SUSTAINABILITY ASSESSMENT METHODOLOGY FOR 3D-PRINTED COMPONENTS IN METAL ADDITIVE MANUFACTURING TECHNOLOGY

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ABSTRACT

With the current excessively growing global energy and climate change, the advancement of additive manufacturing (AM) has become one of the innovation ventures in the manufacturing industry as it offers various advantages particularly minimizing the effects on the environment. However, sustainability assessment for the deployment of AM, in particular, the impact on environment, economic and social called triple-bottom-line (TBL) has not been adequately communicated to guarantee high-quality output and consistency in their practices progress in an accumulative manner. This paper aims to develop an integrated sustainability assessment for metal AM, incorporating both fuzzy logic and stochastic methods. The findings underscored and mapped the underperforming and excelling areas across all three pillars of sustainability for the selected metal AM.

KEY WORDS

Additive manufacturing; sustainability assessment; 3D printing

1. INTRODUCTION

The integration of AM technology in Malaysia necessitates the implementation of appropriate regulations and protocols to safeguard public safety and mitigate its environmental footprint.[1] However, there is a lack of studies examining the sustainability outcomes of employing AM technology, highlighting a gap in research concerning the development of a sustainability assessment framework for this issue. Therefore, the objective of this paper is to quantify the metal AM sustainability index, capable of assessing both qualitative and quantitative data through an integrated stochastic-fuzzy method.

2. METHODS

2.1 Sustainability parameter

The identification of parameters is conducted concerning the sustainability assessment's objective.[2] This process involves selecting appropriate systems and technologies, identifying strategies and designing conceptual systems. In this study, the sustainability parameters that will be studied depend on the elementary inputs and output throughout the selected life cycle stages. All the impact categories grouped by environmental, economic and social related to these parameters are studied thoroughly to understand the substances and materials released to air, water and soil for the production of 3D metal components.

2.2 Monte Carlo

The Monte Carlo method is a statistical approach that employs random sampling to derive numerical outcomes. It is frequently utilized across diverse disciplines, such as finance, engineering, and environmental science, to model intricate systems and evaluate uncertainty. By simulating a vast array of potential results based on specified parameters, the method facilitates the estimation of probabilities and the detection of possible risks. This strategy is especially beneficial for decision-making processes, as it offers insights into the likelihood of various scenarios arising.

First, a range or distribution for a variable, such as uniform, lognormal, or triangular, is chosen. Next, samples are generated from the selected distribution. The following step involves analyzing uncertainty based on the mean or variance of the samples. After conducting a substantial number of simulations, the output's distribution function can be accurately established.

2.3 Fuzzy Logic Approach

The main reason for choosing this method is that it can handle uncertainty, subjectivity and individual importance that are implicitly important, especially in the environmental parameters' behaviors. Besides, this method can build proper integration of individual evaluations by evaluating each parameter correctly according to the impact category. Several steps include in the fuzzy logic model can be seen in Fig. 1.

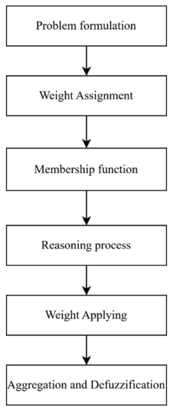

Fig. l: Model of fuzzy logic approach

2.4 Proposed framework
The process of data collection for qualitative data can be done through questionnaires and laboratory experts while quantitative data can be collected through literature and database. To understand the flows of input, Fig. 2 displays the framework to assess the sustainability of 3D-printed metal components through environmental, economic and social. An understanding of input and output flows for metal 3D- printed components can be achieved through inventory analysis gathered in EcoInvent database to understand better the parameters related to the sustainability impact based on the provided inputs. This framework is an improved adaptation of the framework established in earlier studies (see Fig. 3).[3]

