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Building Smarter Roads: Sustainable Infrastructure with Ready-Made Asphalt Blocks

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Abstract: - The construction industry is one of the significant contributors to Greenhouse gas emissions; hence, it has become under pressure to adopt sustainable practices and reduce the environment. At this point, readymade asphalt blocks are an alternative to traditional asphalt mixtures to enhance the efficiency and sustainability of the road construction project. Considering this fact, this study investigated the potential of readymade asphalt blocks for supporting sustainable infrastructure by which environmental and regulatory forms can be achieved to align with the vision of 2030 and COP28 sustainability goals. This work involved semi-structured interviews with industry experts to investigate trends in sustainable construction. The findings suggest that these blocks can expedite construction timelines and reduce carbon footprints. However, challenges like high cost, logistical requirements, and skilled labour demand can hinder the white spray direction of these sustainable materials for road construction; for that, a road map has been provided to influence readymade blocks that align with sustainable development goals.

Keywords: Smarter Roads, Construction Industry, Asphalt Blocks, Sustainability, SDG

I. INTRODUCTION

The research highlights the pressing necessity for sustainable projects in the face of escalating weather changes, especially regarding the development and preservation of street infrastructure. Traditional techniques of asphalt manufacturing are identified as surprisingly weak-in-depth and environmentally unfavorable. Everyday actions can lead to carbon emissions, worsening global warming and climate change. As cities grow and evolve, we often face issues like heavy traffic and crowded streets. We need to find environmentally friendly ways to address these problems. In this context, ready-made asphalt blocks are a possible solution. These prefabricated additives are created using recycled materials, including antique pavement fragments, allowing for more green strength intake while decreasing waste. The unique design of these asphalt blocks brings several advantages. They can help lower construction costs, reduce emissions from machinery during installation, and are generally more durable than traditional asphalt. This increased durability means they require less maintenance, which helps create more sustainable roads. This study aims to explore how these specially designed asphalt blocks can be used to build more advanced and eco-friendly roads, particularly in the context of the UAE and its specific environmental conditions. The examination will explore numerous vital questions, such as how modern-day equipped-made asphalt blocks fluctuate from conventional asphalt, their performance characteristics, and the significant challenges and opportunities related to their implementation. It will also observe any legal implications of using those revolutionary materials in sustainable infrastructure.

The study's goals include examining the materials used in ready-made asphalt blocks. We also compare these modern asphalt blocks to traditional asphalt, focusing on their environmental impact and performance. The study aims to find out what makes adopting new practices challenging, examine the chances of using them, and examine the current laws that affect how they can be implemented. Finally, it will highlight important areas where we can reduce carbon footprints to create more sustainable and environmentally friendly roads. This research highlights how ready-made asphalt blocks could be a game-changer in the construction industry. This work addresses environmental problems linked to traditional road construction methods. It points out that conventional road building often uses much energy and can harm the environment, contributing to climate change. In contrast, a newer solution is prefabricated asphalt blocks made from recycled materials. These blocks are more eco-friendly because they use less energy, create less waste, lower construction costs, and are more durable—plus, they help reduce harmful emissions during construction.

The research examines how these ready-made asphalt blocks can help create more innovative and sustainable roads, especially in cities. It covers critical topics such as how these new blocks differ from traditional asphalt, how

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well they perform, their challenges and opportunities, and any legal issues that may arise. The research also seeks ways to reduce carbon footprints in road construction.

II. Literature Review

Sustainability in creation and infrastructure improvement is an important element that minimizes environmental effects while enhancing price effectiveness. The re-viewed literature exhibits more than a few modern methods and underscores the es-essential importance of integrating sustainable practices into present-day production strategies. The shift toward bloodless mix asphalt (CMA) is a sturdy advancement in sustainable substances. Al-Hashimi et al. [1] reveal that CMA not only serves as a cost-effective opportunity but also notably cuts emissions and energy intake. Elnaml et al. [8] showcase high-density polyethene (HDPE) plastic waste in asphalt mixtures, tackling giant recycling-demanding situations and drastically enhancing asphalt's overall performance. This initiative is a massive step towards embracing a circular monetary gadget. Furthermore, Calandra et al. [4] illustrate how nanoparticles can raise the properties of bitumen. Their findings highlight the essential stability between universal overall performance improvements and financial feasibility, especially in massive-scale infrastructure tasks.

