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Board 30: The Ecological Choice for Engineering Education: Decisions on Sustainability in Civil Engineering and the Impact of Cognitive Bias

Charlotte Robison, Oregon State University

Charlotte is a second year at Oregon State University studying civil engineering. Her main interests lie in sustainability within civil engineering, and has been conducting research on cognitive biases around this topic over the past year.

Cristina G Wilson, Oregon State University

The "Eco"logical Choice for Engineering Education: Decisions on Sustainability in Civil Engineering and the Impact of Cognitive Bias

1 INTRODUCTION

The global climate is changing. Natural disasters, increasing temperatures, and rising sea levels demand the need for civil engineers. The designs they create, such as green roofs [1],[2], help combat negative environmental change. Designs in infrastructure, like those we see in permeable pavements [3],[4],[5], help solve the problems concerning environmental damage that have already occurred. While there are guidelines for sustainability put in place by government agencies such as the Leadership in Energy and Environmental design (LEED) certification [6], civil engineers are the key decision makers when it comes to choosing how sustainable infrastructure should be. In order to appropriately educate and prepare the next generation of civil engineers to make decisions that will lead to a more sustainable future, research is needed on how engineers currently go about making such decisions. In particular, research on the potential cognitive biases that make civil engineers vulnerable to sub-optimal sustainable choices is necessary. In the absence of such research, there is a risk of civil engineers inadvertently designing unsustainable or unstable infrastructure because of flawed (but fixable) decision processes. We envision a future where civil engineers have the opportunity to receive educational curriculum or professional development training on disciplinary relevant problem solving, including instruction on bias awareness and strategies for reducing susceptibility to bias.

The goal of this paper is to provide engineering educators with a high-level understanding of the processes behind how civil engineers make more sustainable decisions. A systematic review of the existing literature on cognitive biases in civil engineering sustainability decisions is presented. We used the current research to draw conclusions about the need to implement decision-based curriculum for civil engineers. This type of curriculum is already seen in other domains where experts must make judgments that have broad, lasting, and highly consequential impacts (e.g., medicine [7],[8],[9],[10] and business [11]). The findings from our systematic literature review represent a first step towards achieving this educational future.

This review is organized as follows: the next section provides a brief background on the causes and effects of cognitive biases, as well as how understandings of bias have been implemented into professional development training and educational curriculum in other disciplines. Section 3 describes our research questions and review methodology, including search procedures and selection criteria for papers. We synthesize findings from the papers that passed selection criteria in Section 4. Finally, in Section 5, we discuss the implications of our review findings for engineering education and offer suggestions for future research on bias in civil engineering sustainability decisions.

2 BACKGROUND

2.1 Cognitive biases

Cognitive biases are systematic deviations from rational or “logical” decision making. Over 50 years of decision making research in cognitive psychology demonstrates that people are vulnerable to biases that arise from reliance on intuitive heuristics, i.e., rules of thumb [12],[13]. Heuristics are efficient in that they are prompted rapidly and with minimal effort, and, on most occasions, do lead to good decisions. However, there are some situations in which intuitive heuristic responses are inappropriate and fail to meet desired goals. For example, the status quo bias occurs when people make decisions based on a desire to keep things the way they presently are; this could lead to suboptimal decisions in civil engineering if the status quo promotes unsustainable infrastructure.

Research on vulnerability to cognitive bias has demonstrated that experts are just as susceptible to bias as laypersons, even in their domain of expertise. For example, business experts have been shown to be susceptible to framing bias, where superficial changes in the description of choice outcomes cause major shifts in people’s willingness to accept risks [14]; medical experts’ diagnostic decisions have been shown to be influenced by a number of cognitive biases [15] and, perhaps most relevant to the topic of this paper, energy systems experts’ estimates of the environmental impact of buildings has been shown to sub-optimal [16]. In sum, even professionals with years of training and experience will still make errors in judgment due to cognitive biases. As one of the co-fathers of heuristics and bias research tradition, Amos Tversky, once said: “whenever there is a simple error that most laymen fall for, there is always a slightly more sophisticated version of the same problem that experts fall for [17].”

2.2 Decision education in engineering and other disciplines

Given the demonstrated propensity for bias amongst domain experts, some fields have responded by introducing decision-focused curriculum. The goal of such educational interventions is to give decision makers techniques and tools to identify and overcome their biases. For example, it is increasingly common for medical schools to offer a course on cognitive bias and diagnostic error [7]. A study assessing the impact of decision curriculum on medical residents’ knowledge and recognition of cognitive biases found that residents were better at identifying biases and debiasing strategies post-curriculum [7].

