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Unearthing the Construction Industry's Awareness of and Reactions to the Global Sand Crisis

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Abstract: The United Nations has declared a global sand crisis. The construction industry, as a major user of sand, needs to significantly reduce the use of this finite natural resource. The purpose of this study is to measure the level of awareness of the sand crisis among construction industry professionals, to assess their reactions upon learning of the crisis, and to determine sources of information for those who are aware of the crisis. The Cognitive-Affective-Conative model was applied as the theoretical framework. The study is based on a survey and in-depth interviews with 75 construction industry professionals in the United States and Canada. Analyses included level of awareness by professional role and by reaction, as well as level of awareness by role and by type of information. Results showed that knowledge of the sand crisis was generally low. A content analysis of interview transcripts categorized five reactions to the crisis. These results suggest that generally across all roles, those with more familiarity with the sand crisis had reactions of proactive and feel bad while those with less familiarity expressed curiosity and surprise. Denial was expressed by a few. Recommendations include: First, greater efforts are required to inform construction industry professionals of the need to reduce the use of sand. Second, it is important to determine reactions upon learning of the crisis in order to generate interest and galvanize action. Third, determining the source of knowledge can help assess effective ways of broadly disseminating information to the construction industry.

Keywords: sand crisis; sustainability awareness; construction industry education; sustainable substitutes for sand; sustainable construction materials; United Nations Environmental Program

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1. Introduction

1.1. The Global Sand Crisis

In 2019 the United Nations issued a major report documenting that the world is facing a sand crisis [1]. Sand is the second largest natural resource by volume, after water, that is extracted and traded [2]. Annual global consumption is estimated to range from 32 to 50 billion tonnes [3], with about 10 billion metric tonnes being consumed annually by the construction industry and expectations of construction use doubling by the mid-20th century [4]. In 2022, 91 million metric tons of sand and gravel were consumed in the US for industrial purposes [5]. In 2021, 88.89 million metric tons of sand and gravel were produced in the Canadian province of Ontario, which is by far the largest producer of all provinces [6]. The primary reason for the crisis is that the world has gone on a building boom, particularly since emerging economies, especially China, have developed more infrastructure and housing. The production of concrete has tripled in the past two decades. That amount of concrete has been compared to circling the equator with a wall more than 27 m high by 27 m wide [1]. Additionally, Singapore has used sand to add more than 50 miles to its land mass since 1965 and has imported over 500 million tonnes of sand in

the past two decades [1]. Dubai has followed a similar course. Silica (essentially sand) comprises up to 25% of cement, and sand constitutes 40% of the aggregate used in concrete, as well as a total of 25-30% of concrete by volume [7]. While construction is by far the largest consumer, sand is also used in hydraulic fracking as well as in dozens of other products including glass, ceramics, paints, plastics, rubber, sealants and grouts, adhesives and resins, and mortar, with the latter consisting of 75% sand [8].

The sand crisis is dire in many parts of the world. The ideal type of sand used in concrete and other construction materials is alluvial sand since its angularity has the requisite binding properties. It is worth noting, however, that desert sand has been considered as a viable substitute for traditional sand, with reported optimal replacement levels falling within the range of 30% to 40%. This phenomenon can be attributed to the rounded particle shape of desert sand, which has been observed to diminish the cohesive forces between coarse aggregates and binding materials [9].

Sand is formed by wave action on coastlines and develops on mountains over millennia, gradually finding its way to riverbeds and coastlines [10]. However, that pathway is too often blocked by dams. Dredging removes and reroutes sand, and canals and coastal barriers interfere with sand flows and natural replenishment. Besides marring the landscape and reducing areas for recreation, the depletion of sand threatens habitats for wildlife and marine life as well as plants and grasses that help prevent erosion. Erosion, in turn, makes the consequences of hurricanes and other extreme weather events more severe by threatening buildings and other structures, not to mention human life. Additionally, sand extracted from inland mines can adversely affect aquifers and natural habitats. Sand shortages also increase costs and greenhouse gas emissions associated with transportation of the material to areas where it is in short supply. Lastly, the sand crisis has negative social consequences, with sand mafias illegally removing and selling sand and even threatening those who try to interfere with their activities [11,12].

Despite the United Nations' call to address the sand crisis, research on concrete and cement has focused to date predominantly on reformulating those materials to reduce greenhouse gas emissions [13–15]. Cement production accounts for 5–10% of annual anthropogenic carbon dioxide emissions [16], with an estimated 1 tonne of CO_2 emitted per tonne of Portland cement. This is due to the CO_2 released in the calcination of calcite, as well as the energy required to heat conventional Portland cement to 1450 degrees Celsius [7]. While research on reducing concrete's greenhouse gas emissions is highly important, greater attention needs to also be paid to the construction industry's impact on the global sand crisis [10,12,17–19].

In summary, the need to reduce the use of alluvial sand is critical for several important reasons: sand is a non-renewable resource, its removal contributes to climate change and the destruction of natural habitats, and shortages lead to transportation costs and emissions as well as to the proliferation of sand mafias.

1.2. Awareness of the Global Sand Crisis in the Construction Industry

Although information about the global sand crisis is available from various sources, including the United Nations [1,17], little is known about the extent to which professionals in the construction industry have been exposed to that information [18]. A recent survey by our research team [20] explored this issue in the United States and Canada and found a low level of awareness among 378 professionals across various roles in the construction industry. The present study seeks to explore in greater depth the level of awareness of a subset of these survey respondents, and to understand their reactions to learning about the need to reduce the use of sand in construction applications. And for those who were aware of the crisis, it is important to determine the sources of information that were accessed. These topics were explored through in-depth interviews with 75 construction professionals.