Incorporating waste materials into construction practices offers compelling benefits for sustainability. Bamigboye et al. [3] provide a comprehensive analysis demonstrating how utilizing waste materials can effectively mitigate reliance on new re-sources while addressing landfill issues. Expanding on this, Hossiney et al. [10] pre-sent innovative techniques for creating geopolymer concrete from recycled asphalt pavement aggregates. This represents significant progress toward resource-efficient urban development that aligns with broad sustainability objectives. Prefabrication is a transformative approach to selling sustainability within the creation industry. Chippagiri et al. [5] outlined decreased material waste, extended construction timelines, and more desirable strength performance.

Using polymers in 3D printing opens up possibilities for producing sustainable building components with exceptional precision, extending far beyond the healthcare sector [2]. Addressing ethical and methodological questions becomes paramount as we integrate new technologies into construction and infrastructure. De Paoli [6] elaborates on the challenges of using inductive thematic analysis with large language models, while Husband [9] emphasizes the critical importance of ethical data collection practices. The workplace centre development study in Kharkiv [7] illustrates the necessity of tailoring sustainability strategies to precise regional contexts, incorporating local socio-monetary and climatic elements. Achieving sustainability is a complex but critical project that requires robust stability of environmental, monetary, and social concerns. The effective integration of waste materials epitomizes the standards of a round financial system. It allows us to lessen resource extraction and waste technology whilst driving closer to positive worldwide sustainability effects.

Koch [11] delves into "sustainability spectacles," particularly in oil-rich nations transitioning to greener economies. It emphasizes that the programs serve two purposes: addressing environmental concerns and enhancing political and social optics. Similarly, Rodriguez-Ubinas et al. [19] discusses a comparative analysis of inexperienced building codes. The World Green Building Council [27] enhances this perspective by means of highlighting the non-public vicinity's characteristics. The findings collectively underline the significance of integrating sustainability into regulatory frameworks to make certain adaptability to nearby contexts. Liu et al. [13] provides a complete review of street lifecycle carbon dioxide emissions, evaluating current disc while ensuring. Their findings stress the key role of cloth innovations and recycling strategies. Building on this, Liu et al. [12] discussed the evolution of asphalt pavement systems, highlighting improvements in layout and substances that improve durability and sustainability. These studies are complemented by Milad et al. [14], who examine warm and heat mix asphalt technologies from environmental and Morfeldt et al. [15] emphasize electric roads' potential to reduce further emissions associated with electric vehicles (EVs). Their study reveals that coupling EVs with electric roads extends the battery range and reduces overall energy consumption and emissions, addressing critical challenges in EV adoption. Radhakrishnan and Dhurai [16] discuss the devel-opment of sustainable bituminous paver blocks. These blocks reduce resource consumption and waste by incorporating recycled materials. Riekstins et al. [17] examine street pavements incorporating multiple sustainable substances and technology. Their findings highlight the environmental and monetary advantages, such as reduced car-bon emissions and decrease lifecycle fees, at the same time as stressing the significance of carefully choosing materials to optimize performance.

Walubita et al. [22] evaluates rigid, flexible, and perpetual pavements in Texas, finding that flexible pavements provide lower emissions all through production and protection phases. This highlights the importance of context-specific picks in sustain-able pavement design. Zadeh and Garay-Rondero [24] attention on modern supply-chain measures' function in lowering smart towns' carbon footprint. They discover key strategies, which include

integrating renewable electricity assets and optimizing logistics, to beautify city sustainability while addressing the challenges of population growth and resource constraints. Singh et al. [20] introduce previous multilayered pavement systems designed for all weather conditions. These systems promote stormwater management, reduce urban heat islands, and lower lifecycle impacts, and advancing sustainable urban infrastructure. The performance of recycled and bio-based materials, studied by Wang et al. [25] and Zahoor et al. [23], remains uncertain over extended lifespans, necessitating further research and standardization. Rodri-guez-Ubinas et al. [18] underlines the need for robust policies to enforce green building standards, while Tarsi et al. [21] calls for better regulations to streamline the use of reclaimed materials. Stanaszek-Tomal [26] explores the concept of anti-smog buildings, which incorporate materials and technologies that absorb airborne pollutants. Such innovations improve air quality and contribute to public health, making them an essential component of sustainable urban design.

