Edited by

GRÜNGLEIS NETZWERK

HANDBOOK Track Greening

Design • Implementation • Maintenance

Eurail press

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The Project

This Handbook for Track Greening has been produced by the members of Green Track Network (Grüngleisnetzwerk). These members are experts from suppliers, transport operators, academic and scientific institutions covering different aspects of Green Track (track and its component parts, design and construction, vegetation, growing medium, irrigation, sound and vibration).

Peter Ahrens, Rheinbahn AG, Düsseldorf

Frank Dreger, Berliner Verkehrsbetriebe

Reinhard Giglmaier, KRAIBURG STRAIL GmbH & Co. KG, Tittmoning

Michael Grätz, SCHMID Ingenieure GmbH, Bau- und Verkehrswesen, Berlin

Dr. Gerd Grütze, edilon)(sedra GmbH, Wiesbaden

Dietmar Haub, ECO Rain® AG, Hünstetten

Christian Heimings, edilon)(sedra GmbH, Wiesbaden

Susanne Hötzl, Stuttgarter Straßenbahnen AG

Dr. Christel Kappis, Institute of Agricultural and Urban Ecological Projects affiliated to Berlin Humboldt-University (IASP), (Editor of the German handbook edition)

Thomas Kröger, Kassel Verkehrs-Gesellschaft AG

Dr. Friedrich Krüger, Research Association for Underground Transportation Facilities e.V. – STUVA, Cologne

Axel Mittelstädt, ViP – Verkehrsbetrieb Potsdam GmbH

Karsten Reichenbacher, Gleiswerkstatt, Karlsruhe (Editor of the German handbook edition)

Dr. Gerd Reidenbach, Education and Research Institute for Horticulture, Erfurt

Dr. Christian Schade, Niedersächsische Rasenkulturen NIRA GmbH & Co. KG, Groß Ippener

Manfred Schmitz, RAIL.ONE GmbH, Neumarkt

Andrea Scholz, KRAIBURG STRAIL GmbH & Co. KG, Tittmoning

Hendrikje Schreiter, Institute of Agricultural and Urban Ecological Projects affiliated to Berlin Humboldt-University (IASP), (Editor of the German handbook edition)

Rüdiger Schwartz, Stuttgarter Straßenbahnen AG

Ryan Stolpmann, RAIL.ONE GmbH, Neumarkt

Thomas Stutz, Rhein-Neckar-Verkehr GmbH, Mannheim

Thorsten Utermöhlen, KRAIBURG STRAIL GmbH & Co. KG, Tittmoning

Anja Wetzel, Münchner Verkehrsgesellschaft mbH

We also thank the following persons for additional input to this work

Walter Burg, Parks Department Karlsruhe

Prof. Dr. Swantje Duthweiler, Weihenstephan-Triesorf University of Applied Sciences

Ulrich Früh, TRAVETTO GmbH & Co. KG, Fahrwegsysteme und Gleisbau, Satteldorf

Oliver Glaser, ViP – Verkehrsbetrieb Potsdam GmbH

Dr. Heiner Grüneberg, Humboldt University Berlin

Stefan Hegelow, H.P.H. Landscape GmbH, Berlin
Wolfgang Henle, Staatsschule für Gartenbau und Landwirtschaft Hohenheim, Stuttgart
Gerd Hirschelmann, Verkehrs-Consult Leipzig (VCL) GmbH
Ralf Jensen, OBERMEYER Planen + Beraten GmbH, Karlsruhe
Bernd Krupka, Planungsbüro Bernd W. Krupka, Bad Pyrmont
Andreas Neukirch, Dresdner Verkehrsbetriebe AG
Conrad Paul, L+P Planen, Beraten, Baumanagement für Freiraum und Landschaft, Munich
Friedrich Pimpl, Amt für Grünordnung, Naturschutz und Friedhofswesen, Augsburg
Andreas Plamann, Berliner Verkehrsbetriebe
Markus Reinacher, Mailänder Consult GmbH, Karlsruhe
Sascha Ruhnow, Mailänder Consult GmbH, Karlsruhe
Bernd Schingen, Leonhard Weiss GmbH & Co. KG, Cologne
Dr. Manfred Seyfarth, Umwelt-Geräte-Technik GmbH, Müncheberg
Herbert Sladek, VDV, Cologne
Dr. Walter Stahl, TU Munich
Transport companies: BSAG, SWA, SWU, VAG, VGF

Members of the Green Track Network

edilon)(sedra STRAILastic RAIL.ONE NIRA

SCHMID ingenieure GmbH BVG rnv Rheinbahn

KVG Kasseler Verkehrs-Gesellschaft Aktiengesellschaft SSB MVG

STUVA LVG in ERFURT iASP

Contents

1 Preface

The successful delivery of Green Tram Track requires the integration of knowledge and experience from rail track engineering and horticultural science.

The handbook for track greening provides recommendations and guidance for the design, implementation and maintenance of Green Track for light rail and tram schemes. It is primarily aimed at transit authorities, planning and design consultancies, contractors and at city planners. It has been developed particularly for light rail and tram schemes which are operated in accordance with the German BOStrab (Ordinance on the Construction and Operation of Street Railways) regulations.

In the German context approvals according to BOStrab have to be requested from the competent technical supervisory authority.

Applications for railway lines which are operated in accordance with EBO (Ordinance on the Construction and Operation of Railways) have to be determined on an individual case basis and be inspected and approved by the competent supervisory authority.

