

Article

Engineering and Sustainability: Attitudes and Actions

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Abstract: The results of an extensive survey of engineers and engineering students suggest there is a strong focus on the implementation of sustainability concepts, actions and measures in engineering. The main sustainable technology priorities are using less energy and natural resources, reducing emissions and material wastes, and utilizing renewable, recyclable and recycled materials. Sustainable engineering within organizations is mainly driven by regulatory requirements, rising energy costs and client demand, but challenges to sustainable engineering like economics need to be addressed to increase the incorporation of sustainability in engineering. Nonetheless, about two-thirds of practicing engineers have worked on sustainable products and processes, and over half of engineering students are involved with sustainable design in their studies.

Keywords: sustainable engineering; attitudes; actions; sustainable technology

1. Introduction

Sustainability has received increasing attention in recent years, and is a topic that has spawned much interest in society. Much research has been reported relating to attitudes and actions regarding sustainability, which is the focus of this article. For instance, many have sought to understand and define sustainability [1–4] and sustainable development [5]. Some have examined the changes, sudden and incremental, associated with shifting towards sustainability [6–8], while others have questioned the merits of the concept and its application [9]. The application and incorporation of sustainability principles has been examined in many areas, including law [10] and government [11]. Barriers to sustainability have also been the subject of much research [12]. The incorporation of sustainability and sustainable development concepts into education, and the requisite transformations, have been

examined extensively [13–17], as have associated challenges [18]. Investigations regarding education are particularly relevant to the present paper given its impact in views and actions in relation to sustainability, especially in youth. All of the results cited here directly or indirectly affect the attitudes of many engineers, and the way they act when practicing engineering.

Actions supporting sustainability have been reported and attitudes towards sustainability have been changing over the last decade. The attitudes towards sustainability have been examined in many constituencies, including business [15], the public [19] and students [15,17], and opinions regarding the merits of and problems with sustainability have been expressed [20].

Efforts have been expended to clarify what is meant by engineering actions that support sustainable development, as this is often not precise or clear. Sustainable engineering has been discussed by many [21–30], and ways to address sustainability and sustainable development in engineering have also been reported [31]. Much of this research relates explicitly or implicitly to attitudes towards sustainable engineering, and includes examples of actions in support of sustainable engineering practices. For instance, some have examined the linkages between technology, sustainability and ethics, and their integration [32,33]. Trends in design for sustainability have also been identified and assessed [34–37]. Some specific aspects of sustainability in engineering have been the topic of investigations, such as efficiency [38] and life cycle sustainability assessment [39]. Applications of sustainability concepts in engineering have been reported in such areas as energy [40–44], infrastructure [45,46] and manufacturing [37,47]. Investigations in sustainability science, which are related to engineering sustainability, have also been reported [28,48–51]. The incorporation of sustainable development and sustainability ideas into engineering education has received increasing attention over the last decade in general [4,8,52–54] and in such areas as design [55–57]. Taken together, the advances reported above appear to suggest that views on what engineering actions support sustainability and sustainable development are starting to coalesce.

Based on the types of studies cited above and other information, many feel that in recent years, there has been a growing focus on and implementation of sustainability measures in engineering, and attitudes of engineers towards sustainability have become more positive. But these views are not often investigated carefully. In this article, we examine this view, using data from a survey of engineers carried out in 2009 [58,59]. The objective is to better understand (i) how attitudes towards sustainability have shifted and the degree to which associated actions have been undertaken by engineers, and (ii) barriers and challenges to further movement towards engineering sustainability, so as to assist in the contributions that engineers and engineering make towards sustainability. Thus, the primary contribution of this article, over the results provided in the original survey [58,59], is that this article expands and extends the interpretations of the results of the original survey so as to provide broad insights into (i) the manner in which sustainability concepts are being implemented into engineering practices and applied in engineering activities, and ii) the views of engineers and engineering companies towards this new dimension of engineering. Also, the results of the surveys are compared with other surveys carried out in other jurisdictions and more recently, in order to detect temporal and spatial variations. Consequently, the present results can assist companies, engineering organizations and government bodies in furthering the goals of sustainable development.

As pointed out in the two preceding paragraphs, other studies on attitudes and actions regarding the incorporation of sustainability into engineering have been carried out. Beyond the study that forms the

basis of this article, a similar study was carried out the year before [60,61], and it exhibited results consistent with those obtained in the subsequent study, e.g., it showed about 5% fewer mechanical engineers expected sustainable design would play a bigger role in the subsequent year, although some temporally changing trends began to emerge. Furthermore, a more recent survey on sustainable design by the same engineering association was recently reported [62], and the present results and contrasted and compared with those.