An integrative technique to sustainable infrastructure and urban planning is vital for addressing the interconnected challenges of weather alternate, useful resource control, and social fairness. The studies reviewed right here endorse for adopting lifecycle tests, multi-fabric solutions, and facts-pushed technology to decorate sustainability results. Combining advanced materials like RAP and bio-oil with progressive technologies consisting of electric roads and smart metropolis making plans can create resilient, low-carbon city systems. However, reaching this vision calls for collaboration amongst policymakers, enterprise stakeholders, and researchers to triumph over technical and monetary barriers.

In precis, literature expectantly reaffirms the multifaceted nature of sustainability challenges in construction and underscores the good-sized position of technological improvements and creative materials in efficaciously addressing these troubles. This assertive technique paves the way for persistent studies and advancement in sustainable construction practices. It underscores the multifaceted nature of sustainability in infrastructure and concrete improvement. From material improvements to coverage frameworks, those studies spotlight the development and challenges in reaching sustainable systems.

III. METHODOLOGY

This study considers the observations and insights collected from interviews and literature reviews, which offered not only a general understanding regarding the implications of using readymade asphalt blocks in road constructions but also the real-time, insightful data collected from multiple sources allowed us to build patterns about the sustainability associated with this innovation. This inductive approach also seems appropriate because this research has gained new ideas and emerging themes without being constrained by pre-existing theories [6]. This study follows qualitative and exploratory research processes to gather insights into using readymade asphalt blocks in building smart roads without carbon emissions. It has proven essential to understanding the multifaceted nature of sustainable road construction. Qualitative methods in this study, such as interviews and thematic analysis of this research environment and the regulatory dimension of innovation, were employed.

The study was conducted using a combination of research strategy of expert interviews and literature review to explore the research question comprehensively. In addition, the data collected from interviews covered the benefits, feasibility, and challenges offered by this approach. The literature review, on the other hand, was conducted to gather background information. Data would be sourced from a range of sources, such as case studies on the industry, interviews with relevant experts in sustainable infrastructures, and simulations in construction to analyse the performance of the application of precast asphalt blocks in road construction in the realm of Vision 2030 for the UAE as well as other global COP28 environmental ends. In this study, four Project Managers and Contractors in Infrastructure Development have been targeted to cover technical, environmental, economic, regulatory, and practical aspects regarding the readymade asphalt blocks used in sustainable road infrastructure.

A. Data Analysis

This research would apply secondary qualitative methods, depending upon existing literature, reports, and case studies for its data. The thematic analysis would then be applied to the views, considering the kinds of patterns and themes found in the re-viewed sources. This approach can point out the recurring ideas, challenges, and opportunities associated with the readymade asphalt blocks used in road construction. It will use secondary qualitative data and apply thematic analysis (Table 1 & 2) to find out what information is crucial about materials, sustainability, implementation hindrances, and legal frameworks that shape the constructions of sustainable road infra-structure. The CO2 emission in asphalt pavement construction is presented (Figure 1).

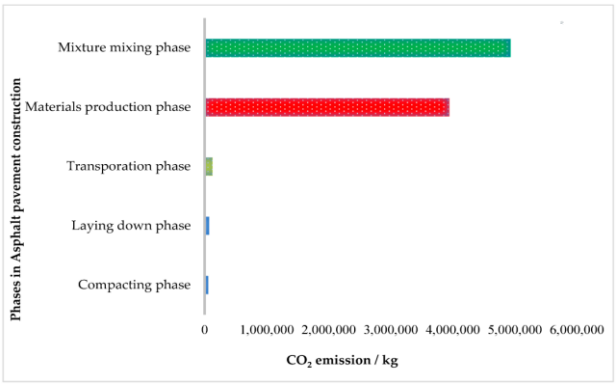

Fig. 1. CO2 emission in asphalt pavement construction

The alternative ready-to-use asphalt materials entail some practical implementa-tion-related challenges, as could be debated from the literature. Environmental and economic challenges are associated with adopting hot and warm-mix asphalt technol-ogies. Although these technologies are reportedly more sustainable than the tradition-al ones, they have very high initial costs and a weak availability of expertise in the technical community, which are considered significant barriers to their use. It also shows that in the "mixture mixing phase" of asphalt pavement construction, most CO2 is emitted, as seen in the figure above.

