IMPACT OF USE OF SUSTAINABLE MATERIALS ON ROAD CONSTRUCTION

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Abstract: The growing emphasis on sustainability has highlighted the importance of eco-friendly and cost-effective approaches, particularly in road construction, where the use of renewable, earth-derived materials is encouraged. However, some professionals still believe that using sustainable materials may adversely affect project outcomes in terms of cost and quality. In line with that, this study aims to investigate the impact of incorporating sustainable materials on road construction projects. The study uses a qualitative approach with semi-structured interviews, utilising the Delphi technique with two rounds of expert interviews to gather empirical data, which is then analysed using content analysis. Findings reveal that construction and demolition waste, recycled tyres, waste plastics, fly ash, recycled glass, polyethylene terephthalate plastic bottles, asphalt shingles, cement kiln dust, colliery spoils, recycled asphalt, and warm mix asphalt are the commonly used sustainable materials in road construction. Furthermore, the study identified eleven positive impacts and sixteen negative impacts of using sustainable materials in road construction, which were later classified under each commonly used sustainable material. Overall, this study contributes to advancing knowledge in sustainable road construction, guiding future research and decision-making in the field, and encouraging the use of sustainable materials to promote environmental responsibility.

Keywords: Negative Impacts; Positive Impacts; Road Construction; Sustainability; Sustainable Materials.

1. Introduction

Sustainability has become an important concern, driving the need for environmentally responsible and economically viable solutions in various sectors, including road construction (Puodziukas, Svarpliene and Braga, 2016; Riekstins et al., 2024). Sustainable materials are the materials that, through their environmental, social, and economic impacts, promote responsible building practices by minimising embodied carbon, reducing waste production, and enhancing indoor environmental quality and building longevity (Arroyo, Tommelein and Ballard, 2016). Thus, the integration of sustainable materials into road construction projects has become a significant step towards minimising environmental impact, conserving natural resources, and promoting long-lasting infrastructure (Khural et al., 2022; Petkovic et al., 2004). Furthermore, the usage of sustainable materials plays a pivotal role as it reduces the reliance on virgin resources and lowers greenhouse gas emissions through more efficient production processes (Voulvoulis, 2022). Accordingly, in road construction, sustainable materials such as construction waste, recycled asphalt, colliery spoils, bio-based binders, and geosynthetics are being used (Segui et al., 2023).

Generally, sustainable materials help mitigate climate change by reducing emissions during their production and use, while also promoting resource conservation through sourcing from renewable or recycled materials, thereby decreasing the demand for new raw materials (Asutosh and Nawari, 2017; Arroyo, Tommelein and Ballard, 2016). Improved air and water quality are additional advantages, leading to greener environments for communities located near construction sites (Lichtfouse, Schwarzbauer and Robert, 2011). Furthermore, the use of sustainable materials can drive economic growth by creating jobs within the renewable materials sector and promoting the development of new industries (Sulich and Sołoducho-Pelc, 2021). However, the adoption of sustainable materials is not without challenges. High initial costs and concerns about their performance compared to conventional materials can hinder their widespread use (Thorpe and Zhuge, 2010). Additionally, the quality and availability of recycled materials can vary, posing further obstacles to their implementation. Addressing these challenges requires a concerted effort to fully understand the benefits and limitations of sustainable materials (Ljungberg, 2007). Thus, research and development in this field are crucial to advancing sustainable construction practices and ensuring that road construction projects align with broader sustainability goals.

