

Integration of 3D Scanning and 3D Printing for Design and Prototyping of Automotive Retrofitting Component

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ABSTRACT

This study explores the combination of 3D scanning and 3D printing technology for automotive retrofitting in the design and create prototypes of automotive retrofitting components. Designs were conceptualized in CAD using 3D scans of the artifacts and 3D prints of accurate physical prototypes were produced. The precision of creating new automotive accessory components, on the other hand, is severely hampered by mistakes made in the early phases of the design process. Such discrepancies result in incorrect fitting, increased production costs, and delayed deliveries, reflecting the necessity of accurate and reliable design methodologies. The combination of high-resolution 3D scanning data with advanced 3D printing techniques demonstrates a high-quality prototype parts production, showcasing an efficient workflow. A comprehensive methodology involving data acquisition via 3D scan, CAD model conversions for the purpose of 3D print, as well as prototypes fabrication is provided. Deviation analysis was performed to assess fitting accuracy and ensure the best match between prototype and carryover components. Result shows that by using the deviation analysis, the prototype produced match with the surfaces of the carryover part within the acceptable range of 0mm to 0.5mm. It shows a significant improvement in design accuracy, manufacturing speed, and overall prototyping speed as compared to traditional processes. How 3D scanning and 3D printing technologies can be integrated was found to be the key to accelerating the automotive components developing, realize faster iteration cycle and higher-quality results. It is expected that future work would further optimize this embedding to explore the process on complex vehicle parts and assemblies.

Keywords: Automotive retrofitting; automotive design; 3D scanning; additive manufacturing; 3D printing

INTRODUCTION

The benefits of the use of 3D scanning and CAD technologies for automotive retrofitting are in the areas of accuracy, precision and time. 3D scans gather a large amount of geometry, which allows the designers to create CAD models that will fit and function as they should. It offers tremendous tolerance check, which cuts down on errors and thus cuts down the expensive rework, resulting in a more rapid prototyping phase and much better fitting, quality components. Over the last several decades, the evolution of 3D scanning and 3D printing has changed the manufacturing paradigm as it is known, most notably in the automotive sector (Gechev 2021). The precision and efficiency these technologies provide in automotive

component design and prototyping makes them powerful resources for retrofitting. Retrofitting requires pin-point accuracy to work with existing systems, but that will become secondary to a low-cost supply of new parts and features on newer vehicles. Conventional design and prototyping processes are not only lengthy but also tedious which results to higher costs and longer duration to develop the actual product (Nayeem & Hossain, 2023).

Three-dimensional scanning allows for the capture of existing automotive parts to accurately reproduce the geometry and create digital models for design modification. Using structured light or laser-based systems, 3D scanners able to capture complex surfaces and produce high-resolution point clouds or mesh data (Othman et al. 2024). This digital model serves as a base to create new retrofit

parts that are designed to fit in with the existing vehicle architecture (Ameen et al. 2018).

Additive manufacturing, generally referred to as 3D printing, is a quick and inexpensive way to manufacture prototypes after scanning (Tuazon et al. 2022). This method of construction, layer-by-layer, enables designs that may be too complex or impossible to create through traditional means. Additionally, its such adaptability further allows for rapid iterations and modifications as it gives the designers the ability to improve prototypes based on testing and insights (Shahrubudin et al. 2019; Sreehitha, 2017).

3D scanning and 3D printing also allow a seamless process for developing and prototyping automotive retrofitting parts. The amount of time and cost traditional techniques involve are minimized with this method, while increasing the accuracy and quality of the end product. The objective of this work is to propose a pipeline for using these technologies in the creation of retrofitting components, both methodological and experimental, with its final outcomes evaluated through real case studies.

The purpose of this study is to combine a 3D scanning and 3D printing process to prototype a side molding for an automotive accessory component of a vehicle model that is already available in the market. Once a carryover part is chosen, scan data will be built up with CAD software to assemble the component. The new prototype design will then be constructed in the CAD application enabling fit testing between the scan data and the CAD model without the need to build a physical model.

Utilizing 3D scanning and 3D printing, retrofitting automotive applications can be more time-efficient and inventive than ever. In the following sections of this study, the methodology of how this study was conducted will be described, the results and discussion and insights and recommendations for future research will be presented.

