European Journal of Sustainable Development (2023), **12**, 3, 91-105 ISSN: 2239-5938
Doi: 10.14207/ejsd.2023.v12n3p91

Sustainability in a Sand-Depleted World: Identifying Barriers to Adoption of Sand Substitutes

By Adel A. Zadeh[1], Yunxin Peng[2], Sheila M Puffer[2]

Abstract
The global sand crisis has gained considerable attention among environmentalists over the last few years, and the United Nations has proposed some initiatives to reduce the use of river sand. Despite the existence of a number of promising sustainable alternatives to alluvial sand, there has been little effort to implement those initiatives in the construction industry. This paper attempts to develop a better understanding of barriers and challenges related to the adoption of sustainable substitutes for sand in the construction industry. An online survey designed by the authors was distributed among construction industry professionals located in 35 US states and 7 Canadian provinces. The findings from 344 respondents show that different stakeholders in construction have different priorities and concerns when it comes to sustainable sand substitutes, with some focusing more on the technical and practical aspects, while others focus more on the long-term and environmental aspects.

Keywords: Construction industry, sand crisis, barriers, awareness, sand substitutes

1. Introduction

The global sand crisis has received significant attention from environmental groups over the last few years and the United Nations has called for reduced sand consumption, and proposed solutions to address the crisis, including adopting sustainable substitutes for sand (UNEP, 2019, 2022). Sand, a seemingly abundant resource, is actually a finite and increasingly scarce commodity that is essential for a wide range of industries including construction, manufacturing, and energy production (Cao & Masanet, 2022). Sand extraction and use have significant impacts on the environment and society, including habitat destruction, water pollution, and coastal erosion (UNEP, 2019, 2022). As the demand for sand continues to increase, it is critical to adopt more sustainable sand substitutes to mitigate these negative impacts and ensure the long-term viability of this vital resource (Torres et al., 2017).

The sand crisis is a complex and multifaceted issue with far-reaching environmental and societal implications (Wesley & Puffer, 2018). The extraction of sand often involves the removal of large quantities of soil and rock, which can lead to habitat degradation and destruction. Also, the transportation of sand can have negative impacts, such as air pollution and the disruption of local communities (UNEP, 2022). In addition, the huge demand for sand has led to conflicts over access to and control of resources, particularly in areas where sand is a valuable commodity. This has led to the rise of powerful sand mafias that illegally remove sand and threaten those who try to interfere with their operations (Beiser, 2017).

[1] College of Professional Studies, Northeastern University, Toronto, ON M5X IE2, Canada
[2]D'Amore-McKim School of Business, Northeastern University, Boston, MA 02115, USA

Sand is a crucial component of the construction industry and is used in a wide range of applications including the production of concrete, asphalt, and glass (Wesley & Puffer, 2018; Zadeh et al., 2022). Alluvial sand is the only type of sand suitable for construction since, unlike desert sand, it possesses the appropriate degree of angularity. In the production of concrete, sand is mixed with cement and water to form a cohesive mixture that can be used as a building material (Hewlett & Liska, 2019). Sand is also used as a component of asphalt, a material commonly used for road surfaces (Dondi et al., 2021). In the construction of buildings and other structures, sand is often used as a fine aggregate in mortar and plaster, and it is also used as a molding and core-filling material in foundries (Srivastava & Singh, 2020). The demand for sand in the construction industry has increased significantly in recent years, driven by population growth and urbanization (Torres et al., 2017).

While there has been extensive research into developing sustainable alternatives to traditional sand used in concrete (Zadeh et al., 2022), there is still little knowledge about the challenges preventing their widespread application. Sustainability initiatives have failed for a variety of reasons when it comes to construction materials that follow specific codes and standards. The purpose of this research on sustainability adoption in the face of the sand crisis is to understand the main barriers to adopting more sustainable options in place of traditional sand. There are many challenges to promoting sustainability adoption in any context, and these challenges are likely to be exacerbated in the context of the sand crisis, given the importance of sand as a non-renewable resource and the difficulties in finding alternative materials. By understanding the challenges and barriers to sustainability adoption in the context of the sand crisis, strategies and approaches can be developed for overcoming these obstacles and promoting more sustainable practices. This research can also help to inform policy decisions and guide the development of regulations and standards that support sustainable sand use. Finally, this research can raise awareness about the sand crisis and the importance of sustainability adoption, and can help to educate individuals and communities about the importance of responsible resource use. Overall, this research has the potential to make a significant contribution to the development of more sustainable practices in the face of the sand crisis. The rest of the paper consists of the following sections. We first provide a review of the literature on barriers to the adoption of sustainable building materials in general. This is followed by a description of the methodology regarding the design of the survey. Results and discussion are provided in the next section, followed by directions for future research, and conclusion.

2. Literature Review: Barriers to the Adoption of Sustainable Building Materials

As mentioned, the sand crisis is a pressing issue and it is crucial to adopt more sustainable materials in order to meet this demand in a responsible and sustainable manner (Cao & Masanet, 2022; UNEP, 2022). Yet there are still huge barriers to widespread implementation of initiatives in this industry despite these calls for action. An overview of the main barriers to adoption of sustainable materials and practices in general in the construction industry is presented in the next section, with particular attention paid to the sand crisis and the use of environmentally friendly building materials.