2. Theoretical Background and Literature Review

The theoretical foundation of this study is the Cognitive-Affective-Conative Model (CAC model), which is a model with a long history [21] developed in cognitive psychology [22] (pp. 417–423). Cognition refers to the psychological process of individual information acquisition, storage, extraction, and application [23] (pp. 71–72). Cognition is the opinion or belief component of attitudes and includes the awareness, knowledge, thoughts, and attributes a person has about an object. The affective component refers to the emotions associated with an object, phenomenon, or experience and includes liking, disliking, and preferences. It is the feeling component of attitudes. The CAC model argues that cognition and emotion are the two determinants of the conative component, which is behavior intention. The latter refers to the likelihood of making a decision to take action.

The CAC model has been applied in a number of studies on sustainability. For example, one study developed a scale to measure the cognitive, affective, and conative domains of sustainable consumption [24]. Sustainable development in tourism has used the model to measure the audience psychological effects of "cloud tourism" [25]. The model has also been applied to determine the relationship between awareness of green products and purchasing decisions [26], consumer environmental awareness, and optimal manufacturing production [27]. The model has also been used to study environmental apathy and its relation to green purchasing intentions of organic food [28].

Purpose, Significance, and Plan of the Study

The purpose of this study is threefold. Addressing the global sand crisis first requires that users of sand be aware of the crisis. Second, it is important to determine people's reactions upon learning of the crisis in order to generate interest and galvanize action to address the crisis. Third, for those who are aware of the crisis, it is useful to determine the source of that knowledge in order to assess whether such sources are an effective way of broadly disseminating related information to the construction industry at large. This research fills a gap by combining both the cognitive aspect of the level of awareness of the global sand crisis, as well as the affective aspect by conducting in-depth analyses of the emotional reactions to that phenomenon. It also investigates how awareness can be developed through accessing various sources of information. The study thus aims to extend the literature that has typically not found a strong relationship between awareness of sustainability issues and changing one's behavior to become more sustainable [29].

This study sought to answer the following research questions:

- RQ 1—What are the cognitive aspects of learning about the global sand crisis? How aware are professionals in the construction industry of the global sand crisis?
- RQ 2—What are the affective aspects of learning about the global sand crisis? What are construction industry professionals' emotional reactions upon learning about the crisis?
- RQ 3—For those who are aware of the sand crisis, how did they learn about it?

The plan of the remainder of the article is as follows. First, the methodology is described. This includes an overview of the quantitative survey from which we drew data, as well as a description of how the interviewees were selected. The research design for interviewing respondents is explained next, followed by a description of the variables. Results are then presented and interpreted in the analysis and discussion section. The conclusion includes limitations of the study and topics for future research.

3. Methodology

3.1. Survey and Interview Instrument

This study is part of a larger project by our research team that designed and administered a lengthy questionnaire to professionals engaged in various roles in the construction industry in the United States and Canada [20,30]. The questionnaire investigated a variety of topics on the global sand crisis and sustainable substitutes for sand. The survey was

pilot tested on a dozen professionals including academics, architects, engineers, managers, and sustainability consultants.

The present study focuses on a subset of 75 survey respondents with whom we conducted and recorded approximately one-hour interviews. The purpose was to obtain more information about their awareness of and reaction to the global sand crisis and, where applicable, the information sources they had accessed about the crisis. The interviews were conducted from 26 February 2020 to 6 May 2021. The first interview was conducted in person and the rest were conducted online due to the COVID-19 lockdown that started in Boston in early March 2020 and also due to geographic distance for most interviewees. Two members of the research team conducted all 75 interviews together and were sometimes joined by a third member. The one-hour interviews provided opportunities for the interviewers to establish a good rapport and trust and for the interviewees to have sufficient time to reflect on the questions and provide a rich description of their knowledge, emotional reactions, and behavioral intentions toward sustainability in the construction industry in general, as well as toward the global sand crisis more specifically. This interview method fits with the case study approach to qualitative research as developed by Eisenhardt [31]. She and other experts in this method have concluded that even a small number of cases can be sufficient to provide rich material upon which to explore new phenomena using grounded theory [32]. For example, in the sustainability literature, a study of regulation and eco-innovation of extracted materials was based on 31 in-depth interviews [33]. Thus, our database of transcriptions of 75 one-hour interviews is more than sufficient to explore the cognitive and aspects of attitudes toward the global sand crisis.

Interviewees were obtained in several ways. We first reached out to people in our professional and personal networks. These included faculty colleagues and personal friends and families involved in the construction industry. We then asked them for referrals to help distribute our surveys and refer others in their networks for an interview with the consideration of gender and geographic diversity and inclusiveness. To obtain as broad geographic representation as possible, we contacted, on an individual basis, nearly 1000 professionals in the construction industry from all US states and Canadian provinces through their LinkedIn pages. The survey was also posted on the Brown University Listserv "https://listserv.brown.edu (accessed on 31 June 2020)" and in the BuildingGreen newsletter "www.buildinggreen.com (accessed on 6 November 2020)". Four $50 gift card drawings were offered to encourage participation. We also provided an opportunity for survey respondents to have a follow up interview with us. After we completed the data collection process, we selected the winners using a random number generator and notified them through emails.

Upon obtaining permission from the interviewees, 72 of the interviews were recorded. One interviewee agreed to participate but without the interview being recorded. The interviewers inadvertently neglected to record two interviews but took notes and included the responses. The terms of use of the responses, ensuring anonymity, were elaborated orally at the start of the interview and again in our thank-you emails. To have the interviews transcribed, we subscribed to otto.ai. The transcribing process included uploading recordings, editing the automated text, identifying the speakers, and downloading the transcription.