METHODOLOGY

The objective of this study is to design and prototype an automotive component using integration of 3D scanning and 3D printing process. In this study, the prototype development focuses on the side molding of the Mazda CX-5 2019 model. Combining 3D scanning and 3D printing creates a powerful workflow for designing and prototyping automotive retrofitting components. Scanned data provides a precise foundation for digital modeling, which can then be directly translated into physical prototypes through 3D printing. This integration streamlines the development process, reduces errors, and enhances the overall quality of the final product. Case studies of successful implementations highlight the practical benefits

of this approach (Alami et al. 2023; Sarma & Srivastava, 2024). Figure 1 shows the process flow which is involved throughout the process. There are four phases based on the process flow.

The first phase is data collection where the scanning process to capture the surface data of the intended component to be constructed. In this study, the side door of the car was chosen as the targeted scanning area for constructing the side molding prototype. The scanning area of the side door will be the carryover part for the prototype development.

Second phase is the design and development, which includes 3D modelling of constructing the new component design based on the data acquisition in first phase. At this phase, the evaluation process involves a Yes or No decision based on the deviation analysis performed using CAD software. If the deviation analysis indicates satisfactory results, the part design progresses to the next phase or otherwise, it is revised. The CAD software used for this process is a licensed version of CATIA V62013X, located in the CATIA Laboratory at the Faculty of Mechanical Engineering and Technology, Universiti Malaysia Perlis (UniMAP).

Third phase is prototyping, where 3D printing was used to fabricate the prototype with the finishing process. Post-processing for the prototype will be implemented to enhance the finishing of the prototype.

Lastly, the fitting process phase, where the finished prototype will be assembled to the targeted designed area. Upon fitting process, the prototype shall match with the surface of the carryover part of the existing vehicle.

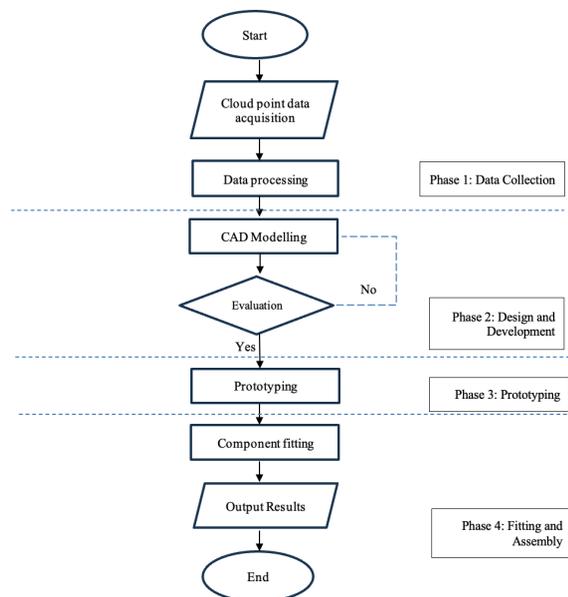


FIGURE 1. Process flow of integrating 3D scanning and 3D printing in automotive retrofitting components

DATA COLLECTION

For the data collection phase, a handheld 3D scanner, Peel3D was used to acquire detailed scans of the automotive components. This handheld scanner employs structured light technology to capture accurate 3D measurements of the object's surface geometry. During the scanning process as shown in Figure 2(a), the scanner was moved around the component to ensure comprehensive coverage from multiple angles, capturing millions of data points that form a dense point cloud (Kuş, 2009). The collected data was

then imported into Peel3D processing software as shown in Figure 2(b). Here, the raw scan data underwent preprocessing steps including noise reduction, alignment, and merging of multiple scans to create a cohesive 3D model (Yahaya et al. 2023).

Following these steps, the point cloud was converted into a polygonal mesh, carefully cleaned to remove any artifacts, and optimized to maintain high fidelity while reducing file size. The final output was a stereolithography (STL) file, which served as a precise digital representation of the scanned component, ready for further design and prototyping work (Dana et al. 2023).

