This paper synthesizes the literature on indigenous ways of doing or what we call ethno-engineering. Western literature on indigenous knowledge is expansive, yet a deliberate focal point and explicit conceptualizations on ethno-engineering in indigenous literature are slim. In this paper, we have collected scholarly literature on indigenous knowledge and synthesized articles specifically on ethno-engineering. We have exemplified this literature with several published case studies in order to contrast indigenous-engineering with Western-engineering. Our literature review methods proceeded in two phases. During the first phase we accumulated relevant sources (N=89), compiled these in a database, and coded them with an eight-item framework. In the second phase, we sampled literature from the initial database (N =32) and coded these items more extensively using an inductively developed coding scheme. In addition, this paper includes four case studies highlighting indigenous engineering practices and associated principles. Our intent was to contribute to a starting conversation on indigenous engineering, bringing it to the forefront of social justice engineering discourse.

KEYWORDS: engineering, indigenous knowledge, ethno-engineering

Disclaimer: This paper was written by two authors who grew up in the developed part of the Western world with experience in different countries and cultures within the developed Western world and to a limited extent in the southern hemisphere world. One of the authors brings with him an academic background in engineering. The other author brings a background in education and Religious Studies, a field of study concerned with the cultural phenomenon of religion, not the doctrine of a particular religion. Both received academic training in philosophy. The frame of reference for this paper is mixed as it draws from the literature of the social justice and engineering reform movement within the United States and from literature, which originated on an international level such as UNESCO and locally at different places around the world. We are cognizant that our backgrounds impact how we frame this paper and do not presume to have escaped them; we attempt to reflect at our personal and professional mindsets, along with our own cultures’ presumptions about indigenous cultures. Our focus on indigenous knowledge could be perceived as a secondary form of colonialism, this time robbing the cultures of their knowledge and innovative processes. For us, by looking at what we can learn from indigenous cultures we attempt to de facto reverse existing prescribed roles making us, as “Westerners,” the listeners and learners in this situation. While our approach and mindsets might be interpreted as naïve, we argue that they are respectful, as we are explicitly conscious that our own cultural norms, including our research approach, may not do justice to other cultures, and our findings are at best approximations.

1 The authors would also like to note that they shared equal authorship for this paper.
INTRODUCTION

In recent research and policy documents of the developed world, we see an increased appreciation that engineering as a practice can contribute to social justice (Leydens, Lucena, & Schneider, 2012; Riley, 2008) and responsible development (Roco, 2005). Organizations such as the U.S. National Academy of Engineering have asked for stronger integration of environmental sustainability into the engineering curricula (National Research Council, 2009) and as Deanna Richards from the National Academy of Engineering (1999) points out, the shift to more sustainable engineering not only requires a major rethinking of current practice but also “human creativity and technological innovation” (p. 16). This emerging trend in engineering is embedded in a larger trend within Western culture today, in which we see a resurgence of emerging grass-root practices such as urban farming, community gardening, engineering service projects, and recycling art—to name a few (Fuad-Luke, 2009)—which has coincided with a long term interest in indigenous knowledge (Hinkson, 2003). In order to infuse and enlighten emerging engineering practices and engineering education in the western world, we turn to a potentially rich source: indigenous knowledge/practice, or ethno-engineering. These terms are discussed more fully below.

Our primary objective in this review is to explore engineering methods that indigenous people employ for their subsistence. These engineering components have not been systematically and explicitly reported in existing literature. This study aims to synthesize literature, which implicitly discusses indigenous- and ethno-engineering and to answer the following questions:

1. What indigenous ways “of doing” or engineering practices are represented in contemporary scholarly literature?
2. What are the sustainable implications of these indigenous ways of doing?
3. How does “ethno-engineering” compare to more Western oriented modes of engineering?

Operational Definitions

Defining “indigenous” and “indigenous knowledge and practice”

In defining indigenous we enter a contentious, intellectual, emotional and social space due to the many existing, often competing dimensions and perspectives, which rest on different definitions of cultural identity, law, autochthony and colonial history. Following a cautionary approach by the World Bank (2006) to not “put forth a rule of what does or does not constitute indigenous” because “that would contribute little and only invite controversy over perceived errors of inclusion or omission” (p. 2), we are defining indigenous rather by (1) the way of knowing and (2) forms of practice and processes than by political and legal dimensions or historical definitions of identity. Unfortunately, indigenous systems of knowledge and practice are often labeled “not by what they are but what they are not” such as “pre-modern” or non-scientific (Prakash, 1999, p. 157). This negative definition leads to an unnecessary dichotomy between Western and non-Western societies, where Westerners “think of Western science as science” (Selin, 1992, p. 11) and other forms of knowing as inferior. In the Western realm, scientists and engineers tend to show a worldview that perceives the environment in a way that “enable(s) them to understand and control the outside world” (Semali & Kincheloe, 1999, p. 25) and so “science-based societies have tended to overuse and simplify such complex ecological systems, resulting in a whole series of problems of resource exhaustion and environmental degradation” (Gadgil, Berkes, & Folk, 1993, p. 151). Our work takes Herrmann’s (2005) stance that “western knowledge is not in essence superior to traditional knowledge; both are complementary and have to mutually enrich each other, rather than replace each other” (p. 132).
To describe in more detail indigenous know-how and practices, we rely on several definitions, which focus on practice. The United Nations Environment Program (ca. 2007) defines indigenous knowledge (IK) as follows:

...the knowledge that an indigenous (local) community accumulates over generations of living in a particular environment. This definition encompasses all forms of knowledge—technologies, know-how skills, practices and beliefs—that enable the community to achieve stable livelihoods in their environment. A number of terms are used interchangeably to refer to the concept of IK, including Traditional Knowledge (TK), Indigenous Technical Knowledge (ITK), Local Knowledge (LK) and Indigenous Knowledge System (IKS). (para. 1)

A closer look at “engineering”

In order to contextualize ethno-engineering, we need to further elaborate on the conventional framework of engineering practice. We argue that ethno-engineering faces a conundrum when situated within traditional and even contemporary definitions of engineering such as the following: “Engineering is the application of mathematics and science in service to humanity and as a bridge that connects the sciences to the humanities” (Grasso, Callahan, & Doucett, 2004, p. 413). This definition incorporates two aspects of popular notions of engineering: (1) the application of mathematics and science and (2) the social relevance and responsibility of engineering decisions. Exploring further, when Pawley (2009) assessed faculty members’ responses to the question, “What is engineering?” three “universalized narratives” emerged with one group defining engineering as “applied science and math . . . problem-solving . . . and making things” (p. 317). The first characterization presupposed that engineering is rooted in and dependent on mathematics and science and “helped society more than science”; the second that engineers solved “problems that mattered”—leaving the question, “Mattered to whom?” answered as, “Society”; and the last grouping “connected engineering to the physical construction of highly technical and mechanized products” (p. 317).

