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From Assessment to Innovation: Multi-Criteria Evaluation of Alternative Pavement Methods as a Prelude to Developing Asphalt Substitutes in Oman

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ABSTRACT

Asphalt remains the dominant pavement material in Oman, the wider Gulf region, and much of the world. Despite its long-standing prevalence, asphalt pavements present persistent challenges: volatile prices linked to oil markets, costly and frequent maintenance, and serious environmental impacts, particularly greenhouse gas emissions and waste generation. This article is derived from the author's MSc dissertation completed at Glasgow Caledonian University (2017) in partial fulfilment of the requirements for the degree of Master of Science in Construction Management. Between 2015 and 2017, the study investigated alternative pavement methods and developed a systematic framework for evaluating their suitability in the Omani context. A multi-criteria decision-making (MCDM) tool was formulated by integrating insights from an extensive literature review, international case studies, and a questionnaire survey of Omani decision-makers and engineers. Thirteen criteria were applied, including construction cost, maintenance, life-cycle performance, availability of raw materials, environmental impact, recyclability, safety, and load-bearing capacity. Findings indicated that precast plastic pavement ranked highest among the examined alternatives due to its recyclability, reduced maintenance needs, and resilience under traffic loads. Other methods such as asphalt–plastic hybrids, recycled glass, recycled rubber, and solar panel pavements showed partial advantages yet notable limitations in desert conditions. Overall, the framework provides a replicable decision-support tool while underscoring the urgent need to investigate non-bituminous, locally adapted pavement materials that can reduce petroleum dependence and better address Oman's climatic and resource constraints.

INTRODUCTION

Road infrastructure is widely recognized as a backbone of socio-economic development. In Oman, as in much of the Gulf region, rapid urbanization, population growth, and diversification of economic activities over the past four decades have placed extraordinary pressure on the transport sector. The country has invested heavily in road networks to improve connectivity, support industrial growth, and meet the mobility demands of its expanding population (Curtis, 1995). Asphalt has been the almost exclusive material for road pavements, reflecting its global dominance and the historical reliance on petroleum-based construction products (Sonnenberg, 2000).

However, the sustainability of asphalt has come under increasing scrutiny. Production relies on petroleum distillation, which exposes national economies to oil price fluctuations while simultaneously contributing to greenhouse gas emissions and volatile organic compounds (Nemeth *et al.,* 2010). In Oman, recurrent maintenance requirements for asphalt roads further strain public budgets. Harsh desert conditions high temperatures, ultraviolet radiation, and occasional heavy rainfall accelerate pavement deterioration, causing cracks, rutting, and potholes that necessitate expensive interventions (Burningham & Stankevich, 2005). Over time, the combined effects of cost volatility, environmental degradation, and performance limitations have created a compelling case for exploring more sustainable alternatives.

Aim and Objectives

This study, carried out between 2015 and 2017 as part of a Master's degree in Construction Management, aimed to develop a systematic framework for evaluating alternative pavement methods in Oman. Specifically, the research sought to design and test a multi-criteria decision-making (MCDM) tool to assist policymakers and engineers in selecting the most suitable method based on economic, technical, environmental, and social factors. The objectives included:

- Reviewing global experiences with alternative pavement methods.
- Identifying evaluation criteria relevant to Oman's environment.
- Conducting case studies of selected methods.
- Administering a questionnaire survey to gauge local expert perspectives.
- Developing and applying an MCDM tool to rank alternatives.
- Drawing conclusions and providing recommendations for policymakers.

Scope of Research

The scope was delimited to Oman's road sector but

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considered lessons from international applications. The alternatives analyzed included precast plastic pavements, asphalt-plastic hybrids, precast concrete pavements, recycled glass pavements, recycled rubber pavements, and solar panel pavements. Asphalt was also evaluated as a baseline. The focus was not to advocate a single global "best" method but rather to generate context-sensitive rankings that reflected Oman's climatic, economic, and material supply conditions.

Methodological Overview

The methodology adopted a mixed-methods approach. A literature review synthesized global practices and identified 13 evaluation criteria. Case studies of seven pavement types were compiled, analyzing their performance across the selected criteria. A questionnaire survey of Omani engineers and decision-makers was then conducted to capture perceptions of the relative importance of each criterion. The data were analyzed using a Relative Importance Index (RII), and the outcomes informed the weighting of criteria in the MCDM tool. Finally, the tool was used to generate rankings of alternative pavement methods.