Extensive research has been conducted on sustainable materials, highlighting their potential benefits and applications in various construction contexts. In terms of road construction projects, research by Zhao, Goulias and Peterson (2021), Petkovic et al. (2004), Segui et al. (2023), Bastidas-Martínez, Reyes-Lizcano and Rondón-Quintana (2022), and Bamigboye et al. (2021) have provided valuable insights into the role and challenges of using sustainable materials. These studies have explored various sustainable materials' potential environmental, economic, and performance impacts. Furthermore, some studies have identified influencing factors, implementation methods and relationships with the circular economy in road construction, such as those by Maelissa, Rohman and Wiguna (2023), Almokdad and Zentar (2023), and Luo et al. (2021). Despite the substantial body of literature on sustainable materials, there remains a notable gap in understanding the

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comprehensive impact of their use, specifically within road construction projects. Most research predominantly focuses on the positive impacts of using sustainable materials, with limited attention given to their negative impacts. Additionally, studies often discuss the overall impacts of sustainable materials without focusing on the specific impacts associated with each type of material used. This gap includes the need for more empirical data on both positive and negative impacts of using sustainable materials in road construction, material-wise.

Therefore, this paper aims to investigate the impact of incorporating sustainable materials on road construction projects with the objectives namely, investigating the commonly used sustainable materials in road construction projects, evaluating the positive impact of each sustainable material on road construction and evaluating the negative impact of each sustainable material on road construction. The paper comprises an introduction to the research, a literature review, research methodology, research findings, discussion and finally, the conclusions from the study.

2. Literature Review

Sustainable construction aims to reduce environmental impacts, improve community well-being, and ensure structural integrity, playing a significant role in promoting economic growth (Rajayogan, 2021). Under sustainable construction, road construction involves sustainable practices, including the use of recyclable, renewable and innovative materials which can reduce energy consumption, waste, and pollution, and offer promising solutions (Hussin, Rahman and Memon, 2013; Henriques and Vaz-Serra, 2017). In line with that, this chapter provides a comprehensive overview of the existing literature, focusing on the materials used and the impact of the use of sustainable materials in road construction projects.

2.1. SUSTAINABLE MATERIALS

Sustainable materials are defined as materials that maintain the functional benefits of conventional products while demonstrating environmentally responsible performance, including concepts such as recycling and reusing to minimise waste and resource consumption (Henriques and Vaz-Serra, 2017). Furthermore, they can be defined as resources derived from renewable sources that balance economic, environmental, and social considerations, thus contributing to long-term community well-being (Bontempi et al., 2021; Flórez et al., 2013).

2.2. USAGE OF SUSTAINABLE MATERIALS IN ROAD CONSTRUCTION

Sustainable materials, ranging from recycled resources to industrial by-products are used in road construction, which provide innovative solutions that reduce environmental impact and enhance road output (Podborochynski et al., 2012). Recycled tyres, glass, waste plastics, and ash are commonly utilised due to their availability and ability to replace significant amounts of traditional virgin materials. Other materials such as Polyethylene terephthalate (PET) plastic bottles, steel slag, and construction and demolition (C&D) wastes contribute to environmental benefits by reducing waste and greenhouse gas emissions (Asutosh and Nawari, 2017). Furthermore, incineration bottom ash, blast furnace slag, Aluminium dross, mine tailings, asphalt shingles, cement kiln dust, and colliery spoils are especially used in road construction (Suescum-Morales et al., 2019; Ojuri, Adavi and Oluwatuyi, 2017). Furthermore, using bio-oils for asphalt binders and fly ash as concrete aggregate reflects the ongoing efforts to find innovative solutions in sustainable construction (Bamigboye et al., 2021). Petkovic et al. (2004) stated that, these materials help reduce waste, carbon footprint and greenhouse gas emissions, and improve road performance, making them crucial for sustainable transportation networks.

