Turf (grass) track for light rail systems

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ABSTRACT

Light rail systems are experiencing a revival in several countries in the world. In many of the new networks, as well as in refurbished ones, turf (grass) tracks are being used as a means to get a reserved right of way that entails enhancements in the city landscape, improving the acceptance of the system by citizens and politicians.

Nevertheless, the visual impact of turf tracks is only one of their many advantages, which are going to be presented in this paper. These advantages range from environmental aspects, as reduction of noise and suspended fine particles, "green lung" effect, improvements in rain water management and heat island mitigation, to the decrease of operational and construction costs of the system.

On the other hand, this solution has, of course, some inconveniences or additional precautions that must be taken into account to ensure a good performance in the long term, as the need for vegetation maintenance and for rail-environment separation. There are, also, some limitations as their non-drivability for buses and emergency vehicles, the additional problems in case of derailment, and the possible incidences in operation due to irrigation, mowing and to vegetation waste and sand combination.

This paper focuses on the explanation of these advantages, inconveniences and limitations, in order to provide a better understanding of the solution and to make the decision of whether to use turf tracks in a new light rail system easier.

1 INTRODUCTION

Light rail systems are experiencing a revival in several countries in the world. In many of the new networks, as well as in refurbished ones, turf tracks are being used as a tool to get a reserved right of way that entails enhancements in the city landscape, improving the acceptance of the system by citizens and politicians.

It is important to note that turf tracks are not a new solution; they appeared in the early 20th century in many European cities and in New Orleans (USA). Nevertheless, new networks need a modern solution that gets all of the advantages of these tracks but counteracting the inconveniences that they can entail, as far as possible. The first designs were built over sand, or even covering ballasted tracks with grass, which entailed an increase in maintenance costs. Soon, these designs gave way to others similar to current ones, based in slab tracks, but with a finishing of vegetation instead of stones, asphalt or concrete. In essence, usually turf track is a form of slab track in which the space above the concrete load-bearing plate –between and beside the rails– is filled with humus and covered with some kind of vegetation.

Although the term turf track is used, actually the vegetation varies from one solution to another, ranging from grass (wet-seeded on a special substrate or as rolled turf on a special grass track bed), to portable vegetation mats (it is, vegetation units pre-sown with grass outdoors), or to other greenery systems, as sedum plants both planted by hand or using a spray technique [1].

In fact, several terms can be used for referring to these tracks, such as turf tracks, grass tracks, lawn tracks, green tracks or naturalized tracks. In this paper, turf track will be used preferably, but some other can appear for avoiding repetition.

2 A BIT OF HISTORY

The idea of turf tracks is not new; they appeared in the early 20th century in many European cities and in New Orleans (USA) [2]. In those days (December 1910), the Poverty Bay Herald newspaper published an article by Mr. S. Symington, a tramway engineer at Invercargill (New Zealand), pointing the interesting characteristics of turf track. Some parts of the paper are as follows [3]:

> *"(Grass track) It consists of the reservation of a portion of the roadway for tramway traffic only, and the laying of grass on this portion. This plan has recently been attracting a large amount of attention in Europe and England, and has been the subject of discussion in technical journals. (…). Many Continental cities are adopting the scheme in varied forms, and are planting trees and shrubs in some instances. These cities include Berlin, Cologne, Munich, Kottigsberg, Dusseldorf, Dresden, and Frankfort-on-Maine. The subject is also under consideration for the streets of Paris. (…).*
> *The principal points in its favor are:*
> *1. The beautification of the streets.*
> *2. Prevention of dust.*
> *3. Less risk of accidents.*
> *4. Greatly reduced maintenance costs.*
> *5. In cases where paved streets are in use, greatly reduced construction costs.*

6. Great reduction in noise and less vibration in buildings fronting street.
7. Higher schedule speed.
8. Less risk of derailment of cars.
9. Convenience to alighting and boarding passengers."

Some of these advantages are still valid, as will be shown in this paper, although others are based in operational characteristics specific of those days, and consequently they are not currently applicable.

3 CURRENT ADVANTAGES OF TURF TRACKS

3.1 Environmental advantages

3.1.1 Esthetic

Possibly the most common reason for politicians and society to be attracted by this turf track solution is its esthetic aspect (its positive visual impact).

The turf layer of naturalized tracks gives them a beautiful finish, making easier their integration in urban green spaces, or enhancing the streets where they are laid (see Figure 1).

3.1.2 Noise reduction

The fact of substituting a closed finish, as asphalt or paving stone, by a porous one (vegetation) leads to a significant reduction of acoustic emissions (this can be assimilated to the effect of noise reduction in cities after snow falls even with thin layers of snow [4]).