Significance of the Study

The research was significant for several reasons. First, it represented one of the earliest systematic attempts in Oman to compare multiple pavement alternatives using a structured, transparent methodology. Second, it highlighted the economic and environmental risks of continued asphalt dependency at a time when sustainability concerns were gaining prominence globally. Third, the research provided policymakers with a practical tool to support evidence-based decision-making. Finally, while the study emphasized available international alternatives, its conclusions also underscored that none fully addressed Oman's unique desert environment thus pointing to the long-term necessity of developing new, locally adapted solutions.

LITERATURE REVIEW

The literature on sustainable pavement materials has expanded considerably in the past two decades, driven by the urgent need to reduce the ecological footprint of transport infrastructure. Traditional asphalt pavements, although dominant worldwide, are increasingly criticized for their negative environmental externalities, economic vulnerability, and limited durability under high traffic and harsh climatic conditions (Agarwal, 2015).

The review in this section focuses on three thematic areas: (1) the conceptual foundations of sustainability, recycling, and multi-criteria decision-making (MCDM) in construction; (2) the challenges associated with asphalt dependency in Oman; and (3) international developments in alternative pavement methods.

Sustainability in Pavement Construction

Sustainability is broadly defined as meeting present needs without compromising the ability of future generations to meet theirs (Brundtland Commission, 1987). Within the construction sector, sustainability encompasses environmental stewardship, economic efficiency, and social responsibility. For pavements, this means reducing life-cycle costs, minimizing environmental impacts, and ensuring safety and resilience over extended lifespans (Lafarge Holcim Foundation, 2015). Recent scholarship emphasizes that sustainable pavement systems must balance four interrelated aspects: (i) reduced energy consumption in material production and construction, (ii) use of recyclable or renewable materials, (iii) minimized emissions and pollution, and (iv) durability to decrease maintenance interventions (Federal Highway Administration, 2014). Research further indicates that sustainability is not solely an environmental concept; it also concerns user comfort, urban quality, and the alignment of infrastructure with long-term planning frameworks (Prezzi *et al.,* 2011).

In Oman, sustainability has been identified as a policy priority through Oman Vision 2040, which emphasizes circular economy principles and the efficient use of resources. However, the translation of these principles into road construction practices remains limited, underscoring the gap between strategic aspirations and practical implementation (Abidin & Powmya, 2014).

Recycling of Materials in Road Engineering

Recycling has become a cornerstone of sustainable construction. Approximately 60% of municipal solid waste can potentially be recycled, including plastics, glass, rubber, and metals (Recycling Guide UK, 2017). In the road sector, recycled materials are used either as substitutes for aggregates or as modifiers for binders. Examples include recycled plastic incorporated into asphalt mixtures, recycled glass ("glasphalt"), rubberized asphalt, and reclaimed asphalt pavement (RAP). Case studies from India demonstrate the potential of recycled plastics to improve road durability, enhance binding properties, and reduce maintenance costs (Kumar & Gaikwad, 2004; Rajasekaran *et al.*, 2013). Similarly, recycled tire rubber has been successfully used as an additive to enhance asphalt performance in the United States since the 1960s, with proven benefits in durability and life-cycle cost reduction (Shu & Huang, 2013). Nevertheless, recycling is not without challenges. Concerns remain regarding the consistency of recycled materials, contamination risks, and uncertainties about long-term performance. These factors highlight the need for robust evaluation frameworks that weigh the trade-offs between economic, environmental, and technical factors.

Multi-Criteria Decision-Making (MCDM) in Construction

Infrastructure decisions often involve conflicting objectives: minimizing costs, maximizing durability, reducing environmental harm, and ensuring social acceptance. Multi-criteria decision-making (MCDM) tools provide a structured approach to navigating these trade-offs (Buchert *et al.,* 2015).

Several MCDM methods are relevant to construction:

• Analytic Hierarchy Process (AHP): Decomposes complex decisions into hierarchies of criteria, allowing pairwise comparisons (Saaty, 2008).

• Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS): Ranks alternatives by their distance from an ideal solution (Hwang & Yoon, 1981).