2.3. POSITIVE IMPACTS OF USING SUSTAINABLE MATERIALS IN CONSTRUCTION

Most of the sustainable materials contribute to reducing the environmental footprint and enhancing the durability of road networks (Petkovic et al., 2004). Materials such as recycled tyres, glass, waste plastics, and ash are commonly used due to their availability and ability to replace significant portions of traditional materials (Asutosh and Nawari, 2017). Furthermore, recycled tyres, when used as an additive in asphalt mixtures, enhance the physical properties of the bitumen binder, leading to better road performance (Akshay et al., 2019). Similarly, recycled glass and waste plastics improve concrete performance and pavement design quality, respectively, offering benefits like better binding, stability, and resistance to water (Raut et al., 2016; Asutosh and Nawari, 2017). Moreover, Luo et al. (2021) stated that repurposing waste materials, recycling by-products, and using innovative resources make road construction more eco-friendly and cost-effective. On the other hand, the use of steel slag in pavement subgrades enhances the strength and density of the pavement while resisting stress and strain (Behiry, 2013). Construction and demolition wastes, with their rough surface texture and higher water absorption, enhance aggregate-mortar adhesion in concrete, making them suitable for road bases in low to medium-traffic pavements (Delongui et al., 2018). At the same time, the use of bio-oil rejuvenates aged asphalt, which then improves low-temperature crack resistance and fatigue resistance of asphalt binders, thus enhancing road longevity (Zhang et al., 2021). Additionally, the use of mine tailings and cement kiln dust as stabilising agents improves the engineering properties of soils and enhances the load-bearing capacity of unpaved roads (Ojuri, Adavi and Oluwatuyi, 2017). Sojobi, Nwobodo and Aladegboye (2016) identified that the use of PET-coated aggregates and PET-modified bitumen in bituminous asphaltic concrete (BAC) surface courses increase Marshall Stability (MS) values by up to 4425 and 4320 kg, respectively, indicating improved stability. Furthermore, Zhang, Gu and Zhang (2019) highlighted that C&D waste materials used in high-way embankments offer less cumulated permanent strain than conventional clay, indicating higher rutting resistance, and structural support. While there are numerous positive impacts of using sustainable materials in construction, there are also negative impacts.

2.4. NEGATIVE IMPACTS OF USING SUSTAINABLE MATERIALS IN CONSTRUCTION

Even though waste rubber tyres provide various positive impacts in terms of improved resilient modulus and resistance to cracking under loading, there is a concern regarding the rigidity of the mixtures (Arulrajah et al., 2019). There, the addition of styrene-butadiene-styrene (SBS) polymer reduces the rigidity, potentially leading to increased susceptibility to permanent deformation under repeated traffic loading. On the other hand, the use of PET-coated aggregates in bituminous asphaltic concrete (BAC) can lead to an increase in the voids in mineral aggregate (VMA) by up to 141.03% (Sojobi, Nwobodo and Aladegboye, 2016). This increase in VMA can potentially impact the durability and performance of the pavement mixture. According to Ismail and Al-Hashmi (2009), the use of glass waste in pavement materials can raise concerns about the potential for alkali-silica reactivity (ASR), which can lead to premature deterioration of the concrete or asphalt mixture. Furthermore, they stated that the use of waste materials may lead to soil and water pollution, and environmental degradation which pose health hazards. In terms of the use of C&D waste, they can also lead to a decrease in resilient modulus with increasing C&D waste content (Perera et al., 2019). This reduction in resilient modulus can negatively impact the structural capacity of the pavement layers. Moreover, the use of fly ash in pavement materials can also lead to a decrease in early-age strength development, which can impact construction schedules and potentially compromise the long-term durability of the pavement structure (Cheriaf, Rocha and Péra, 1999). The limitations of using construction and demolition waste alone, without mixing it with other materials, also pose significant challenges. The inconsistent quality of these materials and potential contamination, further complicate their use, as noted by Sharma (2019).

