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KUWAIT INSTITUTE FOR SCIENTIFIC RESEARCH

Annotated bibliography on

Sustainability in Concrete Construction

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Introduction:

The construction industry is increasingly focusing on sustainability, seeking innovative approaches to mitigate environmental impacts and enhance resource efficiency. This annotated bibliography contains recent scholarly articles from 2020 to 2024, exploring various aspects of sustainable practices in concrete construction. The selected articles examine the integration of waste materials, such as recycled rubber tyres, fly ash, and silica fume, into construction materials, assessing their environmental impacts and potential for resource recovery.

Additionally, the bibliography highlights advancements in geopolymer concrete, circular construction practices, and the use of 3D printing technology. These articles provide a comprehensive overview of the challenges, innovations, and future directions in ensuring sustainability within the concrete construction sector. This bibliography aims to assist the Energy and Building Research Center (EBRC), particularly the Construction and Building Materials (CBM) program.

E-resources used: Web of Science – Scopus

Contact NSTIC to request full-text articles.

Articles' Abstracts:

1. An, D., Zhang, Y., & Yang, R. (2024). Incorporating coarse aggregates into 3D concrete printing from mixture design and process control to structural behaviours and practical applications: a review. *Virtual and Physical Prototyping, 19.*

Abstract: Three-dimensional concrete printing (3DCP) is progressing from lab pilots to large-scale manufacturing, encountering limitations with conventional printable material - cement mortar. Coarse aggregate concrete (CAC) emerges as a promising alternative due to its superior material properties, cost-effectiveness, and sustainability, attracting considerable interest in academia and industry. This paper explores the integration of CAC into 3DCP, focusing on three critical aspects: mixture design of 3D printable concrete, innovative methods of 3D printing process, and structural behaviours of 3D printed concrete specimens, structural members and systems. It elucidates the relationships among mixture composition, processing parameters, early-age material properties, and printability requirements. Furthermore, particle-bed 3D printing technology for CAC is discussed, highlighting advantages and challenges compared to extrusion methods. Ultimately, this review provides valuable insights into the technical challenges and prospects of 3D printing coarse aggregate concrete (3DPCAC) technology, aiming to foster advancements in research and construction practices.

2. Simsek, O., Ünal, M., & Gökçe, H. (2024). Performance of foam concrete developed from construction and demolition waste. *Materials Today Sustainability, 27.*

Abstract: Unconscious industrialization, urbanization and consumption of natural resources pose a serious threat to the environment. The threat can be reduced by upcycling construction and demolition waste (CDW) in the production of foam concrete, which is a special type of concrete used especially for thermal insulation purposes. This study aims to use of CDW as a source of fine aggregate (0 -4 mm) in the production of foam concrete mixtures. A series of mixtures with target density values between 500 and 900 kg/m 3 were designed with various recycled aggregate and foam contents to investigate the physical, mechanical and thermal properties of the mixtures. Findings of the study reveal that mixtures with an elevated foam content possess a greater number of larger pores, which, as observed through microscopy, form interconnected structures that are porous. On the other hand, adding more fine recycled material (FRM) makes the matrix denser, which reduces the overall porosity and increases the packing density. In contrast to increased content of FRM, correlation coefficient of (-0.77) reveal more powerful inverse relationship between risen level of foam content (-0.67) and the reduction

ratio of fresh to -dry density and the increase in compressive strength from 7 to 28 days. It is also known that mixes with more foam have better thermal insulation because they trap more air, while mixes with more FRM show an increase in thermal conductivity. The sensitivity analysis showed that changes in thermal conductivity are almost three times as sensitive for FRM content, which means they have a bigger effect than changes in foam content. Employing the Taguchi method, (R_0.714) emerges as the most efficient tested combination indicative of superior overall performance. Notably, the Taguchi method predicts the untested combination (0.100-F/C ratio + 0.714-R/C ratio) as potentially more efficient, suggesting avenues for further exploration and optimization. This study furnishes valuable insights into sustainable construction practices by reutilizing CDW in foam concrete production, thereby contributing to both environmental conservation and enhanced structural outcomes.

3. Zhang, P., Wang, C., Guo, J., Wu, J., & Zhang, C. (2024). Production of sustainable steel fiber-reinforced rubberized concrete with enhanced mechanical properties: A state-of-the-art review. *Journal of Building Engineering*, *91*.

Abstract: In recent years, the consumption of natural resources and the generation of large amounts of waste have seriously threatened the progress of human civilization towards sustainable development. Waste such as non-biodegradable and non-self-degradable waste rubber tires have aroused widespread concern for the ecological environment, and recycling and reusing them in a way that partially replaces concrete aggregates is an effective approach to solving the issue of waste rubber tire accumulation and achieving sustainable development of the construction industry. However, the introduction of rubber particles into concrete has a negative impact on the mechanical behavior of concrete. Notably, reinforcing rubberized concrete with steel fibers is an innovative solution to address its shortcomings. This paper provides a comprehensive review of the sustainability and mechanical properties of steel fiber-reinforced rubberized concrete. Specifically, a comprehensive overview of the main material sources for steel fiber-reinforced rubberized concrete is presented in terms of recyclability of waste rubber tires, the characteristics of rubber particles, and the characteristics of steel fibers. Given the sustainability of steel fiber-reinforced rubberized concrete, cost-benefit analysis and environmental sustainability are widely summarized. Furthermore, the mechanical properties of steel fiber-reinforced rubberized concrete such as strength (compressive, splitting tensile, and flexural strength), toughness (compressive, and flexural toughness), elastic modulus, impact resistance, and fracture characteristics are critically reviewed and discussed. Then, the

microscopic behavior of steel fiber-reinforced rubberized concrete is evaluated and analyzed. Eventually, research progress in areas related to steel fiberreinforced rubberized concrete is suggested and further possible research is proposed based on the critical analysis. This paper can provide information for the production and application of sustainable steel fiber-reinforced rubberized concrete with enhanced mechanical properties.