3.2. Research Design

Interviewees were walked through the survey shared on screen via Zoom by the interviewers, with responses to the quantitative questions, including responses to RQ 1, entered directly into the Qualtrics database. The interviewers then asked follow-up questions in a semi-structured interview style to gain a deeper understanding of the respondents' quantitative answers and their affective reactions to the crisis (RQ 2).

The semi-structured interview provides flexibility to pursue a free-flowing conversation. And as noted by Gioia et al. [34], the semi-structured interview is "the heart of these [qualitative] studies" and can be considered "'research as engagement' [35], as well

as "engaging research—especially for the informants" (p. 27). The sensitivity to the impact of interviews has been well studied to understand respondents' deeply meaningful and emotional personal experience [36].

3.3. Variables

First, demographic variables were drawn from the quantitative survey for country, state, and province, as well as organization type, organization size, professional role, and gender. For RQ 1 on awareness of the sand crisis, the following quantitative question was drawn from the survey: "How familiar are you with the global sand crisis?" The question was formulated as a Likert-type scale. Response options ranged from 5 = extremely familiar, 4 = moderately familiar, 3 = somewhat familiar, 2 = slightly familiar, and 1 = not familiar at all.

For RQ 2 on emotional reactions upon learning of the sand crisis, we adapted Gioia et al.'s [34] methodology of identifying concepts from the raw interview data. We engaged in concept development to classify reactions to the crisis. As those authors explained: "We draw a subtle but significant distinction between concepts and constructs to connote that concepts are broader, more tenuous notions that can later be more narrowly specified, operationalized, and measured" (p. 27). They indicate that "concepts are precursors to constructs in making sense of organizational worlds" (p. 16). The procedure begins with creating first-order categories, with the objective to remain as close to the responses as possible. In our study, we selected all quotes verbatim that were made in response to the open-ended question: "How do you feel now that you are aware of the sand crisis?"

The first-order categories consisted of grouping the statements into positive, negative, and neutral reactions. We then proceeded to the second-order level of analysis, looking for similarities and differences among the first-order categories of quotes and grouped them accordingly, giving each one a label to denote a particular emotion.

For RQ 3, we asked respondents who had prior knowledge of the crisis to name the sources of information where they learned about the sand crisis. We then summarized them according to sources of knowledge, again in the manner suggested by Gioia et al. [34]. The first-order categories were sources of knowledge such as courses or seminars. Those categories were then grouped in the second-order level of analysis such as education, in this example.

4. Results

4.1. RQ 1: Familiarity with the Global Sand Crisis

As shown in Table 1, the majority of the 75 respondents (70.67%) were from the United States. Approximately half of the interviewees (49.33%) were working at a private organization, and half (49.33%) worked in large organizations with over 250 employees. We also asked interviewees to identify their roles based on the nature of their daily job responsibilities. Close to half were identified as management (45.33%), followed by engineer (25.33%), architect (24%), academic (13.33%), and other (5.33%). The other category of four respondents included a VP of education solutions and a manager of education training and development at NGOs, an evaluation officer, and a government policy analyst. Men comprised 72% and women 26.67% of the interviewees.

Fifteen of the fifty US states (30%) were represented. The two most represented states were Massachusetts (47.17%) and California (9.43%), with the others each having three or fewer interviewees. Canadian respondents were from six of the ten provinces, with the three most represented provinces being British Columbia (27.27%), Quebec (27.27%), and Ontario (22.73%). Thus, the sample covers the major states and provinces throughout the United States and Canada (Table 2).

Table 1. Demographics.

Variable	Value	N	Percentage
All	/	75	100%
Country	Canada	22	29.33%
	United States	53	70.67%
Organization Type	Education	10	13.33%
	Government	5	6.67%
	Non-government Organization	6	8%
	Private	37	49.33%
	Public-listed	8	10.67%
	Self-employed	6	8.00%
	Trade Association	3	4.00%
Organization Size	Large sized	37	49.33%
	Medium sized	10	13.33%
	Small	14	18.67%
	Micro	14	18.67%
Role	Academic	10	13.33%
	Architect	8	10.67%
	Engineer	19	25.33%
	Management	34	45.33%
	Other	4	5.33%
Gender	Female	20	26.67%
	Male	54	72.00%
	Other	1	1.33%

Table 2. Distribution of respondents by province/state.

Canadian Provinces	N	%
Alberta	3	13.64%
British Columbia	6	27.27%
Nova Scotia	1	4.55%
Ontario	6	27.27%
Quebec	6	27.27%
United States	**N**	**%**
California	5	9.43%
Colorado	2	3.77%
Connecticut	2	3.77%
Florida	1	1.89%
Idaho	1	1.89%
Massachusetts	25	47.17%
New Hampshire	1	1.89%
Oregon	2	3.77%
Pennsylvania	2	3.77%
Tennessee	1	1.89%
Texas	3	5.66%
Vermont	3	5.66%
Virginia	1	1.89%
Washington	1	1.89%
Washington D.C.	3	5.66%

4.2. RQ 1: Familiarity with the Global Sand Crisis

For the total sample of 75 interviewees, the mean level of familiarity with the crisis was 2.44 (SD 1.16), representing slightly familiar (Table 3). In total, 1 interviewee (1.33%) was extremely familiar with the sand crisis, 16 (21.33%) were very familiar, 20 (26.67%) were moderately familiar, 16 (21.33%) were slightly familiar, and 22 (29.33%) were not at all

familiar. Overall, only about one-fifth of the sample was extremely or very familiar, and half were slightly or not at all familiar. Notably, the largest group of respondents, nearly 30 percent, was not at all familiar with the crisis.

Table 3. Familiarity with the sand crisis by demographic variables.

