International Journal of Advanced Technology and Social Sciences (IJATSS)
Vol.2, No.12, 2024: 1907-1916

Design Optimization of Mulch Plastic Perforating Machines for Enhanced Agricultural Efficiency

Rino Sukma[1], Dwiny Meidelfi[2*], Fanni Sukma[3], Surfa Yondri[4], Sukartini[5]
Padang State Polytechnic
Corresponding Author: Dwiny Meidelfi; dwinymeidelfi@pnp.ac.id

A R T I C L E I N F O

Keywords: Mulch, Agricultural Mechanization, Perforating Machine, Design Optimization, CAD Modeling

Received : 5 October
Revised : 17 November
Accepted: 23 December

A B S T R A C T

Mulch is widely used in modern agriculture to conserve soil moisture, regulate temperature, and reduce weed growth, significantly enhancing crop productivity. However, the manual perforation of Mulch for planting introduces inefficiencies, including labor-intensive processes, inconsistent results, and time consumption. This research presents the design and optimization of an advanced mulch perforating machine to address these challenges. The research involved a comprehensive assessment of existing designs, identification of critical performance parameters, and integration of modern engineering solutions. The optimized design features a lightweight aluminum frame for enhanced portability, a precision perforation system utilizing solenoids and microcontroller-based control, and modular components for ease of maintenance. A CAD model was developed to refine the design and identify potential improvements before prototyping.

Performance evaluations showed that the optimized machine achieved a production rate of 120 perforations per minute, more than doubling the efficiency of traditional methods. Comparative analyses confirmed their advantages over previous designs, including reduced operational costs and improved usability. This research concludes that the optimized Mulch perforating machine offers significant potential to improve agricultural productivity while reducing labor dependency and operational inefficiencies. Recommendations for future research include field testing under diverse conditions, exploring IoT integration for real-time monitoring, and analyzing the economic impact on smallholder farmers. This innovation represents a step forward in the mechanization of agriculture, supporting sustainable and efficient farming practices

DOI: https://doi.org/10.59890/ijatss.v2i12.81
E-ISSN: 3026-2410
https://journal.multitechpublisher.com/index.php/ijatts

INTRODUCTION

In the modern era, technological advancements continue to influence various sectors, including agriculture. One notable transformation is the integration of machinery into agricultural activities. Agricultural machines, initially developed to assist manual labor, have now become essential tools for enhancing efficiency and productivity. The optimization of agricultural machinery not only reduces reliance on human and animal labor but also accelerates production processes, lowers costs, reduces machine weight, and improves agricultural yields.

The innovation of agricultural tools and machinery (Alsintan) aims to enhance efficiency, quality, and productivity in farming. According to Salokhe and Ramalingam (1998), agricultural mechanization can improve land and labor efficiency, conserve resources, and enhance both the quality and quantity of agricultural outputs. One significant innovation in Alsintan is the development of effective and affordable plastic mulch perforating machines, which simplify agricultural production processes for farmers.

In Indonesia, the use of plastic mulch has become common, especially in vegetable and secondary crop cultivation, due to its cost-saving and soil-preparation benefits. Plastic mulch helps retain soil moisture, suppress weeds and pests, and maintain soil temperature suitable for plant growth. However, manually perforating Mulch after it is laid out presents several challenges, including time and labor inefficiencies and adverse effects on workers' health and productivity.

Employing a mulch perforating machine before the mulch is spread is a more effective solution, addressing the limitations of manual methods and enhancing productivity and farmer well-being. Consequently, optimizing the design and functionality of mulch perforating machines is crucial for supporting sustainable agricultural practices and improving farmer livelihoods.

The objective of this research is to optimize the design of plastic mulch perforating machines to improve their efficiency, functionality, and affordability. Specifically, the research aims to analyze and refine the machine's mechanical components, reduce operational costs, and ensure ease of use for farmers, thereby contributing to increased agricultural productivity and sustainability.

LITERATURE REVIEW

1. *Mechanization in Agriculture*

Recent advancements in agricultural mechanization have focused on enhancing productivity, reducing labor dependency, and improving resource efficiency. Research by (Prakash 2023., وآخ; Rahman 2020., وآخ) highlight the role of mechanized tools in achieving sustainable agricultural practices.

