SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2022
ORGANIZATION AND MANAGEMENT SERIES NO. 160

SUSTAINABLE ENGINEERING

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Purpose: The aim of the paper is to analyze the concept of sustainable engineering.
Design/methodology/approach: Critical literature analysis. Analysis of international literature from main databases and polish literature and legal acts connecting with researched topic.
Findings: The publication concentrate on problems connected with sustainable engineering. Especially there is a presentation of main principles of sustainable engineering. In the case of each principle there is an description of those topic with the approaches and the analysis of its importance in industrial organization. The sustainability is an very important concept which can be used in in Industry 4.0 implementation. We should mention that efficient engineering organization should know how to link the sustainability and Industry 4.0 concepts. This can bring the market advantage due to new technology implementation and sustainable production from business and environmental point of view.
Originality/value: Detailed analysis of all subjects related to the problems connected with sustainable engineering principles.

Keywords: sustainability, sustainable engineering, Industry 4.0, production, engineering.

Category of the paper: literature review.

1. Introduction

Sustainable development is now a very broadly used concept in management and engineering. The term sustainable development was introduced in 1987 in the report published by Burtland Commission (Grabowska et al., 2019, 2020; Hąbek, Wolniak, 2013, 2016; Hys, Wolniak, 2018). The title of the report was "Our Common Future" and authors in it tried to link the issues of economic development and environmental stability (Wolniak, Sułkowski, 2015; Wolniak, Grebski, 2018; Wolniak et al., 2019; Wolniak, Hąbek, 2015, 2016; Wolniak Jonek-Kowalska, 2021). In report they defined Sustainable Development as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (United Nations, 1987). And this was the mostly cited definition of sustainable development concept.

The aim of the paper is to analyze the concept of sustainable engineering.

2. Sustainable development dimensions

The concept of sustainability explores the relationship that exist between economic development, environmental quality and social equity (Wolniak, Jonek-Kowalska, 2022; Wolniak et al., 2019, 2020; Wolniak, Skotnicka, 2011; Wolniak, Skotnicka-Zasadzień, 2008, 2010, 2018, 2022; Wolniak, Sułkowski, 2016). Sustainable development has three main dimensions: economic, environmental and social. These are frequently referred to as the triple bottom line (Fig. 1), and are used to gauge the success of a particular development program or a project. The concept of triple bottom line was firstly used by John Elkington the founder of British consultancy called SustainAbility (Elkington, 1994).

We have three approaches to sustainability each based on emphasis on one of the mentioned dimensions. The description of them there is in table 1.

Table 1.
Main dimensions of sustainable development

Dimension	Characteristic
The economic approach: Maximize income while maintaining constant or increasing stock of capital	The core idea of sustainability is that current decisions should not impair the prospects for maintaining or improving future living standards. This implies that our economic systems should be managed so that we can live off the dividends of our resources. Sustainable economic growth means that real GNP per capita is increasing over time and the increase is not threatened by "feedback" from either biophysical impacts (pollution, resource degradation) or from social impacts. Sustainable development means basing developmental and environmental policies on a comparison of costs and benefits and on careful economic analysis that will strengthen environmental protection and lead to rising and sustainable levels of welfare.
The ecological approach: Maintain the resilience and robustness of biological and physical systems.	Sustainable development is about maintenance of essential ecological processes and life support systems, the preservation of genetic diversity, and the sustainable utilization of species and ecosystems. The term "sustainable development" suggests that the lessons of ecology can, and should be applied to economic processes. It encompasses the ideas in the World Conservation Strategy, providing an environmental rationale through which the claims of development to improve the quality of (all) life can be challenged and tested.
The socio-cultural approach: Maintain the stability of social and cultural systems.	Sustainable economic development is directly concerned with increasing the standard of living of the poor, which can be measured in terms of increased food, real income, education, health care, water supply, sanitation, and only indirectly concerned with economic growth at the aggregate.

Source: Own work based on: (Rogers et al., 2008).

