

Sustainable Low Impact Design (SLID) in Playground Pavement

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Abstract

Playground surfaces are crucial to child safety, public health, and urban environmental quality. This review explores the application of SLID principles in playground pavements, integrating civil engineering, environmental health, and urban planning to overcome the limitations of conventional materials. While traditional rubberized and synthetic surfaces meet impact standards, they often pose risks from toxic emissions, thermal hazards, and poor permeability. Drawing on 70+ peer-reviewed studies, manuals, and municipal guidelines, the review assesses materials across six SLID dimensions: ecological sensitivity, material safety, thermal performance, inclusive design, life-cycle sustainability, and multifunctionality. Findings show that synthetic surfaces can reach extreme temperatures and contain hazardous PAHs, heavy metals, and microplastics. In contrast, SLID-compliant materials like permeable pavers, engineered wood fiber, and rubber-natural hybrids offer safer, eco-friendly alternatives. Yet, inconsistent regulations, insufficient long-term data, and limited child-focused metrics remain obstacles. The study recommends integrating SLID into playground standards, prioritizing non-toxic, permeable, thermally stable materials, and promoting interdisciplinary collaboration and participatory design. SLID emerges not just as a risk mitigation tool but as a strategy for inclusive, resilient, and climate-adaptive urban spaces.

Keywords: Sustainable Low Impact Design (SLID), Playground Pavement, Urban Sustainability, Non-toxic Materials, Thermal Comfort, Child Safety, Permeable Surfaces, Public Health.

List of Abbreviations
 LID - Low Impact Development
 SLID - Sustainable Low Impact Design
 VOCs - volatile organic compounds
 PAHs- polycyclic aromatic hydrocarbons

EWF - engineered wood fiber
 PIP - poured-in-place
 SRI -Solar Reflectance Index
 ERCA- Essex Region Conservation Authority

1. Introduction

1.1. Background and Significance

Outdoor playgrounds are essential for children's holistic development, yet traditional pavement designs have focused primarily on injury prevention without fully addressing broader concerns such as environmental health, accessibility, and sustainability. In response, the SLID framework has emerged, integrating public health, ecological stewardship, and social inclusion into playground design. This shift is especially important in urban areas where synthetic surfacing materials, like rubber tiles, pose risks due to the release of volatile organic compounds, heavy metals, and microplastics, which can cause respiratory issues, chemical exposure, and heat-related injuries (Table 1).

Table 1: SLID-Based Interventions for Key Challenges in Playground Surfacing.

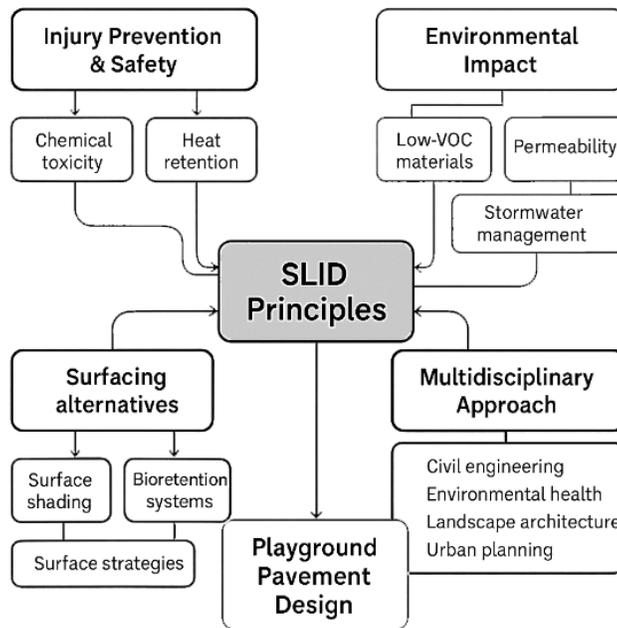
Approach	Conventional Challenges	SLID Approaches	Key References
Injury Prevention & Safety	Focuses on linear acceleration only; ignores angular kinematics and child biomechanics	Incorporates angular kinematics and body biomechanics for better injury risk assessment	(Fahlstedt et al., 2019), (Mack et al., 1997), (Purvis & Hirsch, 2003), (Commission, 2006), (Cradock et al., 2005)
Thermal Comfort & Environment	Heat retention in rubber/synthetic surfaces; climate change worsens risks	Use of shade, vegetation, and reflective materials to lower surface temperature	(Antoniadis et al., 2020), (Vanos et al., 2016)
Health & Accessibility	Some surfaces limit movement for children with disabilities; synthetic surfaces boost play but reduce accessibility	Promotes stable, firm, accessible materials that enable inclusive, active play	(Skulski, 2010), (Seaver, 2015)
Pollution & Life Cycle Sustainability	Use of recycled materials may introduce toxins (e.g., PAHs, heavy metals)	Careful material sourcing and life cycle evaluation; integrates stormwater management and environmental education	(Mostert, 2008), (Programs & Division, 2000)

1.2. Objectives and Scope

This review explores the integration of SLID principles in playground pavement design, highlighting the need to reduce both health risks and environmental impacts associated with materials. It advocates for safer, non-toxic, and permeable alternatives that align with stormwater management and urban

sustainability goals. Drawing from civil engineering, environmental health, and urban planning, the review synthesizes research and best practices to provide evidence-based recommendations for both new and retrofitted playgrounds (Figure 1).