Along the history of track naturalization, several studies have been made to quantify this effect. The following results can be emphasized:

- In 1996, Eisenmann [5] stated that turf tracks generate an improvement of 7 dB(A) if compared with tracks embedded in the pavement, and of 2-4 dB(A) in relation to ballasted track (depending on the sleeper type).
- In Zurich (Switzerland), comparative measurements of noise levels from trains passing at 40 km/h, taken at a distance of 7.5 m, produced the following results: closed superstructures ranged between 85 and 87.5 dB(A), while the quietest superstructure is the one with grass (which also have a concrete bed), with values between 81 and 83 dB(A) [6].
- According to experiences in Linz (Austria), covering-in of the track with grass reduces the airborne noise level by about 5 dB compared with the usual covered-in construction [6].
- A research made in The Hague (The Netherlands) proved that turf tracks lead to a decrease in airborne noise of around 3 dB(A) [7].
- In Dresden (Germany), The *Dresdner Verkehrsbetriebe* (Municipal Transport Services) DVB AG started in 1995 to establish the first turf tracks. To verify the noise reduction of the lawn tracks, some systematic measurements were carried out. The noise was quantified before and after the sod lawn was brought out. Same streetcars, measuring points and drivers ensured significant results. The result of the measurements showed that the reduction of the noise level is approximately 5 dB(A) compared with conventional sleeper rails, independently of the vehicle speed [8].
- TCRP Report 57 by TRB [9] states that turf track has proven to reduce noise by 6 to 8 dB(A).

Therefore, it can be concluded that the fact of covering urban railway tracks with vegetation produces a reduction of acoustic emissions ranging between 3 dB(A) if they are compared with ballasted tracks, and at least 5 dB(A) if compared with paved or asphalted tracks. It is important to bear in mind that the noise levels of individual types of superstructure are substantially affected by rail condition [6].

3.1.3 Reduction of suspended fine particles

Turf tracks produce an improvement in urban environment due to their ability to capture a greater amount of particulate matter, given by the bigger available surface of the vegetation layer in relation to a paved or asphalted layer.

3.1.4 "Green lung" effect

The naturalization of tracks provides an increase in the extension of urban green areas. If a standard 7.5 m wide double track section is considered, a green area of $7.5 \cdot 1{,}000 = 7{,}500$ m^2 (0.75 ha) is achieved per each kilometer of track. In these zones, the vegetation photosynthesis converts carbon dioxide into oxygen (the effect known as “green lung”) in such a way that air pollution decreases around the tracks [1].

There are different studies that give values of carbon sequestration rates for several kinds of forest. As an example, the Agricultural Research Service (ARS) and the Colorado University have found that nearly 2.2 tons of carbon are stored in 1 hectare of green zone per year. Nevertheless, the capacity of vegetation to sequester carbon is driven by average temperatures, annual rainfall, plant type and soil maintenance practices. For the most usual types of plants and conditions in turf tracks, assuming that they have side walk trees alongside the track at around 10 m distance between their centers, the removal of carbon is likely to range between 0.25 and 0.63 tons of CO_2 per trackway hectare [2]. This means 0.19 to 0.47 tons per double track kilometer.

3.1.5 Improvements in rain water management

The way of using the available spaces in the urban areas has a decisive influence on the distribution of precipitation, evaporation and drain, and can therefore allow rain water retention at a specific location [10]. The urban sealing process can affect the amount of precipitation that results in runoff and evaporation. In impervious locations, runoff volume tends to increase and must be moved as quickly as possible into the sewage systems. Flooding may occur in such conditions, because the urban locations concerned do not have the ability to store and subsequently evaporate large amounts of precipitation. Furthermore, air humidity at the sealed areas decreases, as compared with vegetated areas [11].

The naturalization of tracks can contribute considerably as an alternative for implementing storm water management programs that improve the mesoclimate in suitable urban areas [11].

The average water retention capacity for normal rain events is directly dependent on the previous water content of the vegetation mat. The time from the start of the rain event to the beginning of runoff and the maximum runoff volume depends on the intensity of the precipitation event and the initial water content. The greater the precipitation and the higher the initial water content, the faster and more intensively it drains [11]. In general, it can be assumed that turf track can store between 50% (thin-layer systems) and 90% (thick-layer systems) of surface precipitation water and slowly release it back into the environment [1].

3.1.6 Heat island mitigation

The main cause of urban heat islands is the widespread replacement of vegetation by asphalt and concrete for roads and buildings. These surfaces absorb, rather than reflect, the sun’s heat, causing surface and ambient temperatures to rise. Like green roofs, turf tracks can reduce the heat absorbed and then radiated back from the built environment [2].

