

Rapid Prototyping in Pakistan: A Technical Feasibility Study with Analytical Hierarchy Process Analysis, Bridging Civil and Industrial Engineering Perspectives [†]

Ghulam Ameer Mukhtar ^{1,*}, Sana Shehzadi ¹, Muhammad Moazzam Ali ^{2,*}, Abdul Ahad Malik ³ and Muhammad Mohsin Arshad ⁴

¹ Industrial Engineering Department, University of Engineering and Technology, Punjab 39161, Pakistan; sanashehzadi159@gmail.com

² NUST Institute of Civil Engineering (NICE), School of Civil and Environmental Engineering (SCEE), National University of Sciences and Technology (NUST), Islamabad 44000, Pakistan

³ Mechanical Engineering Department, University of Engineering and Technology, Punjab 39161, Pakistan; 20-ME-88@students.uettaxila.edu.pk

⁴ Civil Engineering Department, University of Engineering and Technology, Punjab 39161, Pakistan; 21-CE-77@students.uettaxila.edu.pk

* Correspondence: ameerjaffri6@gmail.com (G.A.M.); mmoazzam.ms23nice@student.nust.edu.pk (M.M.A.)

[†] Presented at the 4th International Conference on Advances in Mechanical Engineering (ICAME-24), Islamabad, Pakistan, 8 August 2024.

Abstract: This study investigates the prospect of using rapid prototyping, particularly additive manufacturing, in Pakistan's construction and manufacturing sectors, aiming to encourage R&D by the analysis of technical feasibility of this technology and collaboration between civil and industrial engineering. To solve this puzzle, we collected data from field experts, academia researchers, and license holders of this technology. Further, analytical hierarchy process (AHP), a sub-branch of multicriteria decision-making method (MCDM), was used to gauge the systematically by prioritizing selection criteria for solving the problem. AHP makes the methodical process more accurate and organized, which helped us to proposed a feasibility study for the technology's success in Pakistan's construction and manufacturing industries. The findings show a 79.4% probability, which indicates interaction among both engineering disciplines. Furthermore, a sensitivity analysis was conducted to enhance the dependability of the AHP model, which assists in sound decision making during ambiguous conditions. Apart from economic technical aspects, sustainability plays a very crucial role in the evaluation process. This text shows the environmental effects and sustainability implications associated with the assimilation of rapid prototyping technologies. This supports the integration of rapid prototyping in Pakistan, contributing to discussions on technological innovations in emerging nations. This will also lay a foundation for future interdisciplinary collaboration and technological enrichments in both engineering domains.

Keywords: assessment of rapid prototyping feasibility; construction and manufacturing industry; integration of civil and industrial engineering; Pakistan



Citation: Mukhtar, G.A.; Shehzadi, S.; Ali, M.M.; Malik, A.A.; Arshad, M.M. Rapid Prototyping in Pakistan: A Technical Feasibility Study with Analytical Hierarchy Process Analysis, Bridging Civil and Industrial Engineering Perspectives. *Eng. Proc.* **2024**, *75*, 30. <https://doi.org/10.3390/engproc2024075030>

Academic Editors: Muhammad Mahabat Khan, Muhammad Irfan, Mohammad Javed Hyder and Manzar Masud

Published: 25 September 2024



Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

In recent times, there has been a rising trend of using rapid prototyping, especially additive manufacturing, in the construction and manufacturing sectors [1–3]. This process involves the layer-by-layer erection of different digital libraries and presents a transformed industry that promises to rationalize the evolution from 3D models to final products. In the context of Pakistan, rapid prototyping could play a very important role in the rapid development of industries and infrastructure. Pakistan's construction firms can leverage this technology to construct sophisticated structures, customize material within components,