2.1 Lack of Information, Education and Research, Knowledge, Awareness, and Expertise

Insufficient education and training and a lack of information have been cited as one of the main obstacles to implementing sustainability initiatives in the construction industry (Ikediashi et al., 2012). According to previous research, the sand crisis issue has received little attention among practitioners (Puffer et al., 2022) and stakeholders had little knowledge about the crisis or of available alternatives to address the problem (Zadeh et al., 2022). The lack of adequate stakeholder awareness of sustainable building materials and their costs and benefits can create a lack of enthusiasm and commitment to the promotion of these substitutes (Marker et al., 2014; Karji et al., 2020). There is a need for technically trained individuals and those with strong managerial skills. It is widely believed that the adoption of newly developed sustainable materials often does not occur due to a lack of information, knowledge or experience on the part of the customer or a lack of confidence in receiving reliable information (Khatatbeh & Alzubi, 2020). Many potential customers have little or no experience with sustainability initiatives and support for the development of such technologies is insufficient. Lack of technical support and expertise can make it challenging for construction professionals to use sustainable materials(Karji et al., 2020).. For example, if sustainable sand materials require specialized knowledge and equipment to use, it can be difficult for practitioners to adopt them without proper training or support

One strategy for promoting sustainability is through education and awareness campaigns (AlSanad, 2015). By increasing public awareness about the impacts of unsustainable materials and the importance of sustainable substitutes and practices, individuals and communities can be empowered to make more informed decisions (Zainul Abidin, 2010).

2.2 Cost

Cost is a critical concern for all key stakeholders in construction and has been one of the most reported barriers to green building adoption in the industry (Chan et al., 2014; Högberg, 2014; Schmidt & Osebold, 2017; Sourani & Sohail, 2011; Zulu et al., 2022). Sustainable materials are often more expensive than traditional materials, making it difficult for practitioners and policymakers to justify the additional cost, especially when budgets are tight (Sourani & Sohail, 2011). For example, sustainable sand materials may require more advanced technologies and processes to extract, process, and transport, which can increase the cost of the material. Additionally, there may be a lack of economies of scale for sustainable sand materials, as they are still not as widely used as traditional materials (Zadeh et al., 2022). These factors can contribute to the higher cost of sustainable materials, making them less attractive to construction professionals and policymakers (Martek et al., 2019). Furthermore, the lack of price transparency and standardization in the market can make it difficult for practitioners and policymakers to compare the cost of different types of sustainable materials, making it harder to make informed decisions. Consequently, customer demand may not be high enough to drive down the price, making it less attractive for manufacturers to invest in sustainable materials (Balasubramanian & Shukla, 2017).

2.3 Lack of Incentives or Support

Lack of incentives and support is also a significant barrier to the adoption of sustainable building materials (Högberg, 2014; Olanipekun et al., 2016). Incentives and support can come in various forms such as financial, technical, or regulatory support that can be provided by governments, organizations, and industry groups (Tokbolat et al., 2020; Williams & Dair, 2007; Zulu et al., 2022). For example, a lack of financial incentives, such as subsidies or tax credits, can make it difficult for construction professionals and policymakers to justify the additional cost of using sustainable materials. This can be particularly challenging for small and medium-sized enterprises (SMEs) and individuals who may not have the resources to invest in sustainable materials (Olanipekun et al., 2016). Furthermore, lack of regulatory support can also be a barrier to the adoption of sustainable materials (Dewick & Miozzo, 2002; Gan et al., 2015; Oke & Aigbavboa, 2017; Revell & Blackburn, 2007; Yin et al., 2018). For example, if there are no regulations or standards in place to promote the use of sustainable materials, it can be challenging for construction professionals and policymakers to justify their use. Previous studies have also provided some recommendations in order to improve adoption with regards to mandatory guidelines as such are requiring certain levels of sustainable building (SB) certification before granting building permits or imposing fines for non-compliance. This approach is considered by a number of studies as one of the most cost-effective ways in promoting SB adoption (Dewick & Miozzo, 2002; Yin et al., 2018). When it comes to some established materials such as concrete, replacing sand with newly developed substitutes can be particularly challenging. This is primarily due to specific standards and specifications that must be followed when preparing construction documents and applying for permits. Again, this underscores the importance of governments in creating mandatory policies and regulations to be followed by key players in construction, because stakeholders tend to adopt SB principles mainly in order to satisfy mandatory requirements (Gan et al., 2015). During the design and construction phases, stakeholder groups include sponsors, engineering teams, consultants, and certifying and regulatory bodies, among others.

To overcome the barrier of lack of incentives and support, governments and organizations can provide financial incentives, such as subsidies or tax credits, to help offset the cost of sustainable materials. Additionally, they can provide technical support and training to help practitioners use sustainable materials effectively (Olanipekun et al., 2016). They can also implement regulations and standards that promote the use of sustainable materials, making it easier for practitioners and policymakers to justify their use. Incentives can be very effective in serving as motivators that influence construction stakeholders to adopt and incorporate green building (GB) practices into their building projects (Revell & Blackburn, 2007).

