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BRINGING URBAN TRANSPORTATION INFRASTRUCTURE UNDERGROUND

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Abstract: Bringing urban transportation infrastructure underground brings many benefits, such as creating space for urban development, the reduction of noise and pollution and, thus, a significant increase in the quality of life, but also improving traffic safety and reducing deterioration of roads and rail by harsh environmental conditions. The high investment costs of building new tunnels or covering existing highways and rail lines with lids pay off on the long term, considering e.g., increasing real estate prices in the adjacent neighborhoods, increased productivity and reduced healthcare costs. The main aspects to be considered during the planning process are (1) total investment and operational costs, (2) impact of construction works, (3) safety, and (4) socio-environmental issues. The paper presents some basic planning principles, and experiences from a few projects in Europe and in the US are shared.

Keywords: Transportation, Tunnels, Lids, Safety, Environment

1. INTRODUCTION

Urban environments, defined by a web of infrastructure, buildings, and bustling activity, grapple with the challenge of harmonizing rapid development and the expectation of streamlined regional mobility with localized quality-of-life concerns, such as multi-modal mobility, access to open space, and public health.

Mass transit projects in many cities worldwide have been built underground and have been operating for more than 100 years, beginning with London underground in 1863, Boston 1898, New York 1904, or Tokyo 1927. The first road tunnels have been built in the US in Pittsburgh (Stowe tunnel, 1909 and Liberty tunnels 1924) and in New York under the Hudson river (Holland tunnel 1927).

Figure 1. *Construction of New York subway in 1900*

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With the development of highway systems in the U.S. and other countries after the 1950s, once deemed essential for social and economic progress, urban highways have been built through cities. Unfortunately, that lead to divided urban centers, fragmented or even eradicated communities, and altered historic, cultural, and natural landscapes worldwide. Urban highways often stand as barriers not only in the physical sense but socially and environmentally as well, and lead to elevated noise and poor air quality. The revitalization and reconnection of urban landscapes brings local socio-economic benefits, fosters community cohesion, facilitates accessibility, improves public health, and provides more equitable access to opportunity.

2. NOISE

Environmental noise from highways and railways is a widespread yet often underestimated public health issue. Beyond being a nuisance, chronic exposure to elevated noise levels is associated with increased stress, sleep disturbances, and elevated risks of hypertension, stroke, and cardiovascular disease. These effects contribute to both a decline in quality of life and measurable economic impacts through lost productivity and increased healthcare costs.

According to a preliminary analysis based on models of road, rail and aircraft noise in 2020 from the U.S. Department of Transportation, nearly a third of the U.S. population lives in areas exposed to noise levels of above 45 dB which are associated with adverse health effects (USDOT 2023).

Economists who analyzed health care spending and productivity loss because of heart disease and hypertension have argued that a 5 dB reduction in noise could result in an annual benefit of $3.9 billion in the US (Swinburn et al., 2015).

Studies also show that noise interferes with learning. In the Bronx, NY a classroom facing an elevated railroad he impact of noise extends to cognitive performance. A study in the Bronx, NY found that classrooms adjacent to elevated rail tracks—exposed to noise levels up to 89 dB – experienced lower student achievement compared to quieter classrooms on the opposite side of the building. After installing effective noise control measures that reduced exposure by 8 dB, test performance between the two groups equalized (Bronzaft et al., 1975).

Bringing transportation infrastructure underground, through tunneling or highway lidding, directly reduces ambient noise levels in adjacent communities. These reductions contribute to lower healthcare expenditures, improved learning environments, and enhanced overall urban well-being. In many European countries, noise mitigation requirements serve as a primary justification—and funding mechanism—for such infrastructure, with the responsible authority (often the state) covering costs under environmental compliance frameworks.

3. TUNNELING VS. COVERING EXISTING ROADS AND RAIL LINES

Urban planners strive to bring road and rail traffic underground. Many new urban highways and rail lines are built preferably as tunnels, and many existing urban highways have been covered in various countries worldwide. Tunnels are also the most expensive type of transportation infrastructure in terms of investment. Boring new tunnels has usually the lowest impact on the existing structure, except at the portals and shafts, but can be very challenging in an urban area with existing underground infrastructure.