2. *Plastic Mulching Techniques*

The use of plastic mulch has become increasingly prevalent due to its benefits in moisture retention, weed control, and temperature regulation (Abebe 2019., وآخ; Madrid 2022., وآخ; Shah & Wu, 2020). However, challenges such as labor-intensive application methods necessitate mechanized solutions (Maguey-González 2018., وآخ; Nandan & Kumar, 2022).

3. ***Design Optimization in Agricultural Machines***

Research on design optimization emphasizes lightweight materials, modular components, and precision control systems (Maguey-González وآخ., 2018; Peto 2024., وآخ; Spinelli 2023., وآخ). CAD modeling has been widely adopted to streamline the design process and preempt potential issues (Carbonell-Carrera 2019., وآخ; Garikano 2019., وآخ; Zhou & Hu, 2024).

4. ***Smart and Automated Systems***

Recent studies explore the integration of automation and intelligent control systems in agricultural machines (Bhatnagar 2022., وآخ; Garcia 2022., وآخ; Parenti 2017., وآخ). Technologies such as fuzzy logic, IoT, and machine learning have proven effective in enhancing operational efficiency (Aboshosha 2023., وآخ; Pathan 2020., وآخ; Wildan, 2023; Yadav 2022., وآخ).

5. ***Comparative Analysis of Existing Perforating Machines***

Several studies have analyzed the performance of manual versus mechanized mulch perforating systems (Yondri 2017., وآخ). Findings suggest that Mulch perforating systems underscores the need for design improvements.

6. ***Sustainability and Energy Efficiency***

The push toward sustainable mechanization is evident in studies focusing on energy-efficient designs and environmentally friendly materials. These approaches align with global goals for sustainable agriculture.

7. ***Economic Feasibility and Adoption by Farmers***

Economic studies evaluate the cost-benefit ratio of mechanized tools, particularly their adoption by smallholder farmers (Xu 2021., وآخ). Affordability and user training remain critical factors.

METHODOLOGY

The research methodology for optimizing the design of the Mulch perforating machine aims to enhance machine performance in creating holes in mulch by considering various technical aspects such as efficiency, durability, speed, and operational cost. The following steps outline the research process:

1. ***Preliminary Study and Problem Identification***

Evaluation of current machine limitations by analyzing weaknesses and issues with the existing mulch perforating machines, focusing on labor efficiency, hole accuracy, production speed, and machine durability. Identification of Critical Variables with the determine key factors affecting machine performance, such as the size and type of mulch material, perforation speed, hole dimensions, applied force, and machine durability.

2. ***Literature Review and Design References***

Review of related research to examine existing studies and technologies related to plastic mulch perforating machines, focusing on design and innovations implemented in similar industries. Understanding latest technologies with explored trends and advancements in industrial machine design, including new materials, automated control systems, and computer programming techniques for machine operations.

3. ***Conceptual Design Development***

Initial design development with redesign or modifying the Mulch perforating machine based on the analysis and literature review. This may involve improving cutting mechanisms, enhancing the drive system, and optimizing energy use.

4. ***Application for Computer-Aided Design (CAD)***

3D Modeling with develop a 3D model of the machine using CAD software to visualize technical details and identify potential design issues before creating a prototype.

5. ***Design Revision and Refinement***

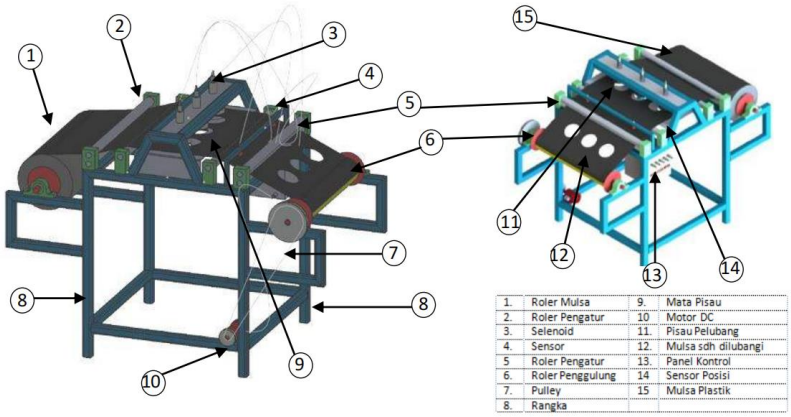
Evaluation and Testing for conduct evaluations and trials to test the performance of the initial design. Design improvements with address identified issues through revisions, such as adjustments to technical parameters or enhancements to machine components. Iterative improvements are made to ensure the final design meets performance, efficiency, and reliability goals.

