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"Green" Tram Tracks for the Sustainability of the Urban Environment

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Greening tram tracks has ecological, urban planning and economic impacts. Greening of the tracks supports the development of sustainable stormwater management as well as improving the visual appearance of the city. The restoration of the natural water cycle is achieved through water-sensitive design: the innovative solution used achieves both the retention of water, the reduction of run-off and the increase of the surface area available for evaporation. The literature data (Grüngleis Netzwerk, 2011) show that 50-70 % of the annual precipitation projected onto the green runway is absorbed and re-evaporated. The urban climate impact of the vegetation systems to be developed is most pronounced in the summer months. The microclimate of green track environments has a positive impact on the health of the population. Our work will investigate the effects of green vegetated areas. In this study, we analysed the ecological impact and the capacity to sequester of carbon dioxide from the atmosphere by photosynthesis of grass- and crowfoot-lined tracks. The Sedum green roofs quantified carbon storage is approximately 160 gC/m^2 during a two-year period (Collazo-Ortega et al., 2017). The concept of a vegetated track leads to an improvement of green space indicators in a complex system of urban environments through the correct choice of vegetation plants. Prioritising and encouraging the construction of green tracks is one of the possibilities to make the urban environment more livable. It is also necessary to encourage this at the regulatory level in cities.

1. Introduction

Since the 1990s, in Hungary tram transport has been on the up again, thanks to urban planning practices that have reinforced the idea of discouraging car traffic. This has reduced congestion and air pollution, laying the foundations for a healthier, more livable urban environment. Trams have again become a key element of public transport in livable modern cities. Currently, tramways operate in 4 of our cities - Budapest, Szeged, Miskolc and Debrecen. Tramway transport, which started in Hungary in 1887, is still the preferred mode of travel in our cities today, providing a convenient alternative to private car travel. The choice of mode is greatly facilitated by the appropriate track condition and the constantly modernising fleet. In these cities, large investments have recently been made or are being planned. Most of the investments have been for upgrading and renewing existing lines, but there are also examples of new lines being built. The new tracks that have been created are gradually deteriorating after the first train has rolled over. The deterioration process is an exponentially accelerating process and, in the absence of appropriate interventions, can cause the track to fail before its design life. Unfortunately, in our country, the budget for maintenance and train care is very limited, and thus interventions are more of a fire-fighting nature than preventive. The structural design of grass tracks is also quite varied worldwide, with concrete longitudinal beam structures, classic rigid slab structures and traditional concrete sleeper track structures. It can be seen that grass tracks can be designed at different technical and cost levels. This is an important fact, since in Hungary the travelling public has a long history of traditional crushed stone tracks, which can be revitalised by rebuilding/renovating them, improving their aesthetic appearance and their impact on the quality of urban life. Perhaps the most attractive aspect of grassed tracks is their water demand. The irrigation system (without it, the operation of watering trucks is necessary) is a major cost factor in the maintenance and operation of the tracks. The irrigation system is not only expensive but also

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an extremely fragile structure, which, if damaged or damaged (by cars), requires considerable repair work along its length. Another pressing question is whether it is permissible to irrigate them with drinking water from the public network, especially at a time when water consumption in large cities is soaring and water restrictions are often necessary for their agglomeration areas. Fortunately, this serious drawback can be overcome by the right choice of vegetation plants, which can minimise the water demand of the structure. With an appropriate selection of vegetation species, these corridors can be used to offset carbon emissions from railway operations (Blaira et al., 2016). During our research, we adapted available relevant literature data into the Hungarian planning practice, supplemented with our own calculations and analyses."The exact methodology was published by Major et al. (2023) for paved tramway tracks." In addition to the scarcity of resources, there is a welcome trend towards making the urban environment more livable, with the result that more and more tram tracks are being built in Hungary, with ever greater frequency and lengths, as shown in Figure 1 for example in Budapest. The traditional design of the track in the city is shown in Figure 2. The photos were provided by our colleague Áron Szennay.