2.4 Lack of Interest and Demand

The implementation of green buildings involves numerous internal and external stakeholders, with project initiators (sponsors, clients and customers) playing a major role and having the greatest influence in adopting sustainable construction (Zadeh et al., 2022). Lack of interest or demand can happen for various reasons such as lack of awareness or understanding of the benefits of sustainable materials, the perception that sustainable materials are not as good as traditional materials, or the belief that sustainable materials

are too expensive, as explained the previous section. It is very important to highlight that the construction industry will be motivated to meet GB standards primarily if clients and customers prefer green buildings over conventional ones. Additionally, lack of client demand can make it difficult for manufacturers and suppliers to justify investing in sustainable materials, as they may not see a return on their investment (Costa et al., 2018; Kappenthuler & Seeger, 2020). This can make it challenging for construction professionals to access sustainable materials, as they may not be readily available in the market.
Furthermore, since clients play an integral role in the adoption of GB (Diyana & Abidin, 2013), implementing GB practices if clients do not express an interest may prove challenging (Hwang & Tan, 2012). The potential benefits of sustainable materials will not be realized if clients and customers are unaware of them, making it difficult for them to show interest or demand. Hence the need to increase sustainability awareness is essential in order to have greater adoption in the construction industry (Häkkinen & Belloni, 2011).

3. Methodology

3.1 Lack of Interest and Demand

To meet the research objectives, a survey was developed as the primary method of data collection. The survey was designed to gather information on the attributes and concerns related to the adoption of sustainable sand substitutes in the construction industry. To develop the survey, a thorough review of the literature on sustainable sand practices was conducted and a list of attributes and concerns relevant to sustainable sand adoption were identified and included in the survey. The survey was distributed to a dozen individuals in the construction industry including architects, engineers, managers, and academics. Respondents were asked to rank their top three attributes and concerns related to the adoption of sustainable sand substitutes. By asking respondents to rank their top concerns, the survey aimed to identify the most pressing issues related to sustainable sand adoption in the construction industry.
The following sections provide detailed information on the design and distribution of the survey, and the data analysis approach.

3.2 Survey Instrument and Data Collection

This study is part of our larger research program on sand substitutes in the construction industry. We designed a survey using Qualtrics that included a range of questions designed to elicit responses about the attributes that practitioners value in sustainable sand replacement materials, their concerns about these materials, as well as demographics and topics to be covered in other studies. The instrument was developed with the guidance of colleagues specializing in survey design.

The survey was administered from May 2020 to June 2021 and was distributed to a diverse group of professionals in the construction industry in the United States and Canada. The respondents were recruited through professional networks, referrals, online postings, and individual outreach. The survey was also posted on LinkedIn and on the Brown University Listserv and in the BuildingGreen newsletter. The goal was to attract respondents from all 50 US states and 10 Canadian provinces. The study focused on these

two countries because of their large construction sectors and potential to enact legislation promoting the use of sustainable substitutes. Four $50 gift card drawings were offered to encourage participation. A total of 344 usable responses were collected for the attributes question and 341 for the concerns.

Survey respondents were asked to select three attributes they value about sustainable sand replacement initiative and rank them based on their importance, with 1 being most important, 2 second, and 3 third most important The options provided were availability or ease of purchase, customer demand, environmental friendliness, performance (e.g., durability, strength, permeability), price, regulatory approvals of use, and not enough knowledge to answer. The attributes were listed in alphabetical order. Respondents were also given the opportunity to add any attributes that may have been missing in the options provided. It should be noted that separate questions regarding the respondents' level of knowledge about the sand crisis and their familiarity with specific promising alternatives to alluvial sand that were not included in this study.

Similarly, we provided respondents with the following options regarding their concerns about sustainable sand replacement materials, again listed in alphabetical order: availability and ease of purchase, customer demand, capital investment needed in sand substitute infrastructure, environmentally friendly, performance (e.g. durability, strength, permeability), price, regulatory approvals of use, sunk costs in current sand manufacturing infrastructure, not enough knowledge to answer, and allowing respondents to add any concerns that we may have missed in the options provided.

4. Results and Discussion

This research gathered demographic information from survey respondents to understand the characteristics of the sample population. The majority of respondents were found to be from medium-sized organizations ranging from 50 to 250 employees, with 6-15 years of experience, and an average age of 30-49 years old. The majority of respondents were male (67.06%) and from the United States (69.48%). Engineers (31.11%) and managers (29.60%) were the most represented roles, followed by academics (21.14%), architects (12.99%), and others (5.13%). The "others" category included sustainability consultants and representatives of trade associations, government, and NGOs. Results for key demographic data are provided in Figure 1.

