A STUDY TO FIND OUT DESIGN FOR SUSTAINABLE MANUFACTURING: INTEGRATING ECO-FRIENDLY MATERIALS AND PRODUCTION TECHNIQUES IN INDUSTRIAL PRODUCT DESIGN.

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ABSTRACT

Industrial product design that incorporates eco-friendly materials and modern production procedures is the primary emphasis of this research, which delves into the ideas and practices of sustainable manufacturing. The goal is to find and assess design techniques that make manufacturing processes more efficient and less harmful to the environment. This study seeks to answer the question, "How can innovative materials and methods be integrated into product design in industrial contexts to minimise environmental impact, increase resource efficiency, and support long-term sustainability goals?" by examining this question from many angles. Effective design solutions that reconcile ecological issues with practical manufacturing demands are explored in the research via an examination of case studies and existing practices.

Keywords: Sustainable Design, Eco-Friendly Materials, Manufacturing Techniques, Industrial Products.

INTRODUCTION

The design and manufacturing sectors have been at the forefront of the sustainability movement in the last few years. It encompasses a more holistic approach to product creation that considers the whole product’s lifetime and how it affects society, the environment, and businesses. Decisions made throughout the business opportunity identification, idea creation and selection, and product and technology development stages of a product's life cycle have a significant impact on the product's sustainability performance. The development process must be guided towards more sustainable solutions by sustainability-related design factors (Bontempi et al., 2021).

As awareness of environmental issues like pollution, resource loss, and climate change has grown, there has been a marked movement in industrial design towards more sustainable practices. Throughout a product's lifetime, designers and manufacturers are starting to realize how important it is to reduce the negative effects on the environment. To make this change, experts from many different disciplines needed to work together, such as environmental scientists, materials scientists, industrial designers, and engineers. Environmental, social, and economic factors may all be

thoughtfully balanced by interdisciplinary teams working together to find novel solutions (Hotha, 2023).

Resourcefulness, ecological consciousness, economic vitality, cultural sensitivity, and social cohesion are the hallmarks of sustainable production. To put economic development on a sustainable trajectory, it may encourage optimization in industrial structures, strike a balance between economic growth and population increase, safeguard the environment, and efficiently extract and allocate resources. Additionally, it has the potential to greatly impact energy consumption, industrial growth, the creation and use of environmentally friendly materials, as well as the growth of cultural and touristic pursuits (Awan, 2022).

BACKGROUND OF THE STUDY

There is increasing worry about the social and environmental impacts of business practices and consumer goods. According to the IPCC, human-caused greenhouse gas emissions are the leading cause of the highest levels of carbon dioxide, methane, and nitric oxide seen in 800,000 years. Those who fight for the environment are putting pressure on businesses and individuals to do all they can to lower emissions of greenhouse gases. Efforts to galvanize global support for environmental reform were spearheaded by academics in the late 1980s. The United Nations Sustainable Development Goals (SDG) and the Paris Agreement are two examples of the new global accords and collaborative initiatives that have ushered in a new sustainable age (Lambrechts et al., 2019).

In the business world, an increasing number of scholars have concentrated on the level of eco-design integration during product creation. Even though many businesses have stated their intention to adopt eco-design practices, research shows that both the adoption rate and level of implementation are rather low. Arguing that eco-design has not progressed quickly enough to create a sustainable society, there has been a limited dissemination of eco-design methods and technologies (Ilugbusi et al., 2020).

PURPOSE OF THE STUDY

The research team behind this project hopes to find out how to make industrial product designs that use environmentally friendly materials and production methods more sustainable in the long run. Research and assess potential eco-friendly materials for use in manufacturing product designs. Considerations for their impact on the environment, including their biodegradability, recyclability, and decreased carbon footprint, must be considered. Investigate both established and new production methods that aim to make manufacturing more environmentally friendly. Efforts to reduce waste, energy consumption, and negative effects on the environment are being considered. Make concrete suggestions on how to integrate environmentally conscious materials and

manufacturing methods into the design phase. Making sure that designers and manufacturers have all they need to include these eco-friendly methods is part of this. Determine how well and how beneficial it is to include eco-friendly materials and methods in product design. Evaluating the whole effect on product efficiency, cost-effectiveness, and environmental sustainability is part of this process. Based on the study's results, provide practical suggestions for manufacturers and industrial designers on how to incorporate sustainable practices into their manufacturing and design processes.