4. Salgado, F., & Silva, F. (2022). Recycled aggregates from construction and demolition waste towards an application on structural concrete: A review. *Journal Of Building Engineering, 52.*

Abstract: The construction sector, in addition to being very important for the economy of several countries, also has a significant impact on the environment as it causes a huge natural resources depletion and generates an enormous amount of waste. Therefore, the use of recycled aggregate from construction and demolition waste, instead of conventional aggregates, has a double environmental advantage: it decreases the consumption of natural resources and reduces the land needed for waste disposal. Thus, in the last decades, many researches have been conducted to analyse the feasibility of recycled aggregate in several civil engineering works, which can help in a long way the economic and environmental sustainability of countries. This article presents a literature review on the production and utilization of recycled aggregate in concrete. Because of its higher water absorption and lower density, the use of recycled aggregate can cause a slight reduction in workability and compressive strength of concrete. Thus, authors have evaluated methods to remove the adhered mortar or to seal the pores of recycled aggregates, enhancing the material quality. Some articles also show the feasibility of using recycled aggregate concrete in structural elements, either through reduced-scale elements at a laboratory or full-scale elements in real projects. Summarily, this review may help to alleviate the concerns of consumers and further promote the use of recycled aggregate on a larger scale in civil engineering. The literature survey was conducted on an extensive database; however, a greater emphasis was placed on articles published after the year 2000.

5. Ahmed, H., Mohammed, A., Rafiq, S., Mohammed, A., Mosavi, A., Sor, N., & Qaidi, S. (2021). Compressive Strength of Sustainable Geopolymer Concrete Composites: A State-of-the-Art Review. *Sustainability,13*.

Abstract: The building industry, which emits a significant quantity of greenhouse gases, is under tremendous pressure due to global climate change and its consequences for communities.

Given the environmental issues associated with cement production, geopolymer concrete has emerged as a sustainable construction material. Geopolymer concrete is an eco-friendly construction material that uses industrial or agricultural by-product ashes as the principal binder instead of Portland cement. Fly ash, ground granulated blast furnace slag, rice husk ash, metakaolin, and palm oil fuel ash were all employed as binders in geopolymer concrete, with fly ash being the most frequent. The most important engineering property for all types of concrete composites, including geopolymer concrete, is the compressive strength. It is influenced by different parameters such as the chemical composition of the binder materials, alkaline liquid to binder ratio, extra water content, superplasticizers dosages, binder content, fine and coarse aggregate content, sodium hydroxide and sodium silicate content, the ratio of sodium silicate to sodium hydroxide, the concentration of sodium hydroxide (molarity), curing temperature, curing durations inside oven, and specimen ages. In order to demonstrate the effects of these varied parameters on the compressive strength of the fly ash-based geopolymer concrete, a comprehensive dataset of 800 samples was gathered and analyzed. According to the findings, the curing temperature, sodium silicate content, and alkaline solution to binder ratio are the most significant independent parameters influencing the compressive strength of the fly ash-based geopolymer concrete (FA-BGPC) composites.

6. Ahmed, W., & Lim, C. (2021). Production of sustainable and structural fiber reinforced recycled aggregate concrete with improved fracture properties: A review. *Journal of Cleaner Production*, *279*.

Abstract: In recent years, due to the ever-increasing demand of concrete the need for sustainable and economically feasible structural concrete has obtained special attention of both researchers and various construction industries. Fiber reinforced recycled aggregate concrete (FRAC) is one such material that has gained popularity since the beginning of twenty-first century due to its high strength, eco-friendly, and cost-effectiveness benefits. Fiber reinforcement in recycled aggregate concrete (RAC) tends to reinforce and retard the crack propagation and thus results in ductile behavior of cementitious matrix. Despite an increasing interest in the use of FRAC, there are still some doubts about the dosages and reinforcing effects of fibers in RAC containing recycled concrete aggregate (RCA) in partial or complete replacement mode. This article presents a comprehensive review on the workability and mechanical properties of FRAC. Specifically, the aim of this review study is to highlight the most promising and feasible strength enhancement methods for the FRAC mainly using steel

fiber (SF), polypropylene fiber (PPF), basalt fiber (BF), and glass fiber (GF). Furthermore, it comprehensively reviews the effect of these fibers on the flowability, compressive strength, flexural strength, splitting tensile strength and other durability aspects of the FRAC. It also presents the relationship among the volume fractions of fiber, percent replacements of RCA and strength enhancement in RAC which may help in identifying the optimum dosage of each fiber for the strength improvement in FRAC. The effective utilization of these fibers will enable the full-scale utilization of RCA in the fabrication of sustainable and structural concrete and will help the construction sector in implementing the concept of circular economy model.

7. De Brito, J., & Kurda, R. (2021). The past and future of sustainable concrete: A critical review and new strategies on cement-based materials. *Journal of Cleaner Production*, *281*.