Both the definitions presented by Grasso et al. (2004) and Pawley (2009) seem to be aligned and necessary for the proper function of any society, indigenous or modern. However, even in these seemingly socially conscious and all-encompassing or “universalized” definitions, engineering is partially defined by what Oldenziel (2000) calls the “cultural authority of math and science” (p. 20). This hegemonically prescribed dominance of mathematics and science, by definition, excludes alternative or non-Western ways of knowing. Any definition of ethno-engineering must be inclusive to different forms and representations of knowledge. To articulate such a definition, in the next section, we introduce the term “ethno-engineering” to define alternative ways of knowing and doing to combine our understanding of indigenous and engineering.

Introducing “ethno-engineering”

According to Pacey (2008), when we apply “engineering” to a “non-Western” context “the word ‘engineering’ is best limited to construction works” such as “fortifications, monuments, and water management” (p. 748). Pacey continues: “the smallest of such works, as carried out by individual house builders or farmers practicing irrigation, may often be better considered in other contexts, such as ‘building’ or ‘agriculture’” (p. 748). Jodha (1990) introduced the term ethno-engineering, which he refers to as “local resource-centered diversification being interlinked activities” which are “supported by systems of self-provisioning, on-farm storage, and recycling” (p. 67). He continues to suggest that “this approach not only serves sustenance needs in a relatively closed system (due to

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2 Referring to the title of Pawley’s 2009 paper: “Universalized narratives: Patterns in how faculty members define ‘engineering.’”
inaccessibility), but has potential to benefit from heterogeneity of the resource base without damaging the fragile and marginal resources” (p. 67). Mukerji (2009) is one of the first written documents introducing the term “indigenous engineers” when describing the role of mountain dwellers in building the Canal du Midi in the South of France (p. 14, 119, 153, 189). She describes particularly the conflicts between the existing class of engineers (French royal corps of engineers) and the localized and sophisticated knowledge of peasants.3

Jodha (1990, p. 67) and Reij’s (1991, p. 4) definitions limit ethno-engineering to the very specific context that they were working in: “... such practices as terracing mountain slopes, harnessing the runoff and developing small drainage systems” (Reij, 1991, p.4). Although never systematically defining the term, Mukerji’s use of the term indicates that ethno-engineering is similarly highly contextual—in this case the context of mountain farming—yet boundaries of indigenous engineering are implicitly broader than Jodha's (1990) or Pacey's (2008) describing a class of practices and attitudes to be observed at different places.

Ethno-engineering or indigenous practices may define “right” in a spiritual, cultural, or sustainable context that does not necessarily involve Western-style advanced mathematics, a formal degree, or the maximization of economic profit. Indigenous ways of doing are highly empirically evolved through observations of nature for hundreds to thousands of years. Due to its lack of advanced Western mathematical, scientific and technological knowledge it could easily be argued that an indigenous perspective could very well contribute to the “definition of the problem” yet might be less usable for the “solving of the problem.”4 We, however, argue that indigenous engineering could and is contributing to both the definition and the solution of the problem.

The question remains, why we chose to use the term “engineering” to label practices in an indigenous context, especially if the practices stand in contrast to existing definitions and practices of engineering? To put it simply, considering the “status-minded community of engineering educators” (Noble, 1977, p. 45) and engineers, defining indigenous practices anything short of engineering and hence not using the term explicitly would be contradictory to the premise of our paper that Western and indigenous knowledge and practices are equal in value and complementary to each other.

For the remainder of the paper, we use the term ethno-engineering to define a broader class of practices in the following working definition: a method of defining and solving complex issues with constantly evolving deep experiential knowledge of the environment, without utilization of modern mathematics, science and technology, relying on bottom-up management, practicing resourcefulness, and being contingent upon a holistic worldview.

**THEORY & BACKGROUND**

We perceive indigenous knowledge as a realistic source of inspiration for environmentally sustainable engineering practices. Mazzocchi (2006) suggests that indigenous societies are more interested “in preserving their own social, cultural and environmental stability and integrity than in maximizing production. Consequently, there is commonly no ‘exploitation’ of nature” (p. 463) within indigenous societies, although this is by no means the rule. Likewise, natural resource management is often based on shared meanings and knowledge and avoidance and reduction of waste (Berkes, Colding, & Folke, 2000). Indigenous societies do not see themselves separated from

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3 A more detailed account is presented in one of the case studies later presented in this article.
4 See Lucena and Downey (2006) for the distinction.
nature. Indigenous people “(a) have a long history without apparently disrupting ecosystems, (b) have a rich inventory of traditional environmental knowledge, (c) have specific management practices based on such knowledge about nature, and (d) have religious beliefs about ritual uses of animals and plants that safeguard their sustainable use” (Selin & Kalland, 2003, p. 3). Compared to western sciences and epistemologies, indigenous knowledge relies strongly on intuition, directly perceivable evidence, and an accumulation of historical experiences (Farrington & Martin, 1998) acquired through learning-by-doing, or knowledge-building through experimentation (Berkes & Berkes, 2009). Often-times, existing indigenous engineering strategies have proven to be environmentally sustainable (Apffel-Marglin, 1998; Diemont et al., 2006; Herrmann, 2005) and although the explicit notion of sustainability may be absent, implicitly, sustainability concerns are commonly present in the broader holistic worldview of the indigenous people (Blaser, Feit, & McRae, 2004; Loomis, 2000).