• Best-Worst Method (BWM): Requires decision-makers to identify the most and least important criteria, simplifying weight assignment (Rezaei, 2015).

• Evidential Reasoning: Integrates qualitative and quantitative evidence, particularly under uncertainty (Wang *et al.,* 2006).

Applications in civil engineering include ranking bridge rehabilitation strategies (Abu Dabous *et al.,* 2008), highway management alternatives (Selih *et al.,* 2008), and building system selection (Balali *et al.,* 2010). The advantage of MCDM is its flexibility: it accommodates both objective data (e.g., cost, durability) and subjective preferences (e.g., environmental priorities). This dual capacity makes it particularly suitable for contexts like Oman, where sustainability criteria are rising in importance but economic constraints remain dominant.

The Asphalt Challenge in Oman

Asphalt remains the sole pavement material in Oman, mirroring global trends. Yet its drawbacks are especially pronounced in the Gulf's desert environment. Three main challenges stand out:

1. Oil Price Volatility: Asphalt costs are directly linked to crude oil markets. While oil prices dropped by 70% in 2014, asphalt prices fell by only 5.4%, breaking historical correlations and imposing financial strain on governments (Sullivan & Moss, 2016).

2. Environmental Impacts: Asphalt production and application release carcinogenic volatile organic compounds (Nemeth *et al.,* 2010). Runoff from asphalt surfaces pollutes watercourses, while mining for aggregates depletes natural resources (World Highways, 2015).

3. Maintenance Burden: Rutting, cracking, and fatigue failures are common in Oman's roads, exacerbated by temperature extremes and high traffic volumes. Maintenance consumes significant portions of infrastructure budgets (Burningham & Stankevich, 2005).

These factors collectively justify the exploration of alternative pavements tailored to Oman's conditions.

Alternative Pavement Methods in Global Practice

Precast Plastic Pavements

Precast plastic pavements are modular road systems manufactured from recycled plastics. Their advantages include lightweight prefabrication, rapid installation, and high recyclability. Studies in the Netherlands and India report lower costs and longer service lives compared to asphalt (Wong *et al.,* 2012; PlasticRoad.eu, 2017). Challenges include potential slipperiness when wet and higher upfront transportation costs for prefabricated units (Sompura & Avetisyan, 2017).

Asphalt-Plastic Hybrids

This method integrates shredded plastic into asphalt mixes, enhancing binding capacity and resistance to temperature fluctuations. India has pioneered this approach, reporting increased strength, reduced maintenance, and cost savings of up to USD 1,400 per kilometre (Swami & Salokhe, 2012). However, concerns about chemical emissions during plastic processing remain (Nikolov, 2017).

Solar Roadways

Solar pavement systems replace asphalt with engineered solar panels capable of generating renewable energy. Pilot projects in France and the Netherlands demonstrated technical feasibility (Anthony, 2014), but prohibitive costs up to USD 4.3 million per kilometre limit widespread adoption (Anthony, 2016).

Precast Concrete Pavements

Precast concrete panels are fabricated offsite under controlled conditions, enabling rapid installation and reduced weather-related disruptions. Widely used in airport runways and seaports, they offer durability and high load-bearing capacity (Tayabji *et al.*, 2013). However, they require careful alignment and grouting, and initial costs are high (Kohler *et al.,* 2007).

Recycled Glass Pavements

"Glasphalt" incorporates crushed glass into asphalt mixes, typically up to 15% by weight. Benefits include waste reduction and cost savings, but higher percentages risk stripping of binder and reduced pavement durability (FHWA, 2014).

Recycled Rubber Pavements

Rubberized asphalt, produced from scrap tires, has been used since the 1960s in the US. It improves flexibility, reduces noise, and extends service life (Shu & Huang, 2013). However, variability in recycled rubber quality and higher initial costs pose adoption barriers (Presti, 2013). For arid regions such as Oman, the scarcity of water, abundance of desert sand, and high thermal gradients create conditions distinct from the temperate climates where most recycled pavement methods have been tested. Existing literature provides little guidance on how these methods would perform under desert-specific stresses, underscoring the need for context-specific evaluation frameworks (Disfani *et al.,* 2009; Ruuska & Hakkinen, 2014). While numerous studies evaluated individual alternatives, few provided an integrated framework to compare multiple options simultaneously. This gap was particularly evident in the Gulf region, where policymakers lacked systematic tools to weigh economic, technical, and environmental trade-offs. The present study sought to bridge this gap through the application of a multi-criteria decision-making (MCDM) tool, contextualized for Oman.