The statements made in this book are based on current legislation and guidelines as well as the knowledge and experience of the authors. They are intended as recommendations for professional work under normal circumstances. Individual projects may require further detailed specification.

The application of the designs and management regimes described in this book relate to the applications currently used in Germany, which are compliant with German standards as noted.

2 Benefits and Effects of Green Track

Following the construction of the first segregated tram ways[1] in Greater Berlin at the beginning of the 20th century, the first Green Track began to appear. Many pictures from that era show that Green Track was very common especially in the inner city area, such as in Berlin Hardenbergstraße, in vicinity of the Kaiser Wilhelm Memorial Church, in Tauentzienstraße and at the Kurfürstendamm. In 1916/1917, there were already approx. 37.5 km of Green Tracks (with grass) in Berlin (Giese 1917).

Figure 1: Grass Tracks at Potsdamer Platz, Berlin 1933 (Picture: [20])

Figure 2: Grass Tracks in Hardenbergstr., Berlin 1918 (Picture: [21])

Figure 3: Grass Tracks in Tauentzienstr., Berlin 1930 (Picture: [22])

1 Segregated tram ways are located in public roads but structurally separated within their own right-of-way (e. g. kerbs) (BOStrab § 16).

Grass Track designs were used in Berlin until the 1930s, but ceased due to increasing demands on the track structure, in particular regarding corrosion protection and electrical insulation.

Since the mid 1980s, the re-emergence of the use of Green Tracks owing to a growing environmental awareness of transit authorities, urban planners and urban ecologists has been seen. Numerous Grass Tracks have been installed in many German cities, e. g. Bremen, Berlin, Düsseldorf, Dresden, Freiburg, Kassel, Leipzig, Mannheim, Munich and Würzburg as well as in other European cities, e. g. Den Haag, Zurich and Linz.

A survey carried out at the end of 2009 indicated that there were more than 425 kilometres of Green Tracks in Germany[2] (IASP 2009). A current survey from December 2015 (IASP 2015) indicates the rapid growth in the extent of Green Track in Germany, now listing a total of 565 kilometres. By the end of 2017, at least 12 further kilometres of Green Track is scheduled for completion nationwide.

The reasons for installing Green Track are complex. Many transit authorities install Green Tracks because it offers increased public acceptance of schemes, in fact the implementation of Green Tracks are often a condition for approval by the Authorities Having Jurisdiction. Furthermore, Green Tracks are often installed as part of track renewal projects.

The main requirements by Authorities Having Jurisdiction are the reduction of noise emission and the visual enhancement of the urban area associated with greening the tracks. Additionally, Green Track has many important ecological benefits and effects which are not always fully considered by the decision-makers, partly because the benefits of track greening are not yet entirely documented. They apply particularly in hard landscaped inner city areas.

The following benefits and effects are associated with Green Tracks:

Benefits for urban design

- Visual enhancement of track structure.
- Better public acceptance of the tram schemes.
- Better reputation for cities and their transit authorities.
- Urban green-space becomes a location factor attracting businesses and increasing property values.

Ecological benefits

Stormwater retention in the track structure

- Annual average: 50 - 70 % of stormwater for each m² of Green Track; this corresponds to an average annual stormwater retention of 400 - 550 litres for each m² of vegetation area.

Mitigation of heat island effect in track structure

- Cooling effect due to the evaporation of the stored stormwater.
- Protection of the ground and the track structure from direct solar radiation and the corresponding heat absorption.

2 This is considered a conservative estimate since not all transit authorities were included in the survey. The real number is considered to be higher.

- Vegetation systems have a low thermal capacity cooling down faster during the night compared to hardscaped areas such as concrete and asphalt.
- High-level vegetation systems reduce the exposed area of the rail and thus reducing the rail temperature in particular on hot days.
- Contribution to the reduction of local heat island effect.

Absorption and retention of pollutants

- Reduction in airborne particulate matter and other pollution through deposition on the vegetation surface and the vegetation base layer.
- Absorption of pollutants by plants and vegetation base layer.
- Additional metabolic reaction with some pollutants by plants, or hosted enzymes/bacteria.
- Reduction of continued dust dispersion within the track area.

Noise reduction

- Reduction of noise emissions – in particular with high-level vegetation systems.
- Noise reduction of up to 3 dB(A) compared to optimised ballasted track.
- Green Track is subjectively perceived to be unobtrusive.

Increasing biodiversity in the city

- Green Tracks provide important habitats (biotopes) for biota (cp. Krupka 1992).

Health benefits and well-being

- Positive effects as a result of above-mentioned ecological benefits on health (noise reduction, absorption of fine dust, cooling effect).
- Close link between provision of green space and levels of respiratory and heart problems indicate the significance of green areas.
- Positive effect of greenery on social and mental well-being.

Economic effects

- Green Tracks can be recognised as a compensatory or replacement measure; municipalities may decide to not implement compensatory measures when installing Green Tracks.
- Green Tracks can significantly reduce the stormwater run-off and hence requirements for drainage (storm drain, stormwater retention, impact on watercourse) compared to hardscaped areas.

The following sections describe the benefits for urban design, ecology and economy (which are closely connected and complementary) in more detail.

2.1 Urban Design and Visual Appearance of the Tracks

The light rail and tram tracks have an ever present visual impact on the city landscape and therefore play an important role in urban planning. A major benefit of Green Tracks is the significant aesthetical improvement of the track area compared to ballasted and embedded track. This is particularly important for urban areas such as city centre areas with little foliage.