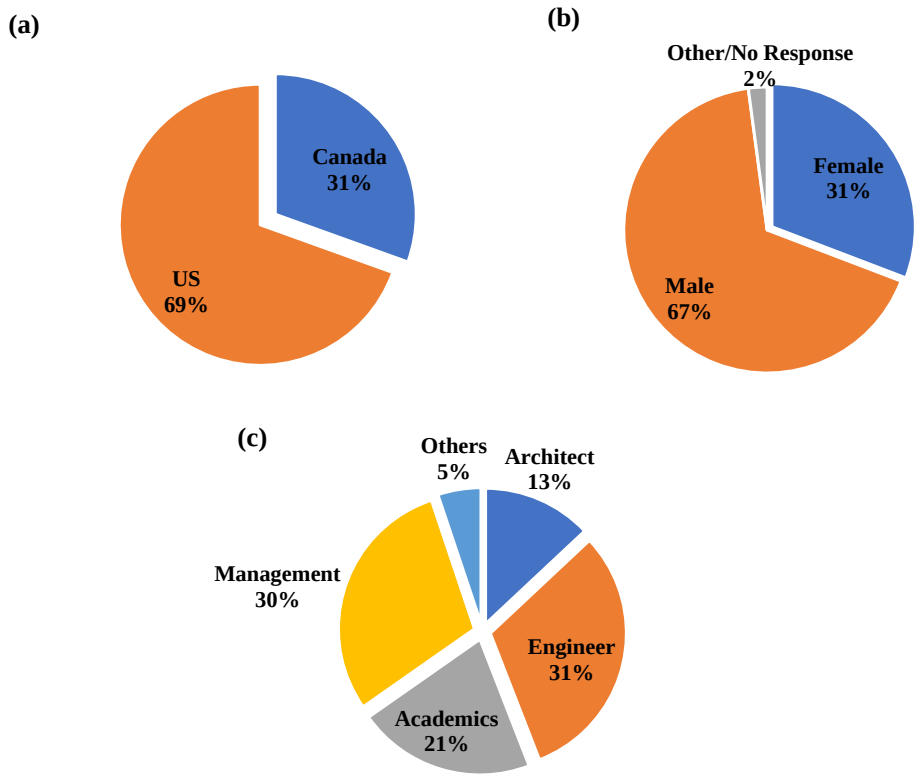

Figure 1. Demographic data of respondents (%)

4.1 Valued attributes of sustainable sand substitutes

Error! Reference source not found. shows the attributes selected by the greatest number of respondents in each professional role as their top three priorities. The results indicate that key stakeholders in the construction industry view environmental friendliness, performance, and availability/ease of use as their most important attributes when it comes to sand sustainability. The fact that these attributes were selected as the top three by multiple groups, including architects, academics, and engineers, suggests that they are widely recognized as important in the industry.

It is not surprising that architects selected "environmental friendliness" as one of their top attributes, as they are often responsible for designing and constructing buildings that are sustainable and energy efficient (Puffer et al., 2022; Zadeh et al., 2022). Architects are also likely to be conscious of the environmental impact of the materials they use and, as a result, would prioritize environmentally friendly materials (De Gaulmyn & Dupre, 2019). Engineers and academics also picked "environmental friendliness" as one of their top attributes, which may be due to their knowledge of the environmental impact of different materials and their desire to use materials that have a lower environmental impact (Kevern, 2011; Lewis, 2004; Weisenberger, 2011). Performance and price are also important for

these groups, which can be attributed to the fact that they are responsible for ensuring that the materials are suitable for the intended purpose and that they are cost-effective (Nasereddin & Price, 2021).

As shown in Figure 2, management selected performance, price, and availability/ease of use as their top three attributes. This observation is also understandable as this group is responsible for overseeing the construction process and ensuring that materials are available and easy to use, and that the materials are cost-effective and perform well (Hinze et al., 2013). Overall, the survey findings suggest that sustainability, performance, and cost-effectiveness are key attributes for stakeholders in the construction industry when it comes to sustainable sand substitutes. This finding also serves as guidance for building practitioners and policymakers on how to consider the needs and goals of various stakeholders when designing sustainable materials and practices.

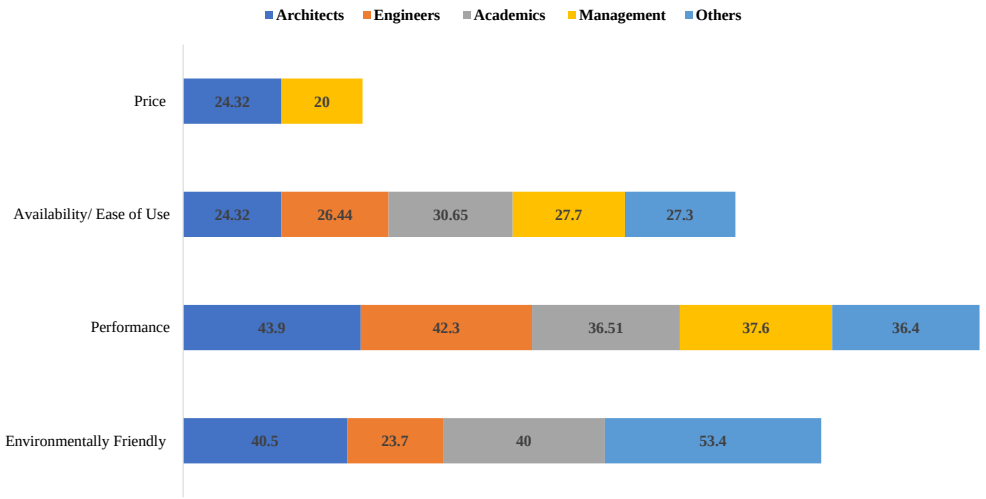

Figure 2 Top three attributes ranked by professional roles (%)

4.2 Concerns about sustainable sand substitutes

As reported in Figure 3, each stakeholder role provided their set of top three priorities that shape their concerns. As with the attributes described above, the table shows the concerns selected by the greatest number of respondents for each role.