Figure 1: Grassed tram track in Budapest

Figure 2: Traditional paved track in Budapest

2. Problem statement

The challenges posed by urbanisation are manifold, and urbanisation that ignores green spaces causes adverse social and physical impacts on the population (Anguluri and Narayanan, 2017). There is a large body of research on the urban heat island phenomenon and its solutions (Nwakaire et al., 2020). The existence of an urban ecosystem is an essential element of human survival in cities, as the services people need are derived directly or indirectly from ecosystem functions and ecosystem services (Bolund and Hunhammar, 1999). A significant proportion of the ecosystem services, including provisioning services, consumed by urban residents are produced outside the city (Harangozó et al., 2019), often in areas far from the settlement (Kiss et al., 2021), as expressed in the concept of ecological footprinting (Wackernagel and Rees, 1996). The development of green streetcar systems has become a common solution to meet the growing demand for green space in many European cities (Sikorski et al., 2018). In urban ecosystems, public land managers are responsible for making complex decisions about vegetation and management of public spaces, with ecological, economic and social consequences. Globally, the question is whether to shift from commonly used vegetation that requires multiple inputs (e.g. water, fertilizers, pesticides) and intensive management (e.g. mowing, reseeding) to more sustainable, low-input vegetation planting that requires less human intervention (Barnes et al., 2018). Among other environmental benefits, vegetation cover also reduces noise emissions from tram tracks (Harangozó and Marjainé Szerényi, 2014). In its planned, deployed form, the city of Berlin has been a good practice since 1995 with its green light tram tracks. In addition to the grass sections, a pilot project with maintenance-free plants is also justified, as the long dry summer period is not a problem for these plant species and maintenance costs are lower.

3. Methodology and results

3.1 Calculation of the CO_2 emission of the tramway tracks

It was made a comparison in order to determine the ecological footprint of the traditionally designed paved tramway tracks, compared to the grassed version, which is considered to have an equivalent load-bearing capacity. The traditional concrete slab design is illustrated in Figure 3, while the grassed design in concrete beams is illustrated in Figure 4. The figures were made by Zoltán Major.

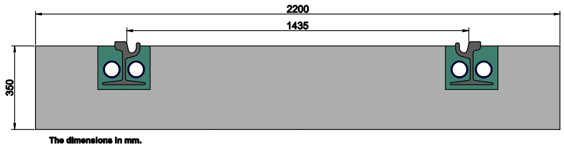

Figure 3: Traditionally paved tramway track

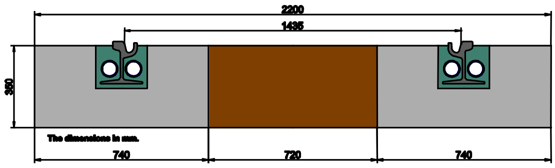

Figure 4: Grassed tramway track

In order to perform the comparative analysis, the four components shown in the following subsections were examined in detail. The specific CO_2 emissions for each material were all considered according to the Inventory of Carbon and Energy Database (ICE) v3.0 for 1 track meter (Embodied Carbon Footprint Database, 2022): rail steel, elastic embedding material, track slabs / beams, soil. The applied methodology was presented by Major et al. (2023). The first step was in this study to determine the mass of rail material per 1 m of track for both test cases. This was 116.28 kg/track meter for 59Ri2 rails. Based on ICE database v3.0, the specific value of CO_2 emissions is 1.27 kgCO_2/kg (structural steel). In determining the amount of elastic embedding material, it was assumed that the thickness of the bottom layer of embedding compound used was a uniform 20 mm. The specific volume is 52.61 l/track meter for rail 59Ri2. The specific volume of the embedding material per 1 m of track was calculated. In the case of the 59Ri2 rail, the placement of 2 material-saving PVC tubes with a diameter of 70 mm each was also considered. As different materials from several manufacturers may be technically suitable for use in the track structure as elastic embedding, an average density value of 0.9 kg/L was considered for the embedding material. The specific value of CO_2 emissions based on ICE V3.0 is 4.84 kgCO_2/kg (flexible polyurethane foam). The specific volume of the concrete beams was first determined from its geometrical dimensions to calculate its own emission. The specific volume of the beams was calculated to be 0.518 m^3/track meter for two beams with 740 x 350 mm cross section. For concrete, a density of 2,500 kg/m m^3 was assumed. Thus, the specific mass of the concrete for the 59Ri2 rail is 1.295 t/ track meter. Based on ICE V3.0, the specific value of CO_2 emissions is 0.132 kgCO_2/kg (precast concrete pavement). The specific volume of the concrete slab was first determined from its geometrical dimensions to calculate its own emission. Assuming a panel width of 2,200 mm, the specific volume of the slab was calculated to be 0.770 m^3/track meter for a 350 mm thick slab. For concrete, a density of 2,500 kg/m^3 was assumed. Thus, the specific mass of the concrete for the 59Ri2 rail is 1.925 t/ track meter. Based on ICE V3.0, the specific value of CO_2 emissions is 0.132 kgCO_2/kg (precast concrete pavement) In the absence of exact data, the effect of reinforcing steel was not investigated in the slabs and beams. In determining the amount of soil, it was assumed that the thickness of the layer was a uniform 350 mm and the width of the layer is 720 mm. The specific volume of the soil was calculated to be 0.252 m^3/track meter. For soil, a density of 2,000 kg/m^3 was assumed. Thus, the specific mass of the soil is 0.504 t/ track meter. Based on ICE V3.0, the specific value of CO_2 emissions is 0.024 kgCO_2/kg (compacted soil). To determine the CO_2 value from the transport of each component, the authors calculated the specific masses per 1 track meter. The source of the initial data is from “Treibhausgasemissionen durch die Schieninfrastruktur und Schienenfahrzeuge in Deutschland” (Mottschall and Schmied, 2013). The transport distance for the rail is 500 km on railway. The specific emission is 26.7 g/tkm. The transport distance for the embedding material is 500 km on road. The specific emission is 199.3 g/tkm for solo truck (>26 t). The transport distance for the track slab is 250 km on road. The specific emission is 199.3 g/tkm for solo truck (>26 t). The transport distance for the USTM is 50 km on road. The specific emission is 199.3 g/tkm for solo truck (>26 t). The results of the analysis is summarised in Table 1.