Figure 1: Synthesis of SLID Principles in Playground Pavement Design: Intersections of Safety, Sustainability, and Material Performance.



Source: Authors

1.3. Methodology and Review Approach

This review uses a quantitative, document-based synthesis method to analyze SLID strategies in playground pavement design. It draws from peer-reviewed articles, government manuals, municipal guidelines, and sustainability reports focused on health, environment, and material safety. Sources were selected based on relevance to SLID, stormwater management, and playground surface performance. Key references include LID design guides. (Li et al., 2015), (Ishaq et al., 2019) and (Martin-Mikle et al., 2015), municipal planning standards, and studies on surface permeability, biocompatibility, and chemical safety (Table 2).

Table 2: Methodology and Literature Selection Criteria for Review on SLID in Playground Pavement.

Criteria/Source	Details
Relevance to SLID Principles	Focus on studies directly addressing SID in playground pavements, including material sustainability and health/environmental impacts.

Quality of Research	Prioritized peer-reviewed articles and reputable journals to ensure credibility and scientific rigor.
Impact on Health and Environment	Included studies examining the effects of playground surfaces on children's health, including toxicity, thermal comfort, and environmental factors like microplastic contamination.
Geographical and Temporal Scope	Studies from global and local contexts, particularly urban environments, with a focus on recent research (last 10-15 years).
Experimental and Case Study Focus	Emphasized research with real-world applications, case studies, and experimental data on playground materials and their performance.
Scholarly Articles	Academic papers from reputable journals in urban planning, environmental science, and civil engineering.
Case Studies	Specific examples of playground projects implementing SLID principles, detailing successes and challenges.
Experimental Research	Studies involving experiments on playground materials, testing environmental effects, and safety outcomes.

2. Conceptual Framework of SLID

The Conceptual Framework of SLID establishes a theoretical and practical foundation for integrating environmentally responsible, health-conscious, and socially inclusive strategies into urban surface design, with a particular emphasis on public playgrounds and other spaces occupied by vulnerable populations such as children. This framework builds upon conventional LID approaches, traditionally focused on stormwater management, by expanding the scope to include key components such as ecological sensitivity and source control, material safety and pollution prevention, thermal performance and safety, multifunctionality and inclusive design, and lifecycle sustainability and durability (*Table 3*).

Table 3: Key Components of SLID In Playground Pavements.

Key Component	Research Example	SLID Recommendations	References
Ecological Sensitivity and Source Control	A study of playground paving in 40 apartment complexes (100+ households each) in Jeonju found material use shifted from sand (1990s) to sand-rubber mixes (2000s) and rubber chips/blocks by 2010 for safety and easier maintenance. Accidents were reported by 50.4% of users, 47.5% from play equipment, and 19.5% from paving. Rubber chips/blocks had the highest satisfaction, though issues like poor drainage, pitting, and loosening were common.	Using permeable pavements, tree canopies, and implementing distributed infiltration systems	(Jeong & Park, 2012)
	This study analyzed 127 soil samples from 24 sites in Istanbul and found that 5 sites with treated wood structures had elevated As, Cu, Cr, or Zn levels, often above Turkish limits. Hazard indices were below 1 for all metals in both ingestion scenarios, but arsenic's carcinogenic risk exceeded 1×10^{-6} . Soil ingestion rate was the most influential risk factor.	Avoid using treated wood structures that may leach metals like As, Cu, and Cr into soil.	(Guney et al., 2010)
Material Safety and	Only 4.7% of 402 Victorian school playgrounds with arm fractures met the 20 cm tanbark depth standard; actual depths ranged from 0–27 cm, averaging 11.1 ± 5.0 cm. Impact tests at	Use of non-toxic, low-emission, and	(Gunatilak a et al., 2004)