LITERATURE REVIEW

As businesses strive to reduce their negative effects on the environment and make better use of their resources, sustainable manufacturing has become an increasingly popular goal. Drawing on current research and advancements in the area, this literature review delves into the incorporation of environmentally friendly materials and manufacturing processes into industrial product design. The core principle of sustainable manufacturing is to lessen the negative impact of industrial operations on the environment without sacrificing product performance or functionality. There is a lot of evidence that says using sustainable materials in product design is important (Aitken, 2019).

Research into materials with the ability to reduce trash and carbon emissions is on the rise. These include natural fibres, recycled metals, and biodegradable polymers. Hopewell et al. and Derkzen et al. are just two examples of the many studies that highlight the materials' potential to lessen lifetime effects while also drawing attention to problems like price and performance. Sustainability has also benefited greatly from developments in manufacturing practices. Some revolutionary techniques have been brought to light, such as closed-loop manufacturing systems that enable recycling and reusing of resources and additive manufacturing (3D printing), which permits precision material utilisation and minimal waste. These methods improve production flexibility and efficiency while reducing waste (Cooke, 2020).

RESEARCH QUESTIONS

- How can designers effectively evaluate and select eco-friendly materials for industrial product design?
- What criteria should guide material choices to ensure both functionality and sustainability?
- What innovative manufacturing processes can minimize energy consumption, waste, and emissions?
- How can we balance efficiency with environmental impact in production techniques?

RESEARCH METHODOLOGY

China's many different organisations were responsible for carrying out the research. A quantitative technique was chosen by the researcher because of the restricted resources and the short amount of time available. Using a random sampling process, every respondent was contacted for the survey. Following this, a sample size of 623 was determined using Rao Soft. Individuals confined to wheelchairs or who are unable to read and write would have the survey questions read aloud by a researcher, who would then record their answers word for word on the survey form. While participants waited to complete their surveys, the researcher would inform them about the project and field any questions they may have. On occasion, it is asked that people finish and send back questionnaires simultaneously.

SAMPLING

Research participants filled out questionnaires to provide information for the research. Using the Rao-soft programme, researchers determined that there were 623 people in the research population, so researchers sent out 635 questionnaires. The researchers got 557 back, and they excluded 32 due to incompleteness, so the researchers ended up with a sample size of 525.

DATA AND MEASUREMENT

A questionnaire survey was used as the main source of information for the study (one-to-correspondence or Google-form survey). Two distinct sections of the questionnaire were administered: Both online and offline channels' (A) demographic information, and (B) replies to the factors on a 5-point Likert scale. Secondary data was gathered from a variety of sites, the majority of which were found online.

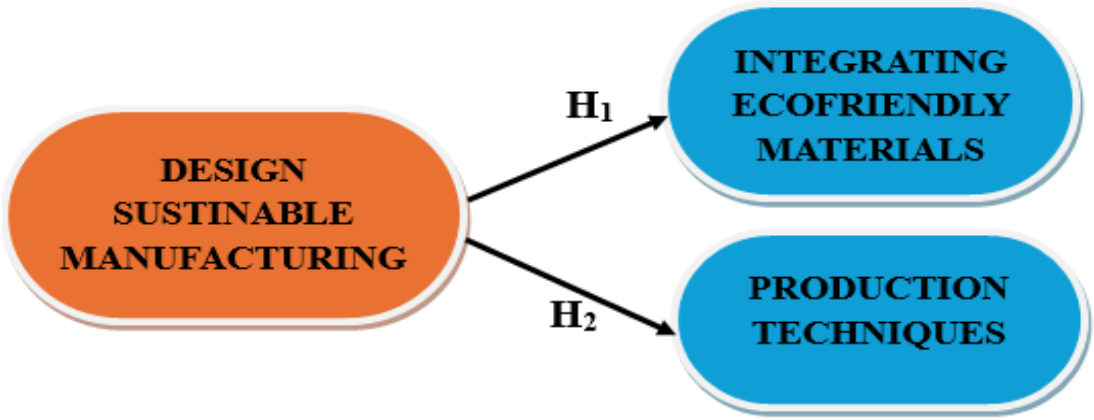
STATISTICAL SOFTWARE

SPSS 25 was used for statistical analysis.