Abstract: The negative impacts of cement-based material (CBM) production are way bigger than ever expected. To illustrate the scale of this phenomenon, all the forests in the world, regardless of the fact that they are disappearing at an alarming rate, are not enough to offset even half the environmental impact (EI) of global aggregates and cement production. Thus, it is necessary to promote scientific research and guide more researchers and professionals in the construction industry to investigate the undiscovered sustainability paths, namely for concrete before and after end-of-life. For that purpose, a global and extensive review is made here to provide an overall view of concrete sustainability in all possible paths. Then, each path is organized as follows: (i) brief introduction, (ii) presentation of non-traditional materials and techniques that can be used for the selected strategy, (iii) their limitations and (iv) future trends. The study also identifies what is already known to avoid putting valuable research resources into redundant scientific studies. The following paths of concrete production sustainability were identified: mix composition (e.g. reduce the El and resources use of binders, aggregates, water and reinforcement), materials manufacturing (e.g. new production techniques of cement, aggregates and steel bars), concrete mixing (e.g. mixer type and mixing method), on-site application (e.g. regular casting and digital concrete/3D printing), and in-service performance (e.g. increase the durability of reinforced concrete and carbon capture and thermal conductivity). On most of these paths, many studies have been made on the same non-traditional materials and techniques and similar outputs were obtained. Yet, many other nontraditional materials and techniques have not been explored before, or are incomplete in terms of the characteristics analysed. More than providing definite solutions, this contribution

intends to open the minds of the readers to the vastly unexplored world of "green concrete".

8. Farooq, F., Xin, J., Javed, M., Akbar, A., Shah, M., Aslam, F., & Alyousef, R. (2021). Geopolymer concrete as sustainable material: A state of the art review. *Construction and Building Materials, 306.*

Abstract: The rise in population and improvement in the lifestyle of human beings has caused a rapid increase in energy demands for buildings in the present day. An upsurge in energy demand, lack of fossil fuels, and environmental issues provide a crucial motive to the development of sustainable and viable infrastructure. Geopolymer (GP) composite free from cement, made from various waste materials with a high amount of Al2SiO3 and Na2SiO3/ NaOH (alkali-activated silica) is evolving as an eminent material for sustainability purposes. They are also preferred due to the lesser emission of greenhouse gases as compared to ordinary Portland cement (OPC). This paper aims at presenting a sustainable domain and state of the art review of GP composite. The properties of composites made from various geopolymeric waste binders are presented. Besides, the microstructure and chemical characterization of GP composites are also discussed. The durability of GP composite is also highlighted considering its deterioration in various aggressive environments. In the end, a global warming potential (GWP) assessment was conducted and the practical applications of GP composites in the building industry are also provided.

9. Han, Y., Yang, Z., Ding, T., & Xiao, J. (2021). Environmental and economic assessment on 3D printed buildings with recycled concrete. *Journal of Cleaner Production, 278.*

Abstract: With increasing attention on sustainable development, 3D printing construction and recycled concrete have drawn extensive interest as emerging construction technology and novel building materials. At this intersection, we attempted to evaluate the environmental impact and economic benefit of 3D printed buildings made of recycled concrete employing life-cycle assessment tools. Goal and scope definition, materials and scenarios, life-cycle inventory analysis, life-cycle assessment impact, and interpretation were detailed based on the characteristics of concrete 3D printing to better quantify the sustainability potential of recycled concrete used in 3D printed buildings. We found that although increases in using recycled aggregate could produce less pollutant emissions, the environmental impact caused by 3D printing concrete construction is generally larger than traditional cast-in-situ concrete

construction. This is because additional cement is required in the 3D printing process to maintain dependable concrete performance. From the economic perspective, 3D printing concrete construction technology has significant advantages over traditional cast-in-situ concrete construction, saving the heavy cost of formwork and labor. Such benefit is even more pronounced in geometrically irregular buildings. We also found that the cost of buildings made of recycled concrete decreased as the proportion of recycled aggregate increased, owing to the higher price of natural aggregate. This paper contributes to identifying key factors in the life-cycle evaluation of 3D printing construction with cementitious materials.

10. Miller, S., Habert, G., Myers, R., & Harvey, J. (2021). Achieving net zero greenhouse gas emissions in the cement industry via value chain mitigation strategies. *One Earth*, *4*, 1398-1411.

Abstract: Cement is used globally in construction materials for nearly all civil infrastructure systems supporting improved quality of life, and there is currently no substitute that can meet its functional capacity. The magni-tude of cement production leads to more than 7% of annual anthropogenic greenhouse gas (GHG) emissions, resulting from both energy use and chemical reactions, which imposes a notable barrier to reach net zero emissions by 2050. This barrier is exacerbated by the interconnectivity of industries responsible for cement consumption. Here, we articulate current emission reduction challenges facing industries responsible for the production and use of cement and its products, and propose a compilation of solutions that focus on miti-gating emissions from cement production at various stages along its value chain. We present frameworks for design within a circular economy and for policy decisions. We anticipate that these strategies can deliver cement production with zero GHG emissions and alleviate other environmental impacts.

11. Onaizi, A., Huseien, G., Lim, N., Amran, M., & Samadi, M. (2021). Effect of nanomaterials inclusion on sustainability of cement-based concretes: A comprehensive review. *Construction and Building Materials*, *306*.

