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QUIET TECHNOLOGIES FOR DELIVERIES IN URBAN ENVIRONMENTS

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The aim of this paper is to review current research on materials and methods that can be incorporated within local environment and building design concepts to mitigate noise due to deliveries. The use of innovative materials, design and master planning to minimise noise are presented in three main areas: a) The source of the noise issues, informed by complaints and looking into which stages of delivery and aspects of delivery lead to noise issues; b) Existing good practice guidance; and c) Current technologies and innovative solutions. Quiet technologies and equipment used for the reduction of vehicle noise are outside the scope of this review. Suggestions on the applicability of the various solutions to the control of impacts from delivery noise are offered. A summary of the generic solutions is included, together with a discussion of case studies where available. The findings indicate that fundamental research and development is required to create specific technologies to generate options for embedding noise reduction materials and processes into street and building design for the mitigation of impacts of noise from deliveries.
Keywords: deliveries, noise mitigation, urban environment

1. Introduction

As more people migrate to urban areas, an increase in demand is imposed onto the transportation and delivery system. In London, roads remain the dominant method for deliveries [1], where 13% and 4% of all vehicle kilometres travelled on London's roads for light good vehicles (LGV) and heavy good vehicles (HGV) respectively. The size and frequency of freight delivery vehicles generate issues surrounding air-pollutant emissions, efficiency, safety and congestion on the roads and noise. A quarter of traffic in London between 07:00 and 11:00 (Mon-Fri) are goods vehicles [2]. Whilst a shift in delivery times for freight vehicles has the benefit of reliving the road network at peak times and helping to meet demand, the noise generated by such vehicles impacts on residents, especially at night-time. It is therefore important to encompass methods for reducing noise impact, thereby creating an efficient and sustainable delivery system, meeting the needs for city inhabitants. Anand et al. [3] perform an extensive review of city logistics, concluding that current urban freight models are falling short at considering solutions such as the planning and management of freight facilities currently in place, and the utilisation of technological advancements. The importance of vehicle design is highlighted in more recent studies with the introduction of electric vehicles and quiet technologies [4].

The European Environment Agency (EAA) report 'Noise in Europe 2014' [5] assesses the action being taken and what needs to be considered to preserve the European soundscape currently under threat. It highlights the problem of noise pollution and its contribution to significant health effects, identifying road traffic as the dominant source of environmental noise with an estimated 125 million people affected by noise levels greater than 55dB L_{den}. Alongside this, almost 20 million adults are annoyed with a further 8 million suffering sleep disturbance. The EAA [6] stress the importance of urban freight for the urban economy, servicing both residents and businesses, the combination of better and more efficient logistics, as well as the use of low emission vehicles to reduce the environmental impact of urban freight. Noise is a subjective measure, typically defined as unwanted sound; not just the physical measure is of importance but also psychological and perceptual factors. This paper presents current technologies and available solutions, which can be incorporated into building and landscape design.

2. Source of the Noise Issues

The elements contributing to the perception of traffic noise are as follows: vehicle speed, traffic flow, traffic operations (free flow vs stop-start), road surface, weather and vehicle type/condition [7]. Frei et al. conclude that perceived noise annoyance is independent of the effect of nocturnal traffic noise on objective sleep quality (p=0.25) but is strongly related to self-reported sleep quality (p<0.001) [8]. Noise exposure is found to correlate with objectively measured sleep quality (p=0.02) but only moderately correlate with self-reported sleep quality (p=0.07). Surprisingly, subjects who are not annoyed by traffic noise have a significant decrease in noise-induced sleep efficiency (p=0.001).

Geissner et al. explore the perception of events generated by an urban delivery [9]. The closing of the driver's cab was easily recognized by subjects, however short events such as the tailgate stop shock and the hand pallet truck set up were not as well identified. The engine was perceived as the most unpleasant sound, with other loud or impulsive events similarly classified. Actions relative to door events were perceived as less unpleasant. It is suggested that physical sound characteristics are used to rate unpleasantness along with whether the event signifies the end of the delivery process. Morel et al. find that for buses, heavy vehicles and light vehicles passing-by in isolation at either constant speed, in acceleration or in deceleration, "Noise Level" and "Noise Source" had a significant effect on annoyance responses. ''Noise Level'' is better explained by Zwicker's loudness N than by the index L_{Aeq} and "Noise Source" is explained by indices related to temporal envelope such as maximum roughness and fluctuation strength, which are both related to engine noise [10].