To our knowledge, no such decision curriculum is offered in graduate engineering programs, specifically in civil engineering programs. The basis of the curriculum in other domains (like medicine) has been on the heuristics and cognitive biases shown to impact decision makers. Therefore, research evidencing susceptibility to bias by domain experts seems a necessary precursor to the development of the curriculum. In the next section we walk through a literature review that establishes how civil engineers are vulnerable to biases, in this case within sustainability. This research is essential to eventually build decision based curriculum around sustainability for civil engineers, and those in other other engineering disciplines.

3 METHODS

This section describes the method used to develop this literature review. We used a systematic approach to collect all publications relevant to our research questions and pre-defined inclusion criteria; this approach was modeled after a similar review about cognitive biases in software engineering [18].

3.1 Research questions

The research questions for this literature review are:

[RQ1] What bias types were being studied?
[RQ2] What are the heuristic antecedents of the biases being studied?
[RQ3] What method was used for studying the biases?
[RQ4] What outcome resulted from the method used for studying the biases?
[RQ5] What populations were studied?

3.2 Criteria

The criteria for this literature review are shown in Figure 1 and listed here:

a) Search all selected databases for keywords *Sustainability* AND *Cognitive Biases* for all years including 2022 and 2023. (See section 3.3.1) (retrieved 345 papers)
b) Manually remove all duplicated papers. (See section 3.3.2) (excluded 4 papers)
c) Screen the titles for relevance within sustainability, civil engineering, and cognitive biases. (See section 3.3.2) (excluded 318 papers)
d) Screen abstracts for further relevance within the scope of this literature review. (See section 3.3.2) (included 5 papers)
e) Use references and authors to snowball for more papers. (See section 3.3.3) (retrieved a total of 6 papers)