Abstract: Negative effects of carbon dioxide (CO2) emissions due to rapid development in several countries worldwide are of increasing concern for the sustainable growth. To overcome such problem, the production of less clinker-based modified concretes with lower levels of CO2 emission became challenging in the building sectors. Such concretes can offer satisfactory strength performance and durability in the construction sector. Meanwhile, various

nanomaterials incorporated concretes generated immense interests for attaining the sustainability objectives in the civil engineering field. Based on these factors, a comprehensive sustainability assessment of diverse nanomaterials included cement-based concretes was made. In addition, the mechanisms behind the influence of different nanomaterials on the strength characteristics, workability and durability performances of the proposed improved concretes were examined. The past progress, recent drifts, ongoing challenges, effects on environmental sustainability, pros and cons of these nanomaterials-activated cement-based concretes were emphasized.

12. Poudyal, L., & Adhikari, K. (2021). Environmental sustainability in cement industry: An integrated approach for green and economical cement production. *Resources Environment and Sustainability, 4.*

Abstract: The carbon footprint of cement industries has been a major environmental issue in recent decades. Carbon Capture and Storage (CCS), use of Supplementary Cementing Materials (SCMs) as partial replacement to cement, and use of nanotechnology are some approaches that are being tested and practiced for reducing the carbon dioxide (CO2) emissions from the cement industries. Each of these approaches, however, comes with their own limitations and the implementation in real industrial scenarios is yet a concern. This paper proposes an integrated approach where CO2 captured from cement plant will be utilized within the plant for producing nano calcium carbonate (CaCO3) for use in cement manufacturing process. This technology incorporates all the above three approaches and help cement industries produce sustainable, durable, and economical cement while reducing the CO2 emissions into the atmosphere: thus, leading towards green infrastructure and global environmental sustainability. Additionally, adoption of this technology ensures proper dispersion of nano materials thereby improving the performance of concrete. Further, this technology is economically attractive to cement industries as they will have a new product (nano CaCO3) with much higher cost than cement with potential of additional economic revenues.

13. Shah, S., Mo, K., Yap, S., Yang, J., & Ling, T. (2021). Lightweight foamed concrete as a promising avenue for incorporating waste materials: A review. *Resources Conservation and Recycling, 164.*

Abstract: Several million tons of different types of wastes are generated every year globally

and this is expected to increase in the future. Most of these wastes are dumped via landfilling or incineration which creates environmental concerns. One of the possible methods of utilizing these wastes is by incorporating them as alternatives to common concrete constituents. In this regard, foamed concrete could provide an excellent medium for incorporating these wastes in a large volume primarily due to low strength requirement of foamed concrete. A significant number of research is carried out to explore the idea of integrating waste materials in pre-foamed concrete. However, the limited knowledge available to recognize the utilization of these waste and the influence on foamed concrete limits the adoption of the concept and further development. Hence, this paper compiles and reviews the usage of various types of wastes such as industrial, agricultural, quarry, and construction industry wastes as a potential replacement for cement and fine aggregate in foamed concrete. Due to the unique composition and the resulting chemical and physical properties, as well as the nature of replacement (either as cement or fine aggregate replacement), each type of waste contributes differently to the performance of foamed concrete. Generally, a non-load bearing foamed concrete with low thermal conductivity, low density, and adequate compressive strength can be produced by incorporating the waste materials. This paper also describes the advantages of incorporating waste materials in foamed concrete compared to conventional concrete and proposes the further development of the concept for future application of a more sustainable and eco-friendly foamed concrete.

14. Tam, V., Soomro, M., & Evangelista, A. (2021). Quality improvement of recycled concrete aggregate by removal of residual mortar: A comprehensive review of approaches adopted. *Construction and Building Materials, 288*.

Abstract: With the goal of achieving sustainable development, numerous research studies have been conducted aimed at reducing construction and demolition waste for improving sustainability and environment and reducing greenhouse-gas emissions. Recycled concrete aggregate due to its residual adhered mortar has low specific gravity and high water absorption. Both of these impediments contribute in the increase of permeability and shrinkage, decrease in compressive strength and hence concrete quality produced from recycled concrete aggregate. Consequently, it is essential to improve the recycled concrete aggregate quality such that their properties become comparable with those of virgin aggregate. In order to improve the recycled concrete aggregate quality, researchers have adopted two main pathways: (1) removal of adhered mortar from aggregate grains and utilisation of the separated mortar, and (2)

fortification of residual mortar to make it stronger, less permeable and hydrophobic. The present study focuses on the first pathway and aims to comprehensively review huge variety of treatment techniques available in the literature, which can be applied to enhance the recycled concrete aggregate quality, by removing maximum amount of the attached mortar, thereby increasing its density, reducing its water absorption, and subsequently producing high quality aggregate. In addition, the processes which can effectively utilise the removed mortar have been reviewed. The combination of both, separation of mortar from aggregate grains and its complete utilisation make these treatments economically viable. These treatments which are based on the published literature, have been individually analysed based on their applicability and efficacy.

15. Zhang, C., Nerella, V., Krishna, A., Wang, S., Zhang, Y., Mechtcherine, V., & Banthia, N. (2021). Mix design concepts for 3D printable concrete: A review. *Cement & Concrete Composites, 122*.