and automate construction using advanced methods [4–6]. Simultaneously, in manufacturing, rapid prototyping can be facilitated quickly, expediting the product design, increasing product efficacy, and minimizing lead time during the initial phase of prototyping [7–9]. This study is based on the convergence of civil and industrial engineering perspectives and aims to conduct a technical feasibility analysis of utilizing rapid prototyping in Pakistan. The analytic hierarchy process (AHP) is used. This not only offers an opportunity to improve decision-making efficiency and effectiveness but also lays the stage for potential collaboration among disciplines. The assessment principles will highlight some key factors, such as cost savings at initial phases, design impacts, and sustainability considerations. The use of rapid prototyping not only increases efficiency in these sectors, but it will provide an opportunity to implement sustainable goals. Rapid prototyping can contribute to sustainable development goals by minimizing material waste, reducing energy consumption, and enabling the use of environmentally friendly materials [10]. The growth of 3D printer production in Pakistan can greatly contribute to the development of green industries, such as recycling and repurposing plastic and aluminum waste into materials for 3D printing. These materials can be used to create various items like furniture and building materials. This advancement supports sustainable initiatives and aligns with the Sustainable Development Goals (SDGs) while promoting Industry 4.0, which integrates modern manufacturing with digital technology [11]. The global 3D printing market, valued at USD 23.7 billion in 2023, is projected to reach approximately USD 149.4 billion by 2030, with a compound annual growth rate of 20.5% from 2023 to 2030 [12].

Previous studies have used ANOVA [13,14] and chi-square [15,16] for similar types of investigations; our approach distinguishes itself by using AHP as an investigation tool. The analytic hierarchy process (AHP) is a popular decision-making tool that simplifies complex decisions by breaking them down into a hierarchy of sub-problems and using pairwise comparisons to establish priorities among various options. Compared to other methods like multicriteria decision analysis (MCDA), which includes techniques such as TOPSIS and simple additive weighting (SAW) that focus on ranking alternatives based on their similarity to an ideal solution, AHP places a strong emphasis on the consistency of judgments. Another approach, the Delphi method, involves iterative rounds of surveys among experts to achieve a consensus, making it particularly useful for capturing expert opinions in subjective areas. Each method has its strengths: AHP provides a structured mathematical approach, while MCDA and Delphi offer alternative perspectives that can be more suitable depending on the specific decision context, data characteristics, and the needs of decision makers. AHP effectively handles complex situations through its hierarchical structure, allowing for systematic and logical analysis [14].

2. Methodology

This is a qualitative study that aims to evaluate the technical feasibility of incorporating rapid prototyping in Pakistan's construction and manufacturing sectors. As in Figure 1, data collection, a structured questionnaire is designed that aligns with the methodology of AHP and is then circulated among the different stakeholders, which include industrial experts and universities including site engineers, technical foremen, university professors, and lab engineers in construction and manufacturing industries in Pakistan. The responses obtained from the questionnaire are served as the input for analysis, and analysis is conducted by using expert choice software.

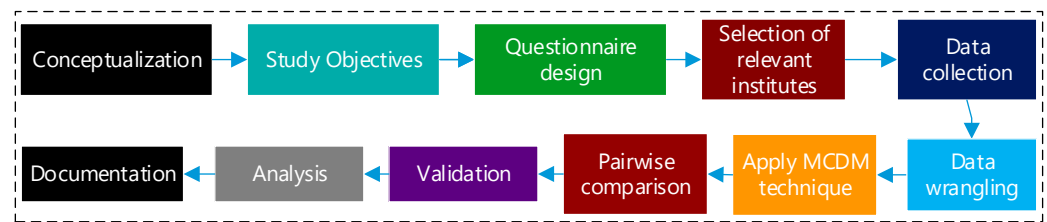


Figure 1. Work design.

We employed the AHP, which involves comparing criteria hierarchically to determine their relative importance. We assigned numerical values to criteria such as production impact, design and innovation, sustainability and environment, time and efficiency, and process integration, to calculate priority weights. AHP was chosen for its versatility, pairwise comparison, consistency check, weighting criteria, logical approach, and effectiveness in handling complex scenarios, enabling a structured and transparent analysis. Our methodology for determining the questionnaire's quantity was guided by a specific formula, emphasizing the importance of precision and stakeholder insights in the decision-making process:

$$N = n(n - 1)/2, \text{ where } n \text{ represents the number of variables.}$$

2.1. Hierarchy Structure

The criterion chosen for this study investigates the probability of integrating rapid prototyping in targeted sectors, based on some key factors ensuring thorough and industry-specific assessment. Each principle, including time and efficiency, process integration, sustainability and environment, design and innovation, and production impact, was accurately chosen for its direct relevance to the study's objective, assessing the practicality of rapid prototyping in Pakistan's engineering landscape. The selected criteria form a balanced evaluation framework that goes beyond typical considerations, to encompass a spectrum of aspects crucial for a nuanced analysis.