2. Approach and Methodology

This research utilizes data from an online survey carried out in late 2009 that questioned members of the American Society of Mechanical Engineers (ASME) [63] about sustainability trends in mechanical engineering and manufacturing, and on how mechanical engineers and manufacturers are practicing green design [58,59]. The intent of the survey was to try to understand the views and actions of engineers and their companies about the concept of “sustainability,” which often draws extreme responses (positive or negative) and is often thought to be an imprecise term that is difficult to interpret. The survey was intended to improve clarity in this area, to allow further efforts to enhance engineering sustainability to be based on a factual understanding.

The survey included 16 questions and was emailed to ASME members in the U.S. The survey questions were designed to elicit responses regarding sustainability that were based on either the views and attitudes of the respondents, or the actions of respondents and their companies. The first category of questions is highly subjective, while the second category is more objective and evidence based. Thus a balance between perceptions and actual actions was sought.

There were nearly 4,400 responses, including 3,029 from practicing engineers (representing a response rate of 5.7%) and 1354 from engineering students (representing a response rate of 6.8%). The demographics of respondents were not correlated with those of respondents, so it was not possible to check for any bias. Nonetheless, it is possible that a degree of bias exists in the results in relation to demographics as well as regarding the fact that those who responded to the survey may have particular interests (positive or negative) about sustainability.

Note for clarity that the present author had no relation performance of the surveys. Rather, he used data about the survey objectives, methods and results, reported in various publically available sources, in order to undertake his research and write this article. Note also that there is, of necessity, some overlap between the results provided here and those reported in other references, for instance [58–61]. This overlap is not readily avoidable, as it is required for explaining the contributions made in the present paper, especially where the survey results are expanded upon.

2.1. Data

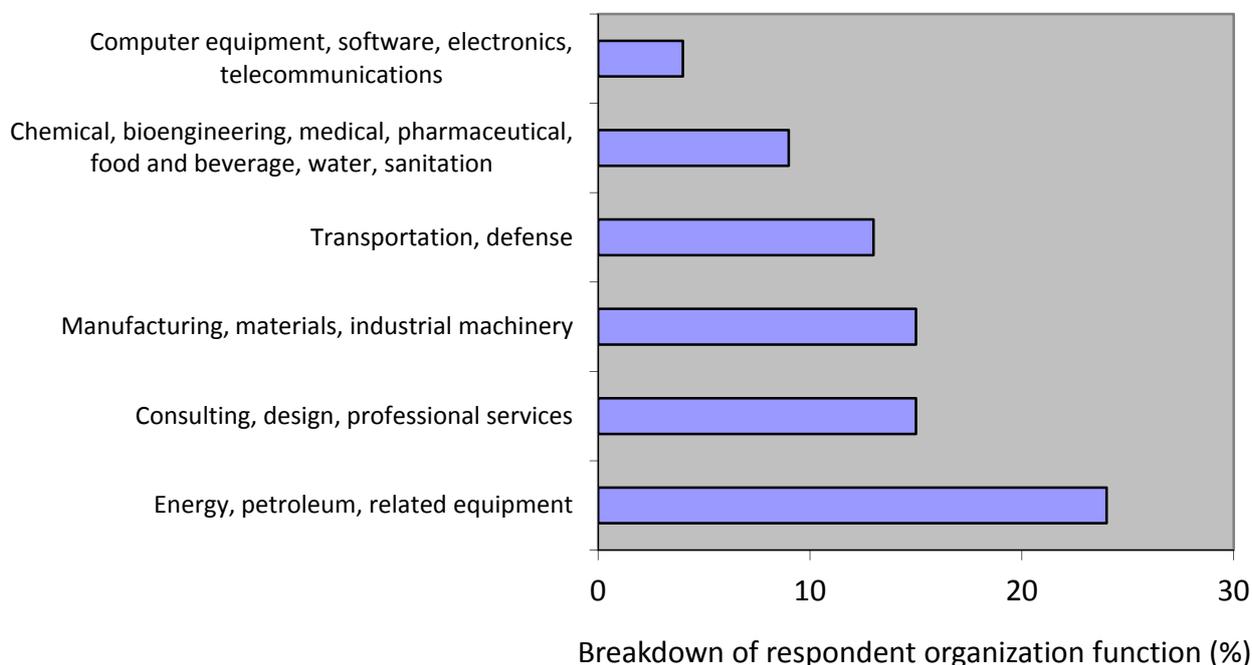
Most of the practicing engineer respondents to the survey are experienced, with 65% having been employed as an engineer more than 20 years, 15% for 11–20 years and 15% for less than 10 years. The majority of the practicing engineer respondents are middle aged or older, with only 20% aged 21–40, but 55% aged 41–60 and 26% over 60. Only 5% of the practicing engineer respondents are female. 46% of the practicing engineer respondents are licensed professional engineers.