RESULTS

In previous research, the design of a Mulch Perforating Machine system using Fuzzy Logic Control was outlined through a comprehensive design scheme encompassing hardware design, software development, and construction planning. The DC motor used is a penetrator motor, chosen for its high torque and adjustable speed. Speed control of the motor was implemented using an Atmega microcontroller, functioning as a minimal system, and utilizing Pulse Width Modulation (PWM).

The plastic mulch perforation system employs a blade controlled by a solenoid, complemented by position and distance sensors. To ensure consistent motor performance underload fluctuations and precise Mulch perforation at pre-set distances, an intelligent control system based on Fuzzy Logic Control (FLC) was implemented.

A critical aspect of this machine design involves constructing a robust framework and strategically positioning components such as the plastic mulch rollers, adjustment rollers, solenoid, perforating blades, sensors, drive motor, and control panel. The layout of these elements was optimized to ensure operational efficiency and accessibility, as illustrated in Figure 1.

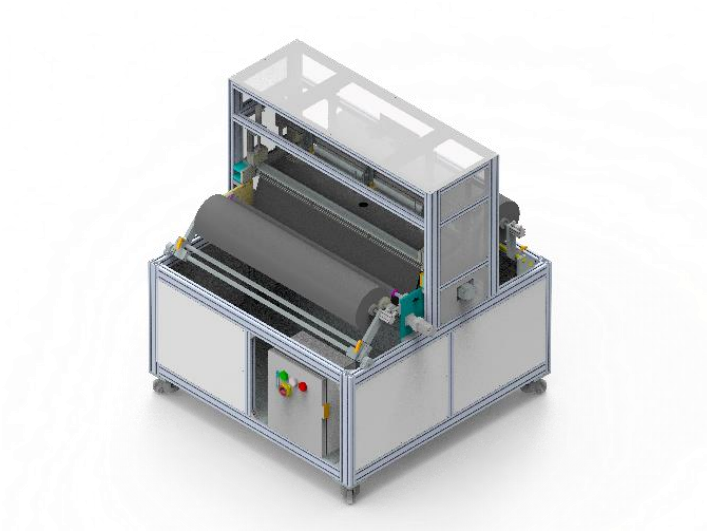


1.	Roler Mulsa	9.	Mata Pisau
2.	Roler Pengatur	10	Motor DC
3.	Selenoid	11.	Pisau Pelubang
4.	Sensor	12.	Mulsa sdh dilubangi
5	Roler Pengatur	13.	Panel Kontrol
6.	Roler Penggulung	14	Sensor Posisi
7.	Pulley	15	Mulsa Plastik
8.	Rangka		

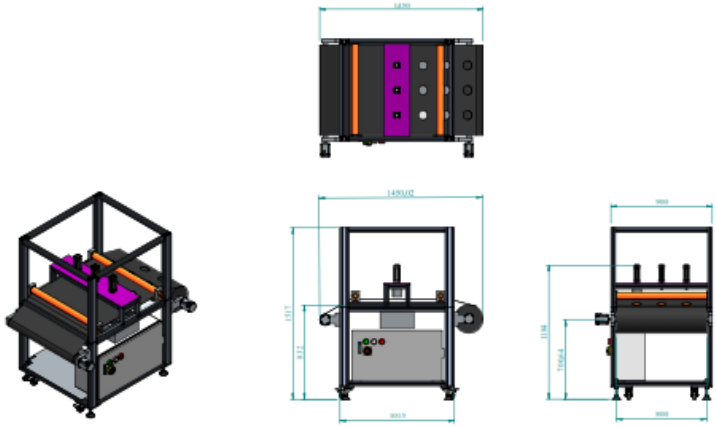
Picture 2. The Old Design of a Plastic Mulch Perforating Machine

In this research, it achieved the primary objective of developing a plastic mulch perforating machine using a CAD-based model. The new design was optimized to enhance machine performance in creating holes in plastic mulch, considering key technical aspects such as efficiency, durability, speed, and operational cost. The main results of the machine design are as follows:

1. Machine Frame: Constructed from aluminum profiles, resulting in a lighter yet robust structure to improve portability and durability.
2. Perforating System: Redesigned to incorporate more precise perforating blades capable of producing uniform mulch holes.
3. Machine Drive: Powered by an electric motor with a microcontroller-based automated control system, enabling the operator to adjust perforating speed and patterns as needed.
4. Modular Components: The new design allows for quicker and easier replacement of components such as perforating blades and plastic rollers.
5. CAD Implementation: A 3D model of the machine was developed to visualize technical details and identify potential issues before prototype fabrication.



