [132].

**Denmark:** As part of its overall strategy to become a carbon neutral city by 2025, Copenhagen has become the first Scandinavian city to adopt a policy that requires green roofs for all new buildings with roof slopes of less than 30 degrees. Copenhagen presently has 20,000 square meters of flat roofs. It is hoped that as much as 5,000 square meters of new development each year will be covered with vegetation [133].

The UK do not have an explicit national policy that requires or encourages the use of green roofs, however there are key national policies that support them. These include “Securing the Future” – the UK Government’s sustainable development strategy 2005, and “Climate Change” – the UK Programme 2006. The use of green roofs is also consistent with other planning policy statements and guidance documents such as PPS1 - Delivering sustainable development, PPG2 - Green belts, PPS3 – Housing, PPS9 - Biodiversity and geological conservation, PPG17 - Planning for space, sport and recreation and PPS25 - Development and flood risk [126].

**The Netherlands:** Examples of Dutch cities that have policies to support the implementation of green covered roofs are Groningen, Rotterdam, Amsterdam and The Hague [134].

- In Groningen private households can obtain subsidies for green roof construction, amounting to € 30 per square metre. The subsidy is limited with a maximum of €1.500.
- In Rotterdam subsidies are available from the city government, amounting to €25 per square metre, another € 5 per square metre can be obtained from the district water board.
- In Amsterdam a subsidy of € 20 per square metre to a maximum of €1,000 can be obtained.
In The Hague a subsidy of € 25 per square metre to a maximum of €20,000 is available.

3.4 Research

Carbon Footprint of Pavements in Urban Space. A detailed survey of the City of Vienna compares the carbon dioxide emissions and sustainability of various pavement systems over their lifetimes. The study considers (1) the origin of materials and their transport impact, (2) maintenance efforts and costs, and (3) waste production and material reuse. A key conclusion of the survey is that material transport is the highest contributor to overall CO₂-emissions of pavement systems and that higher investment costs of permeable pavers are outweighed shortly after their installation due to lower maintenance costs [121].

Cost benefit analysis of permeable and impermeable surfaces [114]. A survey completed in 2008 for CIRIA (Construction industry research and information association) demonstrated relatively low awareness among the public regarding legislation but also existing techniques. Moreover general knowledge towards the environmental need to undertake, for example, the use of permeable surface solutions was observed to be low. The latter has the potential to result in resentment on the part of property owners when they are required to undertake action. The same survey also identified that the awareness of the issues by installers, merchants, retailers, etc was thought to be problematic. The survey concluded that ‘There was also thought to be a lack of communications between authorities to determine best practice for materials and specification. Lack of contractor skills, knowledge, familiarity and effective training with regards to implementation of permeable surfaces was considered to pose a significant challenge that needs to be addressed’.

The CIRIA study also identified that industry awareness differed depending upon the technology to be employed. For example there were relatively high levels of understanding in terms of how to install permeable block pavers and their use, with medium levels of understanding regarding the use of reinforced grass and gravel systems. There was little understanding of the use of porous asphalt either domestically or commercially. This variation in awareness regarding the use of relatively common SUD solutions i.e. permeable surface materials, is coupled with concerns over the skills available to install and availability of materials on the market place.

3.5 Best practice

3.5.1 Green tramway tracks

Green tramway tracks are getting more and more popular (see examples Fig. 77). They improve the visual appearance of towns and have an additional drainage function in urban areas. In the city of Graz a novel gravel turf technique was applied on a pilot track of 130 m length. The subsoil preparation included a high share of recycled building rubble and a high share of compost in the vegetation layer. The resulting surface does not require any maintenance (grass cutting) due to the frequent circulation of the tramway.
3.5.2 Sustainable Urban Drainage (SUD) Systems

**Showcase for SUD techniques**. A new residential development of 35 affordable homes was built on a one hectare site in the UK. The project shows the full range of possible Sustainable Water Management Techniques within residential developments, including among other SUD techniques\(^8\) such as permeable paving, water butts; a green roof; swales; detention and wetland basins; and a retention pond. The aim is to control the runoff starting as close as possible to its source.

\(^8\) Other applied SUD techniques: water butts, green roofs, swales, detention and wetland basins; and a retention pond
sealing in front gardens and to convince the local population about the benefits of greening and permeable pavements. The project was established under Ealing Borough Council’s Agenda 21 programme and funded by the local Council. A survey of front gardens in Ealing showed that the average front garden in the borough has 68% of its area covered in hard surfacing. In October 2008, largely in response to extensive flooding in several cities in 2007, limited controls on front garden hard surfacing came into force. (The Town and Country Planning Order 2008 requires front garden hard surfacing of more than five square metres in area to either be made of porous material or, if an impermeable surface, to direct runoff to a soakaway area or rainwater storage within the property’s boundary or require planning permission, the application to include a scale drawing and a fee of £ 150.)