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Pollution Prevention	0.5–2.5 m drop heights showed higher deceleration and HIC with depths under 8 cm. A 9 cm rubber surface equaled the protection of 18 cm compacted tanbark, while hybrid rubber-tanbark performed best. Tanbark below 8 cm is unsafe, highlighting the need for stricter depth enforcement.	recyclable materials	
	A study of 330 injured children (ages 0–14) in Cardiff playgrounds (1992–1994) found that rubber surfaces reduced injury risk by 80% vs. concrete and 50% vs. bark. Monkey bars caused 2× more injuries than climbing frames and 7× more than swings/slides. Higher equipment height correlated with more fractures (p=0.005). Rubber was the safest surface; raising fall height limits above 2.5 m is discouraged.	Safety of Playground Surfaces and Equipment Height	(Mott et al., 1997)
	Eighty sandy substrate samples from 20 Madrid playgrounds were analyzed for trace elements. Ingestion posed the highest risk, with arsenic showing a cancer risk of 4.19×10^{-6} , close to the 1×10^{-5} unacceptable threshold. The non-cancer Hazard Index was 0.28, mainly from As, Pb, Cr, Al, and Mn. Despite uncertainties, the study highlights key exposure risks in urban playgrounds.	Reducing Children’s increased ingestion, inhalation, and dermal contact with pollutants	(De Miguel et al., 2007)
	A study analyzed 120 dust samples from playgrounds near a cement factory in Bursa, Türkiye. Heavy metal concentrations ranged from 2401 to 6832 mg/kg, with the highest levels at sites PG4 to PG1. Detected metals included Cr, Mn, Fe, Co, Cu, Zn, Pb, Cd, As, and Ni. Significant correlations were found (p < 0.01, Cu and Pb at p < 0.05). PCA explained 79.9% of the variance. Despite elevated pollution near the factory, HQ, and Hazard Index values were below 1, indicating low health risk.	Reducing Chronic exposure to heavy metals and PAHs linked to serious health risks	(Birgül, 2024)
	The study in 39 Barcelona schools found PM2.5 levels 1.7 times higher than urban background (UB), mainly from indoor sources and playground dust. NO ₂ levels were 1.2 times higher than UB, with similar indoor and outdoor concentrations, showing strong pollutant infiltration. Traffic-related pollutants (NO ₂ , EBC, UFP, antimony) were higher in central schools, placing children's exposure between UB and traffic station levels.	Comprehensive strategies are required to minimize pollution and thermal exposure.	(Rivas et al., 2014)
Thermal Performance and Safety	A study evaluated 103 U.S. public playgrounds, finding that artificial surfaces reached higher temperatures than ambient air, while natural materials moderated heat. A total of 67% lacked shade between 10:00 a.m. and 2:00 p.m., heightening risks of sunburn and overheating. The results highlight the need for bioclimatic design and green space to protect children's health.	Use light-colored, permeable materials, add vegetation canopy, select low-thermal-mass, reflective materials.	(Olsen et al., 2019)
	Implement shading structures; select light-colored, high-albedo materials; consider thermal properties in surface design	Reduce Surface heat >80°C under sunlight	(Pfautsch et al., 2022)
Multifunctionality and Inclusive Design	The report examines child-friendly urban design in Eindhoven and Jerusalem using indicators in streets, green spaces, and play areas. Fieldwork from 2016–2017 showed that both cities face concerns about safety, inclusivity, and outdoor play, with	dual-purpose spaces that blend play with sustainability	(Krishnamurthy et al., 2018)

Lifecycle Sustainability and Durability	<p>Jerusalem experiencing greater socio-economic inequality. Research included surveys, interviews, and workshops focused on children aged 0–12. Key recommendations include street greening, better traffic safety, and involving children in planning.</p>		
	<p>This study observed children at an inclusive playground, with 52% female and 48% male participants, 96% of whom appeared under age 12. Active play was seen in 71% of cases, with functional play like climbing and running making up 88% of behaviors. Social interactions were mostly with peers (48%) and adults (26%).</p>	<p>promoting active and functional play, age-appropriate accessibility</p>	<p>(James et al., 2022)</p>
	<p>A study of 10 Sydney playgrounds found sun-exposed surfaces often exceeded burn thresholds, with a blue rubber dolphin reaching 91.8 °C. Synthetic turf (40 mm) hit 84.5 °C, dark blue SBR 81.1 °C, and dark green EPDM 77.8 °C. Shaded areas remained below burn-risk levels, emphasizing the need for shade and safer materials.</p>	<p>Use of renewable and durable materials, and adaptive strategies to address climate risks</p>	<p>(Pfautsch et al., 2022)</p>
	<p>This study compares playground equipment from Betta Play (China) and Europlay (Belgium), analyzing materials, safety, environmental factors, and educational value. Both companies demonstrated eco-friendly designs; however, Europlay used more wooden materials, while Betta Play relied more on plastics. The findings suggest Europlay’s approach is more sustainable and better aligned with environmental protection goals.</p>	<p>Prioritize natural, low-impact materials like wood over synthetic plastics to reduce environmental harm.</p>	<p>(Shavkidinova et al., 2024)</p>

3. Playground Pavement Materials

Playground surfacing materials significantly influence environmental safety, health outcomes, and long-term sustainability. Loose-fill materials such as EWF, sand, and bark mulch offer permeability and ecological benefits, yet their impact on safety varies. Solid surfaces like poured-in-place (PIP) rubber and artificial turf provide consistent impact attenuation but introduce health concerns. Sustainable alternatives like permeable pavements, recycled rubber tiles, and reclaimed materials (e.g., plastic lumber, crushed concrete) address runoff, reduce landfill waste, and align with SLID and LEED guidelines (*Table 4*). *Table 5* presents the environmental and health implications associated with three major categories of playground surfacing materials: loose-fill, unitary surfaces, and alternative sustainable materials.

Table 4: Common playground surfacing materials.