Table I. Thematic analysis – Interview extracts

Interview extracts	Code generation
Participant 1:	
"ready-made asphalt blocks significantly enhance the construction process, and reduce carbon emissions and on-site waste. The most significant benefits are making sustainable infrastructure, fast repairs and less use of energy. "	Reduce waste, enhance effectiveness, reduce emissions, minimize waste, fast repairs, and less energy use.
"Based on my experience, these ready-made asphalt blocks will contribute significantly to UAE Vision 2030 and COP 28 by minimising generated emissions and energy consumption with the future goal of UAE."	Reduces emissions, and energy consumption, and supports UAE's sustainability goals.
Participant 2:	
"In my opinion, currently there is rapid application of bio-based binders such as lignin in asphalt. It has become a trend in sustainable construction. However, this innovation decreases the dependency on petroleum products and improves sustainability."	Bio-based binder (lignin), reduces petroleum dependency, and sustainability.
"Adoption and use of ready-made asphalt blocks often face higher costs, logistical issues and a skilled workforce. Government support and stabilised regulations are required to address these barriers."	High costs, logistical issues, need for skilled workforce, regulatory support.
Participant 3:	
"Current sustainable road construction often uses rubberised and reclaimed asphalt from recycled tires and biophilic designs. In my opinion, the most effective reason is to reduce environmental effects and enhance the quality and durability of roads."	Rubberized asphalt, and reclaimed asphalt, reduce environmental effects, and durability.
"I have experienced that application of ready-made asphalt blocks offers a simple installation process, reduction of on-site disruptions and less energy use. These characteristics and benefits are closely aligned with the current trends of eco-friendly practices."	Simple installation, reduced on-site disruptions, and energy savings.
Participant 4:	
"Based on my recent experience, the most severe challenge is the demand for a skilled workforce with modular stimulation techniques. Government can provide training programs on the use of ready-made asphalt and it could bridge the gap and improve sustainable road practices."	Skilled workforce demand, training needed, government support through training.
"Yes, I am confident about the potential application of ready-made asphalt to achieve the 2030 vision in the UAE by minimising environmental impact, inducing green jobs and directly supporting climate goals set forth in COP28."	Minimizes environmental impact, supports green jobs, and climate goals.

TABLE II. Thematic analysis – Code generation

Code generation	Theme generation
Bio-based binder (lignin), reduces petroleum dependency, sustainability, Rubberized asphalt, and reclaimed asphalt, reduces environmental effects, durability	Eco-Friendly Innovations and Materials in Sustainable Road Construction
Reduce waste, enhance effectiveness, reduce emissions, minimize waste, fast repairs, less energy use, Simple installation, reduced on-site disruptions, and energy savings.	Sustainability Benefits of Ready-Made Asphalt Blocks
High costs, logistical issues, need for a skilled workforce, regulatory support, training needed, and government support through training.	Challenges and Need for Government Support in Implementation
Reduces emissions, and energy consumption, supports UAE's sustainability goals, minimizes environmental impact, supports green jobs, and climate goals.	Alignment of Ready-Made Asphalt Blocks with UAE's Sustainability Goals

B. Theme 1: Eco-Friendly Innovations and Materials in Sustainable Road Construction

Eco-friendly innovations and sustainable materials considerably influence the shift in road construction, thereby highly influencing environmental sustainability. Ready-made asphalt blocks are a new shift from the norms since they can be assembled with pre-manufactured components and are more accessible to transport and install with less energy and waste on-site [2]. Primarily recycled materials are incorporated, thus minimizing raw resources and reducing overall degradation of the environment. Other advanced, pre-asphalted blocks have binders that harden better and require much less repair, thereby saving resources while having a lesser environmental impact [3].

It is more than just material selection because sustainable construction would also involve the techniques applied, such as minimizing emissions in production and optimizing logistics for transport. This holistic approach to using materials that sustain the environment would reduce carbon footprint and support circular economies through material reapplication within the construction industry [4]. Additionally, ready-made asphalt blocks also promote energy efficiency because quicker installations reduce the use of heavy machinery required in traditional paving methods. The blocks also reduce the dependency on high-temperature asphalt mixing processes, leading to standard greenhouse gas emissions in typical road construction [26]. More-over, ready-made asphalt blocks are an example of an eco-friendly infrastructure development approach that suits the international goals related to sustainability and unique environmental priorities for countries like the UAE, which seek to be the first concerning innovative green construction solutions.