An economically more feasible approach is lower existing roads and railway lines by excavating and covering, or by simply building a lid over existing depressed infrastructure. This reflects the evolving needs of urban societies, prioritizing human-centric design, environmental consciousness, and holistic urban planning.

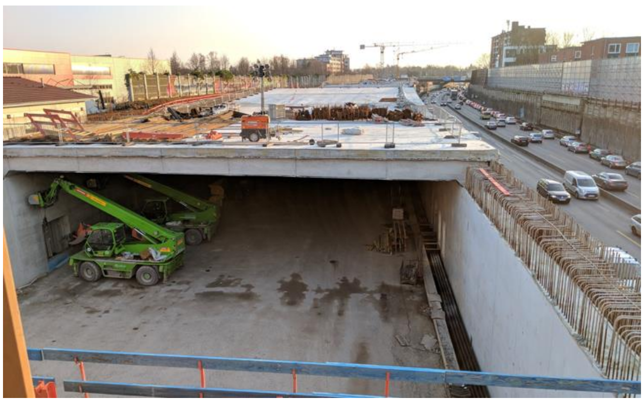

Figure 2. *Building a Highway lid (A7 Stellingen, Hamburg, Germany)*

When considering existing highways, the existing physical conditions and length of coverage needed can dictate whether a tunnel or lid may be most feasible or cost-effective. The driving force behind both lidding and tunneling is to address the often-divisive impact of highways and reintegrate disjointed urban spaces, striving for cohesion and unity. Lids can bear a diverse range of loads, e.g., lush green parks, dynamic recreational zones, or foundational supports for buildings, residential housing or vital public infrastructure.

4. BENEFITS FOR THE CITY

Bringing transportation underground has many benefits:

- Connecting Divided Areas: Lidding projects reunite neighborhoods and areas previously separated by motorways or rail lines, fostering greater community cohesion.
- Maximized Land Use: In densely populated urban settings, where land is at a premium, lids provide additional space, effectively turning air rights into usable real estate. This can pave the way for diverse developmental projects without further land acquisition.
- Recreational and Green Spaces: Parks, playgrounds, and open spaces on lids offer residents accessible open space and green infrastructure in otherwise densely developed urban environments, promoting physical health and mental well-being.
- Diverse Infrastructural Opportunities: The strength and versatility of these lids allow for a range of structures to be built atop them. The possibilities are expansive, from parks and recreational spaces to commercial establishments, residential buildings, parking lots and public amenities.
- Economic Boost and Investment Opportunities, leading to public-private partnerships that can offset some of the costs of lidding projects.
- Job Creation: Construction, maintenance, and the businesses that emerge on these lids generate employment opportunities, contributing positively to the local economy.
- Increased Property Values: Adjacent areas often see a surge in property values due to reduced noise emissions and increased quality of life.
- Multi-Modal Corridors: With regional through-traffic tucked below the lid, there is ample space for multi-modal corridors to accommodate safe and equitable mobility options such as pedestrian pathways, protected bike lanes and dedicated transit-ways, in addition to the potential for low-speed vehicular traffic.