3. Methodology

This research utilised a qualitative research approach to examine the impact of sustainable materials on road construction projects. Qualitative methods capture the detailed perspectives and comprehensive insights of experts and allow for a deeper exploration related to the study (Trafimow, 2013). Therefore, in this study, a Delphi method was central to the approach, selected for its effectiveness in gathering comprehensive insights from experts in the field (Ng, 2018). The Delphi technique is extensively used across various fields, particularly in contexts where expert knowledge is crucial for decision-making or gaining deeper insights into a specific phenomenon (Brady, 2015). Well-known for its flexibility and affordability, the Delphi method emphasises obtaining feedback from a purposive sample of experts rather than seeking generalisability (Brady, 2015; Ng, 2018). Thus, in this study, two Delphi rounds were chosen as at least two are necessary to draw a proper conclusion, with consensus typically achieved by the second round in construction and management studies (Xia & Chan, 2012). Across two rounds, experts were asked to provide anonymous feedback, which was then summarised and circulated to encourage consensus on the positive and negative impacts of each identified sustainable material (Ng, 2018). Semi-structured interviews were conducted over two rounds, each lasting between 60 to 75 minutes and held face-to-face. Data collected underwent manual content analysis to systematically examine data with a deep focus on the contextual meaning of data, free from procedural distractions (Linneberg and Korsgaard, 2021). Under that, directed content analysis was chosen, as it allows for the conceptual extension of theoretical frameworks when existing research is incomplete, allowing the transferability of established conceptualisations from one context to another (Humble, 2009).

3.1. EXPERT SELECTION

Purposive sampling, which enables researchers to gather data representing maximum variation within the sample, is commonly utilised in qualitative research to include a diverse range of perspectives (Saunders, 2012). Moreover, this method is frequently utilised in qualitative research to identify individuals capable of offering comprehensive insights (Etikan, 2016). Therefore, in this study, purposive sampling was utilised to identify the experts, establishing clear selection criteria to identify individuals with the requisite compulsory and additional qualifications. Furthermore, with respect to this research, the listed 'Compulsory Qualifications' guaranteed candidates have the necessary experience within the disciplines, while 'Additional Qualifications' helped enhance their knowledge in relevant areas. When selecting experts, it was mandatory for candidates to have a minimum of either 'eight years of experience in the construction industry' or 'five years in academia or research'. Additionally, they must possess at least three years of specialised experience in areas such as road construction or sustainable practices. These criteria made sure that the selected experts had direct and practical experience with sustainable materials in road construction. The criteria for selecting experts, participation of experts in two rounds and the objectives of Delphi rounds are provided in Table 1.

Table 1, Experts selection criteria and Delphi rounds

Code (Experts)	Criteria							
	Compulsory Qualification			Additional qualifications (Satisfy at least four)				
	Satisfy at least one		At least three years of Industry/ Research experience in following areas	Bachelor's Degree in the built environment	Professional qualification in the built environment	Master's degree in built environment	Knowledge and interest in road construction	Interest in knowing about sustainable materials
	At least 8 years working experience	At least 5 years working experience						

	Construction Industry	Academia/ Research	Road Construction	Sustainable Practice					
R1	✓	X	✓	✓	✓	✓	✓	✓	✓
R2	✓	X	✓	✓	✓	✓	✓	✓	✓
R3	✓	X	✓	✓	✓	✓	✓	✓	✓
R4	x	✓	✓	✓	✓	✓	✓	✓	✓
R5	x	✓	✓	✓	✓	✓	✓	✓	✓
R6	✓	X	✓	✓	✓	✓	✓	x	✓
R7	✓	X	✓	✓	✓	✓	✓	x	✓
R8	✓	X	✓	✓	✓	✓	✓	✓	✓
R9	✓	X	✓	✓	✓	✓	✓	x	✓
R10	✓	X	✓	✓	✓	✓	✓	✓	✓
R11	✓	X	✓	✓	✓	✓	✓	✓	✓
R12	✓	X	✓	✓	✓	✓	✓	x	✓
R13	✓	X	✓	✓	✓	✓	✓	x	✓
R14	✓	X	✓	✓	✓	✓	✓	✓	✓
R15	✓	X	✓	✓	✓	✓	✓	✓	✓
R16	✓	X	✓	✓	✓	✓	✓	✓	✓
R17	✓	X	✓	✓	✓	✓	✓	x	✓

Delphi Rounds			
Round	**Phase**	**Code**	**Objective**
01	I	R1PI	Identify commonly used sustainable materials in road construction projects
	II	R1PII	Identify the impacts of sustainable materials on road construction
02	I	R2PI	Identify the positive impact of each sustainable material on road construction
	II	R2PII	Identify the negative impact of each sustainable material on road construction

4. Findings

Considering the identified themes in the literature review, a directed content analysis was conducted. A total of seventeen (17) and twelve (12) experts in rounds one and two respectively participated in the interviews, and the empirical findings of two rounds of Delphi interviews are discussed in this section.