Green Tracks can create new green spaces on a scale which would be difficult to deliver otherwise in such an environment.

Four kilometres of single track built as Green Track provides more than one hectare of vegetation (Henze, Siemsen 2003). The 565 kilometres of Green Tracks currently existing in Germany have created more than 131 ha (1.31 million m^2) of green space in track areas and its vicinity.

The aspects of urban greenery relevant to health include the increase in mental well-being, especially due to the reduction of stress (Timoshkina 2001). Furthermore, social identification and social well-being may be enhanced. Thus, a successful greening of tracks helps to improve the reputation of transit authorities and can provide an improved public opinion of the particular scheme. Additionally, Green Track can promote the tram or light rail system as an urban-friendly and modern transit system. Recent reports confirmed that green spaces in urban areas, including roadside grassed areas of Green Track, significantly increase the typical land values in major and medium-sized cities in Germany (Hoffmann and Gruehn 2010). The increase in property values linked to urban green space is an economic factor which to date has not been researched in depth but which is likely to gain importance in the future.

The effect of Green Track is dictated by the type of track structure specified – high-level, low-level and mixed-level vegetation (see Chapter 3.1), by the type of vegetation system and the maintenance of the system. A high-level vegetation system provides a more uniform, calmer pattern. Furthermore, the additional volume of the vegetation layer acts as water storage which is important for the plants to remain green during dry periods. The track is visually less dominating when the rail encapsulation (see Chapter 4.1) is kept as narrow as possible.

Some transit authorities however prefer the clear visibility of the tracks with low-level vegetation systems, also because maintenance of the tracks and the rail fastenings can be carried out without further effort. With high-level vegetation systems, often clearly-visible rail encapsulation systems are installed to make crossing pedestrians aware of the tracks.

Different types of vegetation and their specific conditions achieve different visual appearances. According to a survey (IASP 2009), most German transit authorities prefer the standard Grass Track (see Chapter 5.2.1) which shows a thick green sward when it is well taken care of. The addition of herbaceous can create a grassland-like impression due to their habitus, shades of green and blossoms. An advantage of using different types of herbaceous is that during drought they stay green for a longer period of time than grasses.

Additional design options include bands of grassland next to the tracks. However, depending on the maintenance regime, seeds from the grassland next to the tracks may migrate into the track area.

Sedum systems can create a very homogenous surface as well as variable heights depending on the combination of *Sedum* species. During summer, *Sedum* systems stand out due to their blossoms. Under stress[3], e.g. lack of nutrients, the plants turn red. This can be reversed by fertilising.

3 At most track locations plants are sometimes exposed to suboptimal environmental conditions/stress, e.g. extreme droughts or waterlogging, lack of nutrients, foot traffic, wind suction, extreme temperatures, intense light irradiation, pollution, particulate matter. Stress reactions of plants only rarely become pathologic. Usually plants adjust to their surroundings. Plants can react to stress e.g. with growth retardation or impaired reproduction capacity.

Figure 4: Appearance of the tracks before and after the greening process in Berlin (Pictures: [3]; [32])

Figure 5: Appearance of the tracks before and after the greening process in Düsseldorf (Pictures: [1])

Figure 6: Appearance of the tracks before and after the greening process in Berlin (Pictures: [12])

Selecting vegetation systems to meet the design requirements must take account of the location specific conditions and the maintenance requirements associated with the specific locations. In addition, appropriate maintenance and care is required to maintain the desired visual appearance of the vegetation system as otherwise site specific conditions for individual plants may change.

Figure 7: Bands of grassland next to the track in Munich (Picture: [34])

Figure 8: Bands of grassland next to the track in Munich (Picture: [34])

Thus, other species of plants are superior in establishing themselves than the type of vegetation which was actually intended to grow there. This results in a changed appearance. Therefore not only the type of vegetation system and its adjustment to the particular location are important for the visual appearance but also maintenance and care of the vegetation system.

For areas of greenery which are occasionally frequented by emergency vehicles, gravel turf (see Chapter 9.5.1), plastic grass grid systems or concrete grid pavers can be applied (see Chapter 9.5.2). Some sparse native grasslands and gravel turf might appear green and tight when viewed from the side but turn out to be less dense and rather tuft-forming in plan. Appropriate vegetation systems and their adaption to location specific conditions should be kept in mind accordingly. Thin-walled plastic grids are hardly visible when there is a thick layer of plants and do not interfere with the visual impression of Green Tracks. However, plants rarely overgrow and conceal concrete grid pavers completely.

2.2 Urban Ecology

2.2.1 Improved Stormwater Retention in Green Track

Green Tracks help to expand urban green areas; one of the main benefits is the positive impact to the local hydrology.

In Green Tracks, the vegetation system stores stormwater until saturated. Excessive stormwater will be discharged through infiltration or external drainage systems. Retained stormwater is mainly released back by evapotranspiration (transpiration of plants and evaporation from the vegetation base layer), thus increasing humidity and creating a cooling effect. The stormwater retention capacity of greening systems depends on the vegetation system.

The average stormwater retention of the annual total precipitation for Green Tracks is as follows:

50 % for Green Tracks with *Sedum* vegetation system and
70 % for Green Tracks with grass vegetation system (Henze *et al.* 2003; Siegl *et al.* 2010).

Based on an average stormwater of 790 l/m^2/yr (UNIVERSITY OF OLDENBURG) in Germany, a Green Track system retains approx. 400-500 l of stormwater per m^2 each year.