About half of the practicing engineers responding to the survey work in large organizations (over 1,000 employees). The principal job function of the practicing engineer respondents varies significantly, with 23% in design/development engineering, 23% in consulting/professional services, 19% in engineering or other management, 7% in production engineering, 8% in research and development engineering and 6% in education. A wide range of industries are represented by the respondents, with the breakdown of principle business or function of the respondent organizations indicated as follows (see Figure 1):

- 24% energy, petroleum and related equipment
- 15% consulting, design and professional services
- 15% manufacturing, materials and industrial machinery
- 13% transportation and defense
- 9% chemical, bioengineering, medical and pharmaceutical, food and beverage, and water and sanitation
- 4% computers equipment and software, electronics and telecommunications

Note that the percentages in Figure 1 do not sum to 100%. This is because the data is expressed as a percentage of the responses received and only includes the six main industrial sector groupings. Also note that a different breakdown is shown in Figure 1 compared to the raw survey data reported in [1].

Figure 1. Breakdown of respondent organizations, by function (adapted from [60]).



Most of the student engineer respondents to the survey are young, with 88% aged 18–30 and the remainder over 30. 16% of the student engineer respondents are female.

2.2. Assumptions

Even though the survey was sent to ASME members, it was assumed to be representative of engineers more broadly. This was because mechanical engineering is highly diverse and multidisciplinary and overlaps extensively with many other types of engineering. Also, ASME is professional society that fosters collaboration, knowledge sharing and skills development across all engineering disciplines. Mechanical engineering is found in a very wide range of businesses in industries including automotive and transportation, industrial machinery, consumer products, and energy.

Further, it is assumed that the results of the survey are applicable to engineering in many countries, given the multinational nature of engineering and given the fact that ASME has members (over 120,000) from over 100 countries (according to the ASME website [63]), both developing and developed.

Finally, it is assumed that the views expressed by practicing engineers for the most part represent the views of older engineers, while the views expressed by engineering students somewhat represents the views of younger engineers. This is because approximately 65% of the practicing engineers who responded had more than 20 years career experience, while 45% of the engineering students responding were between the ages of 21 and 25. This assumption is approximate and certainly not rigorous, as the views of engineering students can shift rapidly when they encounter the realities of the workplace in companies.

3. Attitudes of Engineers Towards Sustainability

3.1. Practicing Engineers

Personal attitudes of practicing engineers are very positive towards sustainability, with well over 80% indicating that they are personally involved in sustainable information and causes outside of work. More specifically, the responses show that 29% of practicing respondents are extremely involved personally, 55% are somewhat involved, 11% are neutral, and 5% are not interested.

The professional views and attitudes of practicing engineers are generally, but not exclusively, positive. That is, the majority of practicing engineer respondents feels that the use of sustainable and/or green design principles in the design, production, and operation of manufactured products is of increasing interest to colleagues (60% of respondents) and results in more product innovation (66%). 69% of practicing engineer respondents believe that sustainable and/or green design principles typically have higher design costs, and 18% feel that incorporating sustainable and/or green design practices is too complex for her/his company.

3.2. Engineering Students

The personal attitudes of engineering students are very positive towards sustainability, even more so than those of practicing engineers. Outside of engineering studies, 89% are personally involved in green and sustainable information and causes, while only 2% are not interested and 9% are neutral. The differences in engineering student perceptions of sustainability is consistent with those observed in

other studies, such as that of Kagawa [17], and similar qualitative effects were observed for business students [15].