Höstmad et al. modeled different driving conditions and acoustical treatments of vehicles and facades and found that low-frequency correlated with the reported arousal of subjects and that less high frequency content increased the level of pleasantness [11]. For the case when windows are closed, the use of a modified truck with high sound insulation windows is suggested to provide an acceptable indoor environment, however a change in technology would be required to achieve this for the case of a window slightly open.

3. Existing Good Practice Guidance

3.1 European Policies

The European Parliament and Council document *Action Programme to 2020 'Living well, within the limits of our planet'* [12], outlines priority objectives to be achieved by 2020. It highlights the need for improvements in city design as one of various measures and that 65% of Europeans living in major urban areas are exposed to high noise levels (defined as noise levels above 55dB L_{den} and 50dB L_{night}) and more than 20 % to night time noise levels at which adverse health effects occur frequently.

3.2 National Policies

The Noise Policy Statement for England (NPSE) [13] sets out the long term vision of the Government and their policies for effective noise management, aiming to provide clarity regarding current policies and practices. The NPSE uses NOEL (No Observed Effect Level), LOAEL (Lowest Observed Adverse Effect Level) and SOAEL (Significant Observed Adverse Effect Level) to assess the effects of noise in the environment. The NPSE does not provide a single objective noise-based measure to define SOAEL, as it acknowledges that it is likely to differ for different noise sources and receptors, and during different times. Further research would need to be required.

The National Planning Policy Framework (NPPF) [14] sets out the Government's planning policies for England and their suitable application. The NPPF contains general guidance in order to pursue and obtain sustainable development in line with the Government's sustainable development strategy, seeking improvements to the quality of the built, natural and historic environment, along with people's overall quality of life. Planning Practice Guidance (PPG) [15] provides guidance for acousticians. It draws on guidance contained within, the now withdrawn, PPG24 'Planning and Noise' and brings the guidance in line with the NPSE. The newly proposed Professional Practice Guidance (ProPG) [16] focusses on proposed new residential development and existing transport noise sources.

3.3 Acoustics Standards and Guidance

BS 8233 [17] provides guidance on sound insulation and noise reduction for buildings in line with WHO Guidelines on Community Noise [18]. Maximum noise levels $L_{Aeq,T}$ are defined for daytime (07:00-23:00 hours) and night-time (23:00-07:00 hours) for habitable rooms and outdoor areas, from which, the required sound insulation of the building envelope may be determined. For a bedroom these are a daytime $L_{Aeq,16h}$ of 35dB and a night-time $L_{Aeq,8h}$ of 30dB. It is advised by the WHO that to help avoid sleep disturbance, noise events exceeding an L_{AFmax} of 45dB should be limited if possible [18]. Also that during the daytime, few people are likely to be highly and moderately annoyed at L_{Aeq} levels above 55dB and 50dB respectively. During the evening and night-time, the sound levels should be 5-10dB below these. The Night Noise Guidelines (NNG) [19] state that no harmful health effects are observed for an $L_{night,outside}$ of below 40dB. BS 4142 [20] describes methods for rating and assessing sound of an industrial and/or commercial nature.

3.4 Local Guidance and Projects

Local practice and guidance for London include The City of London's Noise Strategy, which sets out and updates policies and measures for the mitigation of noise in the City [21]. Transport for London's Code of Practice for Quieter Deliveries [22] provides guidance to businesses and delivery companies on how noise may be minimized from out-of-hours deliveries. Six successful trials were completed as part of the Quiet Deliveries Demonstration Scheme (QDDS) [23]. It concluded that out-of-hours delivery trials are possible when retailers and local authorities work effectively together, in partnership [24]. Subsequently the Department for Transport released a series of Good Practice Guidance's following the completion of the scheme and the trial during the 2012 London Olympics [25,26,27,28].

4. Current Technologies and Innovative Solutions

Noise mitigation requires a coherent strategy, encompassing long-term and medium- to short-term measures [30], which tend to either take a broader scale to reducing noise levels or address the particular noise source respectively. This section reviews both established and innovative solutions to mitigation.

4.1 Soundscapes

ISO 12913 [31] defines soundscape as "acoustic environment as perceived or experienced and/or understood by a person or people, in context" and acoustic environment as "sound at the receiver from all sound sources as modified by the environment". With the shift of planning towards sustainable development, design and well-being, analysis of the overall soundscape is desirable; it is however usually more complex and time-consuming than a noise control approach. Adams et al. suggested that a soundscape approach is likely to be more effective if adopted from the beginning of the design process, with frequent contact between people producing sound, people receiving the sound (often local residents) and the designers and planners managing the process [31].