As discussed in the previous section and based on their role in construction, it is not surprising that both architects and engineers have similar concerns regarding sustainable sand substitutes. Both groups are responsible for the design and construction of buildings and infrastructure, and therefore, they have a vested interest in the materials used in these projects (Puffer et al., 2022). Performance, availability/ease of use, and price are all critical factors in the selection of building materials, as they directly impact the functionality, feasibility, and cost of a project (Balasubramanian & Shukla, 2017). In the construction industry, performance refers to the ability of a material to meet the technical requirements of a project, such as strength, durability, and fire resistance. For architects and engineers,

using a high-performance material is essential for ensuring the safety and longevity of a building (Khatatbeh & Alzubi, 2020). With regards to availability/ease of use, for architects and engineers, using a material that is readily available and easy to work with can save time and money on a project. This aligns with prior research demonstrating that resource availability has a direct impact on construction project costs and timelines (Alhassan et al., 2023; Habert et al., 2020). Furthermore, it has been observed that when resources are readily available, it facilitates efficient construction processes and reduces the need to extensively search for alternative materials or methods. Such availability significantly contributes to the overall sustainability and seamless execution of construction projects. And finally, price is a critical consideration for architects and engineers, as materials can make up a significant portion of a project's budget. The lower the cost of a material, the more budget is available for other aspects of the project. However, factors such as cost, availability, and appearance have historically influenced material selection, often overshadowing sustainability considerations (Mohsin & Ellk, 2018). Given the importance of these factors in the design and construction process, it makes sense that architects and engineers would prioritize performance, availability/ease of use, and price when it comes to sustainable sand substitutes.

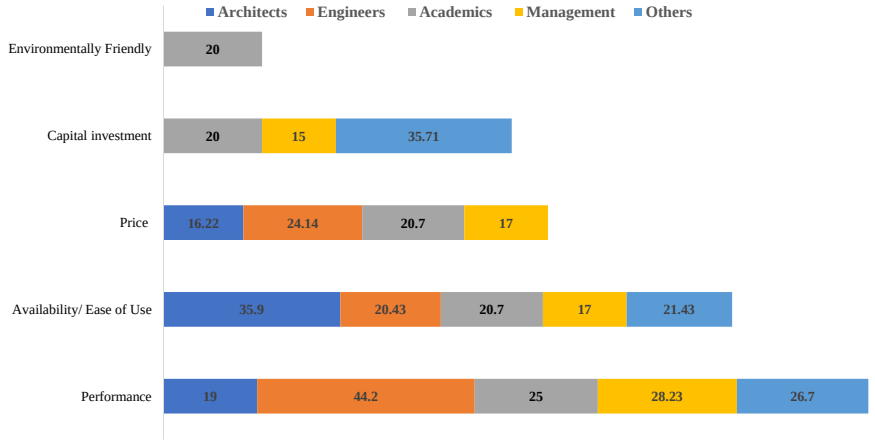

Figure 3 Top three concerns ranked by professional roles (%)

Academics, on the other hand, demonstrated a more broad and long-term perspective. They selected both capital investment and being environmentally friendly as tied for their first concern, which highlights their focus on the future and the need for sustainable development. It is clear to this group of respondents that investing in sustainable materials now can benefit the environment and society in the long run. Sustainable construction practices often require the use of innovative and environmentally friendly materials, which may have higher upfront costs compared to traditional materials (Kiesnere & Baumgartner, 2019; . Capital investment allows companies to allocate funds towards the procurement and implementation of these sustainable materials, such as energy-efficient building systems, renewable energy technologies, and recycled or low-impact construction materials (Kiesnere & Baumgartner, 2019; Alhamami et al., 2020)

Academics also picked performance as their second concern, which shows that they also understand the importance of the technical aspect of materials. Academics indicated a tie among price, customer demand, and availability/ease of use as their third level concerns, which shows they also consider the market and practical aspect of the material. They understand that the material needs to be economically viable and marketable and accessible to be widely used. In addition, they recognize that materials must be easy to obtain and work with in order to be practical in construction. It worth mentioning that academics' concerns regarding sand sustainability reflect their focus on both the technical and practical aspects of materials, as well as the long-term and environmental aspects. They appear to understand that sustainable development requires a balance between economic, technical, and environmental considerations, and that a comprehensive approach is needed to meet the challenges of sand sustainability.

Management selected performance as their first concern, which is important for the success of a project. Performance is especially important for management as it can affect the safety, longevity, and functionality of the building. They also picked price and availability/ease of use (tied) as their second concern, which highlights their focus on the cost-effectiveness and feasibility of a project. They also appear to understand that using a material that is readily available and easy to work with can save time and money on a project. The management group indicated capital investment as their third level concern, which suggests that they are aware of the long-term financial implications of their decisions that they understand that investing in sustainable materials now can have a positive impact on the environment and society in the long term. In summary, management's concerns regarding sustainable sand substitutes reflect their focus on the technical and practical aspects of materials, as well as the short-term and financial aspects. This indicates that they understand that sustainable development requires a balance between economic, technical and environmental considerations and that a comprehensive approach is needed to meet the challenges of sand sustainability.