Hence one hectare (ha) of Track Greening (equal to 4 km of single Green Track) stores

approx. 5.500 m^3 of water per annum in Green Tracks with grass vegetation system and
approx. 4.000 m^3 of water per annum in Green Tracks with *Sedum* vegetation system.

Vegetation systems have a significant impact on stormwater retention, in particular by delaying the run-off from the track after the peak rainfall, reducing the peak flow and discharging the run-off uniformly. Overall stormwater quality is improved due to the filter effect of the vegetation systems. The drainage system in the vicinity of Green Tracks may be considerably relieved compared to ballasted tracks or embedded tracks.

Heavy precipitation in particular during the summer months – potentially causing localised flooding in areas with a high level of imperviousness – can be attenuated by vegetation systems.

Additional related information:

- For basic explanations on urban ecology refer to SUKOPP and WITTIG (1993).
- A comprehensive description of the benefits of Green Tracks on urban ecology is included in the publication 'Benefits and effects of Green Tracks' (2012, www.gruengleisnetzwerk.de) by the Green Track Network. Further Information can be found in SIEGL *et al.* (2010), TAPIA (2002), KAPPIS *et al.* (2010).
- For basic findings from design and construction of green roofs – which can be transferred to Green Tracks – refer to SCHADE (2000), MANN (2000), LIESECKE (2000), KRUPKA (1992).

2.2.2 Improving the Urban Climate by Evaporation from Green Track and Cooling Effect

High levels of imperviousness of inner-city areas and frequent extreme weather events cause increased heat and drought stress. The effect of heat islands occurs since buildings absorb much heat during the day which is released only slowly during the night, the low evaporation rate and the corresponding low cooling effect. That's where vegetation systems can offer relief:

- Plants absorb energy for photosynthesis.
- The evaporation of water from plants and soil creates a cooling effect.
- Plants protect the soil against direct solar irradiation.
- Vegetation systems have a low thermal capacity cooling down faster during the night compared to hardscaped areas such as concrete and asphalt (MILLER 1999).

Different experiments ascertained a temperature regulating effect of vegetation systems on their surroundings and the track due to the increased evapotranspiration rate from plants and soil and the resulting cooling effect as well as the decrease in the temperature gradient in the track (HENZE *et al.* 2003; SIEGL *et al.* 2010, FUCHS *et al.* 2005). This effect depends on the type of vegetation system. Green Track with grass vegetation is rated superior than Green Track with thin-layered *Sedum* vegetation.

A possible cooling efficiency of Grass Tracks was investigated by SIEGL (2010) for a location in Dresden and virtually monetised: With an evaporation of 438 l from each m^2 of Grass Track, the temperature of 88,000 m^3 air annually is reduced by 10 K. 100,000 m^2 of Grass Tracks reduce the temperature of 8.8 billion m^3 air annually by 10 K.

This corresponds to an air volume of 88,000 stadiums. 0.63 kWh are required for the evaporation of 1 litre of water, with an evaporation of 438 litres for each m^2 of Grass Track, this corresponds to an annual energy amount of 27.6 million kWh (for 100,000 m^2 of Grass Track). Based on a price of 0.2 €/kWh, the total value is € 5.52 million per annum.

Studies indicate that despite intense solar irradiation, the vegetation in Green Tracks – both grass and *Sedum* – only heat up to 25 - 30 °C whereas exposed areas such as rail encapsulation and ballast reach temperatures of more than 50 °C (Henze *et al.* 2003; Siegl *et al.* 2010, Fuchs *et al.* 2005).

Vegetation areas do not heat up that much and they also cover the layers underneath preventing them from heating up. As a consequence, the temperature of rails in a high-level vegetation Green Track system is only 25 - 30 °C (Siegl *et al.* 2010).

2.2.3 Bonding of Pollutants

One problem of urban areas is high air pollution by particulate matter and adherent substances which can harm human health but also buildings and structures.

Depending on their local site situation and on the overall system, vegetation systems can support the removal of particulate matter from urban air: Pollutants are being deposited on the enlarged and comparatively rough surface of the plants (e. g. PAH, heavy metals) and are partially bonded to the vegetation surface. Some of the pollutants are metabolised or incorporated.

The absorption of parts of particulate matter and pollutants by the Green Track vegetation system can reduce their local concentration in the air. The deposition capacity depends on different parameters, such as the concentration of particulate matter in the air, the wind conditions or the surface roughness of the vegetation system. This effect is more likely to increase if the ratio of plant cover is high with a high deposition surface and with different heights of the individual plants. Vegetation systems significantly reduce the continued dust dispersion within the track area compared to impervious surfaces. In most cases, Green Tracks are located in the immediate vicinity one of the main emission sources for particulate matter – road traffic. Rail traffic also creates particulate matter. Important sources of emissions from tram and light railway operations are e. g. abrasion of brakes, wheels, rails and overhead contact lines.

Due to the ability of bonding of dust and to some extent the significant area dedicated to track infrastructure in cities, Green Track has a high potential for reducing particulate matter in urban spaces. Currently, there are more than 1.31 million m^2 of vegetation in Green Tracks in Germany which have the ability to bond particulate matter and pollutants (IASP 2013).

Further information:

- On railways and particulate matter can be found at e. g. Burkhardt *et al.* 2005, Bukowiecki *et al.* 2007, Gehrig *et al.* 2007, Heldstab *et al.* 2002, Lorenzo *et al.* 2006.
- On the bonding of particulate matter by plants e. g. at Schreiter and Gorbachevskaya 2011 and Gorbachevskaya *et al.* 2007.