Like for practicing engineers, the professional views and attitudes of engineering students are generally quite positive. The majority of engineering students feels that the use of sustainable and/or green design principles in the design, production, and operation of manufactured products is of increasing interest to fellow students (74% of respondents) and results in more product innovation (86%). 56% of engineering students agree that their school has a sustainable design class, program or assignment, yet some respondents (13%) feel that incorporating sustainable and/or green design practices is too complex for her/his educational institution. A distinct majority (77%) of engineering student respondents believe that sustainable and/or green design principles typically have higher design costs.

3.3. Additional General Comments

Although the attitudes towards sustainability of practicing engineers and engineering students are positive, and some believe it is a critical issue (e.g., some state that they feel engineers have a responsibility to bring sustainable processes to society), there are some who have serious reservations about its merits. These reservations include thinking that sustainability is: a buzzword or a temporary fad, or driven by public relations and politics, or a waste of time and money and harmful to companies, or based on unsound science. However, these views are held by a distinct minority of the respondents to the survey.

Some cite the need for sharing sustainable engineering achievements and successes between developed and developing countries.

4. Attitudes and Actions of Engineering Corporations Towards Sustainability

The involvement of practicing engineers with sustainability or sustainable technologies is notable. About 67% of practicing engineer respondents are involved with sustainability or sustainable technologies (24% extremely involved and 43% and somewhat involved). Conversely, 20% of practicing respondents are either somewhat uninvolved, extremely involved, or not at all involved. About 13% of practicing respondents are neither involved nor uninvolved. Similarly, the involvement of engineering students with sustainability or sustainable technologies is significant, but less notable than for practicing engineers. 48% of student respondents are involved with sustainability or sustainable technologies, while 26% are uninvolved and another 26% are neither involved nor uninvolved.

The majority (66%) of practicing engineer respondents indicated that at least a small portion of their projects over the past year included sustainable and/or green design principles beyond those mandated by regulations. Only 14% of respondents felt that more than half of their projects included specifications that were based on sustainable and/or green design principles beyond those mandated by regulations.

The most common sustainable technologies with which organizations are currently involved are shown in Table 1. They include designs that use less energy and reduce emissions (71% of respondents' organizations), and designs that comply with environmental standards and regulations (also 71%).

Similarly, the sustainable technologies that have been worked on the most by practicing engineers over the past year include designs that use less energy or reduce emissions (64% of respondents), and designs that comply with environmental standards and regulations (54%). In the past year, more than two-thirds of working respondents have worked on designs that use less energy or reduce emissions. More than half have worked on designs that comply with environmental standards and regulations.

The most important sustainable technologies are considered by all engineers to be designs that use less energy or reduce emissions (64% of practicing engineer respondents and 66% of engineering student respondents). The second most important sustainable technologies are viewed as manufacturing processes that use less energy and natural resources (27% of practicing engineer respondents and 43% of engineering student respondents).

Table 1. Usage and Views on Selected Sustainable Technologies and Measures*.

Sustainable technology/measure	Organization currently involved with (%)	Worked on in past year (%)	Considered one of two most important (by practicing engineers)	Considered one of two most important (by engineering students)
Designs that reduce energy use or emissions	71	64	64	66
Designs complying with environmental standards and regulations	71	54	23	7
Designs using renewable/recyclable/recycled materials	43	27	24	0
Designs that reduce material waste in manufacturing	40	22	13	21
Designs with non-toxic materials	37	20	10	10
Designs with low carbon footprints	36	21	10	11
Manufacturing with less energy and natural resources	33	21	27	43
Manufacturing processes that pollute less	31	15	11	14
Products that can be disposed of safely	29	15	9	13
Products that require less packaging	16	9	4	6

* Data are adapted from [60].

In the coming year, most practicing engineers expect their organization to become more involved in sustainable and/or green design. Approximately 63% of practicing respondents expect their organization's involvement in sustainable and/or green design to increase. Only 1% of practicing respondents expect their organization's involvement in to decline in the coming year, while 36% expect no change.

5. Factors Influencing Sustainable Design

Numerous factors influence the use of sustainable design and practices, according to practicing engineers. Many of these are listed in Table 2. Regulatory requirements are most likely to influence

organizations' use of green design practices and procedures (indicated by 42% of respondents as the greatest factor and by 69% as one of the top three factors). Client demand was cited as the second most likely factor (by 19% of respondents as the greatest factor and by 51% as one of the top three factors). Rising energy costs was also indicated to be significant factor (with 16% of respondents considering it the greatest factor and by 53% as one of the top three factors).