4.1. COMMONLY USED SUSTAINABLE MATERIALS IN ROAD CONSTRUCTION PROJECTS (R1P1)

Initially, fifteen (15) sustainable materials used in road construction were identified from the literature review. In addition to these, six (6) new materials used in road construction were identified during Round 1 Phase 1 of the Delphi interviews. The newly identified materials are given in bold letters in Table 1 below. During the first phase of the first round, the experts accepted eight (8) materials from the literature as commonly used sustainable materials in road construction. Additionally, experts modified "Ash" into "Fly Ash," as demonstrated in italic letters. According to Alkaissy et al. (2021), to ensure rigour in Delphi studies, a 75% response rate should be there. Thus, the threshold was set at 75%, with only responses meeting or exceeding this rate accepted for further evaluation. Therefore, ten (10) materials were omitted due to a lack of 75% consensus among experts. The commonly used sustainable materials used in road construction are presented in Table 2 within the highlighted cells.

Table 2, Commonly used sustainable materials used in road construction

No	Sustainable Materials	Total	Percentage %
1	Construction and demolition waste (CDW)	17/17	100
2	Recycled Tyres	17/17	100
3	Waste Plastics	16/17	94.12
4	*Fly Ash*	15/17	88.24
5	Recycled Glass	15/17	88.24
6	Polyethylene terephthalate (PET) plastic bottles	15/17	88.24
7	Asphalt shingles	15/17	88.24
8	Cement kiln dust	14/17	82.35
9	Colliery spoils	14/17	82.35
10	**Recycled Asphalt**	14/17	82.35
11	**Warm Mix Asphalt (WMA)**	13/17	76.47
12	Bio-oils	12/17	70.59
13	Steel slag	12/17	70.59
14	Aluminium dross	11/17	64.71
15	Mine tailings	11/17	64.71
16	Incineration bottom ash	10/17	58.82
17	Blast furnace slag	10/17	58.82
18	**Recycled Concrete Aggregate (RCA)**	10/17	58.82

19	**Granulated blast furnace slag (GBFS)**	9/17	52.94
20	**Sand**	9/17	52.94
21	**Quarry dust**	9/17	52.94

RCA, GBFS, sand, quarry dust, recycled asphalt, and WMA were identified as sustainable materials used in road construction by the experts, which were not identified in the literature review. Furthermore, experts identified that construction and demolition waste, recycled tyres, waste plastics, fly ash, recycled glass, PET plastic bottles, asphalt shingles, cement kiln dust, colliery spoils, recycled asphalt, and warm mix asphalt as the commonly used sustainable materials in road construction.

4.2. POSITIVE IMPACTS OF USE OF EACH SUSTAINABLE MATERIAL ON ROAD CONSTRUCTION (R1PI, R1PII, R2PII)

At the end of the literature review, twenty-one (21) impacts of the use of sustainable materials in road construction were identified. Subsequently, through expert interviews in Round 1 Phase II, experts were requested to validate the literature findings and identify new impacts of the use of sustainable materials in road construction. Thirteen (13) new impacts of the use of sustainable materials were identified in addition to the literature findings during Delphi round 1 phase II. In Round 2 Phase 01, experts were provided with eleven (11) commonly used sustainable materials used in road construction (identified in R1P1) and the thirty-four (34) impacts of the use of sustainable materials in road construction (identified in R1PII) and experts were requested to identify positive impacts on road construction by each commonly used sustainable material. In there, impacts which received a 75% or more response rate were identified as suitable positive impacts. The experts' responses are illustrated in Table 3. The newly identified positive impacts by interviewees on road construction are highlighted in bold in Table 3 below.