3.2 Construction cost reduction

In general, turf track construction costs are lower than the ones for tracks with rigid finish. Although the values of costs are very changeable depending on the country, the source, etc., some examples are going to be shown in this section.

In the case of Line 2 of Tenerife light rail network, built in 2009, the cost of turf track was 35 €/m^2 (49 \$/m^2), while the one for rigid finish track was 50 €/m^2 (70 \$/m^2). These amounts do not take into account common elements for both solutions (rails, sleepers, switches, etc.) [12].

The Technical Directives for Tramways of *Transport Publics Genevois* [13] state that the construction cost of grass track is 60% of the one for bituminous finish, considering only the cost of the covering above the rail’s bottom plane.

In Zurich, construction costs of superstructures with grooved rails on a concrete bed were compared, and a paved finish is 1.1 times more expensive than a concrete layer finish, while grass with grass-pavers entails 0.95 times the cost of concrete layer, and the cost of simple grass finish is 0.80 times the one of the concrete layer [6].

Finally, in the conclusions of URBANTRACK European Project it is stated, at a certain section, that embedded slab tracks with asphalt covering and turf tracks nearly lead to the same costs, when they are based on the same slab track design. But at another section, a comparison for Freiburg (Germany) is shown in which the construction cost in €/m for embedded track with asphalt covering is 1.2 times the one for green track [14].

3.3 Operational cost reduction

This is an advantage that is not usually taken into account, but that has been corroborated by Tenerife light rail experience. It is due to the fact that, on turf track, light rail trainsets can run at higher speeds because pedestrians do not seem to be so encouraged to trespass the tracks in other places than in pedestrian crossings (which lower, in turn, the risk of running over). It should be noted, nevertheless, that other operators state that turf tracks attract people trespassing, as will be shown in Table 1. This is considered a subject for further research.

The experience of Tenerife light rail confirms that in pedestrian zones with rigid finish of the track, speed limit must be 25 km/h, while in the same area, if grass track is disposed, speed limit rises to 40 km/h [12].

Considering the specific characteristics of Tenerife light rail network (15 km long with 70% of turf track), the current commercial speed is 21 km/h, and with maximum frequencies of 5 minutes in rush hour, this leads to the need for 17 consists for providing the services, without considering reserves. If the whole area of grass track had been constructed with a rigid finish, reducing the speed limit to 25 km/h, that would lead to a commercial speed of 18 km/h, with the need for 21 consists instead of 17, as well as the increase of drivers needed from 51 to 59. The cost of a driver per year for the operator is 35,000 € (48,700 $), which leads to an extra-cost of 280,000 €/year (389,600 $/year) due to this subject. On the other hand, vehicle amortization has to be taken into account, considering that the cost of a new vehicle can be around 3 million € (4.2 million $) [12].

4 SPECIAL PRECAUTIONS FOR TURF TRACKS

4.1 Vegetation maintenance

An important aspect of turf tracks is the fact that all vegetation systems, even relatively undemanding ones, require maintenance to be kept in a satisfactory condition [1]. On the other hand, not all the species are suitable to be used in any location. In this sense, it is important to consult the municipal authorities' horticultural staff to learn about which species should be used, what kind of care they need, etc.

Maintenance tasks in this sort of track include, mainly, fertilization, irrigation (if the climate makes it necessary) and mowing (although there are species with low rates of growth, which can minimize this necessity). In URBANTRACK European project the use of Sedum in naturalized tracks is proposed, and it is stated that the only foreseen maintenance needed for Sedum tracks will be fertilization once a year and maybe removal of fallen foliage from adjacent trees during Autumn. This is due to the fact that Sedum is a drought resistant plant, because of the water-retaining properties of its leaves [15]. This characteristic is important since the water consumption for irrigation can reach, depending on the climate, 1 to 1.5 $m^3/(m^2 \cdot year)$. On the other hand, the water for irrigation can make the vehicles dirty due to lime rests when it dries up, if irrigation is performed during operation periods.

In any case, maintenance costs can be kept under reasonable limits, especially when the turf track is disposed in conjunction with slab track. In the case of Porto light rail (Portugal), maintenance cost of grass track does not reach twice the maintenance cost of paved track. In Zurich, the maintenance cost of green track is considered to be around twice the maintenance cost of a paved one [6]. In the case of Tenerife network, maintenance cost of turf track is 500,000 €/year (695,700 $/year), including cleanliness and water for irrigation, which means an average cost of 8 €/$(m^2 \cdot year)$ (11.1 $/$(m^2 \cdot year)$). In comparison, the annual cost for cleanliness of rigid finish in Tenerife is 1.5 €/$(m^2 \cdot year)$ (2.1 $/$(m^2 \cdot year)$) [12]. Mowing operation in Tenerife can be seen in Figure 2.