Picture 2. The New Design of a Plastic Mulch Perforating Machine



Picture 3. The Engineering Drawings New Design of a Plastic Mulch Perforating Machine

The updated machine design is depicted in Figure 2, showcasing the integration of technological innovations with practical field requirements. In Figure 3, showing the engineering drawings new design of a plastic mulch perforating machine.

Comparative Analysis of the Old and New Designs

A comparison between the old and new designs was made based on several key parameters.

Table 1. Comparison the Old and New Designs

Parameter	Old Design	New Design
Frame Material	Steel, heavy	Aluminum profile, lightweight
Perforating System	Manual, less precise	Automated, highly precise
Production Efficiency	50 holes/minute	120 holes/minute
Maintenance Ease	Fixed components, hard to replace	Modular components, easy to replace
Energy Consumption	Inefficient	Energy-efficient

The results highlight that the new design offers significant improvements in efficiency, precision, and user-friendliness compared to the old design. These enhancements enable faster and more consistent mulch perforation, ultimately boosting user productivity.

Based on the design results and comparative analysis, the following points are discussed:

1. Preliminary Study and Problem Identification: The new design successfully addresses the shortcomings of the old design, such as low labor efficiency, inconsistent hole accuracy, and prolonged production time. Critical variables such as hole size, mulch material type, and machine durability were identified and used as the foundation for design development.
2. Literature Review and Technological Integration: Current technological trends, such as automated control systems and aluminum profiles, were incorporated into the new design to ensure reliability and ease of use.
3. Productivity Enhancement: The new design doubles productivity compared to the old model due to its automated system, allowing continuous perforation without interruptions.
4. Design Reliability: The use of aluminum profiles reduces the machine's overall weight while improving corrosion resistance, making it suitable for humid or sun-exposed environments.
5. Energy Efficiency: The electric motor, equipped with an energy-saving control system, significantly lowers long-term operational costs.

6. User Impact: The ergonomic and modular design ensures that operators can use the machine more comfortably and safely. Maintenance and component replacement processes are simplified, reducing downtime and enhancing operational efficiency.

CONCLUSIONS AND RECOMMENDATIONS

This research successfully developed an optimized design for a Mulch perforating machine, integrating advanced technical features to enhance performance, efficiency, and reliability. The key outcomes of this research include Optimized Structural Design: The use of lightweight yet durable materials, such as aluminum profiles, improved the portability and longevity of the machine. Enhanced Perforation System: The incorporation of precision blades and solenoids ensured uniform hole dimensions and consistent performance. Advanced Automation: The adoption of a microcontroller-based control system with Pulse Width Modulation (PWM) facilitated adjustable speed and perforation patterns. Energy Efficiency: The redesigned system significantly reduced energy consumption, lowering operational costs. Ease of Maintenance: Modular components allow for faster replacement and reduced downtime, improving overall productivity. The optimized design demonstrated a notable improvement in production speed, precision, and operational efficiency compared to traditional methods. These advancements address critical challenges faced by farmers in using plastic mulch, such as labor intensity and time inefficiency.

FURTHER STUDY

To expand on the findings and ensure the continued development of the Mulch perforating machine, the following areas for further study are proposed:

1. Optimization of Control Systems: Investigate the integration of advanced control algorithms, such as machine learning or adaptive control systems, to improve precision and adaptability in various operational conditions.
2. Material Innovation: Explore alternative materials for components to further enhance durability, reduce weight, and improve sustainability, such as biodegradable or recycled materials.
3. Field Performance Metrics: Conduct comprehensive field tests to gather performance data under diverse climatic and soil conditions, enabling the design of region-specific modifications.
4. Ergonomics and User Experience: Assess and improve the machine's ergonomics to ensure ease of use for operators of varying skill levels and physical capabilities.
5. Economic Feasibility Study: Perform an in-depth economic analysis to evaluate the affordability and return on investment (ROI) for smallholder farmers.
6. Automation and Smart Features: Investigate the feasibility of integrating smart features, such as automated troubleshooting and maintenance alerts, to enhance operational reliability.