Table 3, Positive and negative impacts of each commonly used sustainable material on road construction.

Sustainable Materials	Positive Impacts (Response rate ≥ 75%)	Negative Impacts (Response rate ≥ 75%)
(In **Bold** – Newly identified impacts based on the comments of the experts)		
Construction and demolition waste (CDW)	• **Reduce the traditional road material scarcity.** • **Resources can be preserved for the future.** • **The production and use of sustainable materials creates jobs in industries related to recycling, manufacturing, and installation.** • **Long-Term Cost Savings**	• Inconsistent quality and limited regulation pose challenges to sustainable practices. • Municipal solid waste incineration bottom ash in road construction may pose a risk due to the release of salt and heavy metals. • **Require high skilled experts to work in construction projects which deals with sustainable materials.** • **Higher maintenance cost**
Recycled Tyres	• **Reduce the traditional road material scarcity.** • Waste Reduction • **Resources can be preserved for the future.** • **Enhance the public image of infrastructure projects, leading to increased community support and satisfaction.**	• Rubberised asphalt processing at higher temperatures can incur higher costs. • **Higher maintenance cost** • Leading to soil and water pollution if not managed properly.
Waste Plastics	• **Reduce the traditional road material scarcity.** • Waste Reduction • **The production and use of sustainable materials can create jobs in industries related to recycling, manufacturing, and installation.** • **Resources can be preserved for the future.**	• Plastic waste may reduce the stiffness and fatigue properties of asphalt mixes. • Leading to soil and water pollution if not managed properly. • Lead to environmental degradation and pose health hazards.
Fly Ash	• **Reduce the traditional road material scarcity.** • **Long-term cost savings** • Carbon Footprint Reduction	• **Additional time required for construction pro-cess such as curing time.** • Municipal solid waste incineration bottom ash in road construction may pose a risk due to the release of salt and heavy metals.
Recycled Glass	• **Reduce the traditional road material scarcity.** • Carbon Footprint Reduction • **Long-term cost savings** • Lower greenhouse gas emissions compared to conventional materials	• Inconsistent quality and limited regulation pose challenges to sustainable practices. • **Require high skilled experts to work in construction projects which deals with sustainable materials.** • Require careful selection of optimal glass content for maximising compressive and flexural strengths.
PET Plastic Bottles	• **Reduce the traditional road material scarcity.** • Carbon Footprint Reduction • Waste Reduction	• Plastic waste may reduce the stiffness and fatigue properties of asphalt mixes.
Asphalt Shingles	• **Reduce the traditional road material scarcity.** • Long-term cost savings • **Resources can be preserved for the future.**	• Shingle pieces may become loose, requiring additional maintenance efforts and potentially affecting road safety. • **Higher maintenance cost**

Sustainable Materials	Positive Impacts (Response rate ≥75%)	Negative Impacts (Response rate ≥75%)
(In **Bold** – Newly identified impacts based on the comments of the experts)		
Cement Kiln Dust	• **Reduce the traditional road material scarcity.** • Waste Reduction • **Resources can be preserved for the future.**	• Can lead to environmental degradation and pose health hazards. • Land and water contamination, as well as habitat fragmentation, are associated challenges. • Municipal solid waste incineration bottom ash in road construction may pose a risk due to the release of salt and heavy metals.
Colliery Spoils	• **Reduce the traditional road material scarcity.** • Carbon Footprint Reduction	• **Constructability challenges** • Inconsistent quality and limited regulation pose challenges to sustainable practices. • Challenges related to the optimal application, environmental effects, and durability in various weather conditions.
Recycled Asphalt	• **Long-term cost savings** • **Improved Resilience and Performance** • **Decreases the construction cost.** • **Preserve resources for the future.** • **Increase the design life of road construction**	• Challenges in bitumen modification include poor stability and low aging resistance.
Warm Mix Asphalt (WMA)	• **Long-term cost savings** • **Improved Resilience and Performance** • **Increase the design life of road construction.** • Lower greenhouse gas emissions compared to conventional materials	• Challenges related to the optimal application, environmental effects, and durability in various weather conditions. • Challenges in bitumen modification include poor stability and low aging resistance. • **Additional time required for construction process such as curing time**