2.3 Noise and Vibration Emissions

2.3.1 General

The operation of tram and LRT systems is inevitably connected to noise and vibration emissions. The intensity of those emissions depends on several parameters, namely the type of track, the design and the condition of the track structure. Some parameters affect both noise and vibration emissions (e. g. the speed and rail surface condition) and other parameters affect either noise or vibration emissions.

Figures 9 and 10 indicate a schematic overview of noise emissions. The main sources are the wheel, rail and sleeper or concrete beams of slab track systems, generating both noise and vibration emissions. But the propagation paths differ – noise is primarily emitted horizontally while vibrations are directed into the ground through the rail fastening, the sleepers or concrete beams of slab track systems. Thus, there are different approaches for reducing these emissions.

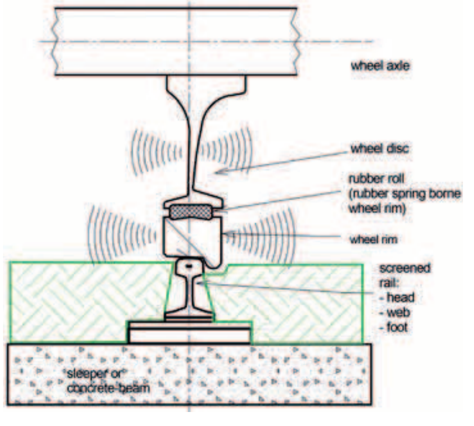


Figure 9: High-level vegetation system, screening of the rail (Graph: [19])

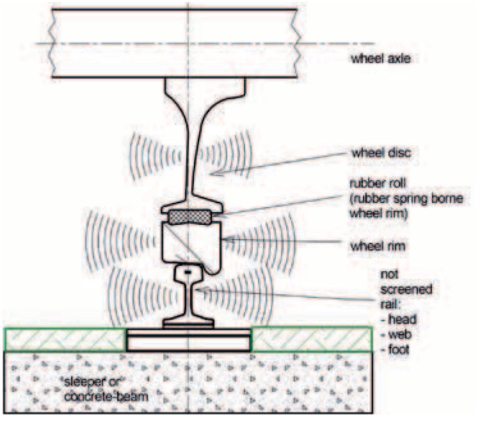


Figure 10: Low-level vegetation system, no screening of the rail (Graph: [19])

2.3.2 Noise Emissions

The intensity of noise emissions caused by tram/LRT operations is mainly determined by the following effects:

- Roughness of the rail head and wheels.
- Emitting characteristics of wheels, rails and sleepers or concrete beams of slab track systems.
- Vehicle speed.
- Noise caused by vehicle engine and propulsion.
- Covering of the wheels by lateral wheel apron.
- Absorption properties of the vehicle bogie (undercarriage, side panels).
- Absorption properties of the track bed (areas inside and outside of the track).

Noise emissions associated with Green Tracks are primarily influenced by the type of vegetation system (see 3.1). Whereas a high-level vegetation system (Figure 9, Figure 13) largely surrounds the rail and therefore noise can only be emitted in the area of the rail head, low-level vegetation systems leave the rail exposed and consequently noise can be emitted by the entire rail surface area (Figure 10, Figure 13). Acoustically, the latter corresponds largely to the standard track structure with sleepers and ballast.

Based on the assumption that the wheel and the rail contribute to noise emission in equal parts, completely embedding the rail could reduce noise by a maximum of 3 dB(A). This reduction corresponds to the magnitude of noise reduction which was monitored for Green Tracks with high-level vegetation systems compared to ballasted tracks with exposed rails. Green Tracks with low-level vegetation systems achieve a noise reduction of just under 1 dB(A) compared to ballasted track systems.

For the evaluation of noise emissions, a noise reduction of 2 dB(A) has to be taken into account irrespective of the vegetation level.

Note:

The German Traffic Noise Ordinance (16. BImSchV) is currently being revised. The revised German Traffic Noise Ordinance (16. BImSCHV) came into effect on January 1st, 2015.

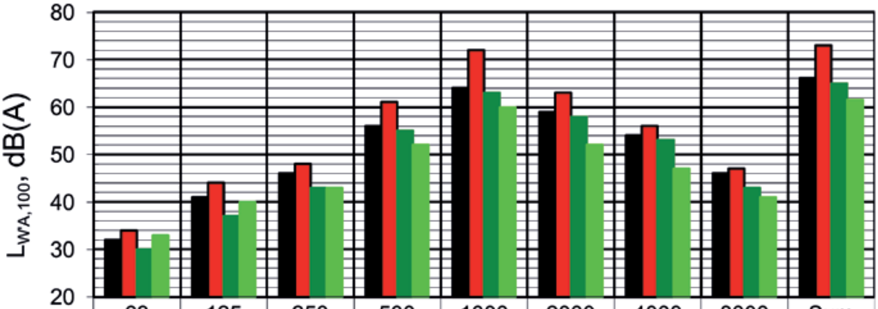
The figures included in Guideline ‘Schall 03’, which have also been revised, are now integrated in the revised Ordinance. Green Tracks are being differentiated between high-level and low-level vegetation systems and different noise level correction factors apply. The correction factors are specified for octaves ranging from 63 Hz to 8000 Hz and are indicated in Table 1 in accordance with the Ordinance:

Track type	Level corrections in dB for octave mid band frequency in Hz							
	63	125	250	500	1000	2000	4000	8000
Embedded track and slab track	2	3	2	5	8	4	2	1
Green Track – low-level vegetation system	–2	–4	–3	–1	–1	–1	–1	–3
Green Track – high-level vegetation system	1	–1	–3	–4	–4	–7	–7	–5

Table 1: Noise level correction factors compared to ballasted track

Residents in the vicinity of Green Tracks generally value them favourable compared to ballasted tracks or embedded tracks with asphalt/paved surfaces. This also has an effect on how noise emissions are perceived – as less intrusive. Compared to embedded tracks with asphalt surface, noise emission from ballasted tracks as well as Green Tracks is reduced considerably, ranging from 5 dB(A) to 8 dB(A).