Table 2. Factors Influencing an Organization's Use of Green Design Practices and Procedures.

Factor	Most likely (%)	One of top three most likely (%)
Regulatory requirements	42	69
Client demand	19	51
Rising energy costs	16	53
Ability to gain a market advantage	6	30
Long-term return on investment	5	25
Personal sense of environmental responsibility	5	19
Government/industry incentives	3	32
None of the above	3	5

* Data are adapted from Ref. [60].

Sustainability is addressed at many points in the stages of work in any project, and the stage at which it is addressed often affects how well and comprehensively sustainability is incorporated into a project. Usually, sustainability is better worked into a project when it is first addressed as early as possible within the project and then re-addressed throughout all subsequent stages. The survey supports this view, showing that sustainability is most commonly addressed in the conceptual design phase, according to 76% of practicing respondents. Also, 50% address sustainability during materials selection, 44% during process selection and 21% during reporting. Some engineers note that approaching sustainability is more straightforward if the design and manufacturing processes are addressed in tandem.

Factors that influence the use of sustainable design and practices must be balanced by organizations against other priorities, especially economics and production. In general, most organizations consider sustainable technologies for new products only if they yield some form of economic benefit. More specifically, the balance between sustainable methods and other priorities is achieved by working respondents' organizations as follows:

- 34% consider sustainable technologies for new products only if they are cost-saving;
- 27% invest in sustainable technologies only if they increase throughput and cut costs of existing products/processes;
- 24% invest in sustainable technologies if they do not affect throughput or cost of existing products;
- 19% will spend extra to incorporate sustainable technologies in most new products;
- 15% do not invest in sustainable technologies;
- 9% invest in sustainable technologies to make a statement with some flagship products but not others.

6. Changing Attitudes and Views

Given the typical age of engineering students who responded to the survey (20–30) is much lower than that for practicing engineers (40–60), the results of the survey can be somewhat interpreted to show the changes in attitudes and views that are occurring over time. This partly presumes that the views held by senior engineers are somewhat influenced by the views they developed when they were young. In this case, the results in Section 3, which show greater interest in sustainability among engineering students than practicing engineers, suggest that interest in sustainable engineering is increasing over time. Stronger views in support of incorporating sustainability in engineering were sometimes expressed by students, e.g., some commented that they feel sustainability is the most important issue of our time and that it should be at the forefront of engineering.

7. Barriers and Challenges

Based on comments made by respondents to the survey, there exist many barriers and challenges to enhancing the way sustainability is utilized by engineers and the extent to which it is incorporated in engineering work. Many of these follow:

- *Economics and cost.* Respondents indicated that cost is a major consideration when deciding to factor sustainability into a new product or process. The concerns include high start-up and re-tooling costs, and the long-term nature of the return on an investment in sustainability.
- *Competitiveness.* Many feel that adopting sustainable practices in engineering will make the work non-competitive relative to those, within a country or abroad, that do not enhance sustainability.
- *Market forces and customer demand.* Many believe that expanded sustainable engineering is hindered by inadequate customer demand for more sustainable engineering and a lack of corresponding market forces that drive sustainable engineering practices.
- *Corporate culture and commitment.* There is normally not an ingrained corporate culture that supports and fosters sustainable engineering in companies, and other corporate priorities usually receive much greater attention. Further a firm commitment from corporate leaders is commonly not present.
- *Incentives.* Corporations often list inadequate incentives from governments as a barrier to improved engineering sustainability, while practicing engineers often cite a lack of employee incentives.
- *Inertia and change.* With many corporations and engineers, there is often a reluctance to change, combined with an inertia, that renders it difficult to introduce sustainable engineering practices. This is partly due to the transitional nature of a shift to more sustainable engineering practices and the uncertainty regarding the ultimate destination.
- *Practices.* Commonly accepted and consistent practices for performing sustainable engineering and for developing sustainable products are often indicated to be lacking. In particular, it is often indicated that an improved understanding of best practices would be very useful.