C. Theme 2: Sustainability Benefits of Ready-Made Asphalt Blocks

Ready-made asphalt blocks have significant sustainability advantages over conventional asphalt paving and represent an innovative green infrastructure solution in the broad area of asphalt paving [2]. Their primary benefit is a modular design, which helps increase installation speed and efficiency and reduces energy consumption typical of conventional road construction processes. This modularity also allows individual blocks to be replaced or repaired without requiring extensive resurfacing, reducing material waste and minimizing environmental disruption associated with significant construction works.

As for the carbon footprint of ready-made asphalt blocks typically contains recyclable material and more environmentally friendly binders [8]. Thus, their overall carbon footprint is lower. Since these blocks are produced in controlled environments, the use of resources will also be at an optimal level while minimizing emissions. They are much less energy-intensive and polluting than on-site asphalt mix and paving. Also, the blocks have been durable and resilient to withstand a lot of heavy traffic loads as well as variations in temperature, which prolong the life of road sur-faces by reducing their frequent repair needs, thus conserving resources and the emissions caused by the ongoing maintenance [17]. These benefits fit global sustainability goals well because of their energy efficiency, resource conservation, and waste reduction. Additionally, these support local sustainability initiatives, such as the UAE's focus on reducing its carbon footprint and setting up sustainable infrastructures [13]. Therefore, ready-to-apply asphalt blocks are innovative and scalable and provide an ecological sustainability/functional performance solution that makes it practical for regions focused on sustainable growth and environmentally responsible construction practices.

D. Theme 3: Challenges and Need for Government Support in Implementation

Although these blocks are promising in terms of sustainability, using prefabricated asphalt blocks is associated with various implementation challenges that rely heavily on government support. The initial cost of adopting these new materials and the new apparatus required for manufacturing and installation determines its widespread use because of its high cost. In addition, being new, having limited experience and data related to long-term performance in each climate raise fear within the industry and limit the adoption of this full-scale technology [14]. A much more significant challenge relates to the regulatory framework, where standards and guidelines for the construction of roads still may need to include modular asphalt blocks. It is here that government intervention becomes very important in revising standards to incorporate 'green' materials, incentives for adoption, pilot projects demonstrating the positive impacts, and public financing and subsidies to offset the higher initial investment and ensure that the private sector does invest in 'green' infrastructure [8]. Government support is critical to overcome these barriers, as it can drive research, facilitate knowledge sharing, and create certification systems with an accompanying confidence-boosting effect on this technology. Thus, government support can actively contribute to making ready-made asphalt blocks a feasible solution for road construction in the long run toward sustainability.

E. Theme 4: Alignment of Ready-Made Asphalt Blocks with UAE's Sustainability Goals

Adopting ready-made asphalt blocks is pertinent to the UAE's sustainability goals, reducing carbon emissions, promoting resource efficiency, and enabling green infra-structure to support long-term environmental resilience. As a leader in sustainable urban development, the UAE has set ambitious targets under initiatives like the UAE Net Zero by 2050 Strategic Initiative - targeting net-zero emissions across sectors, including construction [1]. The ready-made asphalt blocks are helpful towards the realization of the goals since they minimize energy consumption during production, reduce emissions from transportation, and contribute to reducing carbon footprints through their durability and low maintenance requirements [10].

The private sector of the UAE has agreed to reach severe standards of energy efficiency, and new buildings are expected to have a minimum consumption reduced by 40% [27]. This also relates to the overall strategy of reducing the construction sector's ecological impact [11]. To achieve this objective, these blocks are effective since they are designed to incorporate friendly materials that include recycled content synonymous with the circular economy that the UAE longs for. The prefabricated asphalt block helps reduce dependence on fresh raw materials and is recyclable. The wastage that occurs during construction also decreases, thereby cutting down on this objective of the UAE's environmental approach. Satisfying these objectives of sustainability in the UAE relates to the new materials used that are better suited to the local climate needs [18]. This would be related to evolved materials like the Superpave Performance Grade system. The temperature changes that will most affect the performance of asphalt binders are considered in this work to ensure the durability and longevity of the road infrastructure in the abrasive environment of the UAE.

Government and industry stakeholders need to collaborate to create appropriate training programs that focus on installing readymade asphalt blocks. Educational initiatives from the end of industry and government subsidies can be affected to equip engineers and construction workers with the necessary skills. By launching public awareness, Industrial escorts and environmentalists educate the general public, especially stakeholders in the construction industry, regarding the environmental benefits and advantages of using readymade asphalt blocks for constructing roads, which can lead to increased demand while accelerating the demand for these innovative materials.