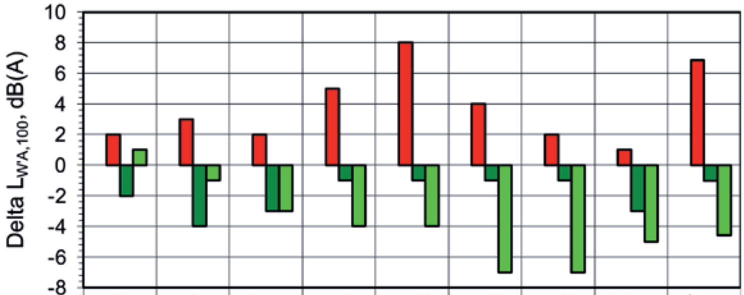
The revised Ordinance specifies the linear noise power level (LW’A,100), based on V = 100 km/h, as emission level. Figure 11 indicates the numeric results for these emission levels for trams/LRT on ballasted track systems (BT), embedded tracks with asphalt surface or slab track systems (ST), Green Tracks with low-level vegetation (at foot of rail – level (FOR)) and Green Tracks with high-level vegetation (at top of rail – level (TOR)). The differences in the emission levels compared to ballasted tracks are indicated in Figure 12.



	63	125	250	500	1000	2000	4000	8000	Sum
BT	32,0	41,0	46,0	56,0	64,0	59,0	54,0	46,0	66,1
ST	34,0	44,0	48,0	61,0	72,0	63,0	56,0	47,0	72,9
FOR	30,0	37,0	43,0	55,0	63,0	58,0	53,0	43,0	65,0
TOR	33,0	40,0	43,0	52,0	60,0	52,0	47,0	41,0	61,5

Octave middle frequency , Hz

Figure 11: Linear noise power levels in accordance with the Traffic Noise Ordinance (Graph: [19])



	63	125	250	500	1000	2000	4000	8000	Sum
BT	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
ST	2,0	3,0	2,0	5,0	8,0	4,0	2,0	1,0	6,9
FOR	-2,0	-4,0	-3,0	-1,0	-1,0	-1,0	-1,0	-3,0	-1,0
TOR	1,0	-1,0	-3,0	-4,0	-4,0	-7,0	-7,0	-5,0	-4,6

Octave middle frequency, Hz

Figure 12: Difference of linear noise power levels compared to ballasted track (Graph: [19])

Liepert, Sigl, and Möhler (2006) quote the following changes in emission levels compared to ballasted tracks:

- ‘The noise emission of embedded tracks is approx. 6 to 7 dB(A) higher compared to ballasted tracks. According to ‘Schall 03: 1990’, the corresponding correction factor for slab track systems is 5 dB(A) compared to ballasted track with timber sleepers and 3 dB(A) compared to ballasted track with concrete sleepers (irrespective of type of vehicle or speed).
- The emission level of Grass Track with low-level vegetation system is approx. 1 dB(A) lower and the emission level of Grass Track with high-level vegetation system is approx. 4 - 5 dB(A) lower compared to ballasted track.’

Thus the numbers in Figure 11 confirm the statements of LIEPERT, SIGL, and MÖHLER (2006).

The current Traffic Noise Ordinance (16. BlmSchV) classifies noise from railway traffic less disturbing than noise from road traffic. A railway specific bonus of 5 dB(A) can be considered when calculating the noise rating level. However this railway specific bonus will be omitted for railways as of 2015 and for tramways/LRT as of 2019. Consequently, considerable noise reduction measures will be required for new projects and existing schemes subject to major re-construction in order to adhere to the limits of the Traffic Noise Ordinance and Green Track with high-level vegetation system can make a significant contribution.

2.3.3 Vibration Emissions

The intensity of vibration emissions caused by train operations is mainly determined by the following effects:

- Irregularities in the wheel-rail-interface, in particular flat wheels, rail corrugation flats or rail joints including fishplated joints, insulated rail joints and welded joints.
- Axle load, unsprung mass of wheelset.
- Distances between the wheels and the rail supporting points (frequency excitation of the sleeper bay or rail supporting point frequency); if possible, the distances between the wheels should not be a whole multiple of the distance between the rail supporting points.
- Vehicle speed.
- Vertical stiffness and damping of the rail support.
- Size and mass of the ballast underlay or the track supporting slab in mass-spring systems (see series of standards DIN 45673 [4]).
- Properties of the substructure and the subgrade.

In general, the greening of the tracks and in particular the level of vegetation does not have an immediate impact on the intensity of vibration emissions.

2.4 Economic Benefits of Track Greening

Immediate benefits for transit authorities

The reduction of stormwater discharge into the local sanitary system can be rewarded financially in cities which impose different charges for waste water and stormwater. This is regulated at the Federal State Level.