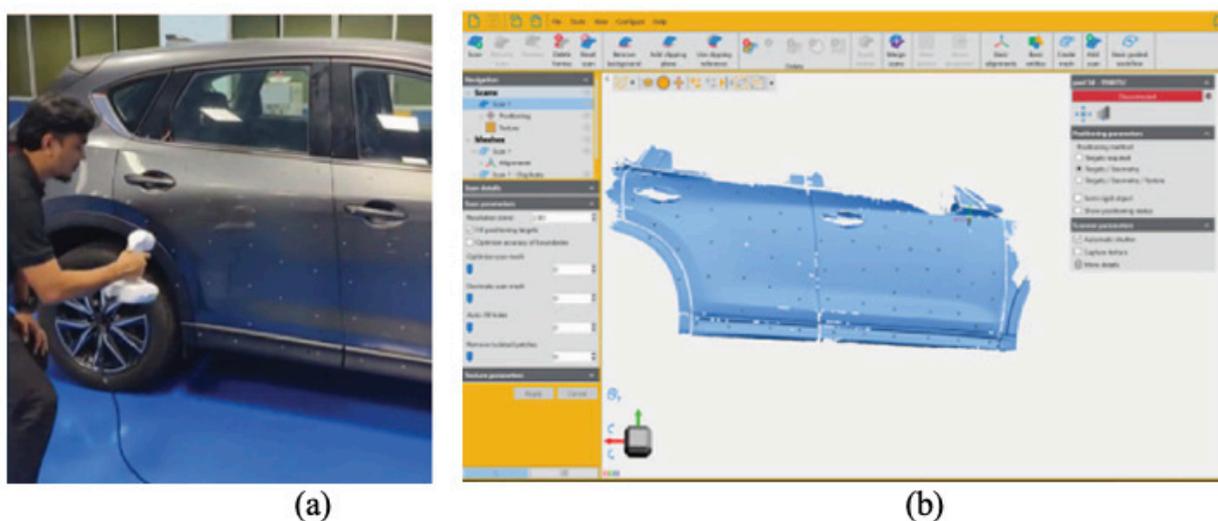
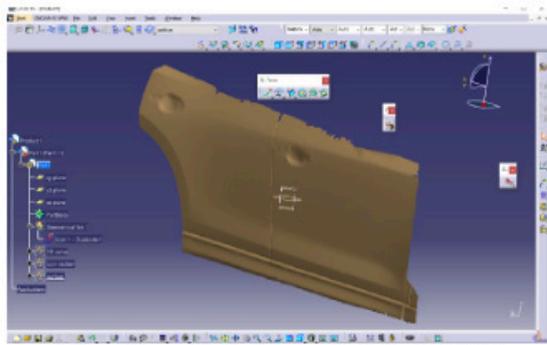


FIGURE 2. (a) 3D scanning process at door area for side molding prototype (b) Post-Processing Cloud point data

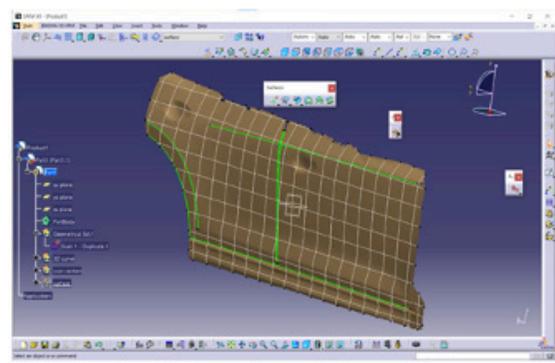
DESIGN AND DEVELOPMENT

In the initial design phase, the high-resolution STL file obtained from the 3D scanning process was imported into CATIA software. Using CATIA, the scanned data was utilized to create a precise 3D model of the retrofitting component (Fabian et al. 2022; Fabian & Kupec, 2021). The software's advanced tools allowed for editing and refinement of the digital model to ensure that it accurately matched the original part's geometry. Critical features, such as mounting points and surface contours, were carefully

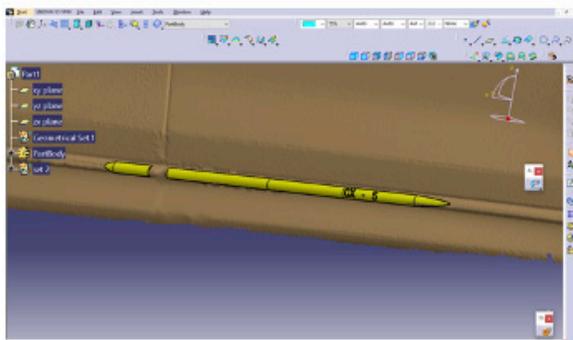
designed to fit seamlessly with the existing vehicle structures. The model was subjected to rigorous virtual fitting tests, where the digital prototype was placed on the vehicle surfaces to verify alignment and compatibility. Any inconsistencies were addressed through iterative adjustments to the model. This process ensured that the final 3D model maintained high precision and conformed perfectly to the vehicle's surfaces, guaranteeing a good fit and for the retrofitted component. Figure 3 shows the process involved in the design and development phase.