Variable	Value	n	Percentage	Leve of Familiarity Mean (SD)
All	/	75	100%	2.44 (1.17)
Country	Canada	22	29.33%	2.32 (1.21)
	United States	53	70.67%	2.49 (1.54)
Organization Type	Education	10	13.33%	2.8 (1.14)
	Government	5	6.67%	2 (0.71)
	Non-government organization	6	8.00%	2 (1.26)
	Private	37	49.33%	2.30 (1.13)
	Public-listed	8	10.67%	2.38 (1.06)
	Self-employed	6	8.00%	2.83 (1.47)
	Trade Association	3	4.00%	4 (1)
Organization Size	Large sized	37	49.33%	2.38 (1.04)
	Medium sized	10	13.33%	2.1 (1.37)
	Small	14	18.67%	2.5 (1.02)
	Micro	14	18.67%	2.79 (1.48)
Role	Academic	10	13.33%	2.44 (1.17)
	Architect	8	10.67%	2.8 (1.14)
	Engineer	19	25.33%	2.25 (1.16)
	Management	34	45.33%	2.16 (1.12)
	Other	4	5.33%	2.65 (1.2)
Gender	Female	20	26.67%	2.15 (1.31)
	Male	54	72.00%	2.54 (1.11)
	Other	1	1.33%	3 (0)

As shown in Table 4, no difference in level of familiarity with the sand crisis was found by organization size, all being within the range of slightly familiar.

Table 4. Familiarity with the sand crisis by organization size.

	Percentage of Size of Organizations	Level of Familiarity	Not at All	Slightly	Moderately	Very	Extremely
		Mean (SD)	Percentage	Percentage	Percentage	Percentage	Percentage
Overall	100.00%	2.44 (1.17)	29.33%	21.33%	26.67%	21.33%	1.33%
Large	49.33%	2.38 (1.04)	24.32%	29.73%	29.73%	16.22%	0.00%
Medium	12.00%	2.1 (1.37)	55.00%	20.00%	0.00%	30.00%	0.00%
Small	18.67%	2.5 (1.02)	21.43%	21.43%	42.86%	14.29%	0.00%
Micro	20.00%	2.78 (1.48)	35.71%	0.00%	21.43%	35.71%	7.14%

Regarding roles, interviewees classified as academic (Mean 2.8, SD 1.14) and management (Mean 2.65, SD 1.2) were more familiar than the rest of the roles (Table 5). However, the frequency distribution was different for those two roles. Nearly all academics had at least slight familiarity, with only 10% having no familiarity, whereas nearly one-quarter of managers (23.53%) had no familiarity. Academics were bifurcated, with 40% being slightly familiar and another 40% being very familiar. Managers were more evenly distributed across levels of familiarity, ranging from roughly one-fifth to one-quarter in the four levels, except for one manager who was extremely familiar, being the only interviewee in the sample. A large percentage of architects (37.50%) and engineers (42.11%) were not at all familiar.

Table 5. Familiarity with the sand crisis by role.

Role	% of Roles	Level of Familiarity	Not at All (1)	Slightly (2)	Moderately (3)	Very (4)	Extremely (5)
		Mean (SD)	Percentage	Percentage	Percentage	Percentage	Percentage
Overall	100%	2.44 (1.17)	29.33%	21.33%	26.67%	21.33%	1.33%
Academic	13.33%	2.8 (1.14)	10.00%	40.00%	10.00%	40.00%	0.00%
Architect	24.00%	2.25 (1.16)	37.50%	12.50%	37.50%	12.50%	0.00%
Engineer	25.33%	2.16 (1.12)	42.11%	10.53%	36.84%	10.53%	0.00%
Management	45.33%	2.65 (1.2)	23.53%	20.59%	26.47%	26.47%	2.94%
Other	5.33%	1.5 (0.58)	50.00%	50.00%	0.00%	0.00%	0.00%

4.3. RQ 2: Reactions to Learning about the Sand Crisis

We carefully read each interview transcript and selected relevant quotes about the reactions to learning about the sand crisis. As described in the methodology section above, these quotes were then categorized as five distinct types of affect: denial, curious, surprised, feel bad, and proactive. Interpretations for the five reactions are provided in Table 6. Two sample quotes for each reaction as well as the corresponding interviewee IDs are provided in Table 7.

Table 6. Reactions to the global sand crisis.

Reactions	Interpretation (Created by the Authors)
Curious	The interviewee was intrigued by the sand crisis and wanted to learn more about the interviewers' specific interest.
Denial	The interviewee showed some refusal to accept or engaged in denial of the existence of the sand crisis.
Feel bad	The interviewee expressed feelings of concern and remorse.
Proactive	The interviewee showed a desire to make a positive change from preventing the sand crisis from happening.
Surprised	The interviewee expressed that the sand crisis was unexpected.

Table 7. Reactions to the sand crisis and corresponding quotes.

1st Reaction	Sample Quotes	Interviewee's ID
Curious	I think it is something that we are not aware of. I don't hear people talking about it. And I think if people understood the magnitude of what was happening it would probably get more attention. It's also unfortunately the case that there are so many pressing ecological issues and environmental issues that we're grappling with that sometimes bandwidth just gets parsed into too many pieces that people just pick their battles. I think if people really understood where it was heading, then I think they would be spending more time taking it seriously.	16
	My knowledge about it is that we're running out of sand. And that just that the thought boggles my mind. Because it seems like such an infinite resource. I would have been less shocked if someone told me that the access to clean water or Portland cement was scarce. I wouldn't have guessed sand.	11
Denial	We get our sand from New Hampshire. We have invested lots of money on sand infrastructures. There's lots of sand left and I don't think sand will run out in my lifetime.	1
	In Philadelphia and New Jersey, we've got a lot of sandpits so I can understand it in certain geographical areas. I don't know what the timeline would be in a place like that.	32
Feel bad	The sand crisis is one problem and will become a bigger problem in the next decade or two, maybe even sooner than that.	55
	I was shocked by the degradation of landscape because of sand loss. I have included the sand crisis issue as a topic in one of my courses.	37