Luzzi et al. adopt a soundscape approach to designing quiet areas [32], where an alternative method to using barriers is used to reduce traffic noise, consisting of the combination of landscaping and sound sculptures. Simulations using spatialized audio playback and real-time manipulation are becoming more common in practice [33] and the technology continues to be developed by researchers [34], thus allowing for interactive simulations to enhance communication and understanding shared between designers and stakeholders of environments.

4.2 Barriers

Noise barriers target the transmission path between the source and receiver to reduce the perceived noise level as described in ISO 9613-2 [35] with guidance in The Design Manual for Roads and Bridges Volume 10 Section 5 [36]. The main design objectives of a barrier are that it possesses sufficient mass to attenuate the sound, require little maintenance and be safe [37]. Perceived annoyance of traffic noise is dependent on the spectral variance transmitted through the barrier, where the largest reduction in low frequencies was associated with the lowest annoyance.

Typical materials for noise barriers are timber, masonry, metal, acrylic glass or concrete, however recycled or natural materials offer an alternative solution [38]. Low-height noise barriers (< 1m) may be used to reduce rolling noise from transport, provided they are well designed and positioned near the source. The acoustical performance of metal and wooden barriers with and without sound absorption is evaluated in [39]. The effect of sound absorption is about 3dB(A) on the measured noise reduction. A doubling of barrier height is found to result in a 3-4dB increase in insertion loss. The performance of three different barrier tops was measured by Kragh et al, a Watts-top, T- and L-shaped shaped tops. Traffic noise levels measured 20m and 40m behind the barrier reduced by between 1.5 and 3.7dB depending on distance and screen top [41].

4.3 Balconies

The noise reduction potential of balconies ranges from 5-14dB depending on the width of the windows, the angle between the road and the window, the depth of the balcony and the height of the boundary wall [29]. If balconies are located well above the street level, it is advised that their underside be designed to reflect noise away from the façade or be covered with a noise absorbing material. A semi-enclosed balcony offers an alternative approach, where an open side faces away from the noise source and two fixed floor to ceiling glazing units face the source. The noise benefit determined by Fresnel number has the potential be as high as 21dB(A).

Ishizuka and Fujiwara examine the performance of balconies with ceiling-mounted reflectors on a high-rise building façade [41], the findings of which, also corresponding with those in [42]. Road traffic noise may be reduced by 7-10dB(A) at incident angles of noise close to the design angle, in comparison with the “normal” balcony. This reduction is approximately the same as, or greater than, that of a balcony with an absorbent ceiling.

4.4 Enclosures

Enclosures are generally a more complex and expensive approach to noise mitigation. There is little in the way of available literature where enclosure design is evaluated for the reduction of traffic or delivery noise. Both the reverberant and direct field of the source in an enclosure will contribute to the sound radiated by the enclosure walls as well as to the sound field within the enclosure [44]. BS EN ISO 11690-2:1997 [45] provides recommended practice for the design of low-noise workplace containing machinery, outlining general principles to enclosure design. Reductions greater than 25dB(A) may only be obtained with sufficient silencers, seals, mounting, absorbent lining and structure.

4.5 Absorptive Surfaces

4.5.1 Low Noise Road Surfaces

The main sources of road noise are rolling and engine noise [45]. The former is due to the tire-road interaction and the latter is due to the direct propagation of engine and transmission noise and reflection from the road surface. Aerodynamic sources also contribute to road traffic noise [46]. Above speeds of 50 km/h, the majority of noise is from the tyre/road interaction. The Design Manual for Roads and Bridges Volume 7 Section 5 outlines guidance on surfacing materials for new and maintenance construction of roads [47]. Surface roughness (texture), porosity and texture are the three main characteristics that describe the acoustical behaviour of a road surface [46]. A traffic noise reduction up to 8dB(A) may be achieved when using a porous asphalt double layer construction for urban use, where speeds are in the range of 50-70km/h [46]. Guidelines for low-noise road surface maintenance and rejuvenation are provided in [48].