Category	Material	Description	Pros	Cons
<p>Loose-Fill (Mack et al., 2000), (Himmelsbach & Shorten,</p>	<p>Engineered Wood Fiber (EWF)</p>	<p>Shredded wood, ADA compliant</p>	<p>Cost-effective, natural look, good impact absorption</p>	<p>Needs regular maintenance, degrades over time</p>

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2003), (Olsen et al., 2019), (Marshall, 2021)	Wood Chips / Bark Mulch	Natural shredded wood materials	Eco-friendly, soft cushioning	Can rot, needs topping up, not always ADA compliant
	Sand	Granular natural material	Good drainage, low cost	Poor impact absorption, accessibility concerns
	Pea Gravel	Small rounded stones	Natural look, inexpensive	Can be displaced, not ADA compliant
	Rubber Mulch (Crumb Rubber)	Recycled tire mulch	Excellent shock absorption, long-lasting	Health concerns (toxins), heat retention
Unitary Surfaces (Marshall, 2021), (Olsen et al., 2019), (Hurst et al., 2023), (Keković et al., 2019)	Poured-in-Place (PIP) Rubber	Seamless rubber surface with binder	ADA compliant, customizable, low maintenance	High initial cost, can get hot in sun
	Rubber Tiles	Interlocking rubber tiles	Replaceable, uniform safety	Expensive, seams may separate over time
	Artificial Turf + Shock Pads	Synthetic grass with cushioning layer	Aesthetic, soft, ADA accessible	High cost, heat retention, potential maintenance issues
Alternative Sustainable (Marshall, 2021), (Bulut & Yilmaz, 2008), (Pfautsch et al., 2022)	Pervious Concrete	Porous concrete allowing water infiltration	Good for stormwater management, durable	Less cushioning for falls
	Permeable Pavers	Interlocking blocks with gaps for water flow	Eco-friendly, reduces runoff	Expensive, harder surface
	Rubber-Tanbark Hybrids	Blend of rubber and natural bark materials	Combines resilience and aesthetics	Limited availability, may still carry chemical exposure risk

Table 5: Environmental and Health Implications of Playground Surfacing Materials.

core	Key Points	Sources
Toxic Emissions and Air Quality Concerns	A study tested 10 synthetic playground surfaces, revealing limitations in current safety standards (HIC ≤ 1000 , Gmax ≤ 200) for preventing injuries beyond head trauma. A new metric, the impulse force criterion (If), was proposed, combining HIC duration and momentum change. HIC, Gmax, If, and Jmax showed consistent trends with material thickness and drop height. One viscoelastic foam differed in bounce and absorbed work, highlighting the need for updated criteria to better prevent long-bone injuries.	(Eager & Hayati, 2019)
	This study compared heavy-metal concentrations in soils and sandbox sand from playgrounds in Çanakkale city, highlighting children's vulnerability to contaminants. Soil samples contained iron (Fe) at 12,901 mg/kg, manganese (Mn) at 475 mg/kg, zinc (Zn) at 58 mg/kg, copper (Cu) at 28 mg/kg, nickel (Ni) and chromium (Cr) at 21 mg/kg, and lead (Pb) at 18 mg/kg. Sand had generally lower levels, but prolonged use and accumulation of Fe/Mn (oxyhydr)oxides	(Parlak et al., 2022)

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	reduced the differences between sand and soil. Ingestion was identified as the primary exposure pathway for children, followed by dermal contact and inhalation, with sand posing a similar health risk to soil.	
	This project study found that NO _x , BC, and PM levels were highest at the school nearest to city-center traffic, with concentrations reflecting rush hour patterns. At one school, PM ₁₀ levels spiked 25, 57, and 12 times above night background during mid-morning break, lunch, and dismissal due to sandy playground resuspension. The impact of private car use could not be quantified due to overlap with city traffic.	(Minguillón et al., 2015)
PAHs and Heavy Metals	A study of 14 playgrounds in Seoul found PAH concentrations ranging from 2.82 to 57.93 µg/g, with 3-ring PAHs comprising 79.9% of the total. Monte Carlo simulations showed the 95% cancer risk slightly exceeded the USEPA standard (1.3×10^{-5}). Cancer risk was about 10 times higher in poured rubber surfaces compared to uncovered soil.	(Tarafdar et al., 2020)
	This study analyzed 120 playground soil samples in Ghana and found iron concentrations of 2785.0–15275.0 mg/kg and lead (Pb) levels of 2.1–284.0 mg/kg. Oral bioaccessibility was highest for copper (Cu) at 54.45% and Pb at 47.80%. While most metals had a hazard index (HI) below 1, Pb exceeded safe levels, posing a non-carcinogenic health risk to children.	(Kyene et al., 2023)
Pathways of Exposure and Health Implications	Eighty sandy substrate samples from 20 playgrounds in Madrid were analyzed for children's exposure to trace elements. Ingestion posed the highest risk, with arsenic showing a cancer risk of 4.19×10^{-6} , close to the 1×10^{-5} unacceptable threshold. The non-cancer Hazard Index was 0.28, below the safe limit of 1, with arsenic as the main contributor.	(De Miguel et al., 2007)
Emissions from Synthetic Surfacing Materials	In Israel, 20 out of 30 synthetic playground surface samples exceeded international trace metal standards, with cadmium ≥ 30 mg/kg and chromium ≥ 510 mg/kg. In synthetic grass, 3 of 8 samples had lead ≥ 1200 mg/kg, and 5 of 8 laminate flooring samples contained ~5% DEHT, though formaldehyde levels ($0.7\text{--}1.2$ mg/m ²) stayed below the 3.5 mg/m ² limit. Overall, 72% of playground and grass samples exceeded international safety thresholds.	(Negev et al., 2022)
Mitigation Strategies and Design Solutions	In a study of 60 playgrounds across 10 U.S. cities, innovative playgrounds drew 2.5 times more users and generated 3 times more moderate-to-vigorous activity than traditional ones. Even after adjusting for other factors, they attracted 43% more visitors and reduced the usage gap in high-poverty areas by 60%.	(Cohen et al., 2023)
Thermal Hazards and Surface Temperature Management	Rubber/asphalt can cause burns; organic materials retain less heat; shading reduces surface temperature by 10–20°C, improving safety and comfort.	(Commission, 2008), (Pennino, 2019), (Sanchez et al., 2021),
Microplastics in Playgrounds	Microplastic concentrations in playgrounds were up to five times higher than in other park areas, primarily originating from plastic structures, toys, and synthetic materials, posing a greater ingestion risk to children.	(Koutnik et al., 2023)
PAHs in Rubber Surfaces	In Thessaloniki playgrounds, dust from tartan-coated surfaces had ~6 times higher $\Sigma 12$ PAH and Σ carcPAH concentrations than sand-covered ones, with children's total PAH cancer risk (ILCR) reaching 7.83×10^{-7} —significantly higher than for sand (1.22×10^{-7}) or pavement tiles (9.48×10^{-8})—and in some cases exceeding the 1×10^{-6} risk threshold, mainly via dermal contact, emphasizing the need for further study on PAH migration, particle size effects, and other toxicants like genotoxic metals and benzothiazoles.	(Manoli et al., 2025)