The Federal Nature Conservation Act (BNatSchG 2009) states that the environmental impact resulting from construction activities has to be accounted for. Federal Laws define in detail which projects are considered to have an environmental impact and which projects are generally considered not to have an environmental impact. The Federal States take different measures to compensate for the loss of natural areas resulting from increased imperviousness. So called biotope area factors (BAF) are defined as ecologic planning values in landscaping plans in e.g. Berlin and Brandenburg. Saxony, Saxony-Anhalt, Baden-Wuerttemberg, Lower Saxony and Schleswig-Holstein award ecopoints.

These parameters are taken into consideration for determination of required compensatory measures and can reduce the scope of compensatory or replacement measures.

4 Series of standards: mechanical vibrations – Elastic elements of railway track structures

Depending on the type of vegetation system, Green Tracks can be considered entirely as compensatory measures (e.g. the Green Track of tram line 23 in Munich which incorporates calcareous grassland) or result in a decrease of the scale of compensation (e.g. Grass Track with high-level vegetation system as implemented on the St. Emmeram tram scheme in Munich).

Covering ballast with a vegetation system protects the ballast from litter, fines, leaves, etc. and can therefore result in an extension of the tamping cycle. Due to the rails being embedded in Green Tracks, the rail temperature remains relatively low and the risk of lateral displacement of the tracks is reduced accordingly.

Indirect benefits for transit authorities

Green Tracks help to enhance the reputation of transit authorities regarding their contribution to the improvement of general life conditions as well as public perception.

Immediate benefits for municipalities and the general public

Depending on the extent of greening, the drainage system and water/wastewater treatment plants can be relieved due to the delayed and/or reduced stormwater discharge.

The plants absorb less heat energy and therefore lower the ambient temperature as a result of evaporation and increased reflection of solar radiation of the plants. At large, urban greening can reduce the development of urban heat islands which in turn minimises local energy costs for air conditioning systems during heat waves (HALL 1998). Productivity is increased and the risk of heat-related damage caused to individual's health is reduced (KEMFERT 2007).

The reduction of noise emissions due to Green Tracks can already be considered during the design process and can therefore reduce costs associated with otherwise required noise protection measures such as noise barriers or noise-proof windows. This applies to all types of Green Track systems (see also Chapter 2.3.2).

An attractive urban landscape due to Green Tracks can contribute to a general upgrade of the local neighbourhood and to an increase in property values.

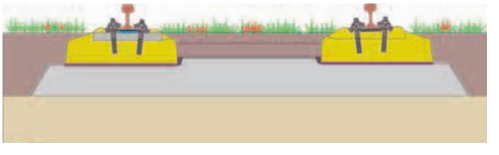
3 Types of Green Track and Track Structure Systems for Green Track

3.1 Types of Green Track

Three different types of Green Track can be distinguished by the varying level of the vegetation systems with both grass vegetation and *Sedum* vegetation. Individual elements of the vegetation system vary depending on the type of the Green Track system. The three different types are indicated in the pictures below.

Type 1: High-level vegetation (top of rail – TOR)

Type 2: Low-level vegetation (foot of rail – FOR)



Type 3: The mixed level type
(Low-level vegetation between rails and high-level vegetation outside of track)

Figure 13: Different types of Green Track (Graphs: [28], Pictures: [32], [25], [32])

Selecting a type of Green Track system is determined by the following:
- The required track performance (insulation, care, maintenance).
- Requirements associated with the vegetation system (site conditions, maintenance requirements).
- Urban design requirements.

3.1.1 Tracks with Vegetation System to Top of Rail Level (High-Level Vegetation)

High-level vegetation systems are generally installed
a) with standard Vignole rail section up to approx. 5 cm below the rail head, or
b) with grooved rail sections up to 1.5 cm below the rail head which can result in the visual impression of an even 'green carpet'.

To reduce the risk for stray current leakage, and the associated issues, the vegetation system should not be in direct contact with the running rails. Thus an insulation/encapsulation system for the rails and fixings is required for Green Tracks with high-level vegetation system (see 4.1).

Advantages	Disadvantages
General	
– Improved noise reduction due to fully encased rails. – Integration of the track bed into urban landscape through uniform Green Track with a high focus on urban design. – Improved effect on urban climate due to significant higher (storm)water storage capacity of the vegetation base layer. – Debris and leaves being carried away by wind much easier.	– The railway right-of-way is to a lesser extent perceived as danger zones. – Increased crossings of tracks by pedestrians. – A higher standard of rail insulation/encapsulation is required to minimise stray current leakage through the vegetation layer and subbase layer. – Access for maintenance of rails and track structure is considerably constrained compared to low-level vegetation systems; increased effort required for monitoring and replacement. – Increased risk of motor vehicle incursion on to tracks.
Grass	
– High capacity to retain and store stormwater due to the deeper layer of vegetation base layer. – Thickness of vegetation base layer provides good growing conditions for grasses and enhancing growth. – Access on to tracks for lawn mowers and tractors allows large-scale mechanised maintenance. – The grass clippings can be removed more easily.	– Depending on the type of rolling stock, the vegetation can be impacted negatively by the heat radiating from the light rail vehicle (when stationary). – After heavy snowfall, the vegetation system can be damaged by snow ploughs. – Ground 'heave' of vegetation base layer above the level of rail encapsulation; e.g. caused by frost action. – Potential for significant rodent infestation.
Sedum	
	– Increased pedestrian traffic can damage the vegetation system. – Motor vehicle incursion on to tracks in particular during frost periods could result in complete loss of the vegetation.