STATISTICAL TOOLS

To get a feel for the data's foundational structure, a descriptive analysis was performed. A descriptive analysis was conducted to comprehend the fundamental characteristics of the data. Validity was tested through factor analysis and ANOVA.

CONCEPTUAL FRAMEWORK



RESULT

Factor Analysis: The process of verifying the underlying component structure of a set of measurement items is a widely used application of Factor Analysis (FA). The observed variables' scores are believed to be influenced by hidden factors that are not directly visible. The accuracy analysis (FA) technique is a model-based approach. The primary emphasis of this study is on the construction of causal pathways that connect observable occurrences, latent causes, and measurement inaccuracies. The appropriateness of the data for factor analysis may be assessed by using the Kaiser-Meyer-Olkin (KMO) Method. The adequacy of the sampling for each model variable as well as the overall model is assessed. The statistics quantify the extent of possible common variation across many variables. Typically, data with lower percentages tends to be more suited for factor analysis.

KMO returns integers between zero and one. Sampling is deemed adequate if the KMO value falls within the range of 0.8 to 1.

It is necessary to take remedial action if the KMO is less than 0.6, which indicates that the sampling is inadequate. Use their best discretion; some authors use 0.5 as this, therefore the range is 0.5 to 0.6.

• If the KMO is close to 0, it means that the partial correlations are large compared to the overall correlations. Component analysis is severely hindered by large correlations, to restate.

Kaiser's cutoffs for acceptability are as follows:

A dismal 0.050 to 0.059.

• 0.60 - 0.69 below-average

Typical range for a middle grade: 0.70–0.79.

Having a quality point value between 0.80 and 0.89.

The range from 0.90 to 1.00 is stunning.

Table 1: KMO and Bartlett's.

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.854
Bartlett's Test of Sphericity	Approx. Chi-Square	3252.968
	df	190
	Sig.	.000

The overall significance of the correlation matrices was further confirmed by using Bartlett's Test of Sphericity. A value of 0.854 s the Kaiser-Meyer-Olkin sampling adequacy. By using Bartlett's sphericity test, researchers found a p-value of 0.00. A significant test result from Bartlett's sphericity test demonstrated that the correlation matrix is not a correlation matrix.

TEST FOR HYPOTHESIS

DEPENDENT VARIABLE

Integrating Eco-Friendly Materials: Choosing and using materials that reduce environmental effects during their whole lifespan is the essence of eco-friendly material integration in industrial product design. Using less non-renewable inputs since they are derived from renewable resources or include recycled materials. Developed for biodegradability, reducing environmental impact over time. Not contaminated with any substances that might be dangerous to humans or the environment. Made using methods that reduce energy use and the release of greenhouse gases. More efficient use of resources, less pollution, and less waste are some of the advantages. To fully harness the power of environmentally friendly materials, the researcher must overcome obstacles including increased prices, performance constraints, and the need for new manufacturing methods (Nuaimi, 2022).

INDEPENDENT VARIABLE

Design Sustainable Manufacturing: As part of our efforts to design sustainable manufacturing, they strive to create products that use the least number of resources feasible without compromising on either the quality or the environment. Use things that are renewable, recyclable, or environmentally friendly to reduce the amount of damage the researcher does to the environment. Ensure that they take advantage of energy-

saving strategies and technologies that are relevant to manufacturing. Waste reduction should be taken into consideration when developing products and processes to make it simpler to recycle or reuse resources. Additionally, it is important to consider the impact that a product has on the environment during its whole lifecycle, not only during the production process. Through the creation of goods and manufacturing systems that include these concepts, designers have the potential to contribute to the achievement of environmental and resource preservation standards (Adekanmbi, 2024).

There are significant relationships between Integrating Ecofriendly Materials and Design Sustainable Manufacturing: The selection of materials has a direct impact on the whole sustainability of production processes, hence integrating environmentally friendly materials and designing for sustainable manufacturing go hand in hand. Using recyclable, biodegradable, or sustainably produced materials helps lessen a product's environmental effects during its lifetime. As a result, sustainable design makes use of these materials in production processes to lessen pollution, energy consumption, and waste. Manufacturers can maximise the advantages of eco-friendly materials and improve the overall sustainability of production systems by aligning material choices with sustainable design principles. This allows them to build products that are both efficient and ecologically responsible.