It comes as no surprise to us that disciplines such as medicine, conservation biology and ecology—to name a few—have researched indigenous knowledge systems extensively. However, it is surprising that engineering has not done similarly (Ross, Sherman, Snodgrass, & Delcore, 2010). A cursory examination of existing literature about indigenous knowledge reveals an emphasis on indigenous science, medicine and ecological practices and only a small amount of studies conducted on indigenous technical knowledge and indigenous technologies. Although an explicit dialogue on indigenous engineering strategies is rare, much of the discussion on indigenous technical knowledge is akin to contemporary understandings of engineering practice.

The body of literature pertaining to indigenous knowledge, or indigenous ways of knowing, has been and is still rapidly growing. In 1992 Helaine Selin published an annotated bibliography of “Non-Western” sciences titled Science Across Cultures with more than 800 references, and in 2008 published the Encyclopedia of the History of Science, Technology, and Medicine in Non-Western Cultures with thousands of entries. The Indigenous Peoples’ International Centre for Policy Research and Education, also known as Tebtebba, has developed a website to disseminate information aimed to aid the indigenous movement (http://www.tebtebba.org/). The World Bank Group has developed a website titled Key Resources for Indigenous Knowledge and Practices which presents methods of integrating indigenous knowledge into development projects (http://www.worldbank.org/afr/ik/key.htm). UNESCO has also developed a database titled Best Practices on Indigenous Knowledge (http://www.unesco.org/most/bpikreg.htm). In all of these resources the term “engineering” is rarely used, if at all.

Indigenous knowledge for technology creation was accumulated through generations and passed down to the next generations (Krug, Berhanu, Yohannes, & Kefeni, 1996; Reij, Scoones, & Toulmin, 1996), principally through verbal transmission from elders’ experiences. This does not mean that these specifications are invalid or “inferior” simply because they are unwritten. The existing scholarly literature about indigenous knowledge focuses particularly on agricultural production and resource management. Indigenous authors tend to explicitly attribute the oppression their own indigenous societies have faced to colonization and globalization (Beijing Declaration of Indigenous Women, 1995, p. 2; Blaser et al., 2004, p. 28). Issues especially begin to arise as Westerners extract resources, pollute waters or expand monoculture on lands held sacred by indigenous societies, depleting the resources indigenous communities depend on or find spiritual value in.

Indigenous knowledge and ethno-engineering are “inseparable from larger worldviews” (Semali & Kincheloe, 1999, p. 40), including a spiritual component that seems elusive and might sound foreign to “enlightened” Western ears. Western dominant worldviews tend to be more individualistic than
collectivistic with a focus on personal well-being. Meyer (2008) calls this Western model “shackles of ignorance” that “could be snapped via ideas that (are) indigenous and authentic” (p. 217). What Meyer discusses is an “indigenous epistemology as viewed by Native Hawaiian mentors, friends, and family” with the underlying premises that “specificity leads to universality,” “knowledge that endures is spirit-driven” and knowledge is not simply learned “about land” but rather “best from land” (pp. 217–219). This does not suggest there is a division between mind, body, and spirit, but that, “Our mind is our body. Our body is our mind. And both connect to the spiritual act of knowledge acquisition” (p. 222). Therefore, in our search we are conscious that integrating indigenous worldviews into contemporary engineering practices will inevitably produce larger tensions and discourse on the role of religion, spirituality and worldviews in the work of engineers.

From the modern Inuit of Canada (Oliver, 2003) to one of the only indigenous societies to overthrow their government, the Kuna of Panama (Hoehn & Thapa, 2009, p. 430), the knowledge of indigenous cultures is being extensively studied, while the relationship between indigenous knowledge and engineering is sparsely found. It is hard to imagine that indigenous peoples that have thrived throughout millennia have done so without some sort of “engineering.”

**METHODOLOGY**

This research project follows guidelines set for literature review research (Hart, 1998), its own genre of analyzing and synthesizing large bodies of research. The research proceeded in two phases.

**Phase 1**

Figure 1 shows an overview of the Phase 1 procedure of collecting literature:

![Figure 1: Phase 1 Literature Collection](image)

The project started with an initial search for indigenous engineering and ethno-engineering related literature. The sources gathered during the literature collection stage helped gather more sources, a process known as Type 1 reading. Synonymous or similar terms for “indigenous” were recorded and used to obtain more sources (e.g. Native, First Nation, Local, Traditional, Aboriginal, Fourth World, and in some instances Non-Western, Rural, or Ethno-terms). Given the limited results from “indigenous engineering,” the search for material using synonymous terms was the most viable means of discovering relevant literature.
Table 1: Phase 1 Literature Review Criteria

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
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<tbody>
<tr>
<td>1</td>
<td>How relevant is this article?</td>
</tr>
<tr>
<td>2</td>
<td>How technical . . .</td>
</tr>
<tr>
<td>3</td>
<td>Are case studies included?</td>
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<tr>
<td>4</td>
<td>Are visuals provided?</td>
</tr>
<tr>
<td>5</td>
<td>Is the text credible?</td>
</tr>
<tr>
<td>6</td>
<td>Is the article scholarly?</td>
</tr>
<tr>
<td>7</td>
<td>Are materials renewable, non-renewable, or both?</td>
</tr>
<tr>
<td>8</td>
<td>Is the author(s) Indigenous, Western, or both?</td>
</tr>
</tbody>
</table>

Next, during “Type 2 Reading” we inductively developed a coding scheme, as shown in Table 1. We added literature to a database and coded each article based on an eight-item framework.

The “Relevance Score” gauged the relative amount of technical discussion within an article that might be considered engineering-like. If engineering practices were only discussed briefly, the score would be recorded as a 1. If the focus of the article was on the engineering-like strategies employed by the indigenous communities, the score would be ranked 10. The “Technicaity Score” gauged the level of emphasis an article put in explaining how the engineering strategy operated.