The respondents whose roles did not fit in any other categories picked performance, capital investment, and price as their top three concerns. This highlights their focus on the technical aspect, the long-term financial implications, and the cost-effectiveness of the material. Overall, this survey shows that key stakeholders in construction have different concerns when it comes to sand sustainability. When indicating their top three priorities, some focused more on the technical and practical aspects, while others focused more on the long-term and environmental aspects.

In order to overcome the challenges highlighted in this research, we offer a number of recommendations. First, to tackle challenges with performance, investing in research and development to improve the performance of sustainable sand materials is a must. This can include developing new technologies and processes to extract, process, and transport sustainable materials, as well as testing and evaluating the performance of various promising alternative materials. Also, it is crucial to implement standards and regulations that promote the use of sustainable materials and ensure that they meet certain performance criteria. This can include conducting a full performance review of possible alternatives to alluvial sand, as well as defining minimum performance requirements for sustainable materials and mandating that products achieve these standards before being utilized in construction projects.

A second recommendation is to invest in more education and create greater awareness about sustainable sand materials and their performance characteristics. This can include providing training and education for practitioners on how to use sustainable sand materials effectively and providing information and case studies on their performance. This is clearly linked to customer demand: if clients and end-users are not aware of the benefits of sustainable sand materials, such as their environmental impact, they may not demand their use in construction.

Similarly, if clients and end-users perceive that sustainable sand materials are not as good as traditional materials in terms of performance or cost, they may be less likely to demand their use. To increase client demand, governments and organizations could implement regulations and standards that promote the use of sustainable sand materials in construction projects. This can help to increase their use and make them more visible to clients and end-users. It is also important to encourage collaboration between industry, government, academia, and other stakeholders to share information about and experience with sustainable sand materials and their performance. This can include organizing workshops, conferences, and other events to bring stakeholders together to discuss and share information. Other activities include showcasing the performance of sustainable sand materials in real-world applications, building pilot projects using those materials and evaluating their performance, as well as sharing the results with practitioners and policymakers to increase their confidence in the use of sustainable materials.

Financial incentives could be an effective way to overcome concerns related to performance when it comes to sustainable sand materials. Governments and organizations could provide subsidies for the use of sustainable sand materials in construction projects. Governments could also provide tax credits for organizations or individuals that use sustainable sand materials in construction projects. Providing low-interest loans to organizations or individuals that use sustainable sand materials in construction projects. All of these offerings have the potential to help reduce the overall cost of projects and make sustainable sand materials more attractive for use. Another solution might be to include sustainable sand materials as a requirement in the public procurement process. This could help increase the demand for sustainable materials and make them more competitive with traditional materials. Governments and organizations could also provide funding for research and development of sustainable sand materials. This can support research to improve the performance of sustainable materials and make them more competitive.

5. Directions for future research

This study suggests a number of avenues for further research in relation to the adoption of sustainable sand substitutes in the construction industry. First, a larger and more diverse survey could be undertaken. This could include recruiting a larger sample of respondents and reaching out to a wider range of professional and stakeholders, such as policymakers and regulatory and certifying bodies, in addition to the architects, engineers, academics, and managers who were the focus of this research. A survey of these other roles would provide a deeper understanding of the different stakeholders' views and perceptions towards sustainable sand materials and allow identifying specific obstacles and

opportunities for adoption. Furthermore, evaluating the implementation and impact of policies and regulations that support the use of sustainable sand materials would be useful to understand their effectiveness. A second avenue of research would be to investigate the availability and accessibility of sustainable sand materials in different regions and identify potential barriers to their wider use to understand the factors that influence their adoption. Additionally, understanding the availability and accessibility of sustainable sand materials in different regions can help to identify potential opportunities for improvement, such as by increasing production or distribution, and targeting education and awareness efforts to overcome specific barriers. Third, conducting a comprehensive assessment of the environmental impact of various types of sand and evaluating their potential for sustainable use would be crucial to understanding the environmental implications of sand extraction and use. This is closely related to the information collected from the survey, as environmental friendliness was identified as both a top valued attribute and a main concern. Such an assessment would provide insights into the environmental impact of different types of sand, and help to identify opportunities for reducing negative impacts and promoting sustainable use. Finally, evaluating the effectiveness of various policies and regulations in promoting the use of sustainable sand materials and assessing their potential for replication in other regions would be a valuable avenue for future research. This can be achieved by conducting a comparative analysis of different policies and regulations, analyzing their impact on the adoption of sustainable sand materials, and identifying best practices that can be replicated in other regions.

6. Conclusion

In conclusion, this research highlights the different concerns and priorities of key stakeholders in construction with regard to valued attributes and concerns about sustainable substitutes for sand used in building materials. Architects and engineers prioritize performance, availability/ease of use, and price, while academics prioritize capital investment and being environmentally friendly, performance and price, customer demand and availability/ease of use. Management prioritizes performance, price and availability/ease of use, and capital investment. The research provides valuable insights into the industry's perspective on sustainable sand substitutes and can serve as a guide for practitioners and policymakers in the construction industry. It is important to note that sustainable development requires a balance between economic, technical, and environmental considerations. This research highlights the need for a comprehensive approach that addresses the concerns of all key stakeholders in the construction industry. It also shows that different stakeholders have different priorities and concerns, and that a collaborative approach is necessary to meet the challenges of sand sustainability.