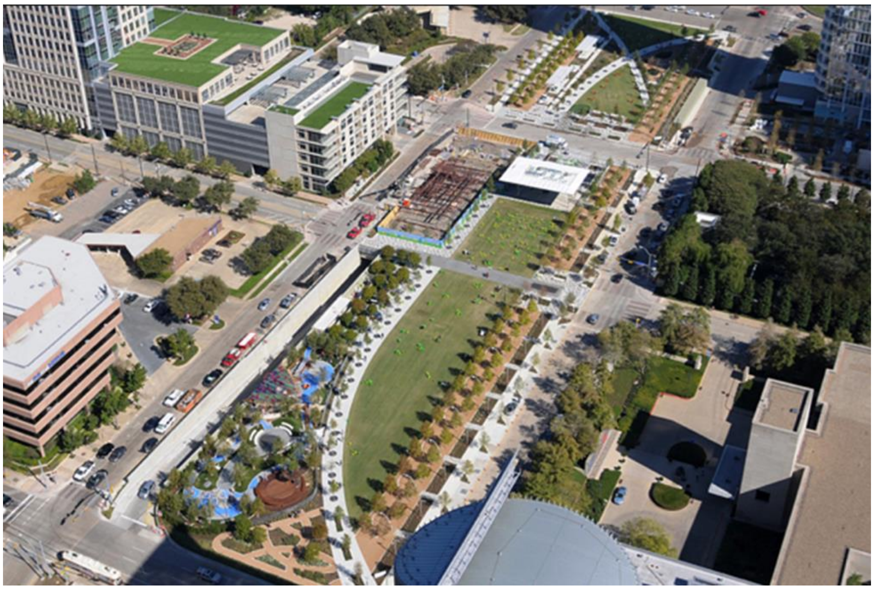

Figure 3. *Klyde Warren Park (Dallas, TX, USA)*

- Reduction of Noise Pollution: The lid shields the highway or rail noise effectively from the environment. This results in quieter neighborhoods, reduced healthcare costs, higher productivity and improved overall well-being for residents. Modern lid designs often incorporate materials that reduce noise in the portal areas and in open stretches.

- Improved Air Quality: A lid improves the air quality by shielding the neighborhood from road emissions. Natural ventilation induced by the moving traffic is sufficient for diluting pollutants below admissible threshold levels inside the tunnel and in portal areas. Only for very long highway tunnels, adequate ventilation measures such as portal exhaust and filters may be evaluated to improve air quality in the portal regions (Pospisil, 2020).
- Urban Heat Island Effect Mitigation: Plants and trees on the lids can reduce the urban heat island effect, a phenomenon where urban areas experience higher temperatures than their rural surroundings. Vegetation provides shade and releases moisture, naturally cooling the surrounding area.
- Urban Ecosystems: Lids landscaped with diverse flora can attract and sustain various fauna, essentially becoming urban biodiversity hotspots. Strategically placed green lids can act as corridors or bridges for urban wildlife, reducing the risk of road deaths and promoting ecological connectivity.
- Managing Flash Storms: Incorporating green infrastructure elements, such as permeable surfaces and bioswales, plays a vital role in managing the challenges of flash storms. Flash storms can overwhelm conventional drainage systems, leading to urban flooding. However, highway lids designed with permeable surfaces allow rainwater to infiltrate naturally, reducing rapid runoff. Bioswales, in turn, aid in the filtration and absorption of rainwater, enhancing water quality while lessening the burden on stormwater systems.

5. BENEFITS FOR MOTORISTS AND ROAD OWNERS

Focusing on roads and highways, bringing transportation infrastructure underground also brings substantial benefits for the road users and owners. Road tunnels and lids provide a safer and more sustainable route than open roads. According to statistical data, the accident rate in tunnels is lower than on open roads. Drivers are shielded from distraction and unfavorable environmental conditions, for instance, sun glare, rain, and ice. Moreover, tunnels prevent collisions by eliminating conflicts with pedestrians and animals crossing.

Shielding from harsh environmental conditions also protects the roadway structure. The lifetime of tunnels is usually longer than that of other infrastructure, such as bridges, and roadway surfaces need to be renewed less frequently than on open roads.