Evaluation Criteria for Pavement Alternatives

The foundation of any MCDM application lies in the careful identification and weighting of evaluation criteria. In the context of pavement alternatives, the literature reveals a broad spectrum of factors ranging from purely technical to socio-environmental. Drawing from global studies (Haas *et al.,* 2009; Wang *et al.,* 2010; Selih *et al.,* 2008) and adapting them to Oman's context, this research adopted thirteen criteria:

1. Construction Cost: Initial expenditure required for material procurement, transport, and installation. Cost-effectiveness is often decisive for policymakers in developing economies (Burningham & Stankevich, 2005).
2. Maintenance Cost: Pavements with high maintenance demands reduce long-term efficiency. Lifecycle cost analysis highlights maintenance as a critical determinant (Huang, 2004).
3. Lifetime (Serviceability): Expected service life under normal traffic and climatic conditions. For example, rubberized asphalt has shown extended durability compared to conventional asphalt (Shu & Huang, 2013).
4. Material Availability: Dependence on imported versus locally sourced materials. Oman's abundant desert sand and limited industrial by-products create unique supply constraints (Disfani *et al.,* 2009).
5. Environmental Impact: Emissions, energy consumption, and ecological footprint during production and use. The FHWA (2014) emphasizes life-cycle assessment as a benchmark for sustainability.
6. Recyclability: Capacity of materials to be reused or reprocessed at end-of-life, a cornerstone of circular economy principles (Ghisellini & Ulgiati, 2020).
7. Safety: Pavement skid resistance, drainage performance, and user safety. Certain recycled plastics may present surface friction issues under wet conditions (Sompura & Avetisyan, 2017).
8. Load-Bearing Capacity: Structural performance under traffic loads, particularly relevant for freight corridors. Precast concrete pavements have demonstrated superior load tolerance (Tayabji *et al.,* 2013).
9. Climatic Resistance: Adaptability to Oman's desert environment, including high thermal gradients and UV exposure (Al-Abri *et al.,* 2013).
10. Implementation Feasibility: Complexity of construction methods, skill requirements, and compatibility with local industry practices (Arulrajah *et al.,* 2017).
11. Social Acceptance: Public perception, community impact, and willingness to adopt non-traditional methods. Studies show cultural acceptance can significantly influence recycling uptake (Hossain, 2015).
12. Policy and Regulatory Compatibility: Alignment with existing standards and regulations. For instance, the EU's Waste Framework Directive has driven C&D recycling (Visintin *et al.,* 2020).
13. Innovation Potential: Capacity for further improvement, integration with smart technologies, and scalability. Solar pavements exemplify high innovation but limited feasibility due to cost (Anthony, 2016).

These criteria provided a comprehensive basis for structured evaluation, allowing the MCDM tool to reflect the multifaceted nature of pavement selection.

Comparable Studies Worldwide

Numerous international studies echo the approach of combining multiple criteria to evaluate pavement alternatives. For example:

- India: Rajasekaran *et al.* (2013) used performance indicators to assess plastic-modified pavements, demonstrating improvements in rut resistance and cost savings.
- Europe: Pavlů *et al.* (2019) highlighted recycling of construction and demolition waste as a viable aggregate substitute, though limited by quality variability.
- United States: Abu Dabous *et al.* (2008) employed MCDM methods to prioritize bridge maintenance strategies, showcasing the tool's applicability across infrastructure types.
- Australia: Arulrajah *et al.* (2017) investigated recycled plastics and demolition waste blends, concluding that they were suitable for subbase applications.
- Middle East: Few studies exist. Aldahdooh *et al.* (2018) explored plastic waste aggregates in concrete in Oman, confirming technical feasibility but underscoring the lack of specifications and policies.

Collectively, these studies demonstrate a global trend towards sustainability and recycling, yet also highlight the fragmented nature of evaluations. Most assess single alternatives or focus narrowly on technical feasibility, with limited integration of economic and social factors.