4.5.2 Building/façade Insulation

Vegetation may be used to reduce noise levels in situations, such as street canyons, where hard and dense materials cause multiple reflections from façades, leading to increased overall sound levels on the street [60]. The noise absorption of soil and plant systems was found to depend largely on the type of soil and moisture content. The project developed a low-density soil, having a similar frequency dependent absorption coefficient to that of glass wool of similar thickness. Leaves improve the absorption of hard soils across a broad frequency range, dependent on the type of plant, leaf angle, amount of foliage on the plant and total leaf area in a unit volume. A green wall containing low-density soil can provide low and high frequency absorption [39]. Yeung et al. address issues of high traffic noise in Hong Kong where the majority of residents live in high-rise buildings and are therefore highly susceptible to road traffic noise [61]. With careful design and use of absorptive materials, a noise reduction of up to 8dB(A) can be achieved without compromising sufficient air ventilations meeting local regulations by the use of a plenum type acoustic window.

4.5.3 Ground Treatments

Reflections over acoustically hard ground, such as a non-porous concrete or asphalt cause an increase in sound level. Soft ground or roughness elements generate destructive interference, thereby attenuating the sound. A roughness configuration 0.3m high and 2m wide can help reduce traffic noise by at least 3dB, compared with smooth, acoustically hard ground, at 10m from the road, while a 3-m-wide configuration of the same height reduces the noise by at least 7dB(A) at 50 m from the road [39]. Incorporating resonators can help to reduce natural resonances in twin-layer porous asphalt surfaces. A reduction of approximately 3-4dB(A) for passenger cars and approximately 2dB(A) for heavy trucks, for a 1.2m high receiver at 7.5m distance, may be achieved.

4.6 Landscaping

Whilst the foliage of trees and shrubs does little in the way of noise reduction unless adequately thick, there is however a psychological effect, increasing the perceived mitigation beyond the measureable reduction of sound level. A noise attenuation of 1-3dB(A) at distances of up to 15m from the rear edge of vegetation may be achieved with a continuous strip of shrubs, at least 2.5 m high and 4.5-6 m wide, planted along the edge of a highway shoulder, increasing to 10dB(A) with a 60m wide strip of trees [44]. The arrangement of trees like sonic crystals improve noise mitigation when compared to typical green belts or forests and especially at low frequencies (<500 Hz) [53]. Periodic rows are the simplest and most effective arrangement for the growth of natural trees, whilst still acting as sonic crystals.

Along urban roads flanked by tall buildings there are multiple reflections between building façades, which greatly increase street noise levels [39]. Noise reduction due to trees in street canyons is expected to be no more than 2dB(A). Significant mitigation of road noise has been achieved in Antwerp as part of the SONORUS project [54], by encompassing road management, low noise road surfacing, low noise vegetated barriers and vegetated areas. The use of water sounds reduces the perceived annoyance of road traffic and construction noise [55].

4.7 Site or Building Layout Design

Geometry and orientation of buildings should be designed to minimise potential reflections from key noise sources, in particular, the reduction of reflections between façades. From analyzing the perceived annoyance of residents due to traffic noise in urban areas, there was little correlation shown between noise levels and annoyance, instead site typology impacted upon the perceived annoyance, where for the same value of day equivalent level, 10% more people are annoyed in L sections (broad streets) than in U sections (narrow streets) [56]. It was also shown that people living in L sections had a higher sensitivity to noise, being measurable to approximately 4dB(A). Nelson states that the shape, orientation and location of buildings and the internal arrangement should be chosen to minimize noise impact, also having the benefit of reducing the required sound insulation in order to reach satisfactory noise levels [57].

Sleep disturbances due to road traffic noise among residents with their bedroom facing a busy road was found to be about three times higher than among those with their bedroom facing a courtyard [58]. Moving noise sensitive rooms to the quiet side of a building reduces noise levels. It is stated in [59] that the average annoyance of people at home is reduced if the dwelling has a quiet façade with traffic noise levels below 45dB or 50dB (day-evening-night level). It is preferable to locate quiet facades adjacent to the traffic noise without direct traffic-noise exposure, such as (semi-)closed courtyards. A curved building may be used to create a quiet area, shielded from the traffic noise, with a reduction of 20-30dB.

5. Conclusion

This paper has reviewed current research on materials and methods that can be incorporated within local environment and building design concepts to mitigate noise from road and street disruption from deliveries. Noise mitigation techniques that are not typically used for deliveries, but are effective in other noise control situations having the potential to be used in this area have been presented. Suggestions on the applicability of the various solutions to the control of impacts from delivery noise are offered. The findings indicate that fundamental research and development is required to create specific technologies to generate options for embedding noise reduction materials and processes into street and building design for the mitigation of impacts of noise from deliveries.

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