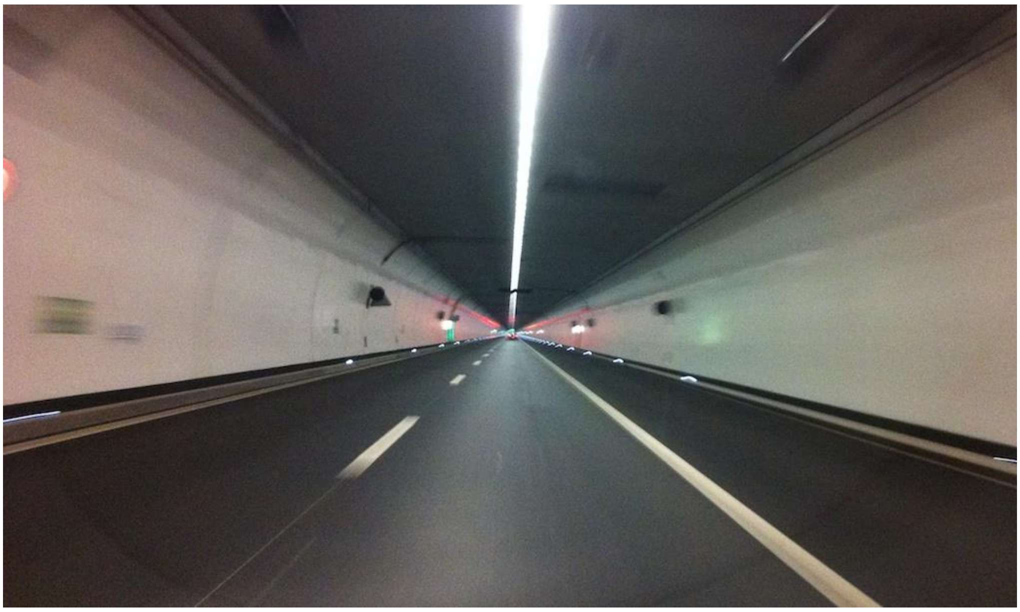

Figure 4. *Inside a highway tunnel*

6. KEY CONSIDERATIONS

While offering substantial advantages, highway lidding is complex and demands meticulous planning and foresight. Ensuring the success and longevity of such projects requires addressing a range of technical, financial, environmental, and social considerations (Theis et al., 2024).

The main purpose of the highway, to provide a safe road connection, must not be impaired by the lid construction. Lane and shoulder widths should be maintained.

During the planning stage, it is critical to determine the planned use of the lid, both in terms of initial intended use and any longer-term anticipated use. One of the foremost considerations is ensuring the lid can support the intended structures or greenery above while allowing safe passage for vehicles below. The use of the tunnel is a driving factor in establishing the appropriate dead loads and superimposed loads for which the lid and supporting structure must be designed for. Careful selection of the loading criteria in the planning stage allows for eventual flexibility where it may be needed in the future.

Managing rainwater drainage, snow loads, and other weather-related challenges is pivotal to the lid's longevity and functionality. Structural durability and minimizing future maintenance are core concerns of all transportation authorities. Urban lid projects provide new challenges with regard to structural detailing to maximize service life. With lids more prone to freeze-thaw cycles than deeper tunnels, proper drainage design becomes paramount. In addition to sloping a lid to maintain a minimum pitch to drain, a lid cross-section should include well-draining fill materials, drainage layers, and waterproofing membranes.

Lidding projects demand significant upfront investment. Determining sources of funding – public, private, or a combination – is crucial. Beyond the initial construction, regular inspection, testing and maintenance, energy consumption mainly for tunnel lighting, and occasional repair works and replacement of equipment, needs to be considered for Life Cycle Costs. To justify those costs, assessing the potential return on investment through increased property values, business opportunities, reduced healthcare costs, and other economic boosts need to be considered

Regulatory and Legal Hurdles can be cumbersome. Especially in densely populated urban centers, navigating the intricacies of land ownership, air rights, and zoning regulations is a fundamental step. Large-scale projects typically require a plethora of permits and approvals from various municipal and state agencies, necessitating careful coordination.

Understanding the potential environmental impacts, including on local ecosystems and water tables, is essential. Soliciting feedback and buy-in from local communities ensures that the resultant development aligns with their needs and aspirations. In areas with historical or cultural significance, the design and execution of lidding projects must be approached with sensitivity.

The very nature of highway lidding means working over or near active traffic lanes. This necessitates understanding and managing the potential disruptions. While some disruptions might last just a few hours or days, others could span weeks or even months. An understanding of the timeframes is essential for planning. To minimize disruptions, significant construction activities might be scheduled during off-peak hours or weekends when traffic volumes are lower. Temporary ramps, bridges, or lanes might need to be constructed to manage traffic flow during the lidding process. Traffic might need to be rerouted. Effective communication to the public is crucial to prevent confusion and congestion.