Based on the above discussion, the researcher formulated the following hypothesis, which was to analyse the relationship between Integrating Ecofriendly Materials and Design Sustainable Manufacturing.

"$H0_1$: There is no significant relationship between Integrating Ecofriendly Materials and Design Sustainable Manufacturing."

"H_1: There is a significant relationship between Integrating Ecofriendly Materials and Design Sustainable Manufacturing."

Table 2: H_1 ANOVA Test.

ANOVA					
Sum					
	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	39588.620	322	5655.517	1123.124	.000
Within Groups	492.770	202	5.356		
Total	40081.390	524			

In this study, the result is significant. The value of F is 1123.124, which reaches significance with a p-value of .000 (which is less than the .05 alpha level). This means the **"H_1: There is a significant relationship between Integrating Ecofriendly Materials**

and Design Sustainable Manufacturing." is accepted and the null hypothesis is rejected.

Table 3: KMO and Bartlett's.

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.871
Bartlett's Test of Sphericity	Approx. Chi-Square	3252.968
	df	190
	Sig.	.000

The overall significance of the correlation matrices was further confirmed by using Bartlett's Test of Sphericity. A value of 0.871 s the Kaiser-Meyer-Olkin sampling adequacy. By using Bartlett's sphericity test, researchers found a p-value of 0.00. A significant test result from Bartlett's sphericity test demonstrated that the correlation matrix is not a correlation matrix.

DEPENDENT VARIABLE

Production Techniques: Low- or no impact on the environment and efficient use of resources are at the heart of sustainable manufacturing production practices. Using a layer-by-layer approach, it builds items while reducing waste and enabling intricate, personalised patterns. Reduces waste and conserves resources by recycling and reusing materials throughout the manufacturing process. Lowers energy usage and greenhouse gas emissions via the application of technologies and practices. Reduces resource consumption, boosts efficiency, and streamlines manufacturing to remove waste. By increasing resource efficiency, decreasing waste, and lessening the overall environmental impact of production, these methods seek to improve sustainability (Adeleke, 2019).

There are significant relationships between Integrating Ecofriendly Materials and Design Sustainable Manufacturing: Environmental responsibility in industrial production is driven by the interdependent principles of planning for sustainable manufacturing and integrating eco-friendly resources. Sustainable production cannot exist without eco-friendly materials, which include components that are either biodegradable, recyclable, or obtained from sustainable sources. When used, these measures lessen the environmental effect of a product at every stage of its lifespan, from manufacturing to final disposal. To maximise the advantages of these environmentally friendly materials, sustainable industrial design includes them in the

production process. Waste reduction, energy efficiency, and product recyclability are the primary goals of this strategy. Material selection impacts production methods, and design checks that materials are put to good use in a manner that doesn't harm the environment. Achieving sustainable manufacturing essentially requires incorporating eco-friendly materials into product design. Manufacturers may bring their goods and manufacturing processes in line with larger sustainability objectives by choosing and using these materials properly, which enhances their environmental performance.

Based on the above discussion, the researcher formulated the following hypothesis, which was to analyse the relationship between Integrating Ecofriendly Materials and Design Sustainable Manufacturing.

"$H0_2$: There is no significant relationship between Production Techniques and Design Sustainable Manufacturing."

"H_2: There is a significant relationship between Production Techniques and Design Sustainable Manufacturing."

Table 4: H_2 ANOVA Test.

ANOVA					
Sum					
	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	39388.620	330	5655.517	1057.457	.000
Within Groups	692.770	194	5.356		
Total	40081.390	524			

In this study, the result is significant. The value of F is 1057.457, which reaches significance with a p-value of .000 (which is less than the .05 alpha level). This means the **"H_2: There is a significant relationship between Production Techniques and Design Sustainable Manufacturing."** is accepted and the null hypothesis is rejected.