An interesting strategy for avoiding extra maintenance costs for the public transport operator is the one applied in Germany, where the plants used for green tracks are often tended by the respective municipal authorities' horticultural staff, as part of their regular plant maintenance. This is especially the case where the turf track was a requirement of the concerned local authority. In such cases, transport companies incur no added costs for plant maintenance [1]. This is a reasonable strategy as the environmental benefits of grass track are enjoyed by the whole community, not only by the light rail company. In addition, the companies that make this kind of services for municipalities usually have the appropriate tools and can get a better performance than the light rail operator. Of course, maintenance work should be coordinated with the operator if it is made during operation periods, in order to prevent incidents from happening.

It is important to bear in mind that, during mowing and irrigation operations, a decrease of adherence coefficient can happen, which can affect the first consist running on the track after mowing or watering. Normally, the influence of this situation in braking capabilities is comprised in the range of variations due to the weather, so no additional precautions must be taken [7].

4.2 Rail-environment separation

The separation of rails from the environment is critically important for guaranteeing protection against stray currents and corrosion.

Stray current is defined by UNE-EN 50122-2 [16] as a current that flows along paths that differ from those foreseen. In the case of urban railway tracks, stray current would be the one that returns to the negative pole of a substation through the ground instead of along the rails. On its way through the ground, this current can enter other metal installations as pipelines, cable screens and steel reinforcements [1]. In the areas where the stray currents exit these metal installations to flow back into running rails, electrolytic corrosion of these installations will happen, causing a material loss which can be dangerous. In order to avoid this from happening, special measures for electrically insulating rails to separate them from the environment are required. The limit value for the conductance per unit length is established by UNE-EN 50122-2 [16] as G'<2.5 S/km for closed urban tracks running above ground (it is, not in tunnel).

There are basically three types of rail insulating systems that have proven to be effective, depending on the kind of track utilized, which are [1]:

- Rail web and rail base elements (see Figure 3a): these are relatively thin rubber elements which are glued to the rails. The growth layer for the grass is laid directly against rails protected in this way. The base and web elements both counteract the transmission of structure-born noise and provide electrical insulation against stray currents. The measured conductance per unit length with turf track is 0.54 to 0.79 S/km [1].
- Rail chamber filling profiles (see Figure 3b): these are molded parts, usually consisting of recycled material that is either polyurethane-based or rubber-based. They can be adapted to different rail shapes. They are usually clamped tight, in such a way that they can be easily removed for necessary repair works and subsequently reused. The measured values of conductance per unit length per track are between 0.23 and 1.46 S/km [1].
  In this solution, it is important to ensure a good drainage into the vegetation layer and to prevent the formation of condensation water (with its danger of corrosion) on rails and fastening elements by means of air vents [14].
- Rail grout (see Figure 3c): this solution consists of the embedding of the rails in a concrete trough or "rail duct" by full elastic material over the rail's entire length, completely eliminating conventional rail fastenings. In general, the rail is pre-welded, fitted with cable conduits, set down on the trough and aligned and fixed in place by using cork wedges every 1.5 m. The remaining cavity in the trough is then fully sealed with polyurethane. This solution results in excellent stray current protection, with a value of conductance per unit length per track of 0.002-0.02 S/km [1].

As it has been stated, any of these solutions are technically very mature and satisfy the limit value of conductance established by UNE-EN 50122-2, although it is necessary a special care, as they can be compromised to some degree in wet weather, particularly when salt is used on the street.

Figure 4 shows some examples of cross-sections with different turf track construction.

4.3 Other precautions

There are some additional precautions that must be borne in mind in relation to naturalized tracks, which are the following:

- In general, turf tracks are not passable for road vehicles. This is a problem for operators that intend to use the same lanes for light rail and buses, and in this case it is a powerful reason to avoid the disposition of naturalized tracks.
  In case that grass tracks have to be passable in an emergency (for example, accessible to rescue vehicles), additional elements must be used, as grass-pavers which strengthen the lawn body [1]. Examples of turf track with grass-pavers can be seen in Figure 5.
- The use of grass tracks is not recommended in sections with derailment risk, because the operation of putting the vehicle back on the rails is more complex than in paved tracks. This is the reason why some networks do not use naturalized tracks in turnouts and crossings, covering the track with concrete, stone or asphalt in these areas. Nevertheless, there are many modern networks in which this precaution is not taken anymore (see Figure 6).
- Some operators have observed a greater incidence of rail corrugation, due to the influence of vegetation waste deposited over the head of the rails, as well as to aquaplaning during irrigation periods. This fact leads to the need for more frequent grinding operations.
- Sometimes, an insulating layer can be formed over the rails, made up of a combination of vegetation and sand, which can hinder the detection of the vehicle in the track and lead to

signaling failures. Although this problem is not exclusive of turf tracks (see Figure 7), it is important to use an adequate signaling system to avoid problems due to this phenomenon.