Synthesis and Research Gap

From the literature, three key insights emerge:

1. Dominance of Asphalt: Despite decades of research, asphalt remains globally dominant, even though alternatives have demonstrated clear benefits. This reflects entrenched practices and economic inertia.
2. Promising Alternatives with Caveats: Methods such as plastic-modified pavements, precast concrete, and recycled rubber show significant potential but also context-dependent drawbacks particularly in hot, arid climates.
3. Need for Integrated Frameworks: Most studies lack a holistic evaluation across technical, economic, environmental, and social dimensions. Moreover, little research specifically addresses the Gulf region's desert conditions.

The present study addresses this gap by applying an MCDM framework that combines international experiences, local expert input, and criteria tailored to Oman's environment. This approach not only benchmarks existing alternatives but also provides a structured foundation for future innovations.

The literature review establishes that while sustainable alternatives to asphalt exist, they must be assessed holistically against multiple, and often conflicting, criteria. Existing research lacks context-specific evaluations for Oman and similar desert regions. Building on this foundation, the next section presents the methodology adopted between 2015 and 2017 to develop and apply an MCDM framework, integrating literature findings, case studies, and expert surveys.

MATERIALS AND METHODS

Research Design

The study adopted a mixed-methods research design, combining qualitative and quantitative techniques to evaluate alternative pavement methods within the Omani context. The approach was structured around three sequential phases: (i) a comprehensive literature review to identify global practices and potential alternatives; (ii) the development of international case studies to assess performance evidence of selected methods; and (iii) a questionnaire survey administered to Omani engineers and decision-makers to capture expert judgments regarding evaluation criteria. These components were subsequently integrated into a multi-criteria decision-making (MCDM) framework, enabling systematic ranking of pavement alternatives.

This design was chosen for two primary reasons. First, the complexity of pavement selection where economic, environmental, and technical factors interact necessitates a multi-dimensional evaluation tool (Haas *et al.,* 2009). Second, the scarcity of local empirical trials on alternative pavements in Oman required reliance on international case evidence complemented by expert insights, rather than experimental field studies.

Selection of Alternatives

Based on the literature review, six alternative pavement methods were selected for evaluation alongside conventional asphalt. The alternatives were chosen to represent a range of material types, technologies, and global practices:

1. Precast plastic pavements: modular systems fabricated from recycled plastics (PlasticRoad.eu, 2017).
2. Asphalt-plastic hybrids: conventional asphalt modified with shredded plastic additives (Rajasekaran *et al.,* 2013).
3. Precast concrete pavements: prefabricated panels designed for rapid installation and heavy load applications (Tayabji *et al.,* 2013).
4. Recycled glass pavements (glasphalt): asphalt mixtures incorporating crushed glass (FHWA, 2014).
5. Recycled rubber pavements: asphalt modified with crumb rubber from waste tires (Shu & Huang, 2013).
6. Solar panel pavements: energy-generating photovoltaic road systems (Anthony, 2016).
7. Conventional asphalt: retained as a baseline for comparative purposes.

These alternatives were selected not as exhaustive options, but as representative of the diversity of approaches available globally. Their inclusion allowed testing of the MCDM tool's ability to capture both traditional and innovative strategies.

Evaluation Criteria

As established in the literature review, thirteen criteria were defined for evaluation (see Section 2.7). These criteria reflected the multidimensional considerations required for pavement selection, covering cost, technical performance, environmental sustainability, and social dimensions.

The criteria were structured into four categories:

- Economic: Construction cost, maintenance cost, material availability.
- Technical: Lifetime, load-bearing capacity, climatic resistance, implementation feasibility, safety.
- Environmental: Environmental impact, recyclability.
- Social/Institutional: Social acceptance, policy/regulatory compatibility, innovation potential.

This categorization ensured a balanced assessment across domains, aligning with best practices in infrastructure evaluation (Selih *et al.,* 2008; Wang *et al.,* 2010).

Case Study Development

To operationalize the evaluation criteria, seven international case studies were compiled one for each pavement type. Data sources included peer-reviewed journals, technical reports, and official project documentation. Each case study summarized:

- Pavement type and location.
- Contextual factors (climate, traffic conditions, policy framework).
- Reported performance across the thirteen criteria.
- Observed challenges and limitations.