2.2. Criterion

The main focus is on the key criteria: time and efficiency, which examines the impact on project schedules and operational efficiency; process integration, which evaluates the seamless incorporation of rapid prototyping into existing construction and manufacturing processes; sustainability and environment, which assesses the environmental effects and sustainability aspects of adopting rapid prototyping technologies; design and innovation, which analyzes the potential for design advancements and innovative solutions; and production impact, which considers the broader effects on production processes, including scalability, adaptability, and overall enhancement.

2.3. Alternatives

There are the following alternatives to those used in this study. (1) Feasible, comprising the following: (i) rapid prototyping is likely to be successful; (ii) aligns with industry requirements; (iii) brings positive outcomes in terms of efficiency, sustainability, and revolution. (2) Not feasible, comprising (i) challenges or problems compensate for the benefits; (ii) deemed hopeless or unlikely to succeed. However, these assist us in selecting the most viable path forward, considering specific criteria identified in our study.

Figure 2 serves as a visual guide to the layered structure, which is essential for our analysis of the technical feasibility. Each principle, including time and efficiency, process integration, sustainability and environment, design and innovation, and production impact, is accurately chosen for its direct relevance to the study's objective, assessing the practicality of rapid prototyping in Pakistan's engineering landscape shown in Figure 2.

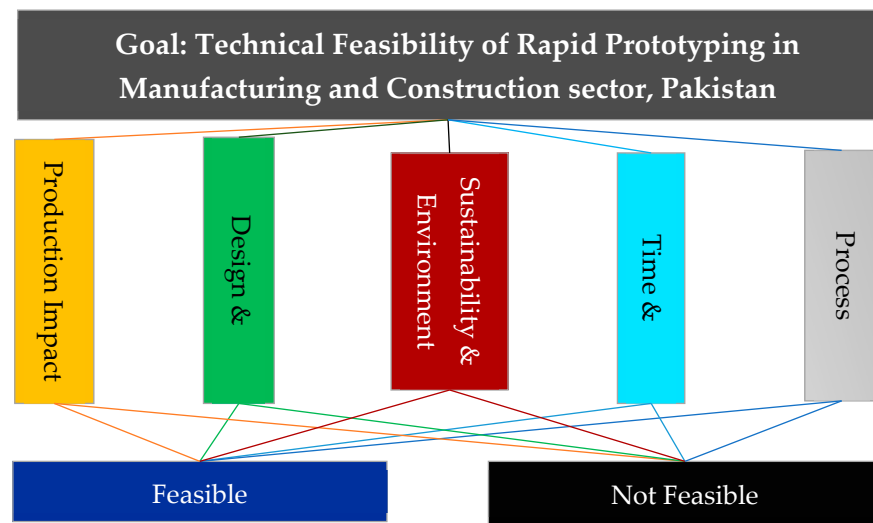


Figure 2. AHP structure.

3. Priority Weights Assigned

The AHP involves a deep analysis of factors and their components, which serve as the foundation for prioritizing choices. This process involves amalgamating collective stakeholders' points of view and combining individual preferences with the perceived importance of different elements within the decision-making process. Figure 3 visually represents the weights allotted to each criterion concerning the overarching goals, derived from an inclusive evaluation of stakeholder verdicts. Likewise, we performed pairwise comparisons, using a nine-point scale to converse preferences to assess each criterion against each other. These comparisons produced a matrix indicating the relative significance of each value. To guarantee reliability, a consistent check was employed, and the eigenvector technique was used to calculate normalized weights. The priority weights assigned to different criteria are as follows. The priority weight of production impact was 1, time and efficiency was 0.59, process integration was 0.13, design and innovation was 0.81, and sustainability and environment was 0.131. Normalization is critical to maintain a consistent sum of weight equal to 1. The calculated weights were subjected to validation and census building among different stakeholders for adjustments. The ultimate weights provide a quantitative basis for decision making, illustrating the significance of each criterion in achieving overarching goals. This approach combines stakeholder preferences, ensuring transparency and consistency throughout the AHP.