7. Environmental Impact Analysis: Study the environmental implications of using the machine, focusing on energy consumption, emissions, and the lifecycle impact of materials used.
8. Adaptation for Multi-Crop Use: Design modular components or add-ons that enable the machine to cater to the specific requirements of different crops, enhancing its versatility.

By addressing these areas, future research can contribute to making the plastic mulch perforating machine more effective, accessible, and environmentally sustainable, further supporting agricultural productivity and sustainability goals.

ACKNOWLEDGMENT

The authors wish to express their heartfelt gratitude to Academic of Vocational College, Ministry of Education, Culture, Research and Technology for supporting this research through the Program Dana Padanan Tahun 2024. This support has been instrumental in enabling the development and optimization of the Mulch perforating machine. Additionally, we extend our sincere thanks to Politeknik Negeri Padang for providing the facilities, resources, and encouragement necessary to conduct this study. The collaboration and contributions from these institutions have been pivotal in achieving the objectives of this research. We also wish to acknowledge the valuable collaboration and contributions from our industry partner, PT. MES Teknologi Indonesia. Their technical expertise and practical insights have significantly enhanced the quality and applicability of this research.

REFERENCES

Abebe, B. T., Weiss, M., Modess, C., Roustom, T., Tadken, T., Wegner, D., Schwantes, U., Neumeister, C., Schulz, H., Scheuch, E., al., et, Abu-Saad, K., Murad, H., Barid, R., Olmer, L., Ziv, A., Younis-Zeidan, N., Kaufman-Shriqui, V., Gillon-Keren, M., … Masha'al, D. (2019). Mindfulness virtual community. *Trials*, *17*(1).

Aboshosha, A., Haggag, A., George, N., & Hamad, H. A. (2023). IoT-based data-driven predictive maintenance relying on fuzzy system and artificial neural networks. *Scientific Reports*, *13*(1). https://doi.org/10.1038/s41598-023-38887-z

Bhatnagar, R., Tripathi, N. K., Panda, C. K., & Bhatnagar, N. (2022). The digital agricultural revolution: Innovations and challenges in agriculture through technology disruptions. في *The Digital Agricultural Revolution: Innovations and Challenges in Agriculture through Technology Disruptions*. https://doi.org/10.1002/9781119823469

Carbonell-Carrera, C., Saorin, J. L., Melian-Diaz, D., & de la Torre-Cantero, J. (2019). Enhancing creative thinking in STEM with 3D CAD modelling. *Sustainability (Switzerland)*, *11*(21). https://doi.org/10.3390/su11216036

Garcia, A. P., Umezu, C. K., Polania, E. C. M., Dias Neto, A. F., Rossetto, R., & Albiero, D. (2022). Sensor-Based Technologies in Sugarcane Agriculture. *Sugar Tech*, *24*(3). https://doi.org/10.1007/s12355-022-01115-5

Garikano, X., Garmendia, M., Manso, A. P., & Solaberrieta, E. (2019). Strategic

knowledge-based approach for CAD modelling learning. *International Journal of Technology and Design Education*, *29*(4). https://doi.org/10.1007/s10798-018-9472-1

Madrid, B., Wortman, S., Hayes, D. G., DeBruyn, J. M., Miles, C., Flury, M., Marsh, T. L., Galinato, S. P., Englund, K., Agehara, S., & DeVetter, L. W. (2022). End-of-Life Management Options for Agricultural Mulch Films in the United States—A Review. في *Frontiers in Sustainable Food Systems* (6. مج). https://doi.org/10.3389/fsufs.2022.921496

Maguey-González, J. A., Nava-Ramírez, M. de J., Gómez-Rosales, S., Ángeles, M. de L., Solís-Cruz, B., Hernández-Patlán, D., Merino-Guzmán, R., Hernández-Velasco, X., Figueroa-Cárdenas, J. de D., Vázquez-Durán, A., Hargis, B. M., Téllez-Isaías, G., Méndez-Albores, A., Angelico, R., Colombo, C., Di Iorio, E., Brtnický, M., Fojt, J., Conte, P., … Chorover, J. (2018). Modeling of Soil Cation Exchange Capacity Based on. *Geoderma*, *3*(4).