Codes 3 and 4 were matters of fact. Codes 5 and 6 were binary and Code 7 was tri-lateral, each being questions that required value judgments. We defined articles as credible (Code 5) if they included references which could be followed to other sound articles (e.g. if articles lacked sources or only cited internet articles, we considered them un-credible). We defined articles as scholarly (Code 6) if they were published in scholarly journals and/or included novel results obtained from following a specified methodology. We determined the type of materials used (Code 7) by relying on the author’s word.

Lastly, we determined whether authors were indigenous, Western, or both (Code 8) by examining biographies included within the text when possible. If this was not possible, we conducted an Internet search. The purpose of this code is to determine whether the author conducted his or her research from the “outside looking in.” It was possible that an author defined his or herself as “both.” This is a unique tension, which involves balancing multiple identities, as Brayboy (2000) explains in detail. Note that it was also possible that an author defined his or herself as Western while disregarding a native or indigenous upbringing.

These attributed scores are subjective in nature. To enhance rigor of assigning codes and reliability of value judgments two students collaborated for each found article.

Phase 2

Phase 2 involved a redevelopment of the initial database, a more in depth coding system, and a second literature review analysis. We eliminated sources that had low “Relevance” scores, low “Technical” scores, or sources that did not present specific case studies. We also looked for “Specificity” in this round. We analyzed indigenous-society-specific ethno-engineering-related case studies which included technical aspects of the engineering practices. A maximum of two sections from a given book source were uploaded into this database in order to minimize categorical shifts. For example, including numerous sources from Howard (2003) would cause the category “Role of Women” to greatly shift.

The final Phase 2 database is set-up to include, Continent, Country, Locality, and Name of (indigenous) People as well as bibliographic information pertaining to the source. The coding schematic is discussed in Figure 2, with explanations of each category.
Figure 2: Phase 2 Coding Schematic

A. What was the engineering discipline?
   1. Agricultural/Biological (ABE) — farming practices, resource management systems, etc.
   2. Civil — structural systems, architectural considerations
   3. Hydraulics — irrigation systems, water management strategies
   4. Materials — items manufacturing
   5. Industrial — trading and systems optimization
   6. Education* — A merger of ethno-engineering related material and education
   7. Biomedical* — Knowledge of local resources used to cure particular diseases, the collection and upkeep of such resources

B. What was the specific practice? We subdivided practices to show what subset of engineering the literature represents. Although agricultural sources might have discussed irrigation or other civil engineering-related techniques, we considered such sources primarily agriculture.

C. How specific was an article? We labeled literature as “Single” when the author(s) discussed one community of Indigenous people or locality. We labeled literature as “Few” when the authors discussed and differentiated between two or three groups or localities. Anything broader in scope we scored as “Many,” such as literature that included numerous Indigenous groups within a region. Literature not specific at all was removed from the Phase 2 Database.

D. Was the literature taxonomic? Did the literature perform statistical analyses or develop classification schemes to obtain results? These may be folk taxonomies or scientific ones.

E. What type of resources did the community require for the practice? If resources were primarily available within the “local” community we labeled the source as “Local.” When communities depended on both imported and local resources we labeled these as “both.” For example, in agricultural literature, farmers may have used seedlings from a distribution center along with their own seeds, or industrial pesticides along with manure.

F. What was the primary source of power used by the people? In many cases Indigenous inhabitants had access to modern technology. Despite this, the use by the Indigenous inhabitants might have been minimal. Such cases we labeled as “Human Power.” We did not code resource management or entrepreneurial practices when energy use was not a focal point.

G. Was the influence or role of worldview on engineering decisions considered important and/or extensively discussed?

H. Was the practice sustainable? Does the author explicitly state if a practice was sustainable? Often this was not explicitly mentioned. We considered ethno-engineering sustainable when the author suggests external influences such as colonization led to the demise of the system after it was in place for long stretches of time. In cases where the author did not hint whether the system was sustainable or when the question was irrelevant we marked as “N/A.”

I. Did the populace participate in a local or global economy? We labeled literature as “Yes” where the authors discussed any form of trade between Indigenous communities.

J. Was the author Indigenous, Western, or both?

K. Was the role/engineering strategies of women in particular explicitly discussed?

L. What type of management is there overlying the practice? We labeled sources as “Bottom-Up” when people made their own decisions at the home level or control was decentralized. We scored “In-Between” when the literature was in between bottom-up and top-down (e.g. community management systems with specific representatives deciding what land is used for what, chief hierarchies). We labeled literature as “Top-Down” when a centralized government agency made all/most community decisions.

* Neither Education nor Biomedical were present in the Phase 2 database but were included in Phase 1
The same two students that developed the Phase 1 database worked on the Phase 2 database. Coder 1, a PhD student in Engineering Education, went through and coded all 32 sources remaining in the database. Coder 2, an undergraduate student in Mechanical Engineering, then went through 10/32 sources and coded independently. 96/120 codes were coded identically, generating an inter-rater reliability score of 80%.

RESULTS

Phase 1 Results
During Phase 1, 88 sources were uploaded with an average Relevance of 7.1/10 and an average technical score of 6.0/10. The literature was published from 1942–2010 with 86.3% of the articles being published between 1990 and 2010. The majority of data stemmed from agricultural related fields (47.7%) and were coded as agricultural and biological engineering sources. The next most common fields include civil engineering (20.5%; primarily articles related to structural components), industrial engineering (10.3%), and hydraulics engineering (8.0%). Other fields covered included materials, mechanical, biomedical, and engineering education. These articles ranged throughout the entire world, with a large amount coming from Asia (29.0%) and Africa (27.5%). When the materials used by ethno-engineers were discussed, renewable resources were dominantly utilized (78.3%). This is largely because indigenous persons tend to use locally available materials. The authors included in this literature generally defined themselves as Westerners (85.2%) which means literature is generally conducted from the “outside looking in.”