DISCUSSION

Design for sustainable manufacturing has come a long way, but there are still many obstacles to overcome. One way to do this is by using environmentally friendly materials and production methods. In this review, the researcher looked at the most important results from the last few studies and saw what they mean for the future of industrial product design. As more people learn about the negative effects that conventional materials have on the environment, they are opting for greener alternatives in industrial product design. Materials including natural fibres, recyclable metals, and biodegradable polymers have shown promise in studies. These materials are in line with larger sustainability objectives because of their many benefits, such as less waste and

fewer carbon emissions. For instance, recycled metals aid in resource conservation and decrease the energy needed for extraction and processing, while biodegradable polymers may decompose more easily in natural settings, reducing long-term pollution. Adopting these materials, meanwhile, isn't a picnic. Researchers have shown that the greater initial investment required to purchase environmentally friendly materials is a major deterrent to their wider adoption. There is also the issue that sustainable materials' performance isn't always comparable to that of conventional materials, which makes one wonder whether they are appropriate for certain uses. Continuous investigation into ways to enhance material qualities while simultaneously decreasing prices via technical advancements and economies of scale is necessary to tackle these concerns (Ilieva, 2022).

CONCLUSION

The research that has been done on environmentally friendly manufacturing processes and materials has shown both significant progress and ongoing challenges. As a result of advancements in manufacturing methods and materials, there are opportunities to reduce the negative effects on the environment; nevertheless, there are also challenges that need to be taken into consideration, such as issues over the cost and performance of the product. To accomplish sustainability goals in industrial product design, it is necessary to have a technique of design that is all-encompassing, as well as methods of implementation that are practical, and these methods must be supported by continual research and innovation. If these challenges are overcome, the sector may be able to make progress towards more sustainable practices that are in line with environmental goals and fulfil the requirements of a world that is always changing (Barrera, 2018).

REFERENCES

1. Adekanmbi, A.O., & Wolf, D. (2024). Solid Mineral Resources Extraction and Processing Using Innovative Technology in Nigeria. ATBU Journal of Science, Technology and Education, 12(1), 1-16.
2. Adeleke, O.K., Segun, I.B., & Olaoye, A.I.C. (2019). Impact of internal control on fraud prevention in deposit money banks in Nigeria. Nigerian Studies in Economics and Management Sciences, 2(1), 42-51.
3. Aitken, R., Watkins, L., & Kemp, S. (2019). Envisioning a sustainable consumption future. Young Consumers, 20(4), 299-313.
4. Al-Nuaimi, S.R., & Al-Ghamdi, S.G. (2022). Sustainable consumption and education for sustainability in higher education. Sustainability, 14(12), 7255.
5. Awan, U., & Sroufe, R. (2022). Sustainability in the circular economy: insights and dynamics of designing circular business models. Applied Sciences, 12(3), 1521.

6. Barrera, N.I.G. (2018). Eco-compatible syntheses of bio-based solvents for the paint and coating industry (Doctoral dissertation, Institute National Polytechnique de Toulouse-INPT).
7. Bontempi, E., Sorrentino, G.P., Zanoletti, A., Alessandri, I., Depero, L.E., & Caneschi, A. (2021). Sustainable materials and their contribution to the sustainable development goals (SDGs): a critical review based on an Italian example. Molecules, 26(5), 1407.
8. Cicconi, P. (2020). Eco-design and Eco-materials: An interactive and collaborative approach. Sustainable Materials and Technologies, 23, e00135.
9. Cooke, S.J., Nguyen, V.M., Anastakis, D., Scott, S.D., Turetsky, M.R., Amirfazli, A., Hearn, A., Milton, C.E., Loewen, L., Smith, E.E., & Norris, D.R. (2020). Diverse perspectives on interdisciplinarity from Members of the College of the Royal Society of Canada. Facets, 5(1), 138-165.
10. Hotha, K.K. (2023). Unleashing the Power of Innovation in CDMOs through Customer-Centricity and Culture of Service. American Journal of Industrial and Business Management, 13(4), 234-246.
11. Ilieva, L., Ursano, I., Traista, L., Hoffmann, B., & Dahy, H. (2022). Biomimicry as a sustainable design methodology—Introducing the 'Biomimicry for Sustainability framework. Biomimetics, 7(2), 37.
12. Ilugbusi, S., Akindejoye, J.A., Ajala, R.B., & Ogundele, A. (2020). Financial liberalisation and economic growth in Nigeria (1986-2018). International Journal of Innovative Science and Research Technology, 5(4), 1-9.
13. Lambrechts W, Gelderman CJ, Semeijn J, et al. The role of individual sustainability competencies in eco-design building projects. Journal of Cleaner Production 2019; 208: 1631-41.
14. Schäfer, M., & Löwer, M. (2021). Ecodesign—A Review of Reviews. Sustainability, 13(1), 315.