IV. CONCLUSION

This research investigates the potential of ready-made Asphalt blocks for fasting road construction and reducing carbon footprints. From the findings, there is a basis to recommend the adoption of readymade asphalt blocks widely in the UAE and beyond toward meeting COP28 and other global environmental initiatives' sustainability targets. Such an approach can adequately reduce carbon emissions, streamline construction, and support a long-term sustainable infrastructure. In embracing such techniques, the UAE will be able to take advantage of its ability to create sustainable roads while helping to shift the world into a green revolution in infrastructure development. Even though there are a few demanding situations, like higher preliminary fees, a lack of professional people, transportation problems, and transparent regulations, prepared-made asphalt blocks offer a promising new way to construct roads. To make the most of this capability, investing in education applications for employees and investing more excellent assets into research and development is essential. Future research must focus on the long-term performance and durability of readymade asphalt blocks to prove effective in long-term use. In addition, investigation into new technology should be continued to improve the performance and environmental impact of

these blocks in road construction so that advanced technology like intelligent sensors or renewable energy sources can be integrated into the production of asphalt blocks.

REFERENCES

[1] Al-hashimi, Z., Al-Busaltan, S., Al-Abbas, B.: Advancements and challenges in the use of cold mix asphalt for sustainable and cost-effective pavement solutions. *E3S Web of Conferences* (2023). https://doi.org/10.1051/e3sconf/202342703006

[2] Apresyan, S.V., Stepanov, A.G., Vikhrov, A.A., Myasoedov, M.S., Prostyakova, A.I., Generalova, A.N.: Polymers in 3D printing of external maxillofacial prostheses and their retention systems. Preprints (2023). https://doi.org/10.20944/preprints202308.1912.v1

[3] Bamigboye, G.O., Bassey, D.E., Olukanni, D.O., Ngene, B.U., Adegoke, D., Odetoyan, A.O., Nworgu, A.T.: Waste materials in highway applications: An overview on generation and utilization implications on sustainability. *Journal of Cleaner Production* 283, 124581 (2021). https://doi.org/10.1016/j.jclepro.2020.124581

[4] Calandra, P., Loise, V., Porto, M., Oliviero Rossi, C., Lombardo, D., Caputo, P.: Exploiting nanoparticles to improve the properties of bitumens and asphalts: At what extent is it really worth it? *Applied Sciences* 10(15), 5230 (2020). https://doi.org/10.3390/app10155230

[5] Chippagiri, R., Bras, A., Sharma, D., Ralegaonkar, R.V.: Technological and sustainable perception on the advancements of prefabrication in construction industry. *Energies* 15(20), 7548 (2022). https://doi.org/10.3390/en15207548

[6] De Paoli, S.: Performing an inductive thematic analysis of semi-structured interviews with a large language model: An exploration and provocation on the limits of the approach. *Social Science Computer Review* 42(4), 997–1019 (2024). https://doi.org/10.1177/08944393231220483

[7] Elkodousy, A.A.A.: Office center in Izyum city of Kharkiv region. *(2022)*.

[8] Elnaml, I., Liu, J., Mohammad, L., Wasiuddin, N., Cooper, S.: Developing sustainable asphalt mixtures using high-density polyethylene plastic waste material. *Sustainability* (2023). https://doi.org/10.3390/su15139897

[9] Husband, G.: Ethical data collection and recognizing the impact of semi-structured interviews on research respondents. *Education Sciences* 10(8), 206 (2020). https://doi.org/10.3390/educsci10080206

[10] Hossiney, N., Sepuri, H., Mohan, M., K., S., Kumar, S., K., T.: Geopolymer concrete paving blocks made with recycled asphalt pavement (RAP) aggregates towards sustainable urban mobility development. *Cogent Engineering* 7, 1824572 (2020). https://doi.org/10.1080/23311916.2020.1824572

[11] Koch, N.: Sustainability spectacle and 'post-oil' greening initiatives. *Environmental Politics* 32(4), 708–731 (2023). https://doi.org/10.1080/09644016.2022.2127481

[12] Liu, N., Wang, Y., Bai, Q., Liu, Y., Wang, P.S., Xue, S., Li, Q.: Road life-cycle carbon dioxide emissions and emission reduction technologies: A review. *Journal of Traffic and Transportation Engineering (English Edition)* 9(4), 532–555 (2022). https://doi.org/10.1016/j.jtte.2022.06.001