Phase 2 Results
The relatively low technical and relevance scores from Phase 1 stimulated the need for removal of sources not directly related to engineering. We included 32 sources in this database (see Appendix for complete list) and coded these based on the Phase 2 criteria given in Figure 2. Table 2, which provides a summation of our findings, shows the number of times each Phase 2 code was employed and a relative percentage for the given category. Only articles which specified the indigenous populace(s)—as opposed to simply mentioning numerous practices without reference to an indigenous people—were included in the Phase 2 database. As Figure 3 shows, the geographic distribution of the scholarly literature on indigenous engineering was not limited to any single continent, suggesting that exemplary ethno-engineering practices are not specific to any locality.

Note that a single publication may be coded across multiple categories, when the specific category does not include mutually exclusive items. The literature was primarily related to agricultural engineering, although other engineering practices were also present, including civil, hydraulics, materials, and industrial engineering. The specific practices emphasized in the article were highly variable, as shown in Table 2.
More than 80% of the practices discussed included the usage of local resources, and none of the articles discussed strictly the usage of imported materials. More than 65% of the articles suggested the populace participated in some sort of economy, trading goods for their engineered products. Most commonly, the source of power for the engineering practice was human power, although in a few cases animals or machines were also used. More than half of the articles suggested the practice was sustainable, and none of the articles suggested the practice was NOT sustainable (note that this does not mean that all articles included practices proven to be sustainable). The role of female engineers was discussed quite highly, explicitly appearing in nearly half of the articles. Similarly, the role of the indigenous people’s worldview was discussed in nearly half of the articles.
**Case Studies**

To provide depth to the results of the literature review, in the following sections we present four ethno-engineering case studies. The purpose of these case studies is to highlight the sustainable implications of the selected ethno-engineering strategies, how Western-oriented assimilating tendencies might negatively impact the thriving of ethno-engineering practices, and the diversity of ethno-engineering practice included within the Phase 2 database. The case studies present a variety of ethno-engineering be it (1) geographic diversity (North America, Asia and Europe), (2) the role of women (for example specifically as part of a female role), (3) the engineering practice involved such as resource management, manufacturing or construction work. Similarly, the case studies differ in the lessons they include about ethno-engineering (see summary in Table 3).

<table>
<thead>
<tr>
<th>Attributes/Cases</th>
<th>Tidal Pulse Fishing</th>
<th>Citrus Ants</th>
<th>Coconut Kerala</th>
<th>Canal du Midi</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Discipline</strong></td>
<td>Agric./Bio</td>
<td>Agric./Bio</td>
<td>Materials/Industrial</td>
<td>Civil/Hydraulics</td>
</tr>
<tr>
<td><strong>Resources</strong></td>
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<td>Insects; Lumber</td>
<td>Plants; Machines</td>
<td>Water; Stone</td>
</tr>
<tr>
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<td>China</td>
<td>Kerala, India</td>
<td>France, Europe</td>
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<td><strong>Context</strong></td>
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<td>Non-western</td>
<td>Non-western</td>
<td>Western</td>
</tr>
<tr>
<td><strong>Gender focus</strong></td>
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<td>Not specified</td>
<td>Specifically female</td>
<td>Specifically female</td>
</tr>
<tr>
<td><strong>Practice</strong></td>
<td>Resource management</td>
<td>Ecosystem management</td>
<td>Manufacturing</td>
<td>Construction</td>
</tr>
<tr>
<td><strong>Improvement area</strong></td>
<td>Process/Structure</td>
<td>Process/Structure</td>
<td>Process/Artifact</td>
<td>Process/Structure</td>
</tr>
<tr>
<td><strong>Synthesis / Lessons</strong></td>
<td>Transformation of the natural environment for subsistence, with concern for sustainability</td>
<td>Replacement of indigenous solutions by Western agricultural practices and its ramifications</td>
<td>Indigenous technology co-developed with Western counterpart</td>
<td>Local knowledge proved superior to contemporary engineering practices</td>
</tr>
</tbody>
</table>

1. **Tidal Pulse Fishing at Prince of Wales Archipelago in North America**

This case study deals with a coastal Alaskan indigenous community, the Tlingit, and their techniques of catching salmon and is a shortened summary of Langdon (2006). The first recorded European observation of the Tlingit techniques, by French explorer Jean Philippe La Perouse, notes that with these Tlingit techniques "healthy runs of fish were returning to the streams in conjunction with these sophisticated technologies" (Langdon, 2006, p. 22). These techniques were therefore sustainable as the Tlingit used selective harvesting methods and did not overexploit the salmon populations. As is the case for most indigenous resource management strategies, "this approach to harvesting salmon relies upon a local cultural explanatory framework that combines detailed ecological knowledge of specific fishing sites with a cosmological explanation of fish behavior in which the fish turn downstream and 'give themselves' to the fishers" (Menzies, 2006, p. 15).

One of these technologies, intertidal salmon fishing, depended on the alterations between high and low tide. Oral tradition credits the brown bear for teaching the Tlingit this method of fishing, as they watched the "bears fish at natural intertidal pools holding salmon" (Langdon, 2006, p. 28). Two different types of materials used by the Tlingit led to two types of intertidal fishing structures,
some all of stone, some all of wooden stakes, and often-times a combination of these two local resources (p. 29). Here we discuss only the stone structures.

One stone structure used by the Tlingit was the weir. These weirs were essentially stone walls spanning a cross-section of a stream in the "intertidal zone of small streams on the outer islands of the archipelago" (Langdon, 2006, p. 29). Weirs constructed by the Tlingit were roughly 30 meters in length. But the Tlingit used two types of stone traps more often than stone weirs. The first kind, simple traps, were those of a “single-arched stone wall” made from “two or three layers of irregular stone cobbles” with no gaps and a circumference ranging from 28 to 70 meters. Most of these traps were located “slightly above high tide” (p. 32). This type of trap was used by roughly “two-thirds of the sites in the central reason of the archipelago” (p. 31).

The second type of trap, the joined trap, had a larger circumference and encompassed a larger fishing area than the simple trap. The basic construction of these traps was the same as simple traps, but “two, or conceivably more, traps are linked together by a shared section termed the stem” (Langdon, 2006, p. 32). Trap and weir systems may be combined to create what is termed a “composite.” Figure 4 shows an example of two simple traps joined together, as well as a composite of a simple trap and weir system.