Table 7. *Cont.*

1st Reaction	Sample Quotes	Interviewee's ID
Proactive	Sand as a nonrenewable resource helps motivate me.	9
	I want to reduce sand use on a regular basis.	25
Surprised	I'm still surprised that we're running out of sand. We've been using what you call sand alternatives for so long, which is just crushed rock. I don't think we ever really qualified sand as opposed to just small rocks. And we get most of our stuff from the Rocky Mountains. So there's plenty of rocks there. And when you're crushing it down, you end up with some fines and some bigger rocks at the same time.	63
	I think most people in the industry just look at it almost like there is as much sand as there is water, and it's just not gonna run out. But I don't think that's the case.	27

Next, we explored the top three reactions according to interviewees' level of familiarity with the sand crisis (Table 8). The reaction of the one interviewee who was extremely familiar was to be proactive in addressing the crisis. Those who were very, moderately, or slightly familiar also expressed the desire to be proactive, while understandably none of those who were completely unaware of the crisis mentioned proactive. Interviewees who were very familiar, moderately, or slightly familiar also felt bad about the crisis, but those who were not at all familiar did not express feeling bad. All the moderately, slightly, and not at all familiar interviewees were curious and surprised. Only the not at all familiar interviewees engaged in denial about the crisis, with one-third of them having that reaction.

Table 8. Top three reactions to learning about the sand crisis by level of familiarity.

Level of Familiarity with Sand Crisis	Top Three Reactions (Number of Responses)
Extremely familiar (1.33%)	Proactive (1)
Very familiar (21.33%)	Feel bad (8), proactive (8)
Moderately familiar (26.67%)	Curious (9), feel bad (4), proactive (4), surprised (3)
Slightly familiar (21.33%)	Curious (7), feel bad (2), proactive (1), surprised (6)
Not at all (29.33%)	Curious (7), surprised (9), denial (6)

We then plotted the level of familiarity with the sand crisis and type of reaction for each role (Figures 1 and 2). Academics and management, who averaged moderately familiar (3.75 and 3.7), were the most proactive, followed by engineers (3.6), while no architects or others took a proactive stance. Management registered the highest percentage of "feel bad," closely followed by engineers, with both roles having a mean familiarity in the 3.5 range for that reaction. "Feel bad" was the most frequent reaction among architects who were moderately familiar (3.3) with the crisis. Academics who averaged moderately familiar (3.0) reacted as "feel bad," which was the least of the roles expressing that reaction. In contrast, architects who averaged moderately familiar (3.0) were the most curious among the roles. Management that averaged slightly familiar (2.35) were next most frequent to be curious, while engineers who were curious averaged very little familiarity (1.5). Those in the other role averaged slightly familiar (2.0), while no academics reacted with curiosity. Reactions of surprise were expressed by those who had slight to no familiarity with the crisis, with engineers averaging 2.4, followed by academics at 2.0, others at 1.3, and architects at 1.1. Denial was expressed only by engineers and managers, and they had no knowledge of the crisis.

Overall, proactive and feel bad reactions were most frequent for all roles for interviewees who averaged at least moderately familiar with the crisis (3.0 and above), except for architects and others who had no proactive reactions. Curious reactions were expressed by those who averaged moderately familiar or less, except for academics who had no curious reactions. Surprised was the reaction of those in all roles who averaged slightly familiar (2.4) or lower, with the exception of management where no interviewee expressed

surprise. These results suggest that generally across all roles, those with more familiarity with the sand crisis had reactions of proactive and feel bad while those with less familiarity expressed curiosity and surprise. Lastly, in the case of three managers and three engineers, denial was the reaction to having no familiarity with the crisis.

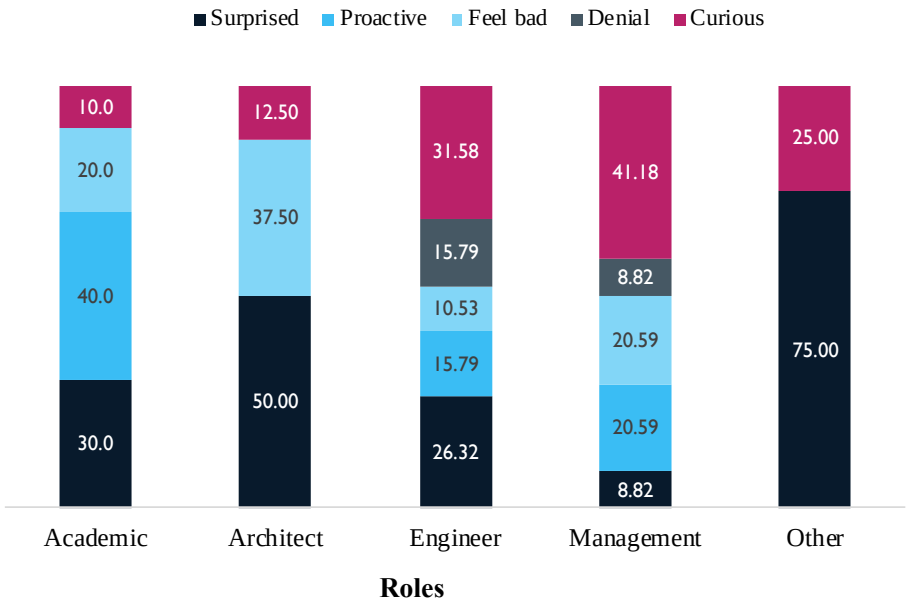

Figure 1. Percentage of reactions for each role.