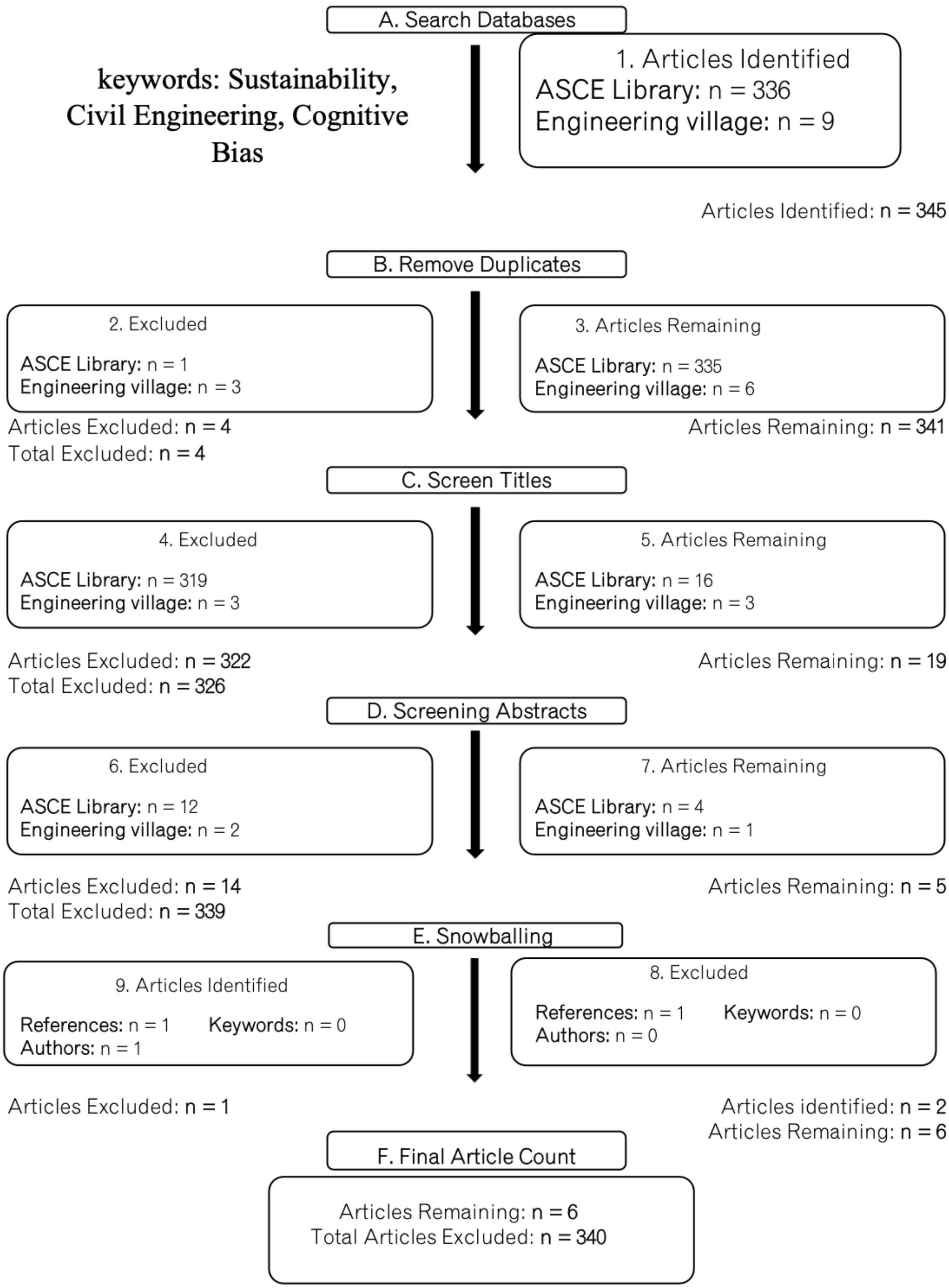

Figure 1: Literature review search flowchart showing the process of finding and eliminating papers for the review

3.3 Literature search

3.3.1 Database selection and string search formation

We determined a number of potential databases through which to conduct our search. Using preliminary search terms – "sustainability", "bias", "civil engineering" – we determined two databases that would provide us with the greatest number of relevant articles – ASCE and Elsevier. We used the string search "sustainability" AND "cognitive bias" after filtering for results within civil engineering – whether that be through using a source that is only dedicated to civil engineering publications (ASCE), or finding the subpage dedicated to civil engineering (Elsevier). The string search in the two databases produced 345 initial papers.

3.3.2 Primary selection

After obtaining the initial papers, we manually removed duplicates. This removed 4 papers, leaving us with 341 to screen. To screen, we used a two step process. First, we read all of the titles to ensure that they were related to civil engineering, sustainability, and cognitive biases. Many of the papers either only had one of the topics, or were construction papers. After screening the titles, we were left with 19 papers. From here, we read each of the abstracts with the following inclusion criteria:

1) The papers had original research (i.e., they were not literature reviews)
2) The research studied some sort of bias.
3) The bias studied was relevant to sustainability measures.

Using this inclusion criteria to screen the abstracts, we removed 14 papers and were left with 5 remaining.

3.3.3 Secondary selection

To find additional relevant papers, we examined the references cited by the 5 papers identified in the primary search, and also reviewed the bibliographies of the primary authors of the papers. Through this process we found 1 additional paper, for a total of 6.

4 RESULTS

This section addresses all our research questions (RQ1-RQ5).

4.1 What bias types (RQ1) were being studied, and what are the heuristic antecedents (RQ2)?

Across the 6 papers, a total of 8 different biases were studied (see Table 1 for bias types, definitions, and antecedents). Nearly all of the papers focused on a single bias type; except [19], which reported 6 different biases (this paper also used a distinct methodology from the others, see Section 4.2). *Status quo bias* was the only bias studied in all papers [19],[20],[21],[22],[23],[24]. The antecedent of status quo bias is reference dependence, where irrational behavior is driven by people evaluating outcomes and expressing preferences relative to an existing reference point. Reference dependence is also the antecedent of *social norms bias* and *professional bias*, which were assessed in [19]. Other biases assessed in [19] were *choice overload* and *information overload*, which have a shared attentional control antecedent (i.e., bias arises from overtaxing limited mental resources needed to direct attention); *temporal discounting*, which has a risk aversion antecedent (i.e., bias arises from an aversion to the uncertainty of future rewards); and *risk aversion bias*, which has a loss aversion antecedent (i.e., bias arises from feeling the pain of a loss more acutely than the pleasure of a gain of equal magnitude).

Table 1. Cognitive biases present in selected papers and their antecedents

Bias Type	**Definition**	**Antecedent**	**Studied in**
Status Quo	Preference to maintain current state, not undertake action to change state	Reference dependence	[19], [20], [21], [22], [23], [24]
Risk Aversion	Preference for certain outcomes over uncertain or ambiguous outcomes	Loss aversion	[19]
Social Norms	Tendency to behave in a way that is considered socially acceptable	Reference dependence	[19]
Choice Overload	Tendency to have difficulty deciding when given with too many choice options	Attentional control	[19]
Information Overload	Tendency to have difficulty deciding when given with too much information about choice options	Attentional control	[19]
Professional	Tendency to behave in a way that is considered acceptable in one's particular profession	Reference dependence	[19]
Temporal Discounting	Preference for immediate rewards over long term benefits	Risk aversion	[19]

4.2 What method was used for studying the biases and what outcome resulted from this method?

The majority of the papers (5 out of 6) used an empirical approach to assess a single bias by randomly assigning participants to either a control or treatment condition [20],[21],[22],[23],[24]. For example, in a empirical study of status quo bias [21], the control condition received the industry norm version of a sustainability rating system (Envision framework [25]), where points are gained (from a reference point of the minimum possible score) for making more sustainable infrastructure choices, while the treatment condition received a version of the system where points are lost (from reference point of near-maximum possible score) for *not* making sustainable choices. Amongst the 5 papers using an empirical approach, 4 used the Envision framework to assess bias [21],[22],[23],[24], with 3 of the 4 assessing status quo bias (and 1 assessing framing bias). The empirical study that did not use Envision [20] also assessed status quo bias, but instead provided decision making scenarios based on real world cases and asked participants to evaluate two infrastructure solutions (one sustainable, one unsustainable); participants in the treatment condition received additional information about a city council resolution that endorsed the use of green infrastructure. Across all empirical studies, there was strong evidence of vulnerability to bias, as demonstrated by statistically significant differences in choice behavior between participants assigned to the control versus treatment conditions.