For example, the PlasticRoad project in the Netherlands (2017) provided detailed data on recyclability and installation speed but also highlighted cost barriers. Similarly, Indian trials of plastic-modified asphalt demonstrated cost-effectiveness and durability but raised questions regarding emissions during plastic melting (Kumar & Gaikwad, 2004). These case studies served two functions: first, they provided empirical evidence for each alternative; second, they offered contextual contrasts that informed the weighting of criteria for Oman.

Questionnaire Survey

Sampling and Participants

To capture local expert perspectives, a structured questionnaire survey was conducted among Omani engineers, planners, and policymakers between 2016 and 2017. A total of 71 questionnaires were distributed, targeting professionals in municipalities, the Ministry of Housing and Urban Planning, and transport-related consultancies. Of these, 50 valid responses were received, yielding a response rate of approximately 70%.

Participants represented a mix of senior engineers, mid-level practitioners, and academic researchers, ensuring diversity of perspectives. Their professional experience ranged from 5 to over 25 years, with most directly engaged in road construction, maintenance, or planning.

Questionnaire Structure

The questionnaire was divided into three sections:

1. Demographic Information: Professional role, years of experience, organizational affiliation.
2. Criteria Weighting: Respondents rated the importance of each of the 13 criteria on a five-point Likert scale (1 = least important, 5 = most important).
3. Alternative Evaluation: Respondents were asked to provide qualitative assessments of the applicability of each pavement method in Oman, based on their knowledge and experience.

Data Analysis

Responses were analyzed using the Relative Importance Index (RII) method, widely applied in construction research to rank factors based on stakeholder perceptions (Doloi *et al.,* 2012). The RII for each criterion was calculated as:

RII = (Sum of weights assigned by respondents) divided by (Highest possible weight × Total number of respondents).

Where:

- WWW = weight assigned by each respondent (1–5),
- AAA = highest possible weight (5),
- NNN = total number of respondents.

The resulting RII values (0–1) indicated the relative importance of each criterion. Criteria with higher RII values were given greater weight in the MCDM framework.

Multi-Criteria Decision-Making Framework

The MCDM framework was developed to integrate data from the case studies and survey results. The process followed four steps:

1. Criteria Weighting: Derived from RII analysis of survey responses.
2. Alternative Scoring: Each pavement alternative was scored against the thirteen criteria based on case study evidence, normalized to a 0–1 scale.
3. Weighted Aggregation: Weighted scores were calculated by multiplying criterion weights by alternative scores.
4. Ranking: Alternatives were ranked according to their total weighted scores, providing a structured hierarchy of suitability for Oman.

This approach allowed combining objective international evidence with subjective local expert judgments, producing results that were both globally informed and locally grounded (Buchert *et al.,* 2015).

Ethical Considerations

All survey participants were informed of the study's academic purpose and assured anonymity of their responses. Participation was voluntary, and no personal identifiers were collected. Ethical approval was obtained from the university supervising the Master's program, in compliance with standard academic research practices.

Limitations of Methodology

Several limitations were acknowledged:

- Dependence on Secondary Data: Case studies were based on published reports, which may not fully reflect local applicability.
- Sample Size: Although 50 responses provided robust input, broader stakeholder inclusion (e.g., contractors, road users) could strengthen results.
- Absence of Field Trials: Practical testing of alternatives in Oman was beyond the scope of the Master's research, though identified as a necessary next step.

Despite these limitations, the methodology provided a systematic and replicable framework, offering valuable insights for policymakers in Oman and other arid regions.

The methodological approach described above generated a structured dataset combining literature evidence, case study analysis, and expert survey input. The next section presents the results of this process, including the relative importance of evaluation criteria, the performance of each pavement alternative, and the final MCDM rankings.

RESULTS & DISCUSSION

Importance of Evaluation Criteria (Survey Results)

Analysis of the questionnaire survey responses using the Relative Importance Index (RII) revealed clear priorities among Omani experts regarding the criteria for selecting pavement methods. Table 1 summarizes the mean ratings, RII values, and resulting rankings.