Heavy Metals in Surface Dust	This study quantified health risks of heavy metal exposure in residential playgrounds across mega-cities, revealing elevated concentrations of As, Cu, and Ni—particularly in suburban soils—with mean carcinogenic risks (CRs) from dust and soil exposure ranging from 2.47×10^{-6} to 5.29×10^{-6} , and highlighted that children faced slightly unacceptable risks mainly due to lithogenic As and Ni, necessitating urgent risk control in suburban areas.	(Peng et al., 2023)
Heavy Metals in Surface Dust	This study analyzed 74 paired soil and equipment dust samples from children’s playgrounds in Bandar Abbas, Iran, revealing that dust had higher heavy metal (HM) pollution and health risks than soil, with arsenic as the primary risk contributor, and identifying suspended local soil, metal production, and aged plastic equipment as major pollution sources, especially for non-carcinogenic cadmium-related dust risks.	(Ghaffari et al., 2023)
toxic elements in surface dust	A study of surface dust from urban playgrounds in Xi’an revealed elevated levels of 7 toxic elements (Cd, Hg, Cu, Ba, Zn, Pb, Cr), with Cd and industrial sources posing the highest ecological and health risks—64.0% of toddlers faced carcinogenic risks—highlighting ingestion rate, exposure duration, and skin contact as key factors, and calling for stronger pollution control, hygiene promotion, and public awareness.	(Yu et al., 2025)
Degradation of Rubber Materials	vulcanised playground and turf materials, especially tyre-derived crumb rubber, can contain up to 2.4% Zn, 5% S, and 117 µg/g TEHP, along with multiple toxic metals (e.g., Co, Cd, Pb) and organophosphate esters (OPEs) from all major groups, with chemical composition varying up to tenfold depending on manufacturing method, coating, and wear, raising significant concerns about human exposure and environmental impacts, while highlighting the need for certified chemical data and sustainable recycling practices.	(Moreno et al., 2023)
Pollution Source Attribution	potentially toxic metals (PTMs) like Hg, Cd, Pb, Cr, Cu, and Zn were significantly above background soil levels, with industrial emissions contributing up to 42.6% (Cr), mixed sources (traffic, paint, plastics, etc.) driving up to 56.3% (Cu), and coal combustion responsible for 39.4% (Hg); Cd was identified as the top eco-risk contaminant, Cr as the top health-risk PTM, and the southwest region was marked as the priority control area.	(Zhu et al., 2024)

4. Thermal Comfort and Microclimatic Considerations

Thermal comfort is a vital but often neglected element of sustainable playground design, increasingly important as climate change amplifies extreme heat events. Commonly used synthetic materials like asphalt and rubber can reach hazardous temperatures—up to 60 °C and even 91.8 °C—contributing to Urban Heat Island (UHI) effects and posing serious burn risks to children, especially in densely built, low-vegetation areas (Pfautsch et al., 2022), (Peng et al., 2023). Studies have shown that shaded playgrounds not only reduce surface heat but also improve user satisfaction and accessibility (Cohen et al., 2023), (James et al., 2022). SLID-aligned strategies emphasize the use of low-thermal-mass, light-colored, and permeable materials, integration of natural and artificial shading, and seasonal adaptability through bioclimatic design elements such as deciduous trees and misting systems. High SRI surfaces can lower ground temperatures by up to 15°C, though care must be taken to minimize glare and sensory discomfort for sensitive users (Medici et al., 2020), (Ross et al., 2022).

5. Policy, Regulations, and Implementation Challenges

5.1. Existing International and National Standards and Guidelines

As playgrounds adapt to meet recreational, environmental, and sustainability goals, their pavements must comply with evolving safety and ecological standards. Implementing SLID effectively requires navigating a complex array of international, national, and municipal regulations (Table 6). However, global standards often focus more on physical safety than environmental concerns, and inconsistencies, outdated guidelines, and slow progress toward sustainability remain major obstacles (Pfautsch et al., 2022).

Table 6: Overview of International and National Frameworks for Playground Surface Design and Safety.