One paper was unique in using a qualitative approach to assess multiple biases [19]. This paper used online questionnaires and in-person interviews from the Smart Energy Analytics Campaign [26] to assess the biases surrounding a new green energy software for monitoring buildings' energy efficiency [19]. Participants were asked about potential problems with implementing the software that could result in missed opportunities for energy savings. From these responses, the authors identified 185 barriers to software implementation, which were then coded to identify emergent cognitive biases (from a list of 50 possible biases). Approximately 30% of the 185 barriers were linked to at least 1 of 6 biases, showing that even when measured qualitatively, there is evidence of vulnerability to biases amongst engineers.

4.3 What populations were studied?

In half of the papers, the population under study was civil engineering undergraduate students [19],[20],[21]. In the other half of the papers, the population under study was civil engineering experts, defined as post-baccalaureate engineers currently working in a civil-related field. [22],[23],[24]. There was no study that explicitly compared a population of students to experts, although the qualitative study assessing multiple biases (discussed in Section 4.2) involved experts from not only civil engineering but also other domains (e.g., real estate, healthcare, finance, K-12 education). Amongst the empirical studies, both student [19],[20],[21] and expert populations [22],[23],[24] were found to be susceptible to status quo bias, while framing bias was only assessed (and observed) in an expert population [24].

5 DISCUSSION OF RESULTS AND CONCLUSION

This review finds strong evidence that civil engineers are vulnerable to bias during sustainability decision making. All 6 papers demonstrated that seemingly inconsequential changes in the presentation of choice information can systematically alter the way civil engineering students and experts make decisions: e.g., by changing the sustainability scoring system reference point [21], [24]. Both civil engineering students and professionals were shown to be susceptible to biases, demonstrating that expertise is not necessarily protective against bias vulnerability.

To combat the influence of bias in civil engineering decisions and improve sustainable choice outcomes, it is important to educate students and professionals on how they make decisions (heuristics and biases). At present, bias training for engineers is generally limited to social biases (e.g., gender or racial discrimination), and occurs after entering the professional workforce. We believe engineering disciplines should follow in the footsteps of the medical field, and incorporate decision curriculum into graduate school training [7],[8],[9],[10]. The more we educate students around the impact of bias on engineering decisions early in their training, the more aware they can be of their biases. Being aware is the first essential step for a decision maker to recognize and overcome their biases.

What would this new engineering decision curriculum look like? While another, more specific study should be done to determine the most effective way to educate civil engineering students on biases and how to reduce them in professional practice, we can form an initial idea, basing the curriculum on existing courses [7],[8],[9],[10]. Using these studies, primarily focused in the medical field, we can extrapolate a few key components of educational curriculum. The main components we found in these studies were: curriculum that had students identify biases in certain case studies or clinical trials [8],[9], small group discussion [9],[10], and evaluation of students ability to reduce bias post-curriculum. In these studies, researchers looked into the current bias training for medical students and found that students who worked in groups to discuss potential biases were more successful in reducing their own biases. While these findings are not directly related to civil engineering, they can be used as a foundation for future research and course design.

To truly build an engineering decision curriculum, additional research is needed on the heuristics and biases impacting engineers; in particular, research on a greater breadth of biases using new ecologically valid methods. In the current review on bias in sustainability decisions, all the papers were focused on status quo bias and the methodological approach to studying bias was highly similar across most. One likely reason for this is that all papers are authored or co-authored by the same individual. This highlights the need for more diverse contributions on the topic of engineering and sustainability decision making.

Sustainability decisions are particularly important for engineers to understand, so that they may better meet the growing demands for more “green” infrastructure. It is important for the climate that our infrastructure conserves energy and reduces pollution while minimizing the depletion of natural resources. Cognitive bias can unknowingly and unintentionally prevent civil engineers from making the most sustainable choices to meet these infrastructure goals. It is therefore vital that future civil engineers are educated on cognitive bias and learn how to best structure and engage with their environment to promote good decision making. How best to teach decision-focused engineering curriculum and what kind of content, guidance, and practice to offer is an important question for future engineering education research.

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