R2, R3, R5, R8, and R11 highlighted that using CDW reduces demand for virgin materials like aggregates and asphalt, thereby easing pressure on natural resources such as aggregates, sand, and gravel. This practice helps preserve these resources for future generations by recycling and reusing waste materials, thus reducing the need to extract new resources from the environment. Moreover, R10 and R12 highlighted that the production and use of sustainable materials create employment opportunities in the recycling, manufacturing, and construction sectors, contributing to economic growth, locally. Recycled asphalt, WMA and fly ash also contribute to long-term cost savings in road construction and maintenance due to lower production costs and extended infrastructure lifespan, minimising the frequency of repairs and replacements as per R1, R4 and R6. Additionally, it was highlighted that incorporating sustainable materials enhances public perception by demonstrating efforts towards environmental protection and resource conservation. Furthermore, most of the experts highlighted that most of the listed sustainable materials reduce traditional road material scarcity and result in long-term cost savings.

4.3. NEGATIVE IMPACTS OF USE OF EACH SUSTAINABLE MATERIAL ON ROAD CONSTRUCTION (R1PI, R1PII, R2PII)

As discussed in section 4.1., thirty-four (34) impacts consisting of twenty-one (21) from literature and thirteen (13) new by interviewees were identified at the end of Delphi Round 1 Phase II. In Round 2 Phase II, experts were provided with eleven (11) commonly used sustainable materials used in road construction (identified in R1P1) and the thirty-four (34) impacts of the use of sustainable materials in road construction (identified in R1PII), and the experts were requested to identify the negative impacts on road construction by each commonly used sustainable material. Impacts which received a 75% or more response rate were identified as suitable negative impacts. The experts' responses are illustrated in above Table 3. There, the newly identified negative impacts on road construction are given in bold letters. Experts said that some sustainable materials, such as recycled tyres and asphalt shingles, might require more frequent maintenance or experience higher wear and tear compared to traditional materials. R2, R5, R7, R9 and R12 noted that "Construction demolition wastes vary in quality and composition, which can impact road consistency." R5 and R6 added that certain sustainable materials, such as fly ash and cement kiln dust, may require additional curing time or extended construction processes compared to conventional materials. This can potentially impact project timelines and schedules. Furthermore, it was identified that the use of sustainable materials as modifiers for bitumen in asphalt mixtures can sometimes lead to challenges in terms of poor stability and low resistance to ageing. R1, R4, R7, R8 and R13 stated that for the usage of recycled glass highly skilled experts are required.

5. Discussion

The use of sustainable materials in road construction, as highlighted in the literature, involves a range of recycled resources and industrial byproducts which provide innovative solutions to reduce environmental impact and enhance road performance (Podborochynski et al., 2012). The findings of the study confirm this by listing various materials such as construction and demolition waste, recycled tyres, waste plastics, fly ash, and seven (7) others, which are commonly utilised in road construction projects. Overall, the literature and Table 3 findings align in demonstrating that sustainable materials are instrumental in reducing environmental impacts and extending the lifespan of road infrastructure, while also highlighting the need for further innovation and regulation to address associated challenges.