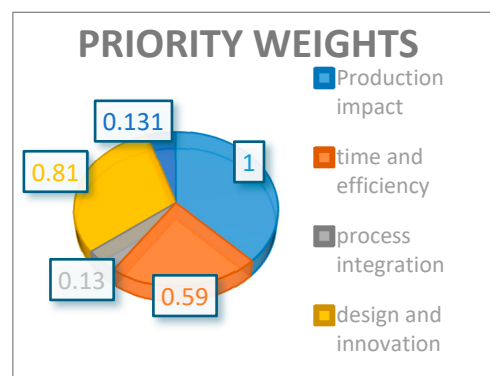


Figure 3. Priority weights.

4. Results

4.1. Inconsistency Ratio

In the framework of the feasibility study on rapid prototyping in Pakistan's construction and manufacturing sectors, the reference to an inconsistency ratio of 0.01 in the AHP highlights the reliability and consistency of the decision-making process. The low inconsistency ratios indicate that our judgments made during pairwise comparisons are reliable and stable. This inconsistency is very important for the robustness of AHP outcomes, particularly when assigning weights to criteria and drawing conclusions regarding the feasibility of rapid prototyping. It indicates that the decision-maker's evaluations were thoughtfully considered and aligned with the principles of a consistent decision matrix, thereby enhancing credibility and confidence in the study's conclusions.

4.2. Alternative Selection

The bar charts shown in Figure 4 offer a deep analysis through the AHP method, illuminating the prioritization weight criteria, and providing valuable insight into the potential integration of rapid prototyping in Pakistan's construction and manufacturing sectors. Production impact emerges as the focal point, having the highest weight of 1, revealing its importance in analysis. Time and efficiency follow with a 0.59 weight, contributing significantly to the overall "Yes, Feasible" conclusion, supported by a noteworthy 79.4% weight. Contrarywise, other factors like process integration follow with 0.13, design and innovation with 0.81, and sustainability and environment with 0.131, exhibiting lower weights, signifying a relatively diminished impact on the decision. It is important to note that the "Not Feasible" aspects carry a weight of 20.6%, acknowledging potential challenges.

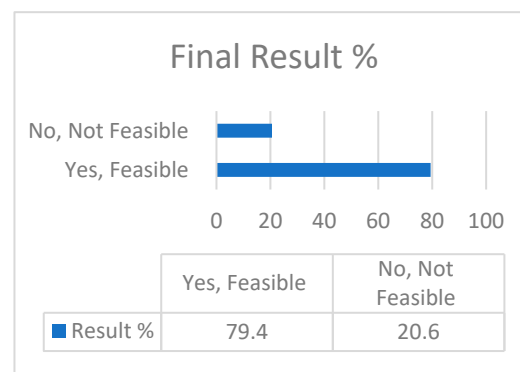


Figure 4. Results of AHP.

These results not only endorse the positive impacts but also provide a beneficial environment for synergies and advancements in construction as well as manufacturing fields, providing stakeholders with a comprehensive perspective when considering the implementation of rapid prototyping practices in Pakistan. The recognition of challenges through the "Not Feasible" aspect adds depth to the consideration, ensuring a well-rounded understanding of the feasibility landscape.