[13] Liu, Y., Su, P., Li, M., You, Z., Zhao, M.: Review on evolution and evaluation of asphalt pavement structures and materials. *Journal of Traffic and Transportation Engineering (English Edition)* 7(5), 573–599 (2020). https://doi.org/10.1016/j.jtte.2020.05.003

[14] Milad, A., Babalghaith, A., Al-Sabaeei, A., Dulaimi, A., Ali, A., Reddy, S., Bilema, M., Yusoff, N.: A comparative review of hot and warm mix asphalt technologies from environmental and economic perspectives: Towards a sustainable asphalt pavement. *International Journal of Environmental Research and Public Health* 19, Article 14863 (2022). https://doi.org/10.3390/ijerph192214863

[15] Morfeldt, J., Shoman, W., Johansson, D., Yeh, S., Karlsson, S.: If electric cars are good for reducing emissions, they could be even better with electric roads. *Environmental Science & Technology* 56, 9593–9603 (2022). https://doi.org/10.1021/acs.est.2c00018

[16] Radhakrishnan, P., Dhurai, V.: Development and evaluation of sustainable bituminous paver blocks. *Recycling* (2023). https://doi.org/10.3390/recycling8010007

[17] Riekstins, A., Haritonovs, V., Straupe, V., Izaks, R., Merijs-Meri, R., Zicans, J.: Comparative environmental and economic assessment of a road pavement containing multiple sustainable materials and technologies. *Construction and Building Materials* 432, Article 136522 (2024). https://doi.org/10.1016/j.conbuildmat.2024.136522

[18] Rodriguez-Ubinas, E.D., Alzarouni, S.A., Alhammadi, N.O., Alantali, M.O., Behzad, F., Sgouridis, S.: Sustainability through energy conservation building codes: Comparative analysis of green building regulations in the Middle East. *WIT Transactions on Ecology and the Environment* 249, 85–100 (2020). https://doi.org/10.2495/SC200081

[19] Rudnicki, T.: The impact of the aggregate used on the possibility of reducing the carbon footprint in pavement concrete. *Sustainability* 14(24), Article 16478 (2022). https://doi.org/10.3390/su142416478

[20] Singh, A., Biligiri, K.P., Sampath, P.V.: Engineering properties and lifecycle impacts of pervious all-road all-weather multilayered pavement. *Resources, Conservation and Recycling* 180, Article 106186 (2022). https://doi.org/10.1016/j.resconrec.2022.106186

[21] Tarsi, G., Tataranni, P., Sangiorgi, C.: The challenges of using reclaimed asphalt pavement for new asphalt mixtures: A review. *Materials* 13, Article 84052 (2020). https://doi.org/10.3390/ma13184052

[22] Walubita, L.F., Martinez-Arguelles, G., Polo-Mendoza, R., Ick-Lee, S., Fuentes, L.: Comparative environmental assessment of rigid, flexible, and perpetual pavements: A case study of Texas. *Sustainability* 14(16), Article 9983 (2022). https://doi.org/10.3390/su14169983

[23] Wang, J., Sha, C., Ly, S., Wang, H., Sun, Y., Guo, M.: Life cycle carbon emissions and an uncertainty analysis of recycled asphalt mixtures. *Sustainability* 15(23), Article 16368 (2023). https://doi.org/10.3390/su152316368

[24] Zadeh, S., Garay-Rondero, C.: Enhancing urban sustainability: Unravelling carbon footprint reduction in smart cities through modern supply-chain measures. *Smart Cities* (2023). https://doi.org/10.3390/smartcities6060143

[25] Zahoor, M., Nizamuddin, S., Madapusi, S., Giustozzi, F.: Recycling asphalt using waste bio-oil: A review of the production processes, properties and future perspectives. *Process Safety and Environmental Protection* 147, 1135–1159 (2021). https://doi.org/10.1016/j.psep.2021.01.032

[26] Stanaszek-Tomal, E.: Anti-smog building and civil engineering structures. *Processes* 9(8), Article 14466 (2021). https://doi.org/10.3390/pr9081446

[27] World Green Building Council: UAE's private sector is committed to achieving sustainability (2023). https://worldgbc.org/article/uaes-private-sector-is-committed-to-achieving-sustainability