Framework / Standard	Region	Focus Area	SLID Relevance	
<i>(Sports and recreational facilities – Impact surfacing testing device, 2022)</i>	International	Impact attenuation, material testing	Supports material testing for eco-design	ISO 24667:2022
(Standardization, 2018)	Europe	Critical fall height (CFH), HIC values	Aligns with safe, resilient surfacing	EN 1177
(International, 2022)	USA	Impact attenuation under equipment	Encourages impact-absorbing eco-materials	ASTM F1292
(International, 2021)	USA	Wheelchair accessibility	Ensures inclusive surface design	ASTM F1951
(International, 2017)	USA	Material selection guidance	Promotes site-specific low-impact materials	ASTM F2479
(Group, 2020a)	Canada	Playground safety, accessibility	Adopts safety & environmental design principles	CSA Z614:20
(Ontario, 2005)	Ontario, Canada	Barrier-free design and access	Mandates accessible and sustainable spaces	AODA (Ontario)
<i>(Guidance Manual for Environmental Site Characterization in Support of Environmental and Human Health Risk Assessment Volume 1 Guidance Manual, 2016)</i>	Canada	Environmental sustainability	Promotes recycled and permeable materials	CCME / NRCan Guidelines

5.3 Gaps and Inconsistencies in Environmental and Regulatory Standards

Despite growing awareness of health and environmental impacts associated with playground surfaces, current regulatory frameworks remain inadequate, notably lacking environmental health criteria and standardized oversight for issues like UV degradation, toxicity, and microplastic emissions (Medici et al., 2020). Existing standards such as CSA Z614:20 (Canada), ASTM F1292 (U.S.), and EN 1177 (Europe) predominantly focus on impact safety and durability, often neglecting crucial aspects such as thermal comfort and environmental sustainability. Regulatory fragmentation further complicates the integration of SLID strategies; for example, while Madrid enforces regular replacements to mitigate contamination,

cities like Uppsala lack basic maintenance protocols, and ADA Accessibility Guidelines (U.S.) provide vague direction regarding material health impacts (Mostert, 2008), (Skulski, 2010). Although frameworks like LEED and Envision promote environmentally responsible materials with low VOC emissions, high reflectivity, and permeability (Chen, 2023), their integration into playground regulations remains limited due to financial constraints, inadequate interdepartmental coordination, and outdated building codes. Initial high costs, ongoing maintenance demands, and stakeholder misalignment further hinder widespread SLID adoption, highlighting the necessity for coordinated policy actions that prioritize health-conscious and sustainable playground designs (Booshi, 2024), (Ross et al., 2022). *Table 7* presents barriers to SLID adoption alongside international case studies demonstrating successful implementation.

Table 7: Barriers to the Adoption of SLID and International Case Studies of Successful Implementation.

Title	Key Issues	Reference(s)
Cost Implications and Maintenance Challenges	High upfront costs for SLID surfaces, specialized installation, maintenance requirements (debris removal, organic material replenishment, inspections), short-term financial decision-making	(Calgary, 2024)
Stakeholder Perspectives	Engineers focus on compliance and ease; planners support SLID but face supply and zoning constraints; policymakers require more public awareness and data; institutional resistance	(Housing, 2019)
Let's Play, Courtenay! – British Columbia	Inclusive, natural playgrounds; community engagement; data-driven and strategic alignment	(LANARC, 2024)
Massachusetts Municipalities – United States	Biodegradable, low-toxicity surfacing (e.g., cork, EWF); alignment with child safety and environmental goals	(Pollard et al., 2023)
Greenstone Master Plan – Ontario	Classification system for playground upgrades; community input; accessibility prioritization	(Greenstone, 2024)
Multi-City Observational Study – United States	Natural elements, permeable surfaces, and shade structures improved engagement and inclusivity	(Cohen et al., 2023)
PlayLab Cph – Copenhagen, Denmark	Integration of child development theory; post-occupancy evaluation confirmed effectiveness	(Refshauge et al., 2015)
Greater Sydney Playgrounds – Australia	Thermal risk assessments; use of lighter surfacing and shade structures improved safety	(Pfautsch et al., 2022)
Iowa Injury Prevention Program – United States	ASTM-compliant surfacing and staff training; injury reduction up to 83%	(Olsen et al., 2010)
Hybrid Surface Systems – United States	Combination of rubber, turf, and carpet for accessibility and impact reduction; requires ongoing maintenance	(Skulski, 2010)

5.4. Regional Recommendations: Applying SLID Principles in Southern Ontario Municipalities

In order to bridge the gap between broad theoretical frameworks and localized implementation, this section offers practical recommendations for integrating SLID principles into playground pavement planning in Southern Ontario, with a particular focus on the City of Windsor. Situated in Canada's southernmost region, Windsor experiences a relatively warm and humid continental climate (Smoyer et

al., 2000) with extended summer heatwaves and increasing precipitation variability (conditions that amplify the risks associated with conventional synthetic playground surfaces, including thermal discomfort, poor permeability, and potential pollutant accumulation (Li et al., 2018)).