5. Sensitivity Analysis

Dynamic sensitivity analysis, an integral component of the AHP, serves as an advanced method for evaluating the impact of uncertainties on decision-making rankings. It addresses variations stemming from both data and preference uncertainties. The graphical representation in Figure 5 illustrates dynamic sensitivity values, providing a clear insight into how criteria respond to potential changes in input parameters. Time and efficiency are on top with a dynamic sensitivity of 62.4, highlighting its heightened vulnerability to alterations and its crucial role in shaping overall decisions. Examined closely, production impact has a dynamic sensitivity of 18.4, indicating a moderate level of responsiveness to

variation. On the contrary, sustainability and environment has the lowest dynamic sensitivity of 7.6, suggesting a relatively lower impact when compared to time and efficiency and production impact. These intricate dynamic sensitivity insights equip decision-makers with a detailed understanding of criteria responsiveness, facilitating a more adaptive and informed approach to navigating uncertainties within the decision-making landscape.

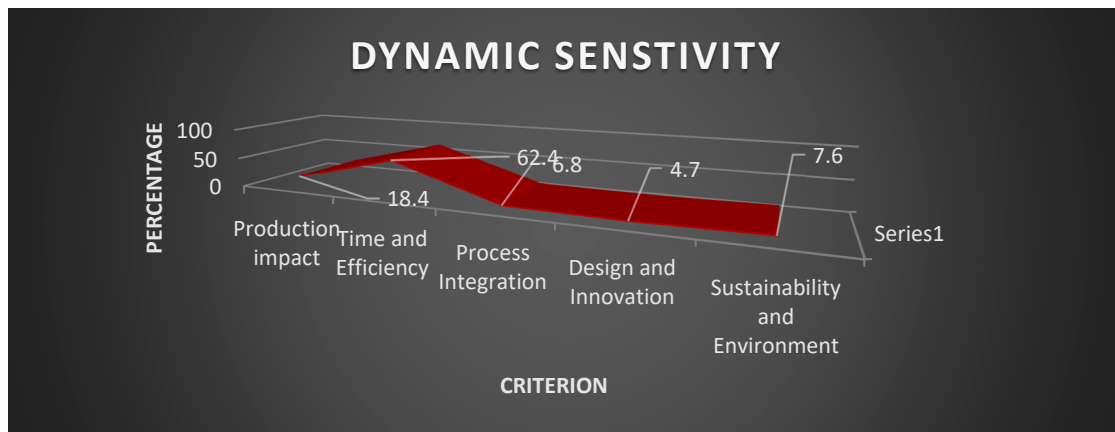


Figure 5. Nodes performance sensitivity.

6. Conclusions

In a nutshell, exploiting the AHP conclusively affirms an impressive 79.4% feasibility for the incorporation of rapid prototyping technology in Pakistan's construction and manufacturing sectors. The logical investigation is guided by a carefully designed questionnaire and adeptly used AHP software, Expert Choice 11.5, which assesses the particularity, cost savings, time efficiencies, and design impacts. The consolidated findings, effectively conveyed via priority weights and pie charts, not only emphasize the feasibility of integrating rapid prototyping but also indicate a promising opportunity for synergy in the traditionally separate domains of civil and industrial engineering. The deliberate inclusion of sensitivity analysis substantially reinforces the AHP model's reliability, instilling confidence in its robustness during inherent uncertainties. Similarly, this work lays a strong foundation for future engineering progress and interdisciplinary collaboration in the evolving industrial context of Pakistan.

Author Contributions: G.A.M.: Conceptualization, technical writing, literature, data collection, and analysis. S.S.: Literature, technical writing, questionnaire development, analysis, and formatting. M.M.A. (Muhammad Moazzam Ali): Technical writing, literature, questionnaire development, data collection, vector designing, analysis, and formatting. A.A.M.: Data collection, editing, Literature, and formatting. M.M.A. (Muhammad Mohsin Arshad): Literature, vector designing, and data collection. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Hamidi, F.; Aslani, F. Additive manufacturing of cementitious composites: Materials, methods, potentials, and challenges. *Constr. Build. Mater.* **2019**, *218*, 582–609. [\[CrossRef\]](#)
2. Huang, Y.; Leu, M.C.; Mazumder, J.; Donmez, A. Additive manufacturing: Current state, future potential, gaps and needs, and recommendations. *J. Manuf. Sci. Eng. Trans. ASME* **2015**, *137*, 014001. [\[CrossRef\]](#)