Abstract: Over the past decade, 3D concrete printing has shown enormous application potential for the industry. The new technology poses specific requirements on 3D printable concrete (3DPC), especially on its rheological properties in the fresh state. The current codes and standards for conventional concrete construction are not applicable for guiding the mix design of 3DPC. Developing robust mix-design guidelines of printable concrete while considering the principles of sustainability, use of indigenous materials and available printer characteristics contributes to a broader practical application of 3DPC. This article presents state-of-the-art on mix design concepts for 3DPC. In this, various aspects of mixture compositions and their effects on properties of 3DPC are highlighted and mix design approaches are described. While currently and out of necessity, a trial and error approach remains the norm, for finding the appropriate mix composition for 3DPC, it would clearly be beneficial to develop rational and scientific guidelines for a particular set of parameters. Thus, the use of models providing a quantitative relationship between the rheological parameters of fresh concrete and its composition is instrumental to guide the mix design of printable concrete. Some such models do exist already, but considerable research is still needed to develop them into reliable mix design tools. Furthermore, the contemporary mix design for 3DPC mainly focuses on the printability of concrete in fresh state, while the characteristics of hardened concrete such as strength or durability are often not targeted explicitly. Given the engineering application of 3DPC, further research is needed to develop mix design concepts involving the

targeted properties of hardened concrete under consideration of process-induced anisotropy.

16. Aslam, M., Huang, B., & Cui, L. (2020). Review of construction and demolition waste management in China and USA. *Journal of Environmental Management*, *264*.

Abstract: It has been observed that the massive urbanization has boosted up infinite construction in the developed as well as developing countries. The construction and demolition waste has been correspondingly increased enormously which results in nasty and fatal impacts on urban sustainability and survival in the term of economic values and environmental safety. Considering construction and demolition waste management (CDWM) in the USA and China and its comparison has not been discussed, this study explores some research questions to fill such gaps: What are the existing CDWM policies and regulations in these two countries? What is the market mode for CDWM? What are the key challenges of CDWM? What are the CDWM contribution and limitations toward circular economy? What are the lessons that must be exemplary for the two economies through mutual learning? Our results show that the CD waste generation and its management are influenced by several factors including population, urbanization, gross domestic product (GDP), and CDWM regulatory measures. The USA has more developed CDWM system. Whereas, China is a growing economy and it has some management deficiencies in the construction industry. Key suggestions for improving CDWM include: i. Government supervision along with an economic incentive approach, ii. Interaction between Stakeholders, iii. Mutual coordination among operational departments, iv. Audit and inspection setup, and v. Continuous development and integration of emerging technologies.

17. Bajpai, R., Choudhary, K., Srivastava, A., Sangwan, K., & Singh, M. (2020). Environmental impact assessment of fly ash and silica fume based geopolymer concrete. *Journal of Cleaner Production*, *254*.

Abstract: Alkali activated geopolymer is an attractive solution to limit the adverse consequences of cement manufacturing. In this paper, an evaluation of environmental impacts of geopolymer containing fly ash and silica fume is conducted. Life cycle assessment is performed by benchmarking the environmental impacts of three geopolymer concrete mixes against the conventional cement concrete, namely: fly ash geopolymer (with hydroxide and silicate of sodium); fly ashesilica fume blend geopolymer (with hydroxide and silicate of sodium); and fly ashesilica fume blend geopolymer (with sodium hydroxide). Impact analysis is performed by using ReCiPe midpoint and endpoint methods in life cycle assessment software

UMBERTO NXT using database of Ecoinvent 3.0. Sensitivity analysis is performed to determine the effect of transportation. One mix design for each concrete of equal water to binder ratio and 28-days compressive strength of more than 35 MPa is analysed. Results of life cycle assessment indicate that alkaline activators and cement are the major sources of negative environmental impacts for geopolymer and cement concrete, respectively. Global warming potential of geopolymer concretes is lower than conventional cement concrete. Fly ashesilica fume geopolymer concrete activated without sodium silicate has lowest environmental impacts. Transportation of raw materials is found to increase the overall negative of all four concrete mixes. Cost reduction of 10.87%-17.77% per unit volume is achieved with the use of fly ash - silica fume based geopolymer concrete. Sustainability in terms of cost and environmental benefits of geopolymer concrete can be further increased by using silica fume. It can be concluded that the use of fly ash - silica fume blended geopolymer in the construction industry has huge possibility to improve its sustainability. Furthermore, waste management can be effectively done by utilization of industrial by-products in concrete.

18. El-Sayegh, S., Romdhane, L., & Manjikian, S. (2020). A critical review of 3D printing in construction: benefits, challenges, and risks. *Archives of Civil and Mechanical Engineering*, *20*.

Abstract: This paper provides a critical review of the related literature on 3D printing in construction. The paper discusses and evaluates the different 3D printing techniques in construction. The paper also discusses and categorizes the benefits, challenges, and risks of 3D printing in construction. The use of 3D printing technology offers several advantages over traditional methods. However, it comes with its own additional challenges and risks. The main benefits of 3D printing in construction include constructability and sustainability benefits. The challenges are categorized into seven groups. The main challenges, found through the literature, are material related. The most cited challenges are material printability, buildability, and open time. Additionally, scalability, structural integrity, and lack of codes and regulations are frequently cited as major challenges. The additional risks are categorized into seven groups: 3D printing material, 3D printing equipment, construction site, and environment, management, stakeholders, regulatory and economic, and cybersecurity risks. The paper fills a gap in the literature as it addresses a new aspect of 3D printing, which is risk. The paper also provides some insights, recommendations, and future research ideas.