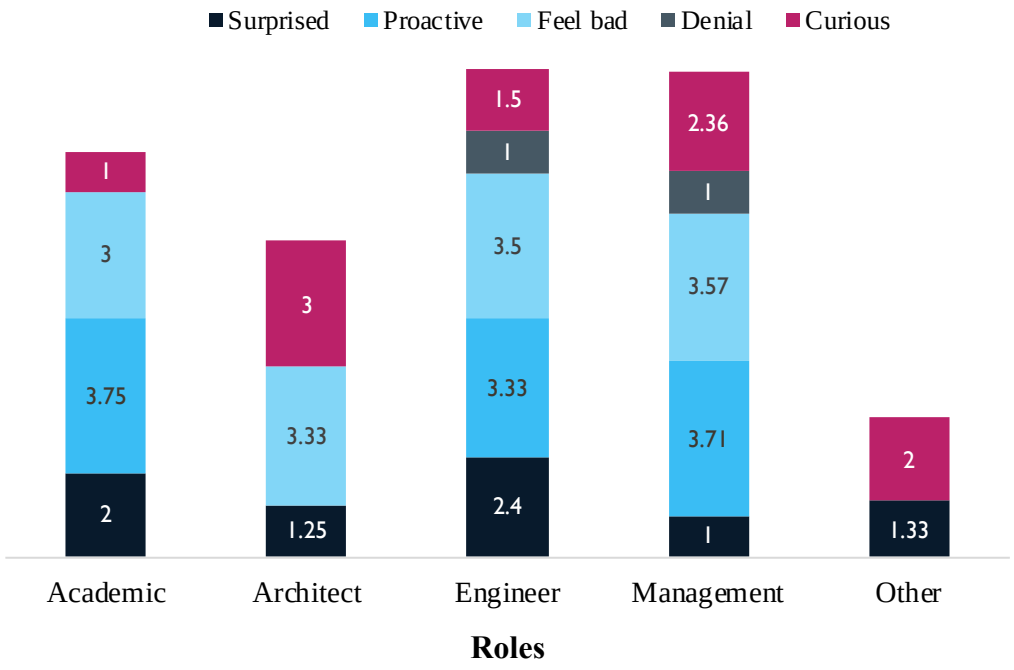

Figure 2. Percentage of reactions by role and familiarity with sand crisis.

4.4. RQ 3: Sources of Information about the Sand Crisis

Respondents who had prior knowledge of the sand crisis were asked to name as many sources of information as applicable. We then categorized the sources of information into six types of knowledge. Each type and an explanation of how we classified the sources are provided in Table 9.

Table 9. Types of knowledge of the sand crisis.

Type of Knowledge	Explanation (Created by the Authors)
Authority	From the word of experts
Education	From school, Certificate training
Experience	Personal and/or professional experience
Impersonal	More accessible and less effort
Intuition and logical reasoning	Sense and judgement in practical matters or the knowledge was captured directly from intellect
Personal networks	Relating to the private, nonprofessional aspects of the interviewee's life
Scientific approach	Establishing the knowledge through testing, experimentation, and research

As shown in Table 10, the most frequently cited types of knowledge were professional experience (20 times), the scientific approach (13), and impersonal (11). Authority, coming from trade publications and professional events, was mentioned by six interviewees. Personal experience and personal networks were mentioned three and four times, respectively. Formal education was mentioned by only two interviewees, and no one mentioned having learned about the crisis in sustainability certificate programs such as LEED, even though some interviewees reported having completed such programs.

Table 10. Types of knowledge about the sand crisis and interviewees' ID.

Type of Knowledge	Source of Information	Interviewee's ID
Authority	Trade publications and events by professional associations	7, 31, 36, 47, 52, 74
Education	College courses and seminars	24, 64
Personal Experience	Training courses provided by sustainability certificates organizations	None
Experience	Personal experience	46, 60, 62
	Professional experience	7, 17, 18, 21, 22, 23, 26, 29, 31, 33, 34, 46, 51, 52, 55, 56, 61, 62, 64, 68
Impersonal	Nonprofessional publications and podcasts, internet, and social media and tv (e.g., news articles, documentaries, podcasts, National Geographic, news magazines)	7, 31, 37, 47, 50, 51, 52, 57, 66, 67, 74
Intuition and logical reasoning	"That makes sense." "It's logical."	16, 42
Personal networks	Colleagues, friends, and family	13, 32, 38, 57
Scientific approach	Academic publications (scientific or peer-reviewed research)	7, 27, 28, 29, 30, 31, 39, 49, 50, 52, 55, 56, 74

We then examined the top three types of knowledge according to interviewees' familiarity with the sand crisis (Table 11). Professional experience was the primary source for the one individual who was extremely familiar, for the seven people who were very familiar, and the ten who were moderately familiar.

Table 11. Familiarity with the sand crisis and types of knowledge.