- The use of grass track is not recommended in areas where vehicles are going to be standing for relatively long periods with their motors running, if the motors are at the bottom of the vehicle, as the vegetation will suffer due to high temperatures and will dry. So, naturalized track should be avoided in terminal stops.
- Finally, in some networks turf tracks are interrupted in stops and substituted by rigid finish, for avoiding a more complex cleanliness process, since stops are susceptible to accumulation of garbage dropped by the users waiting for the trains. In this way, a mechanized sweeper running on tired wheels can be used. This solution facilitates, on the other hand, the crossing of the tracks by users who want to change platform [5]. Although this is very common in many networks, there are others which do not consider this precaution (see Figure 8).

5 THE OPTION OF ARTIFICIAL GRASS

Artificial grass solutions have experienced an important improvement lately, making its use be considered for different applications in cities, with tramway tracks among them.

The avoidance of extra maintenance costs (fertilizing, irrigation, mowing) is the main advantage of this solution, although there will be a cleanliness costs which is necessary to take into account. Other advantages identified by URBANTRACK European project are: the possibility to install on existing tracks; fast and easy installation; permanently green; low life cycle cost compared to natural grass; and good noise absorption [15].

As a counterpoint, artificial grass loses some advantages of natural turf tracks, as the ones related to “green lung” effect, improvements in rain water management and heat island mitigation. On the other hand, the esthetic of artificial grass is arguable, although modern solutions have improved in relation to this subject.

As will be shown in the next point, most present operators of light rail systems do not recommend the use of artificial grass instead of natural grass tracks, due to the loss of many advantages in that case.

6 OPERATORS’ OPINIONS

A survey has been made to UITP (International Association of Public Transport) Light Rail Committee members in relation to turf tracks use. Most relevant responses are summarized in Table 1.

7 CONCLUSIONS

The main characteristics of turf tracks have been shown in this paper, including its advantages and the major inconveniences or precautions that should be taken in order to achieve a good performance of this kind of tracks. The main advantages that have been identified are: the esthetic aspect, the noise reduction, the reduction of suspended fine particles, the green lung effect, the improvements in rain water management, the heat island mitigation, as well as the reduction of construction and operational costs.

The results of a survey made among operators confirm the advantages identified, and give an idea of the most important ones for operators, as the visual impact, noise reduction, cheaper construction, good visibility of track spaces, the impossibility for road vehicles to run over light rail tracks, and less trespassing (a controversial subject that needs further research as it is stated by some operators but refuted by others).

The main inconvenience of turf tracks is the extra maintenance cost generated by the need for mowing, fertilizing and irrigation, but these costs can be kept under reasonable limits if adequate species are used. On the other hand, the main special precaution to be taken is the insulation of rails to avoid stray currents. Finally, it is important to note that turf track is not drivable for buses unless special treatment is applied, and this is a reason for avoiding its use among operators that need ambivalent corridors.

In any case, the results of the survey made among operators show that almost every one of the present users of grass tracks recommend their use for future extension of their networks. Therefore, it seems to be proven that the important advantages of turf track make up for its inconveniences.

So, in conclusion, naturalized tracks are a very competitive solution for light rail tracks, which enhance the city landscape, increase the acceptance of the network by citizens, and improve light rail operation in several aspects.