5.1. POSITIVE IMPACTS OF USING SUSTAINABLE MATERIALS ON ROAD CONSTRUCTION

Supporting the findings from the literature, experts emphasised that sustainable materials minimise environmental impact while enhancing road performance as highlighted in Table 3 (Petkovic et al., 2004). The literature emphasised that materials such as recycled tyres and waste plastics play a crucial role in reducing waste and improving material properties (Luo et al., 2021). Additionally, literature indicated that using materials such as construction waste, recycled glass, and fly ash results in long-term cost savings and reduced carbon footprints (Asutosh and Nawari, 2017). Experts corroborated these findings, emphasising substantial economic benefits and job creation within the recycling, manufacturing, and installation industries. Altogether experts identified nine (09) other positive impacts material-wise, apart from what was identified in the literature review, such as the reduction of scarcity of traditional materials and the preservation of resources for the future, and improved resilience. In line with that, they highlighted how using recycled asphalt, WMA, and fly ash contributes to long-term cost savings and improved public perception of environmental responsibility in infrastructure projects. Moreover, the experts highlighted that recycled asphalt and WMA enhance road stability and performance, thereby extending road design life. These suggest that the literature may understate some indirect benefits, such as public support and enhanced project funding potential due to improved environmental credentials.

5.2. NEGATIVE IMPACTS OF USING SUSTAINABLE MATERIALS ON ROAD CONSTRUCTION

Aligning with literature findings, experts have identified three (03) other negative impacts, material-wise, other than what was found in the literature review, as detailed in Table 3. The literature highlighted that recycled materials such as construction and demolition waste and recycled glass often exhibit inconsistent quality due to inadequate regulation, complicating their reliable use in construction projects (Sharma, 2019). Experts agreed with this, stressing the necessity for improved regulatory standards to guarantee material quality. In line with that, experts emphasised that highly skilled workmen are required to work on construction projects which deal with recycled glass. On the other hand, the literature highlighted environmental risks associated with materials such as waste plastics and cement kiln dust, which can contribute to soil and water pollution if improperly managed (Ismail and Al-Hashmi, 2009). Experts highlighted these concerns, emphasising the potential for environmental degradation and health hazards. Moreover, the literature highlighted that sustainable materials frequently incur higher costs compared to traditional materials (Sojobi, Nwobodo and Aladegboye, 2016). Experts supported this finding, noting elevated maintenance expenses associated with materials such as rubberised asphalt and asphalt shingles, as well as increased labour costs for skilled personnel required in such projects. Furthermore, experts pointed out that sustainable materials such as fly ash and WMA may require extended curing times, complicating schedules. Furthermore, in addition to what was identified in the literature review, experts stated that there could be constructability issues with sustainable materials such as colliery spoils.

6. Conclusions

The integration of sustainable materials into road construction projects demonstrates significant potential for environmental, economic, and social benefits. Construction and demolition waste, recycled tyres, waste plastics, fly ash, recycled glass, PET plastic bottles, asphalt shingles, cement kiln dust, colliery spoils, recycled asphalt, and warm mix asphalt were identified to be the commonly used sustainable materials in road construction. Furthermore, the study classified the identified impacts under each commonly used sustainable material, with eleven (11) positive impacts and sixteen (16) negative impacts. The findings indicate that, while sustainable materials offer numerous advantages, it is also important to consider the potential challenges they may pose. Thus, the study recommends considering both positive and negative when selecting sustainable materials and encourages their use in road construction to enhance environmental, economic, and social benefits, thereby supporting sustainable practices and societal well-being.

6.1. IMPACT ON THE INDUSTRY, RESEARCH, AND SOCIETY

There is a dearth of literature discussing the empirical data on both positive and negative impacts of using sustainable materials in road construction, especially material-wise. Thus, this study contributes to research by enhancing the theoretical understanding of both the positive and negative impacts of using sustainable materials in road construction, classified by material. The integration of sustainable materials in road construction represents a significant advancement for the construction industry, by paving the way for future innovations in sustainable infrastructure development. Furthermore, this study will contribute to society by securing social well-being by adaption of sustainable materials in road construction, managing material consumption and leading towards a better environment.

6.2. FURTHER STUDIES

Further research can focus on evaluating the impact of using sustainable materials on the durability and cost of road construction projects.

6.3. LIMITATIONS OF THE STUDIES

Since this study utilised a qualitative approach, it cannot be generalised but serves as a benchmark for future studies in this area. The limited number of experts prompted the establishment of specific criteria to identify suitable participants.

7. References

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