Table 1: Analysis from an ecological perspective – traditionally / grassed design

Component	Material $kgCO_2$/track m	Transport $kgCO_2$/track m	ΣCO_2 $kgCO_2$/track m	Useful life y	Specific value $kgCO_2$/track m/y
Rail	147.7	1.552	149.252	15	9.950
Embedding m.	229.2	4.718	233.918	15	15.594
Track slab /	254.1 / 170.9	95.913 / 64.523	350.013 / 235.423	60	5.833 / 3.923
Soil	0.0 / 12.1	0.0 / 5.022	0.0 / 17.122	60	0.0 / 0.285
				Σ	**31.377 / 29,752**

3.2 Examination of the carbon sequestration by Sedum Species in greening system on the tracks

The vegetated track concept has several advantages:
- The general advantages for the public are: creates a lush green space in the built urban environment; he line is visually prominent, clearly visible in the urban environment; he public is more accepting of the track, as it is more natural and aesthetically pleasing.
- Property values in the area will rise as green space indicators improve along with infrastructure development; it has a positive impact on the social and mental well-being of the population.
- There are also multiple ecological benefits from the new concept: climate change will lead to more and more high intensity rainfall, which will reduce the run-off intensity of water run-off from the area. The plants increase the water retention capacity of the cutting zone by up to 50-70 %, and the construction of the drainage system is ecologically beneficial with less environmental modification. The track temperature rises more slowly and less than in the case of solid track or open track, so it has a positive effect on the temperature change of the environment. The plant cover provides protection from the harmful effects of direct sunlight and increases the durability of the track structure. Pollutants and dust are captured, noise pollution is reduced. The photosynthetic activity of the vegetation cover is pronounced, and the evaporation of vegetation has a cooling effect on the environment, cooling the air around the tracks more quickly and thus having a positive impact on the microclimate. The urban flora provides habitat for other organisms, such as insects, ensuring their survival in highly degraded environments, increasing biodiversity.
In practice, two typical flora track structures are grass and crowsfoot covered track. A comparison is shown in Table 2.

Table 2: Comparison of grass and crowsfoot paved track (BKV, 2019)

Material	Grass-covered track line	Track paved with cattle liver
Planting medium	Thicker than 120 mm	thinner, 40-80 mm
Water demand	high	low
Requires regular watering	yes	only in the year of installation
Frost tolerance	yes	yes
Resistance	yes	yes
Water retention capacity	about 70 %	about 50 %
Degradation tolerance	yes	yes
Stress tolerance	yes	yes
Vegetation carpet	yes	yes
Green corridor	yes	yes

Literature data (Grüngleis Netzwerk, 2011) show that 50-70 % of the annual precipitation projected onto the green runway is absorbed and re-evaporates. Based on an average annual rainfall of 790 l/m^2/year in Germany, the greening system on the track retains about 400-550 L/m^2/y of rainwater. Based on these figures, it can be calculated that 1 ha of turf can retain about 5,530 m^3 of water per year on grass track and about 3,950 m^3 on sedum track, which is a good example of urban stormwater management. (Grüngleis Netzwerk, 2011). The elements of the water regime for a greened tramway are shown in Figure 5. The figure was made by Zoltán Major The general water balance equation is: precipitation equal streamflow plus evapotranspiration plus the change in storage. Compared to the non-green track, the green track has a more natural water balance. The water balance consists of runoff, storage and evaporation. The precipitation water absorbed and stored is returned to the air mainly by evaporation (evaporation from plants and evaporation from the vegetation layer).