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TABLE INDEX

FIGURE INDEX

TABLE 1 Results of survey to light rail operators

Company	General advantages of turf tracks	General disadvantages of turf tracks	Would you recommend the use of artificial grass? Why?	Do turf tracks cost more or less than paved tracks during track construction? Difference in % or €/$?	Is there any specific extra-care needed during construction period?	How much is the extra-cost in relation to paved tracks regarding maintenance? Difference in % or €/$?	Limitations concerning operation when using turf tracks?	Advantages concerning operation when using turf tracks?
VVM De Lijn - Oostende (Belgium)		Maintenance track costs. Water consumption.	No. Not investigated yet.		No.		Long term maintenance.	Visual aspect.
Stadtwerke München GmbH / MVG - Munich (Germany)	Improvement of cityshape. Noise reduction. Climatic and ecological benefits.		No. No need to use artificial grass due to climate. Benefits of natural grass are higher.	Lower cost: cheaper material. Turf tracks ~ 7€/m^2 (9.7 \$/m^2). Paved ~ 45€/m^2 (62.6 \$/m^2). (Without tracks and substructure).	Normal care for lawn until grass is fully established (steamrollering, cutting).			
TCAR - Rouen (France)	Noiseless. Good visibility of tram space. Esthetic. Safety of platform for external road users.	Maintenance.	Yes. Visual quality similar. No consumption of water.	Quicker to put on.	First year of growth is very important.		Cutting and keeping it green. In case of incidents or accidents.	Safety because of the visibility of the track. Quiet view for driver.
Kayseri Ulasim AS - Kayseri (Turkey)			No. No good feeling like natural grass and over time it loses its beauty.	Higher costs: water system, drainage system and soil. +30%.	Type of grass. Drainage system. Amount of soil. Geotextile.	+30%.	Difficult to maintain green. Difficult to water during operational time. Watering at night may not be enough.	Good view. Passenger likes. Good impression.
MES Müller-Eberstein Services GmbH - Dresden (Germany)	No problem in a very long experience.		No. Natural turf tracks are better for the climate. Look more natural. Acceptance is better.	Similar cost.			Not drivable for buses without special constructions. In dry summers the green must be watered and cut.	The acceptance by people for separated tracks is much higher.
Metro Ligero Oeste - Pozuelo de Alarcón, Madrid (Spain)		Water problems with electronics in signaling. Water consumption and cost in dry areas.	No. To get the green effect you can use other alternatives that do not need maintenance.		The more sun received, the more the loss of green color.	+25%.	Turf tracks are used as jogging or biking platforms. Safety problems.	
BVG - Berlin (Germany)			No.	A little bit less than paved tracks.		Rail fastenings need a better maintenance; protection against rust is necessary.	Space for separated tracks is needed.	Less noise. Better implementation into urban design.
HTM - The Hague (Netherlands)		Too expensive in maintenance (construction at HTM on ballasted track).	Yes. It combines the advantage of acceptance (green part of the city) and low maintenance.	Grass 25% less than paved tracks.	Track underlayer essential.	None in regular maintenance. In rail renewal grass 50% less than pavement.	Slippery track after mowing. Grass attracts people (dog area).	Low noise level. Good separation to track.
Metro do Porto - Porto (Portugal)	Creation of green spaces, visual effect. Better distinction of the track space.		No. But depending on the regional climate.	Around 40% less.	Not really.	Around 300% extra.	Need for a compliant signaling system.	Noise reduction.

MVG - Munich (Germany)	Water retention. Noise reduction. Street design improvement.		No. No ecological effects.	Depending on the way to build. +/-10%.		Time.	None.	No tree sprouts growing.
SEMITAG - Grenoble (France)	Esthetic. Non-drivable. Noise reduction. Water absorption.	Water consumption. Need for access for maintenance.	No. Esthetic. Bad environmental image.			Water: 1 €/(m^2· year) (1.4 $/($m^2$· year). Shearing: 1.5 €/(m^2· year) (2.1 $/($m^2$· year)).	Non drivable for buses.	Non drivable for other users.
RATP - Paris (France)	Landscaping. Avoid other vehicles to run on the tracks. Cheaper than stone pavement. Very strong political support.		No. Ugly.	Less than paved tracks. -10%.	Automatic watering system. We are developing new solutions without watering.	Similar in solutions without watering.	Need for specific vehicles for maintenance and cleaning of the tracks.	Tracks are strictly reserved to LRT vehicles.
Metropolitano de Tenerife SA - Tenerife (Spain)			No. Higher investment cost. The plastic base material is not ecofriendly. Experience of people stealing plastic grass.	Turf track costs less. Grass 35 €/m^2 (48.7 $/$m^2$) and paved 50 €/$m^2$ (69.6 $/$m^2$).	Proper drainage and enough height.	Grass: 8 €/m^2 (11.1 $/$m^2$). Paved: 1.5 €/$m^2$ (2.1 $/$m^2$).	Grass cut has to be done with special precautions to avoid accidents with trams.	Higher commercial speed as people do not cross through the grass.
Bybaben AS - Bergen (Norway)	Noise reduction. Esthetic.	Maintenance cost. Track maintenance more difficult. (Our choice is usually turf track instead of ballasted track, not paved track).	Yes. We have no experience, but are considering using artificial grass in the future.	Some extra costs compared with paved track, specifically additional drainage required. +20%.	No.	Our experience is limited to date, but we estimate that the turf track will be about 10% more expensive to maintain in the short term.	Height of grass and earth must be maintained.	Natural noise abatement.
Tramvia Metropolità SA - Barcelona (Spain)	Urban integration. Noise reduction. Safety: less pedestrians and bikes on track.		Yes. High reduction of maintenance costs.	It depends on the methodology but materials are not expensive and less resources are necessary for construction. +20%.	Watering and drainage systems.	Difficult to establish in %. Much higher because of the low maintenance level needed for paved tracks.	Switches, derailments (more difficult to put the vehicles again on rails).	Less risk of finding pedestrians or bikes on track. Clear distinction between track and the rest of urban spaces.