Figure 5. *Residential development over highway (A3 Altendorf, Switzerland)*

7. SAFETY

Collisions impose the most significant risk to drivers on roads. Fires in road tunnels happen less often than collisions but may impose a serious hazard to road users when they get trapped in the smoke inside the enclosed underlying structure. A fire with an extraordinary heat release rate, e.g., burning Flammable Liquid Cargo (FLC), is highly unlikely, but might result in substantial damage and even partial collapse of the lid structure.

The probability of a collision or fire hazard on a defined road section directly correlates to its length and traffic load. Usually, the collision risk in tunnels is lower than on open roads, and the probability of collisions is a magnitude higher than that of vehicle fires. To a large part, the operational risk is related to driver behavior and vehicle conditions, which can only partly be influenced by safety measures on the road infrastructure.

Preventive safety measures are most effective and need to be prioritized (Pospisil, 2011). For road tunnels, such safety measures are:

- Road alignment, considering traffic density, line of sight, lane and shoulder width.
- Most urban highway lids provide unidirectional traffic, with a separation wall between roadways.
- Enforced speed limit adequate to sight distance and traffic conditions.
- Traffic management with signals and barriers for lane or tunnel closures.
- Traffic management in the adjacent road network.
- Tunnel lighting, which is directly related to the allowed speed and sight distance

Since the atmosphere in the tunnel can be wet and corrosive, and adequate protection of the tunnel structure and equipment from corrosion and regular inspections are essential.

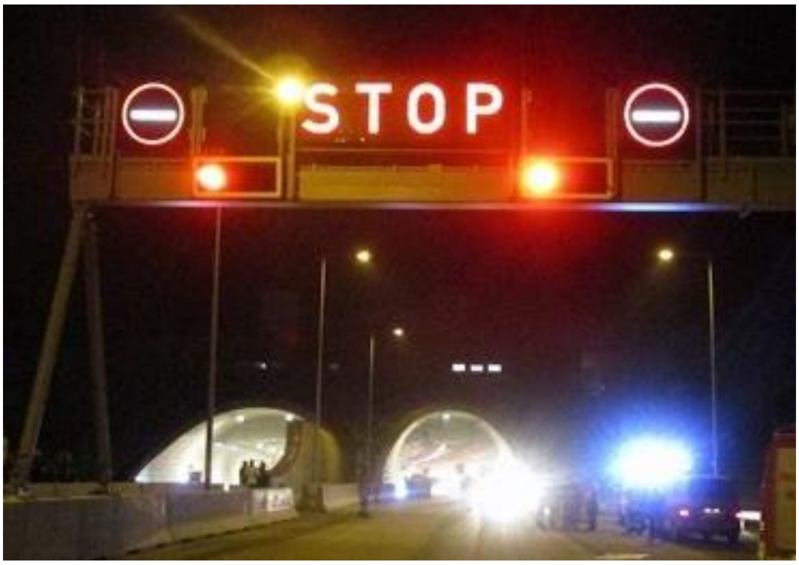

Figure 6. *Lane control signs and variable message signs at tunnel portal*

Fire Life Safety measures in road tunnels may include:

- Emergency exits in short distances
- Smoke and fire detection
- Public Addressing System
- Structural fire protection and/or active fire suppression systems, depending on a risk assessment and expected costs for tunnel closure and refurbishment after a large fire.
- Standpipes with fire department connections and fire fighting water supply.
- Longitudinal tunnel ventilation with flow control for smoke management (Pospisil, 2020)
- For very long tunnels with high probability of congestions and rear-end accidents, additional point smoke exhaust by controllable dampers in short intervals may be adequate.

All tunnel systems must be maintained and regularly tested, to ensure reliable function when required.

A critical planning factor is ensuring that emergency services can quickly reach any point on or beneath the lid. Designing clear, accessible egress and ingress routes for scenarios like vehicle breakdowns, accidents, or fires beneath the lid is paramount.

For rail tunnels, the risk resulting from collisions or fires is much lower than on roads. Focus is on preventive measures, train control systems, and facilitating safe evacuation of large numbers of passengers in case of a stalled train or any other emergency, with or without fire. Unlike mountain tunnels in stable geological conditions, lids may collapse due to an explosion or a catastrophic fire incident. Very large fires resulting from freight trains are highly unlikely, but may be considered for potential fire protection measures.