This increases humidity and creates evaporative cooling. The water retention capacity of the greening system depends on the vegetation system.

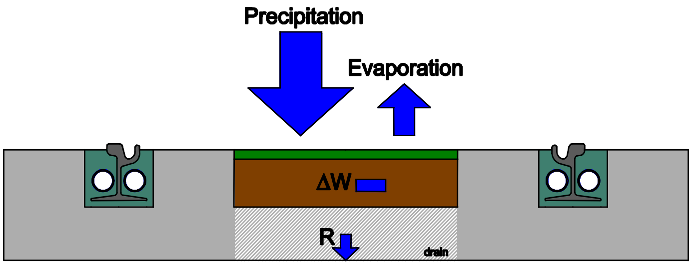

Figure 5: Elements of water management in the greened tramway

Regarding Sedum green roofs, (Getter et al., 2009) quantified carbon storage in green roofs of several Sedum species, by measuring accumulated dry matter in the shoot, root, and soil, obtaining 160 gC/m^2 during a two year period (Collazo-Ortega et al., 2017). Succulent plants, particularly Sedum species, have been extensively used in green roofs (Getter et al., 2006) because of their resistance to prolonged droughts, high temperatures, and strong winds (Collazo-Ortega et al., 2017). Our aim was to estimate the carbon sequestration capacity that grassed tracks can have. Therefore we used the data from measuring individual plants to estimate the overall CO_2 capture by Sedum plants. Based on the study of Collazo-Ortega (Collazo-Ortega et al., 2017) we can use different parameters (plant height, maximum volumetric water content, leaf area index, soil thickness, soil water content) by the calculation. Since all Sedum plants are sun-loving and grow better in the warmer climate, they can be generally show a higher growth rate and carbon absorption after June.The Sedum acre species can reach peak growth rate in mid-spring. In this period it can have 9.4 g of carbon absorption per plant. Based on the scientific results (Collazo-Ortega et al., 2017), when we want to sum the months to estimate the total carbon uptake per plant during year giving 524,040 ppm of CO_2 per plant per year, or 371.27 gC/m^2. The consequences of our theoretical calculation shows that one square meter of grassed tracks with Sedum acre vegetation (with 35 seedlings per square meter) could sequester 0.143 kg of carbon in one year. On the Figure 4 we can see the Grassed tramway track, in this case the green area is just 0,72 square meter/ tramway meter. We can calculate with 25 seedlings per square meter, so the Sedum acre vegetation could sequester 0.102 kg of carbon in one year. When the length of the grassed tramway line is 10 km in the city, we can calculate 7,200 square meter with 180,000 seedlings. In this case this vegetation could sequester 734.4 kg carbon in one year.

4. Conclusions

In connection with the guidelines for the maintenance and development of green spaces, the construction of grassed tracks within the framework of the Green Space Management concept will increase the available green space and will also play a role in urban regeneration. Grass tracks and vegetation cover will help to reduce noise emissions from trams. More sustainable, low-input, low-maintenance vegetation can be an innovative solution, as no extra water is needed, and the water demand of the superstructure can be minimised by the right choice of vegetation plants. In addition to the aesthetic effects, the visually prominent track line in an urban environment will also improve the thermal comfort of the population, thus significantly improving the quality of life of the urban commuting public. The attractiveness of cities lies in the quantitative and qualitative increase in living conditions. In the complex system of the urban environment (environment - economy - society), good environmental quality is becoming increasingly important. Nowadays in current scenario the carbon concentration in the air is increasing because of the intensive use of fossil fuels. This phenomenon is tightly linked to the growth of human populations and the loss of vegetation in our cities, making the design of sustainable and healthy urban areas a challenging task. The grassed tramway linien are an attractive option to reduce the carbon-dioxide concentration of air in the cities while improving urban microclimate. In summary, the frost tolerance, resistance, water retention capacity, degradation tolerance,high survival, fast growth, low or null irrigation requirement, capacity to capture CO_2 and the climate stress tolerance make Sedum an ideal species for grassed tramway, as an innovative green strategy for promoting vegetation in the cities. A green tramway line with 10 km length in the city (7,200 square meter vegetation) with 180,000 seedlings could sequester 734.4 kg carbon in one year. Moreover, the literature data show that 50-70 % of the annual precipitation projected onto the green runway is absorbed and re-evaporates. The limitation of the current research results of the Authors is that it only calculates the emitted and sequestered CO_2 values, it does not provide further examination of the complex environmental analysis. As a further investigation, the Authors request to use the obtained data to determine the ecological footprint and biocapacity values typical of the structures. In their previous research, they already covered this in the case of other types of structures.

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