19. Ghaffar, S., Burman, M., & Braimah, N. (2020). Pathways to circular construction: An integrated management of construction and demolition waste for resource recovery. *Journal of Cleaner Production*, *244*.

Abstract: The challenges of sustainable construction, industrial growth and importance of resource efficiency are clearly recognised by the UK government and are now at the forefront of strategy and policy. A critical component of the government's sustainability strategies concerns way in which construction and demolition waste (C&DW) is managed. In this study a mixed method approach was adopted to investigate current practices of C&DW management and circular construction (re-use, recycle and recovery of materials) concept awareness in the UK. Relevant stakeholders from the construction industry (contracting, demolition and C&DW organisations) were selected and their views solicited on arguments about circular construction to help establish common visions and further encourage sustainable behaviour across the sector. The study revealed that legislation by the government on the re-use and recycling threshold for every new project can substantially improve circularity within the built environment. More specifically, focus should be on smart dismantling of buildings and ways of optimising cost effective processes. This will enable fair competition between stakeholders and eventually lead to investments in innovative approaches for resource recovery from C&DW. Further incentives and appreciations from government should also be given to stakeholders who are innovating and setting benchmarks in circular construction. This can lead to harmonised technological and non-technological solutions, closed-loop material processes and a circular economy.

20. Guo, Z., Jiang, T., Zhang, J., Kong, X., Chen, C., & Lehman, D. (2020). Mechanical and durability properties of sustainable self-compacting concrete with recycled concrete aggregate and fly ash, slag and silica fume. *Construction and Building Materials*, *231*.

Abstract: This research aims to maximize the content of supplementary cementitious material (SCM) and recycled concrete aggregate (RCA) in self-compacting concrete (SCC) by using a combination of fly ash, slag and silica fume. A sustainable SCC was proposed by substantially substituting natural aggregates with RCA and cement with SCM. A total of 23 mixes, including binary, ternary and quaternary mixes were prepared. Binary mixes were prepared with fly ash and ternary mixes were prepared with fly ash and slag. Quaternary mixes were blended with fly ash, slag, silica fume. The mechanical and durability properties were studied. The effect of

RCA and SCM was investigated as well as using a combination of fly ash, slag and/or silica fume. The test results indicate that the proposed combination of fly ash, slag and silica fume can compensate for the detrimental effect of RCA and significantly improve the mechanical and durability properties of SCC with RCA, thus optimize the sustainability performance of SCC by minimizing cement and natural resources content.

21. Kirthika, S., Singh, S., & Chourasia, A. (2020). Alternative fine aggregates in production of sustainable concrete- A review. *Journal of Cleaner Production, 268.*

Abstract: Construction sector is mainly liable for waning of natural resources and environmental imbalances due to its unplanned mining activities. The massive use of concrete due to boom in various infrastructure development has led to over-extraction of river sand from the riverbed. This has called for several harmful consequences of ecosystem and non-availability of good quality of raw materials. Disposal of industrial wastes and construction and demolition waste is yet another leading issue now. In this context, use of different alternative fine aggregates (AFA) from different sources can be considered as an effective elucidation. Crushed rock sand (CRS), industrial by-products (IBP) and recycled fine aggregates (RFA) are different types of alternative fine aggregates. The economic, sustainability and social benefits increases utilizing into concrete. Literatures have shown the possibility of AFA in construction as replacement to natural fine aggregate however, a comprehensive study on different AFA in concrete is required to analyse and gain confidence in using them. Therefore, this paper discusses the physical, chemical, mechanical properties of concrete utilizing different types of AFA. In addition, studies on durability, microstructure and life cycle analysis are also highlighted. These sands make concrete sustainable, durable, economical and viable alternatives. This review paper attempted to intricate the reason why these AFA are impending construction materials in future.

22. Li, P., Brouwers, H., Chen, W., & Yu, Q. (2020). Optimization and characterization of high-volume limestone powder in sustainable ultra-high performance concrete. *Construction and Building Materials, 242.*

Abstract: This paper aims to optimize high-volume limestone powder in sustainable ultra-high performance concrete (UHPC), and characterize its roles on plasticization effect, hydration kinetics, microstructure and hardened properties. The spread flow, hydration products, compressive strength, porosity and pore structure, shrinkage, embedded CO2 emission and unit

cost are investigated with different substitution levels of binders by limestone powder, varying from 0 to 80 vol%. Results show that replacing high volume of binders by limestone powder is an efficient way to develop eco-friendly and low-cost UHPC. Limestone powder shows a positive mineral plasticization effect that should be considered in designing UHPC. The degree of secondary pozzolanic hydration is more intensive than C3S/C2S hydration, which can enhance the later-age strength development potential. An appropriate content of limestone powder can contribute to a higher strength, denser pore structure, diminished total free shrinkage and higher sustainability efficiency. The optimum content of limestone powder appears to be 50 vol% of the total powder content in UHPC.