3. Zhai, Y.; Lados, D.A.; Lagoy, J.L. Additive Manufacturing: Making Imagination the Major Limitation. *JOM* **2014**, *66*, 808–816. [CrossRef]
4. Paolini, A.; Kollmannsberger, S.; Rank, E. Additive manufacturing in construction: A review on processes, applications, and digital planning methods. *Addit. Manuf.* **2019**, *30*, 100894. [CrossRef]
5. Craveiro, F.; Duarte, J.P.; Bartolo, H.; Bartolo, P.J. Additive manufacturing as an enabling technology for digital construction: A perspective on Construction 4.0. *Autom. Constr.* **2019**, *103*, 251–267. [CrossRef]
6. Ghaffar, S.H.; Corker, J.; Fan, M. Additive manufacturing technology and its implementation in construction as an eco-innovative solution. *Autom. Constr.* **2018**, *93*, 1–11. [CrossRef]
7. Attaran, M. Additive Manufacturing: The Most Promising Technology to Alter the Supply Chain and Logistics. *J. Serv. Sci. Manag.* **2017**, *10*, 189–206. [CrossRef]
8. Lakshmanan, R.; Nyamekye, P.; Virolainen, V.M.; Piili, H. The convergence of lean management and additive manufacturing: Case of manufacturing industries. *Clean. Eng. Technol.* **2023**, *13*, 100620. [CrossRef]
9. Walia, K.; Khan, A.; Breedon, P. Polymer-based additive manufacturing: Process optimization for low-cost industrial robotics manufacture. *Polymers* **2021**, *13*, 2809. [CrossRef] [PubMed]
10. Kalinke, C.; Crapnell, R.D.; De Oliveira, P.R.; Janegitz, B.C.; Bonacin, J.A.; Banks, C.E. How to improve sustainability in fused filament fabrication (3D printing) research? *Glob. Chall.* **2024**, *8*, 2300408. [CrossRef] [PubMed]
11. Yadav, A.; Bhatnagar, A. Sustainable digital manufacturing processes in Industry 4.0. In *Sustainability in Smart Manufacturing*; CRC Press: Boca Raton, FL, USA, 2024; pp. 19–36. [CrossRef]
12. Global 3D Printer Market Size, Forecast, Analysis & Share Surpass US\$ 149.4 Billion by 2030, at 20.5% CAGR. *J. Cyber Policy* **2023**. Available online: <https://journalofcyberpolicy.com/latest-global-3d-printer-market-size-forecast-analysis-share-surpass-us-149-4-billion-by-2030-at-20-5-cagr/> (accessed on 12 September 2024).
13. Dixit, N.K.; Srivastava, R.; Narain, R. Comparison of Two Different Rapid Prototyping System Based on Dimensional Performance Using Grey Relational Grade Method. *Procedia Technol.* **2016**, *25*, 908–915. [CrossRef]
14. Kumar, N.; Kumar, H.; Khurmi, J.S. Experimental Investigation of Process Parameters for Rapid Prototyping Technique (Selective Laser Sintering) to Enhance the Part Quality of Prototype by Taguchi Method. *Procedia Technol.* **2016**, *23*, 352–360. [CrossRef]
15. Li, C.; Yang, M.; Xie, Y.; Chen, Z.; Wang, C.; Bai, Y.; Zhu, X.; Li, M. Application of the polystyrene model made by 3-D printing rapid prototyping technology for operation planning in revision lumbar discectomy. *J. Orthop. Sci.* **2015**, *20*, 475–480. [CrossRef] [PubMed]
16. Gil, R.S.; Roig, A.M.; Obispo, C.A.; Morla, A.; Pagès, C.M.; Perez, J.L. Surgical planning and microvascular reconstruction of the mandible with a fibular flap using computer-aided design, rapid prototype modeling, and pre-contoured titanium reconstruction plates: A prospective study. *Br. J. Oral Maxillofac. Surg.* **2015**, *53*, 49–53. [CrossRef] [PubMed]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.