Table 1: Relative Importance Index (RII) of evaluation criteria (n = 50)

Criterion	Mean Score	RII	Rank
Construction Cost	4.75	0.95	1
Maintenance Cost	4.60	0.92	2
Lifetime (Serviceability)	4.50	0.90	3
Material Availability	4.40	0.88	4
Environmental Impact	4.20	0.84	5
Load-Bearing Capacity	4.10	0.82	6
Recyclability	3.95	0.79	7

Safety	3.85	0.77	8
Climatic Resistance	3.80	0.76	9
Implementation Feasibility	3.70	0.74	10
Policy/Regulatory Fit	3.50	0.70	11
Social Acceptance	3.30	0.66	12
Innovation Potential	3.20	0.64	13

The survey indicates that economic factors dominated decision-making, with construction and maintenance cost ranked highest. This finding is consistent with Burningham and Stankevich (2005), who highlighted financial considerations as the primary driver of pavement choices in developing economies. Technical durability (lifetime) and material availability followed closely, while environmental and recyclability factors gained moderate attention. Social, regulatory, and innovation-related criteria were ranked lowest, reflecting limited public awareness and institutional readiness for unconventional solutions in Oman.

Performance of Alternatives (Case Study Evidence)
Each pavement alternative was evaluated against the 13 criteria based on international case study evidence. Scores were normalized between 0 and 1 to facilitate comparison.

Precast Plastic Pavements
- Strengths: High recyclability (1.0), reduced maintenance (0.9), modular replacement reduces lifecycle costs (0.85).
- Weaknesses: High upfront construction cost (0.6), concerns about skid resistance in wet climates (0.7).
- Suitability for Oman: Promising due to recyclability and maintenance reduction, though cost barriers remain.

Asphalt-Plastic Hybrids
- Strengths: Lower construction cost (0.8), better binding, reduced rutting (0.85).
- Weaknesses: Emissions during plastic processing (0.6), moderate recyclability (0.7).
- Suitability for Oman: Feasible as a transitional option, leveraging global experience (Rajasekaran *et al.,* 2013).

Precast Concrete Pavements
- Strengths: High load-bearing capacity (0.95), long service life (>30 years in case studies).
- Weaknesses: Very high construction cost (0.5), need for skilled installation (0.6).
- Suitability for Oman: Useful for ports, airports, and heavy freight corridors, but limited by cost.

Recycled Glass Pavements (Glasphalt)
- Strengths: Waste reduction (0.85), comparable cost to asphalt when glass waste is abundant.
- Weaknesses: Binder stripping beyond 15% content (0.6), reduced lifetime (0.65).
- Suitability for Oman: Limited due to modest glass waste availability and harsh climate.

Recycled Rubber Pavements
- Strengths: Flexibility in hot climates (0.85), reduced noise pollution (0.9).
- Weaknesses: High variability in rubber quality (0.6), relatively higher cost (0.7).
- Suitability for Oman: Attractive for highways exposed to heavy traffic, though supply chain limits adoption.

Solar Pavements
- Strengths: Renewable energy generation (1.0), innovation potential (0.95).
- Weaknesses: Very high cost (0.3), low durability under traffic loads (0.5).
- Suitability for Oman: Currently unrealistic due to costs; potential long-term innovation avenue.

Conventional Asphalt
- Strengths: Low construction cost (0.9), regulatory acceptance (1.0), ease of implementation (0.95).
- Weaknesses: Poor environmental performance (0.3), high maintenance costs (0.5), limited recyclability (0.4).
- Suitability for Oman: Remains dominant but unsustainable long-term.

MCDM Ranking of Alternatives
The weighted scores (survey RII × case study scores) generated a final ranking of pavement alternatives for Oman.

Table 2: Final MCDM ranking of alternatives

Alternative	Weighted Score	Rank
Precast Plastic Pavement	0.82	1
Asphalt-Plastic Hybrid	0.79	2
Recycled Rubber Pavement	0.74	3
Precast Concrete Pavement	0.70	4
Conventional Asphalt	0.65	5
Recycled Glass Pavement	0.62	6
Solar Pavement	0.55	7

The results show that precast plastic pavements emerged as the most suitable alternative, followed closely by asphalt-plastic hybrids. Both scored well in terms of recyclability, maintenance, and cost-effectiveness relative to long-term benefits. Conventional asphalt was ranked fifth, ahead of only glass and solar pavements, confirming its weak sustainability profile despite ease of implementation.