Level of Familiarity with Sand Crisis	Top Three Types of Knowledge
Extremely familiar	Professional experience (1)
Very familiar	Professional experience (7), scientific approach (3), impersonal (2), personal networks (1), authority (1)
Moderately familiar	Professional experience (10), scientific approach (8), personal networks (4), impersonal experience (3), authority (2), college courses and seminars (1), intuition and logical reasoning (1)
Slightly familiar	Impersonal (5), authority (3), college courses and seminars (2), personal networks (2), scientific approach (2), intuition (1), professional experience (1)
Not at all	N/A

Figures 3 and 4 depict the relationship between types of knowledge, roles, and familiarity with the sand crisis. Scientific sources and professional experience were found to be the dominant forms of knowledge across all roles, especially among those with a moderate level of familiarity (3 or higher) with the sand crisis. Additionally, in the "Other" role, one interviewee, despite being slightly familiar (score of 2), also highlighted the importance of the scientific approach as a valuable type of knowledge. This further emphasizes the significance of scientific sources in addressing the complexities of the sand crisis across various roles and levels of familiarity. Education was a source for one academic who was slightly familiar and one engineer who was moderately familiar. No academics, management, or other cited education as an information source. The category intuition and logical reasoning was cited by only two interviewees, who were an academic who was slightly familiar and a manager who was moderately familiar. Authority or the word of experts was cited by two engineers and four managers who averaged slight familiarity (2.5 and 2.7). Impersonal sources were cited only by three engineers and five managers, who averaged slightly familiar (2.4, 2.8). Personal networks was mentioned by three managers and the one other interviewee, all averaging slightly familiar.

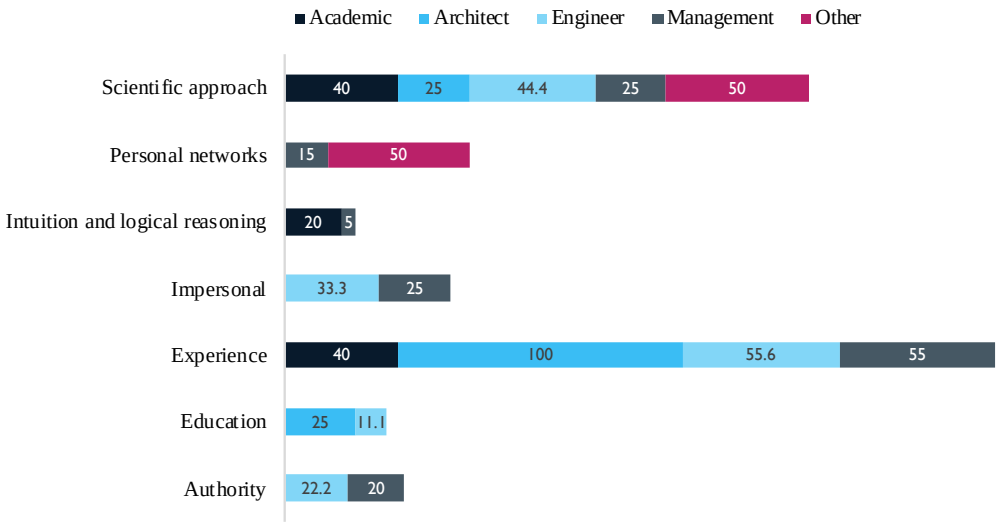

Figure 3. Percentage of types of knowledge by roles (Note: percentages exceed 100% due to multiple responses by interviewees).

Figure 4. Familiarity with the sand crisis by roles and types of knowledge.

5. Discussion

5.1. Summary and Analysis of Findings

The purpose of this study was to address three research questions: to determine the awareness of professionals in the US and Canadian construction industry of the global sand crisis, to understand the various emotional reactions upon learning of the crisis, and to determine sources of knowledge of the crisis. We drew upon the Cognitive-Affective-Conative model from cognitive psychology as the theoretical framework.

The research questions were motivated by findings from the United Nations [1,17] and other sources [12,37–39] that the world is facing a serious sand shortage and that sand mining is a highly important environmental issue that exacerbates climate change. The research questions were addressed through in-depth interviews with 75 construction professionals from across the US and Canada.

Regarding RQ 1, the findings indicated very low awareness of the global sand crisis. Only one interviewee reported being extremely familiar and nearly a third of the interviewees reported having no familiarity at all. In fact, nearly half of respondents were not at all or only slightly familiar with the crisis. Academics and managers were on average somewhat more familiar than architects and engineers, with over 40% of engineers having no familiarity. The findings of the study align with existing literature that emphasizes the lack of awareness regarding the environmental impacts of the construction industry and the importance of adopting green and sustainable practices [40–42]. The interviewees' dominant reliance on scientific sources and professional experience indicates recognition of the significance of accurate information and practical knowledge in addressing the environmental challenges associated with construction activities. Indeed, the findings of the present study align with research conducted by Oluwumi et al. [43] which emphasizes the inadequacy of experience, knowledge, and skills among construction professionals as a significant barrier to sustainability initiatives, and suggests that relying on professional experience and knowledge is crucial in overcoming barriers and promoting sustainable practices.

The absence of education as a commonly cited knowledge source among academics and management professionals supports the notion of the need for increased emphasis on incorporating environmental education and sustainability principles into academic curricula and professional development programs within the construction industry. The findings of our study align with the research conducted by Watson et al. [44] on the impact of university sustainability initiatives on environmentally responsible behaviors (ERBs) among students. Their study revealed that perceptions of legitimacy, which can be influenced by education and awareness efforts, significantly shape students' ERBs and further underscores the importance of education and awareness initiatives in promoting sustainable behaviors not only among students but also within the wider construction industry [45].

Regarding RQ 2, our analysis determined four main emotional reactions to learning about the crisis: surprised, feel bad, proactive, and denial. The reactions based on different levels of familiarity showed some level of consistency. In general, participants had a positive attitude towards sand sustainability. The one interviewee who was extremely familiar with the crisis and those who were very familiar expressed proactive and feel bad reactions, while most of those who were less familiar (moderately and slightly) were curious, surprised, and felt bad, with only one interviewee's first reaction being proactive. Those who had no knowledge about the sand crisis were surprised, curious, or expressed denial upon learning about the sand crisis. As for roles, the most frequent reaction by academics was proactive, surprise was the most frequent for architects and others, while curious was most frequent for engineers and managers. Industrial practitioners' attitudes and behaviors can hinder the promotion of sustainable construction, with a misalignment between sustainability concerns and proactive actions [45]. Construction employees in developing countries may be unaware of sustainable construction concepts and be resistant to change [46]. Limited knowledge, resistance to change, and a lack of demand from clients are identified as key barriers to sustainable construction [47]. The prevalence of proactive

attitudes among academics and the mixture of surprise, curiosity, and concern among different roles highlights the importance of addressing the sand crisis and promoting sand sustainability across diverse professional spheres.