Traps include a depression in each wall (1–2 meters in diameter and 20–30 centimeters deep) where, as the tide begins to sink, salt water will be held and fish will be held. These fish would remain alive until ready for harvest keeping them fresh. The depression also slightly protected the salmon from predators (Langdon, 2006, p. 33).

While these systems of harvesting salmon allowed “sufficient escapement to maintain healthy runs” (Langdon, 2006, p. 43) of salmon, Russians and Euro-Americans “ignored the logic of the Tlingit systems” and developed their own systems that obstructed salmon routes while seeking to maximize salmon harvests, a short-term venture. Such traps eventually were regulated to open their traps “one or two days a week for escapement purposes” (p. 45). This modern logic eventually completely eroded salmon stocks, whereas Tlingit technology “ensured the continuous replenishment of the runs on which they depended” (p. 45).
2. The "Ancient Cultured" Citrus Ant in rural China

This case study deals with the management of the citrus ant (Oecophylla smaragdin) in traditional rural farms of China. The use of the citrus ant was “discovered” by the Western world in 1915 when Walter T. Swingle, a plant physiologist for the US Department of Agriculture at the time, traveled to China in search of a new variety of orange, one that was impervious to citrus canker. What he found was “a small village where the inhabitants said their principal business was ‘growing ants’” (Huang & Yang, 1987, p. 665). The purpose of these ant colonizers was to use the ant to protect their trees and crops. The citrus ant:

... has been in use in the orange groves of southern China for almost 1700 years ... the value of the citrus ant lies not just in its ability to attack the large insect pests of the citrus plant. Equally important, it does not interfere with the activities of the natural enemies of the smaller pests, such as soft scale insects, aphids, and mites. (Huang & Yang, 1987, p. 670)

In order to be effective, a large amount of ants were needed each spring so they would be active during the new growing season. Every winter the ants would “die out.” Solutions were developed by the farmers to overcome this issue. In the province of Huaan each grove “contained not just orange trees, but also pomelo trees in which ant nests are able to survive the winter” (Huang & Yang, 1987, p. 670) and ant colonies did not have to be recreated each Spring. To colonize the groves, bamboo bridges were set up from tree to tree which allowed ants to migrate (p. 667).

Despite its long-term use, during the 1950s and 1960s farmers began to transition from ants to organic insecticides. The last users of the ant technology were from Sihui, but eventually even they “succumbed to the lure of modern technology and began to rely on chemicals for pest control” (Huang & Yang, 1987, p. 669). After traditional farmers completely transitioned to their use, the costs of organic pesticides rose and as prices increased “pests were becoming more and more common in all parts of the province” (p. 668). Sihui farmers tried to reestablish their ant technology, but flooding occurred frequently and their trees became infected. Pesticides were no longer effective, and the reintegration of the citrus ant as a local pesticide was impossible.

This specific case study portrays the ingenuity of local indigenous resource management strategies. It also presents an instance where the substitution of Western practices for indigenous ones eventually lead to failure of a system that had been effective for generations. In the short term the ant farms were likely inferior to organic pesticides primarily in terms of production potential. In the long term, however, the citrus ant was the better alternative.

3. Coconut Fiber Industry in Kerala, India

This case study, brought by Bhatia and Smith (2008), presents the use of natural plant fibers (pp. 7–12), their uses in engineering (pp. 12–14), and the different activities of indigenous individuals who are part of the engineering production process of products coming from coconut (coir) fiber. The final product may be coir mattresses, coir yarn, and coir door mats, among other products (p. 23).

Women in Kerala, India, manufacture products from coir (coconut) fibers through a process of separating fibers, extracting fibers by beating with wooden mallets, transforming fibers into yarn, and weaving the yarn into goods (Bhatia and Smith, 2008, pp. 17–23). Some parts of the coir industry do this entirely by hand, while others use mechanized sewing equipment. Overall, these women have “meager wages, have no health care benefits, have no bank accounts or savings, and work long hours, both at their jobs and for their families, such as preparing meals and washing clothes” (p. 36).
Coir fiber is extracted “from the husk of coconuts, which grow extensively in tropical areas of the world, such as in the Philippines, Indonesia, and India” (Bhatia and Smith, 2008, p. 17). The engineering production process of coir fiber involves four principal manufacturing activities: “retting of husks, extracting of fiber, formation of yarn, and weaving” (p. 17). This engineering production process involves unique cultural factors: typical storytelling and singing to diminish the tedium of hard work, good team relationship, gender and class roles (p. 24). Following are four engineering manufacturing activities of coir fiber production:

1. **Retting (fiber separation)** — this activity is important to help loose the fiber from the coconuts. Green coconuts will yield a white fiber and mature coconuts will yield a brown fiber. In Kerala, the kind of fiber typically produced is the white one. For white coir fiber, “green coconuts are soaked in brackish water for 8 to 10 months to remove natural tannins, which encourage bacterial action to decompose fiber-binding pectin” (Bhatia & Smith, p. 19). Brackish water is the result of mixing freshwater with seawater (p. 19). There is a traditional method “done by driving a pole into the sediment of the backwater, arranging the husks on top of one another in a circle around the pole, covering the husks with mud and palm leaves, and weighing down the bundle under the water with rocks” (p. 19). Brackish ponds are also used to place husks for separating the fiber.

2. **Extraction of fiber** — this activity involves the traditional process, performed by women, of beating the retted husks with wooden mallets. Typically men perform the extraction of fiber with fiber-extraction machines.

3. **Transformation of coir fiber into yarn** — the transformation of coir fiber into yarn involves the spinning of yarn. It is traditionally done using only hand-work, by hand-rotating spinning wheel—known as ratt, or by motorized ratt. This spinning wheel “was introduced in Kerala by the Portuguese, Dutch, and English during the 15th and 16th centuries” (Bhatia and Smith, 2008, p. 21). This activity is mostly performed by women and the mechanical ratts have the drawback of requiring a continuous back and forward walk movement. Later, the yarn is twisted to form a stronger yarn.