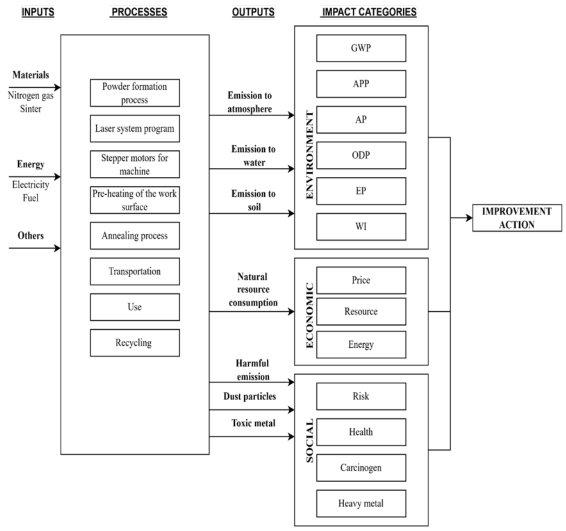

Fig.2: Sustainability evaluation framework

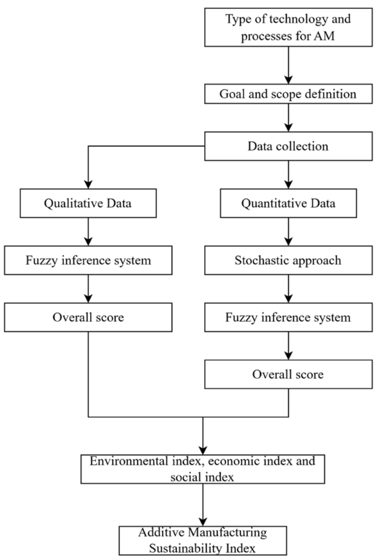

Fig.3: A proposed methodology for 3D metal printed AM.

3. SIMULATION
As previously highlighted, the quantitative data underwent initial processing using the Monte Carlo simulation, followed by the application of fuzzy logic. The Monte Carlo simulation utilized triangular distributions and three-point normalized and weighted data, executing the simulation 1,000 times for each indicator level to ensure robustness in the analysis. To derive the overall performance at the dimension level, the average simulated scores for each parameter were aggregated.
Each pillar of sustainability was assessed from the mean modeled score. These scores were calculated within their respective dimensions to provide a comprehensive assessment.

4. RESULT AND CONCLUSION
4.1 Expected outcomes
The framework is anticipated to yield valuable analyses and stimulate further discussion. Additionally, it will deliver insightful results regarding the overall sustainability index by aggregating the weighted scores of the two subsystems: qualitative and quantitative indicators. By utilizing the sustainability range, the performance of 3D metal printing production can be evaluated, identifying potential enhancements through modifications at various life cycle stages.

4.2 Theoretical implications and future work
This innovative research presents significant implications by introducing a comprehensive sustainability assessment method that effectively combines stochastic and fuzzy approaches to address uncertainties in the field of 3D metal printed. The method serves as a valuable tool for practitioners to monitor their company's sustainability performance and for researchers to analyze and compare the sustainability outcomes within AM community.
Future research could evaluate the sustainability performance of metal AM by encompassing all stages of the supply chain or broadening the assessment framework. This comprehensive approach would provide a more holistic understanding of sustainability impacts and help identify areas for improvement across the entire life cycle stages.

ACKNOWLEDGEMENTS
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REFERENCES
1 A. Waqar, I. Othman and J. C. Pomares, Impact of 3D printing on the overall project success of residential construction projects using structural equation modelling, *Int. J. Environ. Res. Public Health*. 20 (2023) 3800.
2 E. Iacovidou, J. Busch, J. N Hahladakis, H. Baxter, K. S. Ng and B. M Herbert, A parameter selection framework for sustainability assessment, *Sustainability* 9 (2017) 1497.
3 S. Ahmad, K. Y. Wong and B. Zaman, A comprehensive and integrated stochastic-fuzzy method for sustainability assessment in the Malaysian food manufacturing industry, *Sustainability*, 11(2019) 948.