Economic Priorities Dominate

Survey findings confirm that decision-making in Oman remains cost-driven, consistent with global patterns in developing economies (Burningham & Stankevich, 2005). While environmental considerations were recognized, they did not outweigh immediate budgetary concerns. This aligns with Abu Dabous *et al.* (2008), who noted similar cost primacy in infrastructure MCDM applications.

Feasibility of Plastic-Based Solutions

Plastic-based alternatives (precast and hybrid) ranked highest. This reflects international experiences showing plastics' ability to enhance durability, reduce maintenance, and support recycling (Rajasekaran *et al.,* 2013). Their adoption could simultaneously address Oman's waste management challenges and road performance issues.

Limited Applicability of Glass and Solar Pavements

Recycled glass and solar pavements scored lowest, primarily due to contextual misfit. Oman lacks large volumes of glass waste, and solar pavements remain prohibitively expensive. While innovative, these options currently offer little practicality.

Context of Arid Environments

The results underscore that many global alternatives are tested in temperate climates. Their performance under Oman's extreme thermal cycles and sand-laden environment remains uncertain. For example, rubberized asphalt shows promise in hot climates but lacks desert-specific trials (Shu & Huang, 2013). This context gap represents a clear direction for future research.

Policy and Institutional Gaps

Low ranking of "policy/regulatory fit" and "social acceptance" suggests that institutional frameworks and public awareness lag behind technical possibilities. Similar findings were observed in Oman's construction waste recycling sector, where absence of regulation limited uptake (Aldahdooh *et al.,* 2018).

The results demonstrate that while alternatives exist with strong potential particularly plastic-based pavements none fully resolves Oman's long-term sustainability challenges. The MCDM framework provided a structured evaluation, but findings also highlight research and policy gaps that must be addressed before alternatives can be mainstreamed.

CONCLUSION

This study, undertaken between 2015 and 2017 as part of a Master's degree in Construction Management, evaluated sustainable alternatives to asphalt pavements in Oman. Using a multi-criteria decision-making (MCDM) framework based on literature, case studies, and expert surveys, thirteen economic, technical, environmental, and social criteria were applied to rank six alternatives against conventional asphalt. Plastic-based pavements (precast and hybrid) achieved the highest rankings due to durability, recyclability, and reduced maintenance, while rubberized asphalt and precast concrete showed moderate potential. Recycled glass and solar pavements proved less viable in Oman's context, and conventional asphalt ranked only mid-level despite its entrenched use. The findings underscore both the economic dominance in decision-making and the urgent need for non-bituminous, locally adapted solutions suited to desert conditions.

Nearly a decade on, these conclusions remain relevant: the search for sustainable pavement substitutes is not optional but essential.

Recommendations

- Institutionalize MCDM: Integrate multi-criteria evaluation tools in road planning to balance cost, performance, and sustainability.
- Pilot Plastic-Based Pavements: Test precast and hybrid systems under Omani conditions through small-scale projects.
- Strengthen Regulatory Frameworks: Update specifications and introduce incentives to enable adoption of recycled and alternative materials.
- Invest in Local Research: Conduct laboratory and field trials using indigenous materials to validate international findings.
- Develop Non-Bituminous Materials: Prioritize innovation of entirely new substitutes beyond petroleum dependency, tailored to Oman's desert climate and resource base.
- Promote Awareness: Engage stakeholders and the public to build acceptance of innovative methods.
- Encourage Regional Collaboration: Coordinate with Gulf countries to share knowledge, pilot projects, and harmonized standards.

Future Outlook

The results of this study highlighted not only the potential of existing alternatives but also their limitations in Oman's context. The overarching conclusion is that while incremental improvements can be achieved through recycled and hybrid methods, none of the tested options fully resolves the sustainability challenge. This opens the door for future research and innovation aimed at developing materials specifically tailored to Oman's environment and resource base. The study thus stands as both a benchmark and a springboard. It benchmarked the performance of global alternatives against local priorities, and it created a springboard for subsequent efforts to move beyond imported solutions toward context-sensitive innovations. As Oman pursues its Vision 2040 objectives, the road sector must align with national sustainability goals. This requires not only adopting proven global practices but also nurturing local ingenuity to create pavement solutions that are economical, environmentally sound, and resilient under desert conditions. In particular, there is an urgent need to investigate non-bituminous pavement materials that can move beyond petroleum dependency while being tailored to Oman's desert environment.

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