4. **Weaving** — this activity involves the hand or mechanical weaving of coir yarn to produce value-added products, such as mattresses and geotextiles, and final products such as material for fences, scaffolding vines, fishing ropes, and house construction (Bhatia & Smith, 2008, p. 25).

**4. Constructing the Canal du Midi in France**

This case study comes from Mukerji and was published first as a book chapter in 2007 and later as its own book in 2009. Our case study was informed by the later publication.

The Canal du Midi, running through southwestern France, is a shortcut from the Atlantic Ocean to the Mediterranean Sea. It was designed and built during the 17th century and was intended to provide France strategic military advantages. As Mukerji (2009) explains, “Cutting a navigational canal across southwestern France seemed feasible, but actually taking it over uneven terrain with multiple locks was not an enterprise that was obvious to achieve with the engineering expertise of the times” (p. 3). Due to the limited hydraulics engineering knowledge of the 17th century, the project relied on knowledge and engineering skills of locals to build its one hundred locks (p. 1). Particularly in areas of land measurement, construction, and hydraulics, indigenous knowledge was more suited to meet the engineering challenge than the dominant Western expertise. “It was precisely this kind of local knowledge—the intelligence of bandits, fishermen, washwerwomen, masons, charcoal makers, and women indigenous engineers—that made it possible to build a canal in Languedoc” (p. 14). Locals living in the area where the canal was being constructed had developed intricate knowledge of techniques used in building waterways in mountain villages,
knowledge directly applicable to the Canal du Midi. Mukerji explains; "Work in these areas was clearly facilitated by the indigenous knowledge of the laborers. The canal's water supply system was essentially an extended version of the systems used in the Pyrenees to serve large towns" (p. 141).

One particularly challenging problem for engineers was the eight-step Fonserannes Lock with a total elevation change of 21 meters over a distance of 280 meters. Engineers had repeatedly failed at computing necessary water volumes for double and triple locks (Mukerji, 2009, p. 151). Thus, France awarded the Medailhes brothers, illiterate peasants, the contract to build the Fonserannes Lock, who realized Pyrenees women "knew methods for controlling wild rivers, working with rocky soil, and keeping debris out of a water supply" (p. 126). With this knowledge the women also possessed "indigenous engineering skills specifically designed to move water through complex topography and put it to multiple uses" (p. 119). Pyrenees women had already worked on other parts of the canal, designing and constructing terraces (p. 137), silt barriers (p. 144) settling ponds (p. 145), and more. On the Fonserannes Lock, these indigenous women were able to test water volumes through indigenous methods, first digging the locks and then filling the cavities with water before finishing the interiors (p. 153).

To summarize, the role of indigenous women was essential to the engineering success of the Canal du Midi:

. . . allowing us to see more clearly the importance of their indigenous traditions to the design of the canal. The staircase lock at Fonserannes was a vivid demonstration of how powerful and useful peasant expertise could be; it was a testimony to the women who maintained the volumes and the illiterate men who hired them, knowing what they could do together. (Mukerji, 2009, p. 153)

DISCUSSION

Many academics and practitioners in the development field are extensively documenting the ingenuity of indigenous knowledge and exploring ways in which this could benefit local livelihoods. Despite this, ethno-engineering or indigenous ways of constructing a built environment seldom is a focal point in this area. The 32 articles in the Phase 2 database compiled here (see Appendix) are all instances of ethno-engineering, although these articles rarely explicitly label themselves as so, with a few exceptions (Jodha, 1990, 1991; Mukerji, 2009; Reij, 1991).

Most ethno-engineering strategies included in the database, such as the Andean peasants (Apffel-Marglin, 1998) and the Hopi Indians (Wall & Masayesva, 2004), are part and parcel of one’s indigenous worldview. Thirteen of the thirty-two sources explicitly stress this point, whereas eighteen sources neglect to mention this component whatsoever. In the dominant Western worldview spiritual beliefs and religion are portrayed as diametrically opposite from and in competition with principles and practices of science and engineering (Roy, 2002), yet, in order to understand indigenous design strategies we must realize spiritual beliefs and engineering practices are inseparable.

When Western methods are adopted by indigenous communities the result is often the demise of indigenous knowledge systems, such as with the citrus ant colonizers (Huang & Yang, 1987), where global resources become too expensive and ethno-engineering systems become impossible to sustain or re-introduce. In other cases, such as the Tlingit salmon fishermen (Menzies, 2006), the indigenous population finds their resources becoming depleted by a colonizing system of fast-paced mass exploitation. When this happens, the exploiters cannot say “let the tribesmen reclaim and
redeploy their indigenous agricultural and social practices and solve their problems in their own way” (Semali & Kincheloe, 1999, p. 18) as the landscape has drastically changed making it inoperable with their now unsuitable indigenous techniques.

Therefore, it is not surprising that indigenous people are often cautious when Western development organizations reach out to their societies. “Development” may be viewed as a tool to further oppress the indigenous, where indigenous knowledge “is required to fit into the existing framework designed to fulfill the needs of Western ideals” (McGregor, 2004, p. 74). Indigenous societies “remain rather impervious to extension messages that stress high external input agriculture” (Tanzubil, Dittoh, & Kranjac-Berisavljevic, 2004, p. 98). As modern technologies are integrated into indigenous societies, they are adopted by few, perhaps only the richest, and the development goals at which modernists strive are never achieved. This may explain why 83.9% of the articles in the Phase 2 database discuss ethno-engineering strategies dominantly dependent on local resources and none only relied on imported resources. Only 2/32 sources revealed that the indigenous did not participate in some sort of economy, be it local or global.