Building upon the multidisciplinary insights presented throughout this review, a context-specific, multi-layered surfacing strategy is proposed for both newly constructed and retrofitted playgrounds in the City of Windsor. This region, characterized by prolonged summer heatwaves and episodic heavy rainfall, demands surface systems that address not only physical safety but also climatic resilience, ecological compatibility, and long-term public health. The proposed system integrates three interdependent components, each selected for its ability to mitigate a key environmental or safety challenge. At the base, high-albedo permeable pavers serve as the structural foundation. These modular, interlocking units facilitate effective stormwater infiltration, reducing surface runoff and alleviating stress on municipal drainage infrastructure—particularly critical in neighborhoods with aging combined sewer systems. Their light-colored, reflective surfaces also contribute to urban heat mitigation, lowering surface temperatures by up to 15°C compared to traditional asphalt or rubber materials (Pfautsch et al., 2022). Above this layer, engineered wood fiber (EWF) is recommended as the primary impact-attenuating surface. As a loose-fill, ADA-compliant material, EWF meets critical fall height requirements while offering a renewable, biodegradable, and relatively low-emission alternative to synthetic rubber. Its fibrous structure allows for moderate permeability, supporting water percolation and enhancing the ecological function of the entire pavement system. Moreover, EWF's natural aesthetic and tactile properties support a more child-friendly sensory environment, especially for younger children and those with sensory sensitivities.

To address microclimatic concerns and extend thermal protection beyond the pavement itself, the design includes strategic integration of deciduous tree canopies and vegetative buffers around and within the play area. These green infrastructure elements provide passive shading, reduce ambient air temperatures, and contribute to air quality improvements. In combination with the light-permeable paver base and EWF layer, the trees create a holistic surface–atmosphere interface that prioritizes both environmental regulation and child safety. Collectively, this tri-component system responds to the unique climatic and infrastructural conditions of Windsor while aligning with broader sustainability goals outlined in the municipality's Official Plan and regional climate adaptation frameworks. It exemplifies the application of SLID principles as not merely a theoretical construct, but as a practical, scalable intervention that enhances ecological performance, promotes public health, and supports inclusive, climate-resilient public spaces.

In terms of policy alignment, Windsor's Official Plan and the Essex ERCA's watershed management strategies both emphasize stormwater infiltration and heat mitigation through green design interventions (Essex Region Source Protection, 2019). However, these guidelines currently lack specificity regarding recreational surfaces. Embedding SLID-based standards into municipal tender documents and site plan approvals for public parks would institutionalize safer and more sustainable playgrounds.

Moreover, lessons can be drawn from existing regional best practices. For example, the City of Toronto's Green Standards and London's Climate Emergency Action Plan both promote permeable surfaces, non-

toxic materials, and shade structures in outdoor public spaces (Toronto, 2024), (Scherr, 2024). Adapting these practices to the context of Southern Ontario allows smaller municipalities to leverage proven, scalable strategies rather than developing new approaches from scratch. To ensure long-term performance and user satisfaction, it is essential to incorporate post-occupancy evaluation protocols. Conducted seasonally, these assessments can track surface temperature patterns, identify safety concerns, and evaluate maintenance requirements, providing valuable data for ongoing improvement. This iterative process will help cities like Windsor develop playground environments that are not only child-centered and thermally resilient, but also environmentally restorative.

Table 8 provides a comparative overview of four SLID-compliant surface systems, focusing on initial construction cost per square meter, estimated lifespan, maintenance needs, and practical trade-offs. These figures, drawn from municipal guidelines, academic literature, and product specifications, offer local decision-makers a cost-informed framework for selecting sustainable playground pavements aligned with both budgetary and environmental priorities. Although tailored to Windsor, this model is adaptable to other Canadian municipalities with region-specific material combinations based on local climatic and regulatory conditions.

Table 8: Comparative Summary of SLID-Compliant Playground Surfacing Options for Southern Ontario.

Material Option	Initial Cost (CAD/m ²)	Lifespan (years)	Maintenance Needs	Strengths	Limitations
Engineered Wood Fiber (EWF)	60–80 (Gunatilaka et al., 2004)	5–8 (Group, 2020b)	Moderate (replenish fiber every 1–2 years) (Williams et al., 2023)	Natural, permeable, low VOC, accessible (Williams et al., 2023)	Degrades over time, mold risk, frequent upkeep
Poured-in-Place (PIP) Rubber	160–200 (International, 2022)	10–12 (Eager & Hayati, 2019)	Low (annual inspection, some surface cracking) (Eager & Hayati, 2019)	Durable, consistent fall protection, customizable (Janes et al., 2018)	High surface temperature, synthetic emissions
Rubber-Tanbark Hybrid	110–130 (Gunatilaka et al., 2004)	8–10 (Gunatilaka et al., 2004)	Moderate (organic material topping-up) (Tynes)	Balanced aesthetics and resilience, dual material benefits (Gunatilaka et al., 2004)	Limited availability, moderate chemical exposure risk
Permeable Interlocking Pavers	140–180 (Duan et al., 2016)	15–20 (Duan et al., 2016)	Low (occasional cleaning, joint refill)	Highly durable, stormwater control, minimal emissions (Zanandrea & Silveira, 2018)	Harder surface, higher upfront cost

6. Future Directions for SLID in Playground Pavement Design

Despite the increasing application of SLID principles in playground design, several critical research and implementation gaps remain. Long-term performance data for SLID-compliant materials is notably lacking, particularly regarding their behavior under prolonged mechanical stress, UV exposure, and fluctuating climate conditions. While materials like rubberized and permeable pavements are often selected for their impact absorption and stormwater benefits, their aging characteristics, resistance to wear, and potential to release microplastics or leachates remain insufficiently studied. Similarly, thermal performance is frequently overlooked, even though dark or synthetic surfaces can exceed 60°C in summer, creating burn risks and discouraging outdoor play. Surface properties such as color, porosity, and texture play a vital role in thermal regulation, yet there is limited empirical research assessing how these factors interact in SLID applications. Innovative materials like nanocomposites and photocatalytic pavements show promise for multifunctional use, but their performance, safety, and affordability in playground settings require further investigation.