This research contributes to an understanding of the industry's perspective on sustainable sand substitute materials and can serve as a basis for future research and policy development. It also highlights the importance of considering the perspectives of all key stakeholders in the construction industry when developing sustainable materials and practices. The findings of this research can help practitioners and policymakers make informed decisions that promote sustainable development in the construction industry and contribute to the preservation of natural resources for future generations.

Two notable limitations of this study should be acknowledged. Firstly, the narrow focus on stakeholders within the construction industry excludes perspectives from other relevant stakeholders, such as policymakers, environmental organizations, and local communities, potentially limiting the comprehensiveness of the findings. Secondly, the use of a snowball sampling method, rather than a random sample, introduces potential bias and reduces the generalizability of the study's results.

References

Alhassan, M., Alkhawaldeh, A., Betoush, N., Alkhawaldeh, M., Huseien, G. F., Amaireh, L., & Elrefae, *A. (2023). Life cycle assessment of the sustainability of alkali-activated binders*. Biomimetics, 8(1), 58. https://doi.org/10.3390/biomimetics8010058

AlSanad, S. (2015). *Awareness, drivers, actions, and barriers of sustainable construction in Kuwait*. Procedia Engineering, 118, 969–983. https://doi.org/10.1016/j.proeng.2015.08.538

Balasubramanian, S., & Shukla, V. (2017). *Green supply chain management: An empirical investigation on the construction sector*. Supply Chain Management: An International Journal, 22(1), 58–81. https://doi.org/10.1108/SCM-07-2016-0227

Beiser, V. (2017). *He who controls the sand: The mining 'mafias' killing each other to build cities*. The Guardian, 28.

Cao, Z., & Masanet, E. (2022). *Material efficiency to tackle the sand crisis*. Nature Sustainability, 5(5), Article 5. https://doi.org/10.1038/s41893-022-00869-w

Chan, Y. H., Lee, B. C., & Lee, J. C. (2014). *Sustainability in the construction industry in Malaysia: The challenges and breakthroughs*. International Journal of Economics and Management Engineering, 8(4), 1218–1222.

Costa, C., Cerqueira, Â., Rocha, F., & Velosa, A. (2018). *The sustainability of adobe construction: Past to future*. International Journal of Architectural Heritage.

De Gaulmyn, C., & Dupre, K. (2019). *Teaching sustainable design in architecture education: Critical review of Easy Approach for Sustainable and Environmental Design (EASED)*. Frontiers of Architectural Research, 8(2), 238–260.

Dewick, P., & Miozzo, M. (2002). *Sustainable technologies and the innovation–regulation paradox*. *Futures*, 34(9–10), 823–840.

Diyana, N., & Abidin, Z. (2013). *Motivation and expectation of developers on green construction: A conceptual view*. International Journal of Humanities and Social Sciences, 7(4), 914–918.

Dondi, G., Mazzotta, F., Lantieri, C., Cuppi, F., Vignali, V., & Sangiovanni, C. (2021). *Use of steel slag as an alternative to aggregate and filler in road pavements*. In Materials (Vol. 14, Issue 2). MDPI. https://doi.org/10.3390/ma14020345

Gan, X., Zuo, J., Ye, K., Skitmore, M., & Xiong, B. (2015). *Why sustainable construction? Why not? An owner's perspective*. Habitat International, 47, 61–68.

Habert, G., Miller, S. A., John, V. M., Provis, J. L., Favier, A., Horvath, A., & Scrivener, K. L. (2020). *Environmental impacts and decarbonization strategies in the cement and concrete industries*. Nature Reviews Earth & Environment, 1(11), 559–573. https://doi.org/10.1038/s43017-020-0093-3

Häkkinen, T., & Belloni, K. (2011). *Barriers and drivers for sustainable building. Building Research & Information*, 39(3), 239–255. https://doi.org/10.1080/09613218.2011.561948

Hewlett, P., & Liska, M. (2019). *Lea's chemistry of cement and concrete*. Butterworth-Heinemann.

Hinze, J., Godfrey, R., & Sullivan, J. (2013). *Integration of construction worker safety and health in assessment of sustainable construction*. Journal of Construction Engineering and Management, 139(6), 594.

Högberg, L. (2014). *Building sustainability: Studies on incentives in construction and management of real estate [PhD Thesis]*. KTH Royal Institute of Technology.

Hwang, B.-G., & Tan, J. S. (2012). *Green building project management: Obstacles and solutions for sustainable development. Sustainable Development*, 20(5), 335–349. https://doi.org/10.1002/sd.492

Ikediashi, D. I., Ogunlana, S. O., Oladokun, M. G., & Adewuyi, T. (2012). *Assessing the level of commitment and barriers to sustainable facilities management practice: A case of Nigeria*. International Journal of Sustainable Built Environment, 1(2), 167–176. https://doi.org/10.1016/j.ijsbe.2013.06.002

Kappenthuler, S., & Seeger, S. (2020). *From resources to research—A framework for identification and prioritization of materials research for sustainable construction*. Materials Today Sustainability, 7, 100009.

Karji, A., Namian, M., & Tafazzoli, M. (2020). *Identifying the key barriers to promote sustainable construction in the United States: A principal component analysis*. Sustainability, 12(12), Article 12. https://doi.org/10.3390/su12125088

Kevern, J. T. (2011). *Green building and sustainable infrastructure: Sustainability education for civil engineers*. Journal of Professional Issues in Engineering Education and Practice, 137(2), 107–112.