Integrating indigenous engineering strategies into Western engineering thinking is a delicate venture, especially when considering that, globally, “indigenous knowledge exists in immeasurable forms among immeasurable groups of people in immeasurable environments” (Buabeng, 2004, p. 15). Not only are the engineering components largely absent from scholarly literature, but it is also constructed from the outside looking in (90.6% of authors in Phase 2 are Western and commonly “using anthropological jargon” (Buabeng, 2004, p. 15). The approach used by Western authors to understand indigenous ways of doing is often taxonomic (45.2% from Phase 2 database) where “it is the categorizer who decides whether a teaching, technology, or practice is indigenous and unique to a given heritage or society, adopted from Eurocentric knowledge, or a blend of local and introduced components” (Battiste, 2000, p. 6). The databases compiled here are no exception. The goal of these databases has been to find firm ground where we, non-indigenous authors, recognize indigenous persons for their ingenuity. The 32 case studies included in the Phase 2 database are a testament to the fact that engineering is not exclusively located in Western developed societies, yet, “the stories of the engineers involved in small-scale projects are rarely told, and almost never from a critical perspective that encourages self-reflection and analysis” (Lucena, Schneider, & Leydens, 2010, p. 157).

Although it has been argued that indigenous persons may not always be acting sustainably (Diamond, 2005), none (0/32) of the articles from Phase 2 suggested that the indigenous strategies are or were unsustainable. More than half (56.3%) of the Phase 2 sources included practices that the authors themselves considered sustainable, although 43.8% of authors did not solicit any sort of opinion on the topic. Orr (1992) points out that indigenous livelihoods have subsisted in such a way that the modern world would be wise to take heed of, indicating that:

... the only people who have lived sustainably on the earth without damaging it could not read. This does not mean they were ignorant. To the contrary, they had enormous amounts of knowledge. Indigenous peoples’ knowledge of their ecosystems is extensive. We will never be able to match it. (p. 3)

As Arquette and Cole (2004) put it, “we have a great opportunity to learn from the past, reorient our relations, and build a relationship based on mutual respect and partnership in the sharing of responsibility in this land and natural world” (p. 349). But it should be noted that what Menzies (2006) calls “a central strength and weakness” of indigenous knowledge is its limited applicability to only the site at which it has been developed. The “strength” is that it “can provide highly specific
and detailed information crucial for the management of local ecosystems” (p. 2). The “weakness” is that it is non-transferrable, and suitable for a relatively small-scale. Ethno-engineering strategies do not presuppose, as do scientific paradigms of a given time (Kuhn, 1962), that practices used locally may be implementable globally. Rather, if transferred—and we make no claim whether or not they should be, they must be adapted and modified.

Indigenous people’s worldviews are highly salient in the analyzed scholarly literature, generally being discussed alongside indigenous engineering practices. Existing, secular, Western worldviews cannot be understood without their roots in Judeo-Christian monotheistic beliefs, which provide the underlying basis of dominant worldviews even in secular societies. At the core of the Judeo-Christian worldview is an hierarchical order, in which God, who is deemed omnipotent and omniscient, has complete “dominion over his creation” (Salmón, 2000, p. 188). One tier beneath God are human beings who are believed to have “dominion over the creatures of the world” (p. 188), a notion generally absent from indigenous worldviews where instead there are “several aspects of a domain on an equal plane” (p. 188f). The result from the Western model is that societies aim for “personal well-being through material consumption” thereby creating “growing problems with household waste and disposal of slow-moving consumer goods” (Matutinovic, 2007, p. 98). In contrast, indigenous engineering practices are inseparable from the people’s holistic worldviews. The primary difference, and perhaps the most fundamental, between indigenous and Western modes of engineering is that Westerners tend to see themselves as controlling nature and its resources in the name of progress, whereas indigenous people tend to consider themselves part of nature and stewards of the land.

LIMITATIONS

As a technical limitation, this paper is not based on primary data collection through observations or conversations. Taking what we know, and with the developed framework of this paper in mind, further fieldwork is necessary to collect primary data on the topic of ethno-engineering directly from the field.

As non-indigenous authors, we want to emphasize again and explicitly note that we are on the outside looking in. Sandy Marie Anglás Grande (2000) suggests, “Whitestream America has never really understood what it means to be Indian and even less about what it means to be tribal” (p. 474). Notice that less than 10 percent of our literature review sources are authored by indigenous persons. How are we sure even those authors are credible, when they too are on the outside looking in? Nonetheless, these drawbacks do not suggest that “Whitestream America” or Western society should not strive for understanding. We must find the key to our “shackles of ignorance” (Meyer, 2008, p. 217). For us, the key is in the discourse we employ.

CONCLUSION

In this paper we have synthesized indigenous ways of doing that are akin to engineering, what we have called ethno-engineering. We offered a working definition of ethno-engineering as a method of defining and solving complex issues with constantly evolving deep experiential knowledge of the environment, without utilization of modern mathematics, science and technology, relying on bottom-up management, practicing resourcefulness, and being contingent upon a holistic worldview.

5 See Max Weber (1998) as an example of how Christian, and in this case Protestant, traditions secularized into cultural norms of capitalism.
This definition is dynamic, fluid-like, as is indigenous knowledge and indigenous forms of engineering. Indigenous communities have not lived in a vacuum. Western society has exposed itself to indigenous societies and changed their livelihoods, often assimilating these communities against their own will, sometimes exterminating these societies, or even destroying their indigenous modes of subsistence. Beginning the discourse on indigenous modes of engineering is essential to any social justice conversation of indigenous communities. It is undeniable that indigenous communities have subsisted for generations with modes of engineering. As Rolt (1973) explained, “The moral is that engineering talent is no monopoly enjoyed by any particular nation, but that such talent cannot flower unless the particular social, political and economic climate is congenial” (p. 4). Change at any level of engineering first requires “change in the dominant worldview, while its dynamics resembles that of a paradigm change in political and scientific arenas” (Matutinovic, 2007, p. 92).

ACKNOWLEDGEMENTS

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References marked with an asterisk(*) indicate studies included in the meta-analysis.


case studies from Australasia, Melanesia, and Southeast Asia (pp. 66–87). New York, NY: Oxford University Press.


## APPENDIX: STUDIES INCLUDED IN THE META-ANALYSIS

<table>
<thead>
<tr>
<th>Author (Last, First)</th>
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<td>Anschuetz, Kurt F.</td>
<td>Book: Native People of the Southwest: Negotiating Land, Water, and Ethnicities</td>
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<td>2008</td>
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<td>Herrmann, Thora Martina</td>
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