Big data are used to determine quantitative indicators for operational risks, using primarily statistics about accidents and fires on roads and rails. Such statistical data provide input for the event tree development for quantitative risk analysis (QRA). Big data analysis is also applied to evaluate reliabilities and failure rates of specific equipment, which needs to be considered in the QRA event trees. QRA is an important tool for decision making on effective safety systems.

8. SUSTAINABILITY

Transportation lidding projects present a unique opportunity to champion sustainable construction methodologies that prioritize the environment, which in turn benefits the local community.

A key component of this eco-friendly approach is material selection. Projects can substantially reduce their environmental footprint by prioritizing recycled construction materials or locally sourced ones.

The primary construction material is concrete, the production of which requires a high energy demand. Therefore, reducing the amount of concrete by optimizing the lid concept directly reduces the ecological footprint. An example of such a measure is to provide longitudinal ventilation instead of transversal ventilation, which would require ventilation ducts and fan buildings, as in older tunnels. With longitudinal ventilation, the fans rarely need to be in operation. Transversal ventilation would bring about massive energy consumption because it slows down the natural ventilation induced by the piston effect of moving vehicles.

Energy efficiency extends beyond the completed project; it begins during construction. Using green machinery powered by electricity or more energy-efficient ones can dramatically curb emissions during the construction phase. Moreover, by optimizing transportation and logistics, materials can be moved more efficiently, reducing fuel consumption and the associated environmental impact.

Waste management is another crucial facet. Emphasizing the reduction of waste at its source and facilitating the recycling of construction debris might reduce landfill contributions. Moreover, ensuring the responsible disposal of hazardous waste in adherence to environmental guidelines safeguards both the environment and the community.

The integration of nature into highway lidding projects serves multiple purposes. Green roofs and vertical gardens enhance aesthetic appeal and offer functional benefits like improved insulation, stormwater management, and air quality enhancement. Considering the global push towards renewable energy, including solar panels or photovoltaic cells in the lid's design can transform these structures into hubs of clean energy generation.

Water, a resource growing scarcer in many regions, must be used judiciously. Employing sustainable water use practices during construction, such as rainwater harvesting, can ensure this vital resource is conserved. Furthermore, designing sections of the lid with permeable surfaces can play a pivotal role in groundwater recharge and effective stormwater management.

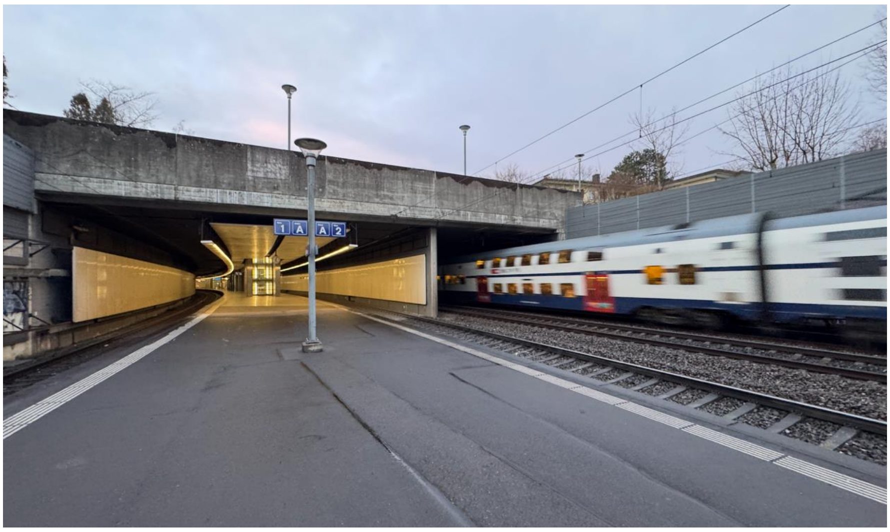

FIGURE 7. *Railway lid with train station (Opfikon, Switzerland)*

9. EXAMPLES

Examples for new tunnels that successfully replace existing urban highways:

- Madrid M30 ring road tunnels, Spain
- Boston Central Artery, US
- Munich middle ring road tunnels, Germany
- Nordtangente Basel, Switzerland
- Seattle SR99 Alaskan Highway tunnel, US
- Tunnel Blanka, Czech republic
- Stockholm West Bypass, Sweden (under construction)

Figure 8. *Glazed portal section of Petueltunnel, Munich, Germany*

Examples of urban highway lid projects:

- Klyde Warren Park, Dallas, US
- Ueberdeckung Schwamendingen, Switzerland
- A7 lids, Hamburg, Germany

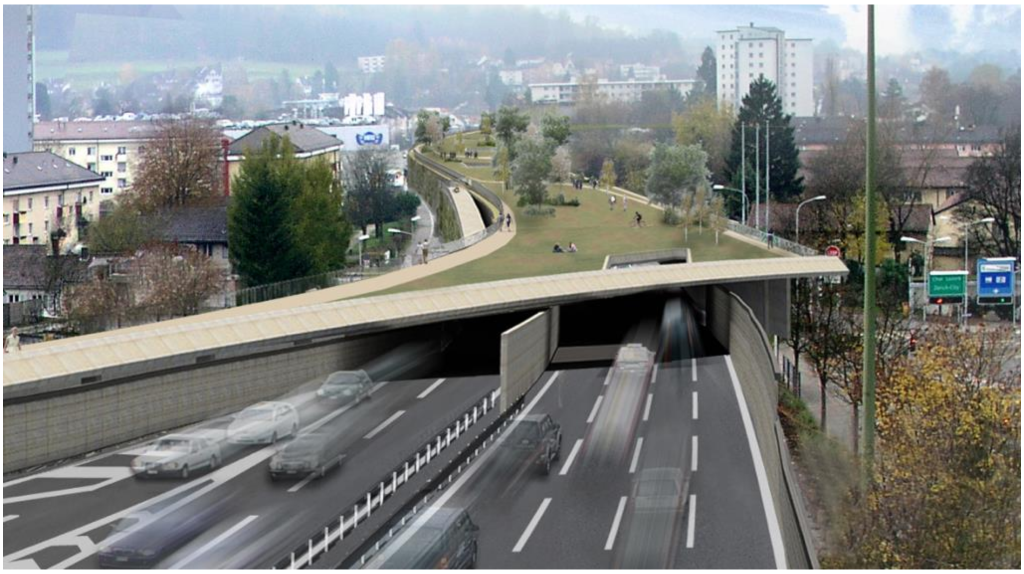

Figure 9. *Einhausung Schwamendingen, Zürich, Switzerland*

A prominent example of covering a railway yard is the Hudson Yards projects in New York City.