- *Assessment.* Corresponding to the previous point, it is often noted that there is a significant lack of commonly accepted and consistent measures for assessing sustainable engineering and, more broadly, sustainability.
- *Codes and standards.* Often engineers cite the lack of codes and standards for sustainable practices and products as a hindrance to the enhancement and extension of sustainable engineering practices.
- *Regulations and laws.* There are few regulations and laws that call for sustainable engineering, or set sustainability thresholds that need to be met.
- *Success stories, failures and best practices.* Many indicate that they feel that more reports of successful applications of sustainable engineering are needed to foster further uses, and that unsuccessful attempts to incorporate sustainable engineering into processes and products need to be explained to help others learn.
- *Confidentiality.* The need for confidentiality to protect competitive advantages often is cited as hindering the sharing of knowledge and lessons learned from applying sustainable engineering.
- *Short-term focus.* The common focus on short-term benefits, rather than a life-cycle approach to benefits, usually hinders the long-term decision making needed to support sustainable engineering practices.

Many of the barriers and challenges listed above were cited by respondents to the survey as comments, so it is not clear from the survey how widespread each barrier or challenge is. Nonetheless, they provide some indication of the need for improved education and debates about sustainability in engineering, and enhanced methods for applying sustainability concepts in engineering activities. Because there is no assessment of the relative importance of the barriers and challenges cited by respondents, the results in this section are of limited usefulness in terms of where to apply effort to remove barriers, and further examinations of these issues appear to be needed. The concerns expressed here about sustainability, including its relevance, are consistent with the views expressed by some researchers [9,20].

8. Comparisons and Further Discussion

The validity of the results seems reasonable, given the large numbers of responses. The results are considered to be somewhat representative of the views of practicing engineers and engineering students. However, the degree to which the results are representative is diminished by the fact that the survey only included members of a mechanical engineering society. But the results likely have a reasonable degree of breadth given mechanical engineering is highly interdisciplinary, with mechanical engineers often involved in many types of organizations and with mechanical engineering often overlapping with chemical, civil, aerospace, electrical and other types of engineering. Nonetheless, further investigations are likely required to reinforce the validity of the results and to confirm that they are adequately representative.

A follow-up survey on sustainable design by the same engineering associations reported in 2012 [62] yielded similar results to those reported here. It is nonetheless instructive to compare and contrast those results with the results reported here. The recent study suggests that attitudes of

practicing engineers towards sustainability have become even more positive, with 87% indicating that they are very or somewhat interested in sustainable information and causes. Additionally, the balance of organizations between sustainable methods and other priorities has shifted towards supporting sustainable approaches in some ways. For example, the proportion of companies that will spend extra to incorporate sustainable technologies in most new products has risen to 28% in 2012 from 19% based on the results reported herein.

The results in this study relate to those presented in several other studies, and are compared and contrasted here. For instance, a similar study recently reported [54] involved engineering students and engineers in Sweden. That study found 35% of alumni claim they encounter sustainability issues at least occasionally in their work, but that only half of them believe they possess enough competences to make decisions from a sustainability perspective. It was concluded that industry demands a broader range of competences in sustainable development in engineers than what is currently provided in engineering education, and that the quantity, coverage and the level of integration in an educational program affect strongly how students perceive sustainable development and the importance they place on it. These results are qualitatively consistent those reported in this article, and exhibit many quantitative similarities. Also, the present results, although different in scope and purpose, mirror some of those presented by Svanström *et al.* [55] in a discussion of experiences in embedding sustainability in engineering education.

9. Conclusions

There appears to be a strong focus on the implementation of sustainability concepts, actions and measures in engineering, by both individual engineers and engineering corporations. The results of an extensive survey suggest that about two-thirds of practicing engineers have worked on sustainable products and processes, and more than half of engineering students are involved with sustainable design in their studies. The large number of engineers involved with sustainability practices suggests that engineers and their companies are finding increasing ways to quantify the general term of sustainability in terms of specific actions and technologies. The main drivers of sustainable engineering practices within organizations include regulatory requirements, rising energy costs and client demand, while engineers consider the main sustainable technology practice priorities to be designs that use less energy or reduce emissions, manufacturing processes that use less energy and natural resources, utilizing renewable, recyclable and recycled materials, and reducing material wastes. Various challenges remain to expansion of sustainable engineering, especially economics, and these need to be addressed to facilitate increased shifts towards sustainability in engineering. The results are subject to the limitations related to surveying mainly mechanical engineers located in the U.S. Since the interpretations provided herein yield broad insights into both the manner in which sustainability concepts are being implemented into engineering practices and applied in engineering activities and the views of engineers and engineering companies towards this new dimension of engineering, the results are likely to benefit companies, engineering organizations, government bodies and policy makers in furthering the goals of sustainable development.

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Conflict of Interest

The author declares no conflict of interest.

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