The project builds on awareness raising, public participation, practical and legal advice for citizens [137].

3.5.4 Parking for the masses

The sealing of large open air parking areas for large visitor streams, like at soccer stadiums, at trade fairs, or in skiing resorts poses several problems. The large sealed surfaces increase the local flooding risk. In many cases these areas are most of the time empty, because they are only seasonally frequented or only for a few hours. Large asphalt areas are always a visual nuisance.

EXPO 2000 World Exposition. The parking area of the EXPO 2000 World Exhibition is the largest parking area with permeable surfaces. The area has the capacity for 25,000 cars and 1,600 busses. In total an area of 300,000 m² was paved with permeable concrete blocks. At the outer and less frequented parking area gravel turf was applied.
Final Report
Overview of best practices for limiting soil sealing or mitigating its effects in EU-27

Fig. 80 Germany: EXPO 2000 parking area in Hannover
Source: [138]

Soccer Stadium Salzburg. The stadium was enlarged and adapted for the Euro Masterships in 2008. The parking area has a capacity of 2,000 cars and has a gravel turf surface.

Fig. 81 Austria: Parking area of the Salzburg soccer stadium.
Source: [130]

3.6 Summary
Permeable surfaces can replace soil functions and mitigate the effects of soil sealing to a limited extent. They increase the local water drainage capacity and can in some cases also fulfill biological or landscaping functions. Presently there is no information in order to quantify the application of the single surface types described.

Green roofs generate new green space and create an added value to the quality of living in particular in very densely built areas. However, they can not necessarily be classified as instruments to reduce soil sealing.
A broad range of materials and concepts is available for permeable surfaces. In addition to their clear ecological advantages most types of surfaces have lower lifespan costs compared to conventional impermeable surfaces. With regard to sustainability it can be said that most permeable surfaces are made of materials that are locally available and reusable.

Barriers to implementation. However, there is not one unique permeable surface that can serve all purposes. All share the fact that site specific know how and building competence is required to construct them correctly. Maintenance is needed to make sure that they function properly. Currently major barriers to the implementation of permeable surfaces are as follows.

- Controversial building legislation. In many cases conventional pavement and the direction of rain water to the sewage system are stipulated by the building license. This is often the case for large parking areas, where contamination of the run-off water is assumed.
- Lack of know-how is currently the greatest barrier to a wider application of permeable surfaces. Therefore conventional asphalt techniques prevail (everybody knows how to do it).
- Prejudice. Permeable surfaces have the reputation to be either expensive or to be troublesome. “The expensive eco stuff makes sludgy puddles” is a common opinion. Bad building practices have supported this prejudice.

Missed opportunities. Parking areas have the greatest potential for permeable surface application. In Europe there are definitely more parking lots than cars. The number of cars is increasing from year to year and together with this trend also the number of parking lots.

- Recreational sites. The application of reinforced grass systems with gravel or grass grids is ideal for large short-term used parking areas, like in ski resorts, soccer stadiums, golf courts, touristic sites, and trade fairs. Such surfaces improve the local drainage capacity and contribute positively to the landscape.
- Households. Private driveways have great potential for the application of permeable surfaces. For this type of use almost all surfaces types are applicable.
- Supermarkets. The use of permeable concrete pavers in combination with drainage ditches is a long lasting solution which allows heavy traffic. This type of surface is more and more applied at supermarket parking areas.

Limitations. Areas with sensitive groundwater resources or shallow groundwater (below 1 meter) are in general not suitable for surface drainage.

Costs. Apart from natural stone pavements, it can be said that permeable surfaces do not bear higher costs than conventional asphalt and are not dependant on the crude oil price (unlike asphalt).

Sustainability. Gravel turf and concrete bricks are made of sustainable materials, which are readily available in most European regions. As these materials can easily be reused their life span is almost unlimited. Conventional asphalt on the contrary has to be recycled for re-application with more energy input.

Trends. Many planning authorities in Europe are currently revising their technical regulations towards surface sealing. Increased drainage capacity has many advantages, in particular in areas with flood risk or overloaded sewage systems. The fact that permeable surfaces can reduce or even avoid costs related to flood prevention, flood damage repair or enlargement of existing sewage systems is attractive for local planning authorities. For example, planning
authorities in England, in the Alto Adige region (Italy), and selected cities in Germany and Austria already restrict surface sealing for new building activities.