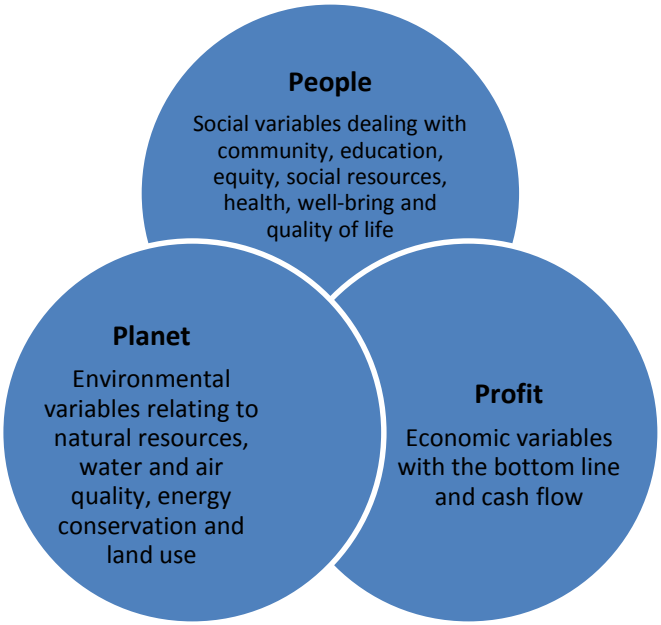

Figure 1. Interconnections of the elements of the triple bottom line concept. Source: (Dalibozhko, Krakovetskaya, 2018).

To implement the goals of sustainable development into a business practice we need to carefully implementation of this concept into the whole business, political and social environment. The indispensable part of it it's the big role of civil society. Civil society are association of citizen (outside their families, friends and business) entered into voluntarily to advance their interests, ideas and ideologies. From sustainable development point of view we can distinguish the following main roles of civil societies (Rogers et al., 2008):

- demand rights to life and health,
- demand access to land, water and other services,
- form user groups to manage common propriety resources sustainably,
- mobilize individual household and community resource groups for improving the environment,
- share information and resources with other groups about common environmental and political concerns,
- pressure industries to clean up, and hold business accountable,
- increase group empowerment,
- pressure governments and developers into taking seriously the rights and needs of marginalized people.

When we think about sustainability there is a spectrum of views about the concept (Fig. 2). At one end of spectrum are those who suggest that we should conserve at all costs, change the way we live and seek a reduction of economic growth as a means of reducing consumption (Drozd, Wolniak, 2021; Gajdzik, Wolniak, 2021, 2022; Gębczyńska, Wolniak, 2018; Grabowska et al., 2021). At the other end of spectrum are those who believe that necessity is

the mother of invention and that a "technical fix" will be invented which will remove the needs for such drastic measures to be taken (Jonek-Kowalska, Wolniak, 2021, 2022; Jonek-Kowalska et al., 2022; Kordel, Wolniak, 2021; Kwiotkowska et al., 2021, 2022).

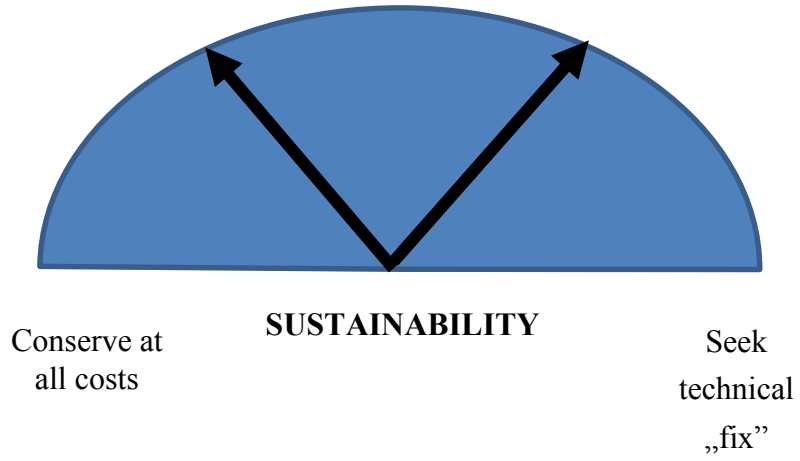

Figure 2. The spectrum of views on sustainability. Source: (Brandon and Lombardi, 2005).

3. Principles of sustainable engineering

If mankind is to achieve sustainable development, we should adopt it's patterns that reflect natural processes (Orzeł, Wolniak, 2022; Ponomarenko et al., 2016; Stawiarska et al., 2020, 2021; Steculа, Wolniak, 2022). The role of engineers in sustainable development is very important and can be illustrated by close-loop human ecosystem that mimics natural system. Engineers contribute to natural ecosystem to all their steeps (Engineers, 2002):

- By developing, processing and transporting natural resources in closed-loop systems, we can reduce waste and increase the efficient use of resources.
- Harvesting renewable resources such as water, fish and trees within the limits allowed by nature will ensure a continuing supply of resources for humans and natural ecosystems. Minimizing our use of non-renewable resources, such as petroleum and scarce minerals, and replacing them with environmentally friendly substitutes will also help extend the supply of natural resources.
- Processing natural resources efficiently and with little or no waste helps to preserve the earth's finite natural resources. We can further preserve resources by designing products and packaging for reuse and recycling, and we can protect resources through industrial processes and facilities that have minimal adverse environmental impacts throughout their full life-cycles.