23. Maraveas, C. (2020). Production of Sustainable Construction Materials Using Agro-Wastes. *Materials, 13.*

Abstract: The construction sector, in modern times, is faced by a myriad of challenges primarily due to the increase in the urban population and dwindling natural resources that facilitate the production of construction materials. Furthermore, higher awareness on climate change is forcing companies to rethink their strategies in developing more sustainable construction materials. Diverse types of agro-waste ranging from rice husk ash (RHA), sugarcane bagasse ash (SCBA), and bamboo leaves ash (BLA) among others have been identified as potent solutions in the development of sustainable construction materials. In this review paper, six different construction materials, made using agro-waste products, are examined. The materials include brick/masonry elements, green concrete, insulation materials for buildings, reinforcement materials for buildings, particleboards, and bio-based plastics. The main criterion adopted in selecting the materials regards their popularity and wide-scale use in modern construction applications. Additionally, as this research emphasizes identifying alternative approaches to develop sustainable construction materials, the focus is directed toward mainstream materials whose continued use has an adverse impact on the environment. The findings obtained from the review showed that the use of agro-waste to develop sustainable construction materials was effective, as the developed materials adhered to established building standards. Therefore, this indicates that agro-waste materials have the potential to replace conventional construction materials and hence achieve economic, environmental, and social sustainability in the long run.

24. Merli, R., Preziosi, M., Acampora, A., Lucchetti, M., & Petrucci, E. (2020). Recycled fibers in reinforced concrete: A systematic literature review. *Journal of Cleaner Production, 248.*

Abstract: Concrete is one of the leading composite materials for construction, therefore the identification of strategies aimed at reducing its environmental impact is crucial for greening the building industry and achieving the Sustainable Development Goals set by the United Nations. One way to reduce this impact involves the opportunity to recycle waste materials as fiber in concrete reinforcement, thus following the circular economy principles. The feasibility of using different waste materials in Recycled Fiber Reinforced Concrete (RFRC) is attracting practitioners' attention. Through a systematic literature review, the paper analyzes the academic literature on concrete reinforcement using recycled fibers. The main goal is to provide an exhaustive analysis of the phenomenon with rigorous and reproducible research criteria. Eventually, 194 articles were analyzed. RFRC is a research topic, which is rapidly growing over the last years and scholars' attention is focused both on engineering aspects, through experimental studies testing the composite mechanical properties, and environmental sustainability considerations. From the analysis, emerged that even though the relevance of the construction industry and, as a consequence, of concrete in the global transition toward sustainability it is widely recognized, there is a gap in investing the potential of RFCR in addressing the triple bottom line of it. Finally, it emerged a great research potential in exploring how recycled fibers may be part of a construction industry oriented and inspired to circular economy principles.

25. Mistri, A., Bhattacharyya, S., Dhami, N., Mukherjee, A., & Barai, S. (2020). A review on different treatment methods for enhancing the properties of recycled aggregates for sustainable construction materials. *Construction and Building Materials, 233.*

Abstract: With global increase in construction and demolition, recycling of construction debris as an aggregate can be a vital step towards achieving sustainability in concrete construction. However, a clear methodology for reuse of construction and demolition (C&D) waste in concrete is warranted for its use in practice. This paper reviews the challenges revealed hitherto such as weak interfacial transition zone, high water absorption and presence of micro cracks in the use of C&D wastes as the recycled aggregate (RA). Methods of mitigation of these weaknesses through various treatments have been reported. This review has a special focus on India, a country that generates one of the world's highest quantity of C&D waste. After

analysing all the treatment methods, the authors summarize that the strengthening of attached mortar (AM) technique is better than removing of AM, which is also cost-effective, eco-friendly and sustainable. Use of nano-materials and pozzolana along with different mixing methods and application of bio-cement is found to be superior and environmental friendly approach for improving the properties of recycled aggregates.

26. Mohajerani, A., Burnett, L., Smith, J., Markovski, S., Rodwell, G., Rahman, M., Maghool, F. (2020). Recycling waste rubber tyres in construction materials and associated environmental considerations: A review. *Resources Conservation and Recycling, 155*.

Abstract: Waste tyres and their accumulation is a global environmental concern; they are not biodegradable, and, globally, an estimated 1.5 billion are generated annually. Waste tyres in landfill and stockpiles are renowned for leaching toxic chemicals into the surrounding environment, acting as breeding grounds for mosquitoes, and fuelling inextinguishable fires. The properties of waste tyre rubber and engineering applications have been previously reported in a range of publications with respect to the environmental, economic, and technical factors. This study compiles and reviews this research with a focus on geotechnical engineering applications, such as earthworks and infrastructure construction. The applications of waste rubber in construction materials includes cementitious concrete, asphalt concrete, and granular materials for earth structures. Crumb rubber, when used as a sand replacement in flowable concrete fill, improved ductility and strength-to-weight ratio. A 40 MPa concrete mix with 0.6% rubber crumb content exhibited optimal strength and air entrainment capabilities, displaying minimal damage after 56 freeze/thaw cycles. Rubber, as a partial replacement for aggregate in road base and sub-base layers, adversely affected the California Bearing Ratio (CBR) of the graded aggregate base course. Rubber-soil mixtures as the interface of foundation and structure yielded a 60-70 % reduction in vertical and horizontal ground accelerations when subjected to earthquake simulation modelling. There is concern regarding the toxicity of waste rubber incorporated products due to leachates of heavy metals and other chemicals common in tyres. Further comprehensive studies in this area are needed. Leachate studies should be conducted under different pH and liquid to solid ratios.

27. Nwakaire, C., Yap, S., Onn, C., Yuen, C., & Ibrahim, H. (2020). Utilisation of recycled concrete aggregates for sustainable highway pavement applications; a review. *Construction and Building Materials, 235*.