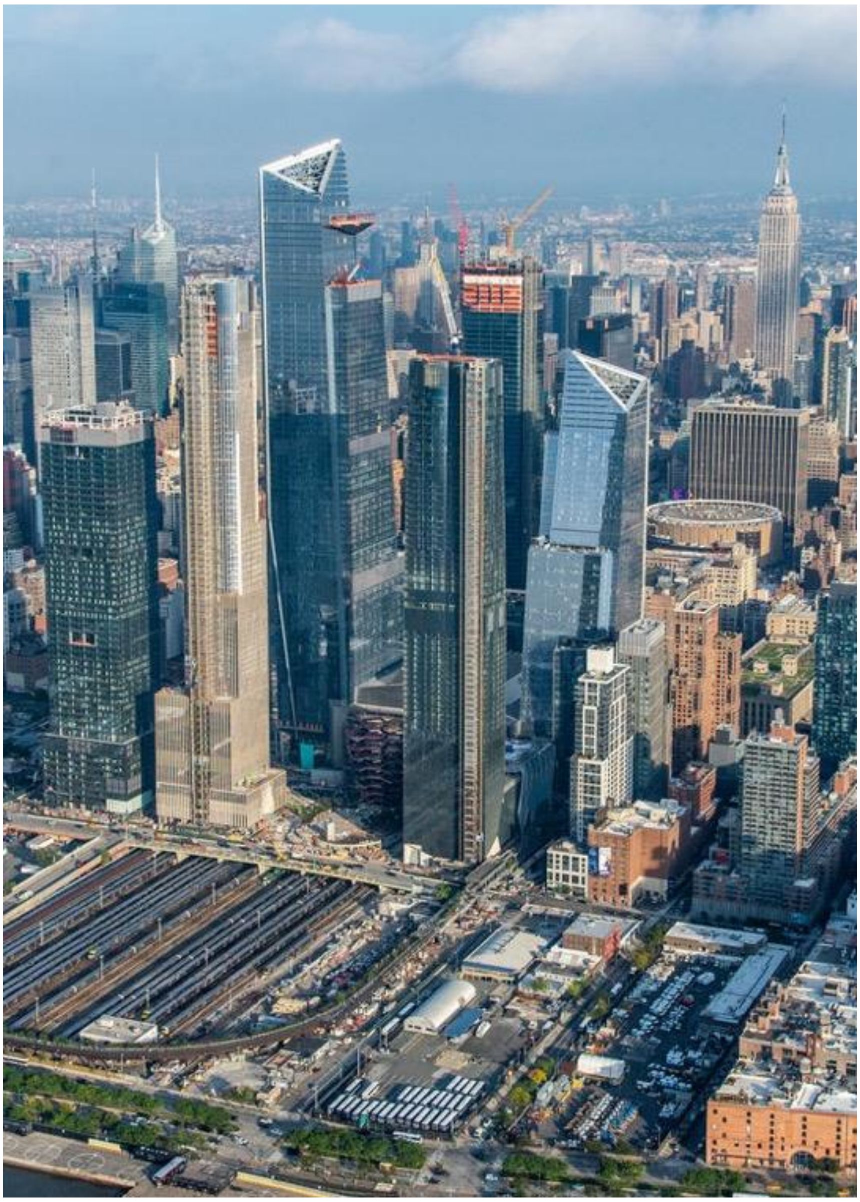

Figure 10. *Hudson Yards, New York, USA*

10. CONCLUSION

Highway lidding and tunneling are a component of the larger urban fabric and should integrate seamlessly with other urban revitalization efforts. This may include connecting lidded areas with pedestrian-friendly zones, creating green corridors that link parks, or designing multi-modal transport hubs that enhance mobility. Integrating these progressive highway projects with initiatives like urban farming, community gathering spaces, or cultural hubs can create vibrant, multifunctional spaces that truly revitalize urban landscapes.

The most significant challenge for highway lidding projects is securing adequate financing. While the initial capital costs are substantial, the long-term economic and societal benefits provide multiple return of investment.

In Europe, the owner of the highway or railway line is responsible to comply with environmental requirements, in particular noise protection. This obligation can be used to finance tunnel and lid projects. In contrast, in the US, highway owners, which are the state DOTs, mostly refuse any contribution to such projects, and the affected cities lack of adequate funds. A solution may be to involve private funding, for instance in the form of public-private partnerships. The generated revenue can offset a significant portion of the construction costs by offering commercial development rights atop or around the lidded sections. Another avenue is leveraging land value capture mechanisms, where the increase in land and property values resulting from the project can be channeled back into financing the project itself.

With improved air quality and reduced noise pollution, there's potential for significant savings in public healthcare costs. Reduced respiratory issues, mental health benefits and lower stress levels can lead to substantial taxpayer savings. An argument can be made for redirecting a portion of these savings back into the project. A model where future healthcare savings are projected, and a fraction is earmarked for lidding projects can be explored.

Construction disruptions represent another challenge. Building a lid over an active highway significantly affects traffic operations and generates noise and dust from the construction, affecting neighboring areas. A staggered construction schedule can minimize traffic disruptions. Many highway lids were built even over ongoing traffic as far as possible. On the other side, the longer the construction period, the greater the inconvenience to the public and potential economic losses due to traffic delays. Implementing night-time construction, offering alternative routes, or providing incentives for off-peak travel can minimize disruptions. Advanced construction techniques, like prefabricated sections or off-site construction, can speed up the on-site assembly process. Tunnel systems should be pre-assembled and tested as far as possible before being installed in the tunnel to minimize commissioning and testing time. Effective communication with the public, perhaps through digital platforms providing real-time updates, can help manage expectations and reduce frustrations.

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