- Transporting goods contributes heavily to pollution; to minimize these effects, we can transport resources and manufactured goods efficiently to consumers by pipelines, rivers, railways, roads, ships and airplanes using technologies that have minimal impacts on the surrounding land use and serve the needs of consumers with little waste.
- How we develop, process and transport resources can improve living standards in many ways. These include providing clean water, energy, housing and commercial buildings and streets and other forms of infrastructure; efficiently storing and distributing food; and meeting acceptable health standards, including high-quality waste management and treatment.
- To allow natural and built environments to be clean and unpolluted, we can reduce waste throughout this ecosystem cycle by continually recycling and recovering residual byproducts of resource development, industrial processing and meeting consumer needs. Some waste in the system is inevitable but should be in forms that have minimal long-term impacts on the natural environment. The impacts from residual waste can be offset by continuing programs to clean up and reuse old waste sites, along with other forms of environmental restoration.
- The effects of developing energy sources on the atmosphere, earth and water can be reduced by more efficient use of power and by production from non-fossil sources.

For example the engineer role is very important in supply chain in the consumption goods production and logistics (Sułkowski, Wolniak, 2015, 2016, 2018; Wolniak, Skotnicka-Zasadzień, 2014; Wolniak, 2011, 2013, 2014, 2016). They should concentrate on improvement of the processes to be more eco-friendly. They should considered at each stage in production process of all good and services following points (Azapagic et al., 2005):

- reducing the material requirements (total mass consumed),
- reducing the energy intensity (energy consumed during every phase of production),
- reducing toxic dispersion (release of toxic substances to all media),
- enhancing material recyclability (reuse of materials or energy),
- maximizing sustainable use of renewable resources (avoiding depletion of finite resources),
- extending product durability (optimising product life),
- increasing the service intensity (creating value-added while reducing environmental impacts).

Linking the conception of sustainability with engineering knowledge we achieve the so called conception of sustainable engineering (Wolniak, 2016, 2017, 2018, 2019, 2020, 2021, 2022). We can define the sustainable engineering as a concept which takes into account interactions in engineering activities of technical, ecological, social and economic systems and avoiding shifting problems from one area to the other (Sustainable, 2021).

We can distinguish twelve principles of sustainability engineering which we described in table 2. Those principles are used in the stage of creating new products/processes.

Table 2.
Principles of sustainable engineering

Principle	Approach	Importance
Strive to ensure that material/energy inputs and outputs not hazardous	Reduce hazard. Reduce exposure.	Reduces/minimizes dangers by reduction of intrinsic hazards.
Waste minimization over waste management.	Good design is creative about use of by-products.	Lowers expenses in purchasing and disposal.
Design for easy separation and purification	Plan for recycle and reuse.	Easy separation/purification = easy waste management.
All components must be designed for maximum mass, energy, and temporal efficiency.	Smaller is generally better. Lowers expenses.	Lowers expenses.
Avoid unnecessary consumption of mass/energy versus.	Production must respond to real-time demands.	Minimization of overproduction.
Use entropy and complexity as guidelines to decide end-of-cycle.	Not all products should receive the same end-of cycle treatment.	Disposal solutions can no longer be seen as one-size-fits-all.
A product must not outlast its uses.	Over-design is a design flaw.	Decrease accumulation of high-tech waste.
A product must not have unnecessary capabilities/capacities.	Design for realistic uses and conditions.	Reduces/eliminates the use of components needed.
Minimize material diversity.	Minimize the use of different materials, esp. adhesives, sealants, coating.	Simplify waste management.
Product creation is only one part of the cycle.	Take into account methods of extraction of needed resources and transport.	Minimize environmental impact of related life-cycle steps.
Evaluate products based on life-cycle analysis.	Take into account methods of extraction of needed resources and transport.	Minimize environmental impact of related life-cycle steps.
Prioritize the use of renewable and readily available resources.	Avoid using non-renewables, except when using renewables may be more damaging.	Minimize the overall impact of resource use.

Source: (The 12 principles, 2021).

4. Conclusion

The publication concentrate on problems connected with sustainable engineering. Especially there is a presentation of main principles of sustainable engineering. In the case of each principle there is an description of those topic with the approaches and the analysis of its importance in industrial organization. The sustainability is an very important concept which can be used in in Industry 4.0 implementation. We should mention that efficient engineering organization should know how to link the sustainability and Industry 4.0 concepts. This can bring the market advantage due to new technology implementation and sustainable production from business and environmental point of view.

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