Regarding RQ 3, how the interviewees learned about the sand crisis, the following types of sources were found: authority, education, personal and professional experience, impersonal, intuition and logical reasoning, personal networks, and the scientific approach. Professional experience was the most frequently mentioned source across all professional roles, followed by a scientific approach. Only two interviewees mentioned learning about the crisis from college courses and seminars. And none of the interviewees reported that the training courses provided by sustainability certificate organizations mentioned the global sand crisis. These findings highlight the diverse range of sources from which construction stakeholders learn about environmental crises and sustainability. Professional experience is a significant source of knowledge, indicating the importance of on-the-job learning and practical exposure in understanding and addressing sustainability issues in the construction industry. The scientific approach is also valued, suggesting that stakeholders recognize the importance of evidence-based information and research in shaping their understanding of environmental crises and sustainability.

5.2. Theoretical and Practical Contributions to the Sustainability Awareness Literature

This study makes significant contributions to the academic literature in a number of areas. Most importantly, this research fills a gap by combining both the cognitive aspect of the level of awareness of the global sand crisis and the affective aspect by conducting in-depth analyses of the emotional reactions to that phenomenon.

Additionally, this study contributes to the general topic of the importance of awareness of sustainability across a broad spectrum of topics in a variety of contexts. Recent examples include the need for awareness of sustainable waste management alternatives in the United Arab Emirates [48] and Indonesia [49], enterprises' green innovation practices in China [50], microplastics [51], and sustainable and mindful clothing consumption internationally [52]. All of these studies emphasize that while many potential solutions to these issues exist, a lack of awareness of the issues themselves is the initial challenge to address.

Further, studying the level of awareness provides a starting point for understanding sustainability issues and contributes to the sustainability attitude–behavior literature. This research did so by applying the Cognitive-Affective-Conative framework. The next step is to assess reactions or attitudes upon becoming aware of the issue, which we investigated as our second research question. Attitude is a psychological tendency that is expressed with some degree of favor or disfavor [53]. Different types of attitudes can be expected to elicit different types of intentions and behaviors, ranging from constructive action to apathy and inaction, to activities that run counter to sustainable practices (e.g., [54]). Research has long determined that a multitude of factors can affect the relationship between attitudes and behaviors in the sustainability space and that attitudes are not a clear predictor of behavior.

This study can be tied to findings in other areas of sustainability, such as behavior change toward energy sustainability [55]. Measuring change in sustainability behavior is complex and is a mix of anthropology, economics, human geography, politics, psychology, and sociology. Additional factors affecting the attitude–behavior relationship include government regulations and incentives, as well as company mission and strategy.

Third, our exploration of the various information sources about the sand crisis cited by construction industry professionals relates to the literature on the importance of opening up communication systems to address sustainability challenges [56,57]. It is important to note that while provision of information may lead to attitude change regarding environmental and energy issues, some studies have failed to find a significant impact on behavior from possession of information alone [29]. Our analysis of the emotional reactions to learning about the sand crisis suggests that tapping into such emotions in appropriate ways might be a moderating factor in the information–behavior relationship.

6. Conclusions

This study based on interviews with 75 professionals in the construction industry provided an in-depth look at the important sustainability issue of the global sand crisis.

Our study has unveiled several critical findings with implications for addressing the global sand crisis within the construction industry in the United States and Canada:

- Awareness Deficiency: The study underscores a pervasive and concerning lack of awareness regarding the global sand crisis across various roles within the construction sector, with engineers notably exhibiting a low level of awareness. In contrast, academics exhibit a higher level of familiarity due to their profession's inherent requirement to remain at the forefront of knowledge for research and pedagogical purposes. This suggests an opportunity to utilize academics as conduits for knowledge dissemination between academia and the industry, thus facilitating the process of addressing sustainability issues like the global sand crisis.
- Effective Educational Campaigns: Our research advocates for the implementation of educational campaigns targeting construction professionals to leverage their favorable reactions. Such campaigns should appeal to their inherent curiosity, mitigate feelings of distress, and offer avenues for proactive engagement in addressing the crisis.
- Information Dissemination Strategies: To enhance awareness and knowledge dissemination, a more deliberate and multi-faceted approach is warranted. This includes targeted efforts through sustainability certification programs and professional associations to ensure that relevant information reaches industry professionals effectively.
- Tailored Messaging Approaches: Diversified approaches must be adopted to target individuals with different reactions upon discovering the sand crisis. Appealing to reactions of curiosity, surprise, feeling bad, denial, and proactivity will require different approaches to engage stakeholders. Future research should explore the drivers and challenges of mitigating the sand crisis from the perspectives of various stakeholders, assessing the most pertinent messaging strategies to stimulate care and action.

One limitation of this study is that the interviews were conducted predominantly with academics, architects, engineers, and managers. It would also be valuable to determine the awareness, reactions, and information sources of other stakeholders such as regulators, NGOs, and contractors. A second limitation is that since the interviews were conducted in the US and Canada, it is not possible to generalize the findings to other parts of the world. In regions that are experiencing severe sand shortages, the level of awareness of the sand crisis may be greater and attitudes, information sources, and learning experiences may be different.

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