Table 2: Advantages and disadvantages of high-level vegetation systems compared to low-level vegetation systems

3.1.2 Tracks with Vegetation System to Foot of Rail Level (Low-Level Vegetation)

The vegetation system is installed up to the underside of the rail foot as maximum. The full height of the rails sits clear of the vegetation base layer, and plants/grass; and the rails remain clearly visible. Subject to design, Green Track systems with both grass vegetation and *Sedum* vegetation systems are feasible.

Advantages	Disadvantages
General	
– Rails and fastenings are always accessible. – Rails can be surveyed and replaced without any additional effort. – The vegetation does not overgrow the track. – Minor risk of stray current leakage. – No additional system components are necessary (e.g. rail insulation/encapsulation). – Ice and snow can be accommodated within the system, no issues with snow removal. – Tracks are clearly visible, the perception of the railway right-of-way is improved. – Pedestrians are more reluctant to cross exposed tracks and incursions by motor vehicles are less likely. – The heat radiation caused by some rolling stock does not significantly damage low-level vegetation systems.	– Increased noise levels due to noise emissions from exposed rails. – The even green area is interrupted by clearly visible rails which is adverse for urban design since the divisive effect of tracks increased. – Increased surface storing heat (exposed rail and concrete elements). – Debris and leaves are trapped in the track (poor visual impression). – Regular cleaning of sleepers/concrete beams required at the rails and rail fastenings (separation of rail and vegetation).
Grass	
– Heave of the vegetation base layer due to frost unproblematic.	– Limited thickness of vegetation base layer depending on the track structure. – Limited capability for water retention due to reduced thickness of vegetation base layer can adversely affect grass growth and appearance during dry periods. – Increased effort for maintenance and ensuring safety for maintenance staff (e.g. use of lawn tractors limited, use of manual lawn mowers necessary which requires multiple lifting of equipment to clear tracks during train operation, additional trimming required, removal of grass clippings more labour intensive).
Sedum	
– Increased inhibition threshold to access tracks; reduced pedestrian loading of the vegetation system. – Installing substrate-free vegetation systems with shallow layer feasible.	– Elaborate adjustment work at the track, track slab and rail fastening is required to some extent to ensure protection against root penetration.

Table 3: Advantages and disadvantages of low-level vegetation systems compared to high-level vegetation systems

3.1.3 Tracks with Mixed-Level Vegetation System (Special Solutions)

The vegetation system is installed as high-level vegetation system outside the rails and between tracks and as low-level vegetation system between the rails of each track. Thereby some transit authorities compromise on both vegetation systems. The track is distinctively more visible compared to a high-level only vegetation system.

The following table indicates selected properties.

Advantages	Disadvantages
General	
– While appearing like an even green area, the track is clearly visible and recognised as infrastructure system. – Rails and fastening elements are visible and accessible on one side of the rails. – The heat radiation caused by some rolling stock does not significantly damage the low-level vegetation system between the rails. – Ice and snow can be accommodated within the system.	– Debris and leaves are trapped in the track. – Depending on the track construction, there is only a limited thickness for the vegetation base layer available. – Limited capability for water retention when thickness of vegetation base layer is reduced can adversely affect grass growth and appearance during dry periods
Grass	
	– The effort for maintenance is comparable with low-level vegetation systems. – Different growth pattern of the grass in and next to the track due to different thickness of the vegetation base layers.
Sedum	
Combination of advantages and disadvantages of both high-level and low-level vegetation systems.	

Table 4: Advantages and disadvantages of a mixed-level vegetation system

3.2 Track Structure Systems for Green Track

Depending on the height of the vegetation system, Green Track systems can either meet the criteria for an ‘open’ or for a ‘closed’ track structure system (VDV Guideline 604). Green Tracks are discussed in the section ‘Track Covering with Grass’ of VDV Guideline 604.

To ensure good growing conditions for the vegetation system (see Chapter 5.2), the industry and transit authorities developed track structure systems which meet the requirements of the vegetation.

At the same time, the design of the vegetation systems was adjusted to the technical requirements of the different track structure systems. Vegetation systems can be installed in both ballasted track with sleepers and slab track systems.

To minimise stray current leakage and corrosion, rails have to be insulated from the adjacent environment (see Chapter 4.1).

Depending on the vegetation system and the climatic site conditions, the track structure system has to accommodate the vegetation system and the respective thickness for the vegetation base layer (see Chapter 5).

Sustainable Track Greening requires the integration of knowledge and experience from railway track engineering and vegetation science. Selection of systems (track structure and vegetation system), location specific conditions as well as maintenance effort are closely related and should be considered at large.

The **Handbook Track Greening** offers a detailed overview and descriptions of established track structure systems and vegetation systems for light rail and tram schemes in Germany. It provides recommendations and practical guidance for the design, construction and maintenance of Green Track, focusing on technical principles. The book has been developed for light rail and tram schemes which are operated in accordance with the German BOStrab (Ordinance on the Construction and Operation of Street Railways) regulations however most of the technical principles apply to Green Track systems in general. Important legal aspects are indicated where applicable.

This Handbook is the first to gather requirements, knowledge and experience on Track Greening and was compiled by the members of the "Green Track Network" – experts from transit authorities, scientific institutes and manufacturers operating internationally.

The Handbook is primarily aimed at experts with technical knowledge of track and vegetation systems but also at urban designers, city planners and beginners as reference guide.

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