Nandan, D., & Kumar, D. P. (2022). Plasticulture for Vegetable Production: A Review. *International Journal of Innovative Research in Engineering & Management*. https://doi.org/10.55524/ijirem.2022.9.1.86

Parenti, P., Cataldo, S., Annoni, M. P. G., Mahmoodan, M., Aliakbarzadeh, H., Gholamipour, R., Magnusson, N., Schmidt, S. H. Ma., Magnoni, P., Rebaioli, L., Fassi, I., Pedrocchi, N., Tosatti, L. M., M Nafis, O. Z., Nafrizuan, M. Y., Munira, M. A., Kartina, J., Amin, S. Y. B. M., Muhamad, N., … Tohirin, M. (2017). No 主観的健康感を中心とした在宅高齢者における 健康関連指標に関する共分散構造分析Title. *Jurnal Sains dan Seni ITS*, *6*(1), 51–66.

Pathan, M., Patel, N., Yagnik, H., & Shah, M. (2020). Artificial cognition for applications in smart agriculture: A comprehensive review. في *Artificial Intelligence in Agriculture* (4. مج). https://doi.org/10.1016/j.aiia.2020.06.001

Peto, M., García-Ávila, J., Rodriguez, C. A., Siller, H. R., da Silva, J. V. L., & Ramírez-Cedillo, E. (2024). Review on structural optimization techniques for additively manufactured implantable medical devices. في *Frontiers in Mechanical Engineering* (10. مج). https://doi.org/10.3389/fmech.2024.1353108

Prakash, C., Singh, L. P., Gupta, A., & Lohan, S. K. (2023). Advancements in smart farming: A comprehensive review of IoT, wireless communication, sensors, and hardware for agricultural automation. في *Sensors and Actuators A: Physical* (362. مج). https://doi.org/10.1016/j.sna.2023.114605

Rahman, A., Ali, R., Kabir, S. N., Rahman, M., Mamun, R. Al, & Hossen, A. (2020). Agricultural mechanization in Bangladesh: Statusand challenges towards achieving the sustainable development goals (SDGs). *AMA, Agricultural Mechanization in Asia, Africa and Latin America*, *51*(4).

Shah, F., & Wu, W. (2020). Use of plastic mulch in agriculture and strategies to mitigate the associated environmental concerns. في *Advances in Agronomy* (164. مج). https://doi.org/10.1016/bs.agron.2020.06.005

Spinelli, G., Guarini, R., Kotsilkova, R., Ivanov, E., & Romano, V. (2023). Experimental, Theoretical and Numerical Studies on Thermal Properties of Lightweight 3D Printed Graphene-Based Discs with Designed Ad Hoc Air Cavities. *Nanomaterials*, *13*(12). https://doi.org/10.3390/nano13121863

Wildan, J. (2023). A Review: Artificial Intelligence Related to Agricultural Equipment Integrated with the Internet of Things. *Journal of Advanced Technology and Multidiscipline*, *2*(2). https://doi.org/10.20473/jatm.v2i2.51440

Xu, B., Liu, Y., Yu, S., Zhang, Y., Song, X., & Tang, X. (2021). Research on the whole process mechanized agricultural machinery allocation of wheat and corn based on economic benefits. *Journal of Chinese Agricultural Mechanization*, *42*(12). https://doi.org/10.13733/j.jcam.issn.20955553.2021.12.32

Yadav, J., Shukla, S., Sharma, K., Soni, N., Agarwal, S., & Pathak, P. C. (2022). Frontiers in Artificial Intelligence and Applications. *Proceedings - 2022 3rd International Conference on Computation, Automation and Knowledge Management, ICCAKM 2022*. https://doi.org/10.1109/ICCAKM54721.2022.9990098

Yondri, S., Azis Nabawi, R., Sunitra, E., Islami, S., & Asrul, J. (2017). The Machine Punch Mulch: A Pneumatic Pierching and Control With Fuzzy Logic Control. *International Conference of Applied Science on Engineering, Business, Linguistics and Information Technology*.

Zhou, R., & Hu, N. (2024). Construction and Implementation of Soft Interior Design System Based on Deep Learning Aided CAD Modeling. *Computer-Aided Design and Applications*, *21*(S1). https://doi.org/10.14733/cadaps.2024.S1.101-115