Abstract: Highway pavements are very expensive infrastructures that consume very high amounts of natural resources. Utilisation of recycled concrete aggregates (RCA) for highway pavement construction can bring a number of benefits towards environmental, economic and societal sustainability. This would reduce the carbon footprint of the construction industry, result in natural resource conservation, reduction in harmful emissions, and minimisation of cost of pavement construction. This paper reviews available literatures on the use of RCA for highway pavements. Both flexible and rigid pavements were covered. The studies revealed that RCA can be applied in all pavement layers; subgrade, capping, subbase, roadbase, and surfacing. The physical and mechanical properties of the RCA and how they affect its performance were studied and compared with those of natural aggregates (NA). Available techniques for improving the performance of RCA in concrete and asphalt mixes were also discussed. The benefits and sustainability gains of RCA utilisation were summarised from available life cycle assessments conducted in the literatures. RCA has been considered as a feasible sustainable alternative to NA in highway pavement applications, but there still exists a large disparity in the recommendations of the replacement levels for asphalt mixes. To ensure that the pavements are sustainable without compromising their quality and functionality, the utilisation of RCA should be encouraged after further indebt studies that would lead to a more consensus standard specifications and guidelines.

28. Rahman, M., Mohajerani, A., & Giustozzi, F. (2020). Recycling of Waste Materials for Asphalt Concrete and Bitumen: A Review. *Materials, 13.*

Abstract: Waste management has become an issue of increasing concern worldwide. These products are filling landfills and reducing the amount of livable space. Leachate produced from landfills contaminates the surrounding environment. The conventional incineration process releases toxic airborne fumes into the atmosphere. Researchers are working continuously to explore sustainable ways to manage and recycle waste materials. Recycling and reuse are the most efficient methods in waste management. The pavement industry is one promising sector, as different sorts of waste are being recycled into asphalt concrete and bitumen. This paper provides an overview of some promising waste products like high-density polyethylene, marble quarry waste, building demolition waste, ground tire rubber, cooking oil, palm oil fuel ash,

coconut, sisal, cellulose and polyester fiber, starch, plastic bottles, waste glass, waste brick, waste ceramic, waste fly ash, and cigarette butts, and their use in asphalt concrete and bitumen. Many experts have investigated these waste materials and tried to find ways to use this waste for asphalt concrete and bitumen. In this paper, the outcomes from some significant research have been analyzed, and the scope for further investigation is discussed.

29. Revilla-Cuesta, V., Skaf, M., Faleschini, F., Manso, J., & Ortega-López, V. (2020). Self-compacting concrete manufactured with recycled concrete aggregate: An overview. *Journal of Cleaner Production, 262.*

Abstract: The use of different types of waste in the manufacture of concrete is increasingly common, due to unabating concerns over climate change and sustainability in the construction sector. It is now widely accepted that the optimal behavior of vibrated concrete produced with the addition of certain wastes can rival the behavior of conventional products. The manufacture of special concretes, such as self-compacting concrete, is also currently under investigation, although the state of knowledge in this field is not so well developed. In this review paper, current and past research articles on the design of self-compacting concrete with recycled concrete aggregate, both by itself and in combination with other wastes, are summarized and assessed. Research is presented into recycled concrete aggregate properties and the mix-design of the self-compacting concretes that contain them, as well as relevant results on the fresh state (workability, rheology), the hardened state (compressive strength, splitting tensile and flexural strength, modulus of elasticity, density, and porosity), durability (resistance to aggressive agents), long-term properties of concrete (shrinkage, creep), and structural elements manufactured with self-compacting concrete containing recycled concrete aggregate. The results under review reaffirm that the incorporation of recycled concrete aggregate can produce a suitable self-compacting recycled concrete, on the basis of careful designs that are essential for successful performance.

30. Sandanayake, M., Gunasekara, C., Law, D., Zhang, G., Setunge, S., & Wanijuru, D. (2020). Sustainable criterion selection framework for green building materials-An optimization based study of fly-ash Geopolymer concrete. *Sustainable Materials and Technologies, 25.*

Abstract: Green materials are considered as one of the prominent elements in designing an environmentally sustainable construction project. Studies have highlighted cement

replacement is a popular method of reducing greenhouse gas (GHG) emissions and replacing virgin materials in concrete. These options incur cost implications through sophisticated designs and technologies. The importance of maintaining a balance between environmental and economic benefits of a green design is critical for the decision making stakeholders in a construction project. However, designers often lack the resources and tools to initiate informed decision making for the optimum selection of a green material. In order to systemize the optimising process, the current study suggests a multi objective optimisation based decision making framework for optimising the cement replacement materials in concrete. The study aims to present a sustainable criterion optimisation framework that could well be adopted to assess the sustainability of green materials in concrete production. A case study using fly ash geopolymer concrete in Melbourne demonstrated a reduction of 3.63% to 41.57% and 23.80% to 30.25% can be achieved for GHG emissions and production cost respectively if the developed optimisation based framework is implemented. The scenario results highlighted around 3% to 8% GHG and cost increase if material is not available locally. A similar approach can be utilised to optimise the environmental and cost savings of other cement replacement materials. Further studies are encouraged on comparing environmental and cost savings of other cement replacement materials using the developed framework. The framework will be valuable for designers in making decisions on sustainable cement replacement materials.

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