Note: every conversion from € to $ in the paper has been made using the exchange rate: 1 € = 1.3915 $.

FIGURE 1 Turf track visual effect. a) Porto (Portugal); b) Florence (Italy); c) Zaragoza (Spain); d) Tenerife (Spain).

FIGURE 2 Mowing operation in Tenerife (Spain).

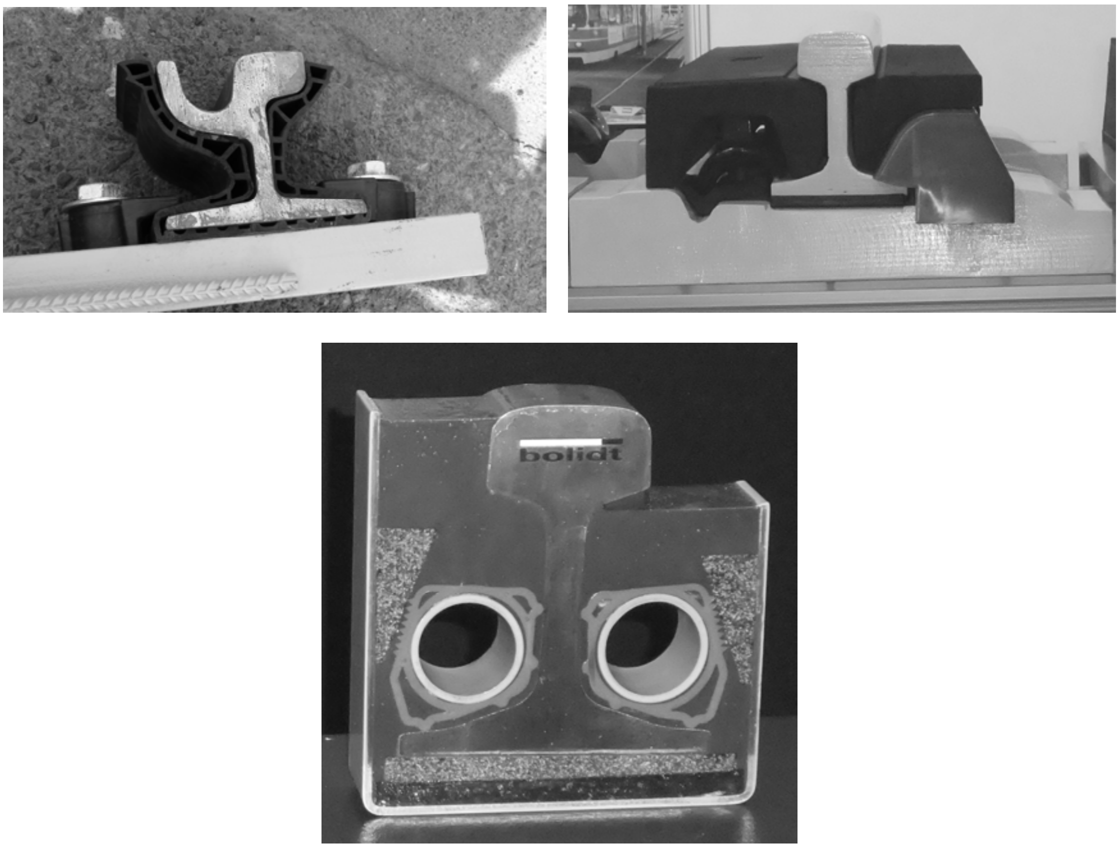

FIGURE 3 Rail insulating systems. a) Rail web and rail base elements in Portland light rail extension; b) Rail chamber filling profiles; c) Rail grout solution.