Khatatbeh, A. A., & Alzubi, Y. (2020). *Role of materials and labor allocation in cost-effective soundproof house construction orojects*. Journal of Civil Engineering and Architecture, 14(12). https://doi.org/10.17265/1934-7359/2020.12.004

Lewis, M. (2004). *Integrated design for sustainable buildings*. ASHRAE Journal, 46(9), S22.

Marker, A. W., Mason, S. G., & Morrow, P. (2014). *Change factors influencing the diffusion and adoption of green building practices*. Performance Improvement Quarterly, 26(4), 5–24. https://doi.org/10.1002/piq.21160

Martek, I., Hosseini, M. R., Shrestha, A., Edwards, D. J., & Durdyev, S. (2019). *Barriers inhibiting the transition to sustainability within the Australian construction industry: An investigation of technical and social interactions*. Journal of Cleaner Production, 211, 281–292.

Mohsin, A. H., & Ellk, D. S. (2018). *Identifying barriers to the use of sustainable building materials in building construction*. Journal of Engineering and Sustainable Development, 22(2), 107–115. https://doi.org/10.31272/jeasd.2018.2.87

Nasereddin, M., & Price, A. (2021). *Addressing the capital cost barrier to sustainable construction*. Developments in the Built Environment, 7, 100049.

Oke, A. E., & Aigbavboa, C. O. (2017). *Sustainability in construction*. In Sustainable Value Management for Construction Projects (pp. 87–106). Springer.

Olanipekun, A. O., Skitmore, & Bo Xia, P. (2016). *Green building incentives: A review*. Renewable and Sustainable Energy Reviews, 59, 1611–1621. https://doi.org/10.1016/j.rser.2016.01.028

Puffer, S. M., Zadeh, A. A., & Peng, Y. (2022). *Awareness of the global sand crisis and sand substitutes in the construction industry in the United States and Canada: A stakeholder analysis*. International Journal of Construction Management, 0(0), 1–13. https://doi.org/10.1080/15623599.2022.2146277

Revell, A., & Blackburn, R. (2007). *The business case for sustainability? An examination of small firms in the UK's construction and restaurant sectors*. Business Strategy and the Environment, 16(6), 404–420.

Schmidt, J.-S., & Osebold, R. (2017). *Environmental management systems as a driver for sustainability: State of implementation, benefits and barriers in German construction companies*. Journal of Civil Engineering and Management, 23(1), 150–162.

Sourani, A., & Sohail, M. (2011). *Barriers to addressing sustainable construction in public procurement strategies*. Proceedings of the Institution of Civil Engineers-Engineering Sustainability, 164(4), 229–237.

Srivastava, A., & Singh, S. K. (2020). *Utilization of alternative sand for preparation of sustainable mortar: A review*. Journal of Cleaner Production, 253, 119706.

Tokbolat, S., Karaca, F., Durdyev, S., & Calay, R. K. (2020). *Construction professionals' perspectives on drivers and barriers of sustainable construction*. Environment, Development and Sustainability, 22(5), 4361–4378. https://doi.org/10.1007/s10668-019-00388-3

Torres, A., Brandt, J., Lear, K., & Liu, J. (2017). *A looming tragedy of the sand commons*. American Association for the Advancement of Science. https://doi.org/10.1126/science.aao0503

UNEP. (2019). Sand and sustainability: Finding new solutions for environmental governance of global sand resources. United Nations Environment Programme Geneva, Switzerland.

UNEP. (2022). *Sand and sustainability: 10 strategic recommendations to avert a crisis*. GRID-Geneva, United Nations Environment Programme, Geneva, Switzerland.

Weisenberger, G. (2011). *Sustainability and the structural engineer*. Practice Periodical on Structural Design and Construction, 16(4), 146–150.

Wesley, D. T. A., & Puffer, S. M. (2018). *The end of sand: Confronting one of the greatest environmental challenges of the new millennium*. In Reusable and Sustainable Building Materials in Modern Architecture (pp. 1–27).

Williams, K., & Dair, C. (2007). *What is stopping sustainable building in England? Barriers experienced by stakeholders in delivering sustainable developments*. Sustainable Development, 15(3), 135–147. https://doi.org/10.1002/sd.308

Yin, B. C. L., Laing, R., Leon, M., & Mabon, L. (2018). *An evaluation of sustainable construction perceptions and practices in Singapore*. Sustainable Cities and Society, 39, 613–620.

Zadeh, A. A., Peng, Y., Puffer, S. M., & Garvey, M. D. (2022). *Sustainable Sand Substitutes in the Construction Industry in the United States and Canada: Assessing Stakeholder Awareness*. Sustainability, 14(13), Article 13. https://doi.org/10.3390/su14137674

Zainul Abidin, N. (2010). *Investigating the awareness and application of sustainable construction concept by Malaysian developers*. Habitat International, 34(4), 421–426. https://doi.org/10.1016/j.habitatint.2009.11.011

Zulu, S. L., Zulu, E., Chabala, M., & Chunda, N. (2022). *Drivers and barriers to sustainability practices in the Zambian Construction Industry*. International Journal of Construction Management, 0(0), 1–10. https://doi.org/10.1080/15623599.2022.2045425