Another underexplored dimension is the integration of child-centered design metrics into SLID evaluation. Current literature often focuses on hydrological and structural efficiency without adequately addressing sensory engagement, inclusivity, or perceived safety. The absence of participatory design approaches and post-occupancy evaluations restricts the ability to create responsive, equitable spaces for children. Moreover, existing guidelines for sustainable pavement lack a unified framework that aligns environmental, social, and economic outcomes through a child-focused lens. To address these issues, SLID should be embedded in municipal planning tools with standards emphasizing non-toxic, durable, and permeable materials, thermal comfort strategies such as high-SRI surfaces and shading, and routine maintenance protocols. Collaboration among environmental engineers, designers, public health experts, and child development specialists—alongside direct child engagement—is essential. Policy mechanisms, including grants and regulatory support, can further enable experimentation with new technologies, ensuring playgrounds are not only sustainable and safe but also inclusive and responsive to community needs.

6.1. Evidence-Based Material Selection, A Decision-Making Matrix

To support evidence-based material selection in municipal playground design, a weighted decision-making matrix was developed using key SLID principles as evaluation criteria. The matrix compares four commonly used surface types, Engineered Wood Fiber (EWF), Poured-in-Place (PIP) Rubber, Rubber-Tanbark Hybrid, and Permeable Interlocking Pavers, against six performance dimensions: safety and injury prevention, pollution prevention and material safety, thermal comfort, stormwater management and permeability, initial cost efficiency, and durability with maintenance requirements.

Each criterion was assigned a weight based on its relative importance to sustainable public space design in Southern Ontario, with greater emphasis placed on child safety, environmental health, and heat resilience. Scores were derived from a synthesis of peer-reviewed literature, municipal reports, and technical specifications. The resulting matrix *Table 9* enables transparent prioritization among surface

options, highlighting trade-offs across ecological, economic, and functional domains. This structured approach provides decision-makers with a replicable tool to assess surface systems not only by their immediate compliance but by their long-term contribution to resilient, inclusive, and health-centered playground infrastructure.

Table 9: Weighted Decision-Making Matrix for Evaluating SLID-Compliant Playground Surface Materials in Southern Ontario.

Material Option	Safety & Injury Prevention	Pollution Prevention & Material Safety	Thermal Comfort	Stormwater Management & Permeability	Initial Cost Efficiency	Durability & Maintenance	Total Weighted Score (/5.0)
Engineered Wood Fiber (EWF)	4.0	5.0	4.0	4.0	5.0	3.0	4.25
Poured-in-Place (PIP) Rubber	5.0	2.0	2.0	1.0	2.0	5.0	2.75
Rubber-Tanbark Hybrid	5.0	3.0	3.0	3.0	3.0	4.0	3.5
Permeable Interlocking Pavers	3.0	5.0	5.0	5.0	2.0	5.0	4.15

7. Conclusion

This review has synthesized multidisciplinary evidence on Sustainable Low Impact Design (SLID) strategies in playground pavement systems, with a focus on their environmental, health, and functional implications. By linking technical literature to municipal planning priorities, the study offers a practical framework for integrating SLID principles into urban play environments across Canada. The analysis identifies several recurring challenges with conventional surfacing materials, including thermal discomfort, pollutant exposure, inadequate permeability, and high maintenance requirements. These issues are particularly pronounced in regions such as Southern Ontario, where rising summer temperatures, aging infrastructure, and stormwater stressors intersect. In response, a context-specific surfacing approach has been proposed for the City of Windsor. This strategy combines permeable interlocking pavers, engineered wood fiber, and vegetative shading to enhance safety, accessibility, and environmental resilience in a unified system.

To support evidence-based decision-making, the study introduces a comparative assessment of key surfacing options based on construction costs, durability, injury prevention, pollution control, and stormwater performance. In addition, a weighted evaluation framework is applied to guide

material selection using a transparent, criteria-driven process. These tools collectively demonstrate that engineered wood fiber and permeable pavers offer the most balanced performance under current environmental and municipal conditions, both independently and when used in combination. The findings reinforce that SLID is not an abstract ideal but a tangible, scalable model for sustainable urban design. By embedding SLID principles into procurement guidelines, site plan approvals, and performance audits, municipalities can deliver safer, more equitable, and climate-adaptive playgrounds. Further validation through pilot projects and real-world data collection will strengthen the model and expand its applicability. As communities across Canada navigate climate uncertainty and public health concerns, SLID offers a timely and actionable path toward more restorative and inclusive public spaces.

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