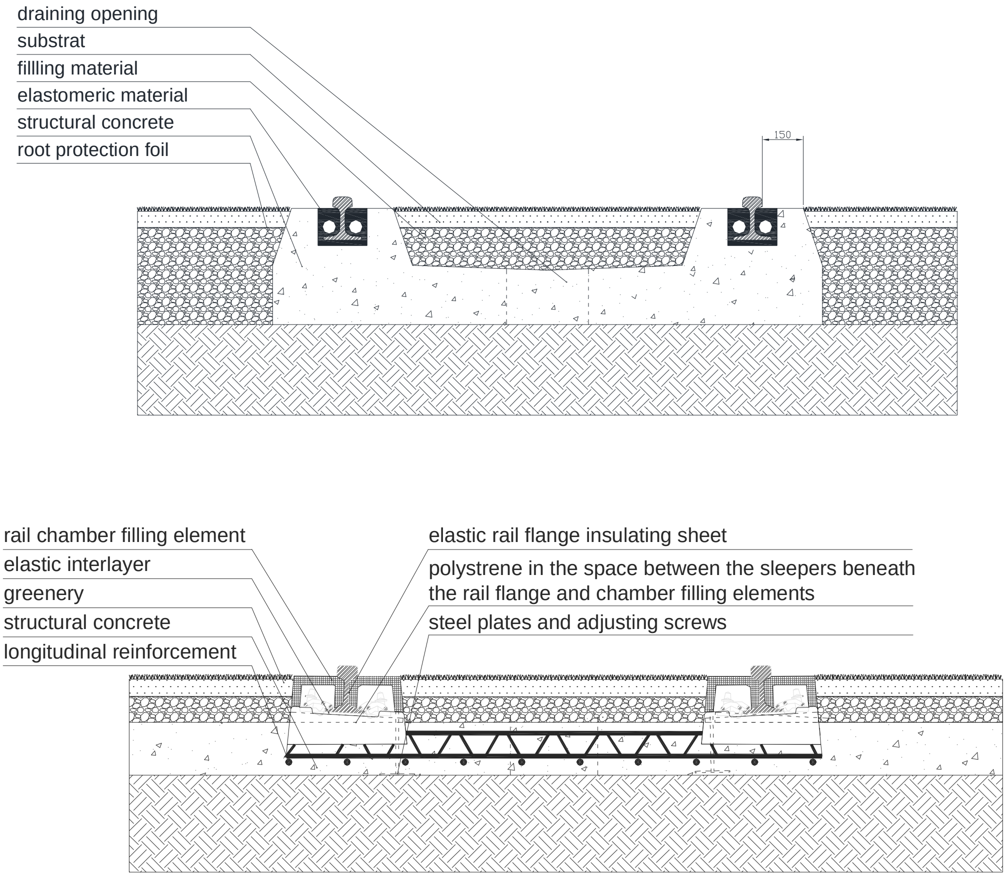

Figure 4 Examples of turf track cross-sections.

FIGURE 5 Grass pavers. a) Paver elements; b) Finish detail; c&d) General view of the track. Courtesy of *Element-s Bauelemente & Bodensysteme*.

FIGURE 6 Turnouts and crossings in turf track. a) Strasbourg (France); b) Tenerife (Spain).

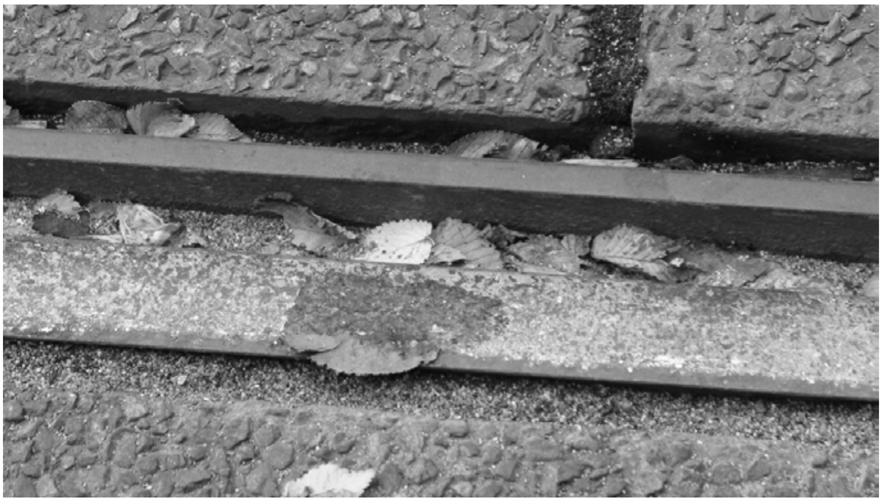

FIGURE 7 Leaves stuck to rail head.

FIGURE 8 Stop treatment in turf track. a) Turf track interruption at stop in Porto (Portugal); b) Turf track interruption at stop in Tenerife (Spain); c) Turf track through stop in Zaragoza (Spain); d) Turf track through stop in Mulhouse (France).