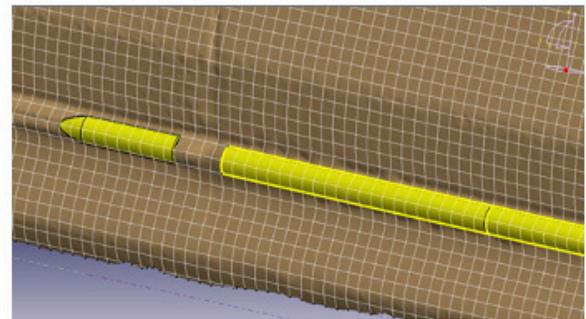
(a) Scan Data imported to CATIA



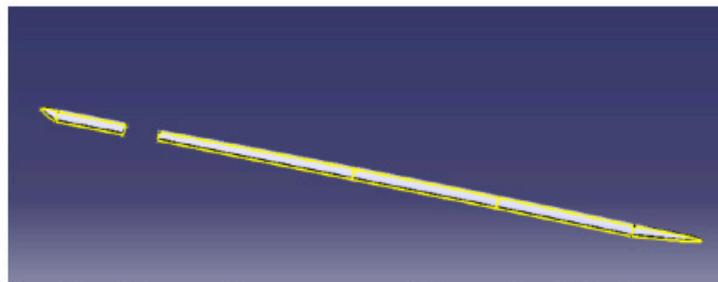
(b) Sectioning and profiling of important details to capture



(c) Part design using Generative Surface Design



(d) Detailing and evaluating the design proportion and fitting



(e) Detailing and convert to solid part for STL file conversion

FIGURE 3. Processes involved in CAD modelling shown from (a) to (e) contribute to phase design and development.

DEVIATION ANALYSIS

Deviation analysis was also performed, as a prototype design process to decide whether the part is eligible to move to the next phase or needs to be redesigned. This step is important to make sure that the component matches the carryover part exactly so that compatibility and functionality can remain maximized. At this phase, the deviation analysis carried out will indicate the gap from the prototype developed with the carryover part where the surface of the prototype should be matching with the surface of the existing car surface that located the prototype component.

PROTOTYPING

At the prototype development phase, the adjusted 3D model obtained in the design phase was implemented in STL file format and prepared for 3D printing on Fused Deposition Modeling (FDM) technology. The STL file was then post-processed, which was composed of mesh repairing and slicing to be print-ready (Cano-Vicent et al. 2021; Mohseni et al. 2023).

This will include generating the G-code using slicing software such as Cura or Simplify3D for 3D printer to create the part layer by layer. The selected material, usually a strong thermoplastic such as ABS or PLA will be loaded into the 3D printer to build the prototype.

This prototype also needed extra post-processing after printing to achieve a high-quality finish. This included post-work like removing support structures, sanding rough surfaces or applying surface treatment methods like acetone vapor smoothing, primer coating and painting for the produced parts. These post-processing steps were key to optimizing the prototype's surface quality so that it accurately resembled the intended and final production part in terms of form and function. The end point would be a prototype to be given a good workover in terms of fit and performance, allowing it to be treated as a production basis model.

FITTING

Throughout the fitting phase, the 3D-printed prototype was carefully aligned and installed onto the actual vehicle to verify its fit and proportionality (Rud et al. 2023). This step involves the side molding attached at the designated location to ensure that the part matches with the surface contours. Detailed measurements and visual inspection were conducted to assess the alignment of the prototype. The fitting process provided crucial feedback in terms of the prototype accuracy and allowing for iterative refinements. The successful fitting will confirm that the prototype meets the design specifications and ensure the best fitting with the carryover part of the existing vehicle.

RESULTS AND DISCUSSION

The results indicate that 3D scanning and 3D printing offer substantial advantages for automotive retrofitting. The increased precision and reduced development time translate into cost savings and higher-quality components. In the scanning process, it is crucial to conduct thorough post-processing of the scanned data. This ensures that the data accurately represents the target area's contours, allowing the constructed component to fit perfectly (Setyanto et al. 2020).

Figure 4 illustrates the deviation analysis between the prototype and the carryover part. The results of this analysis were used to evaluate whether the design phase in CAD can progress to the prototyping phase. The deviation values are represented by green dotted colors, indicating whether the part has acceptable deviation and reflecting the gap dimensions between the two components. Based on the analysis, the distance between the prototype and the surface of the carryover part is within the acceptable range of 0 mm to 0.5 mm.

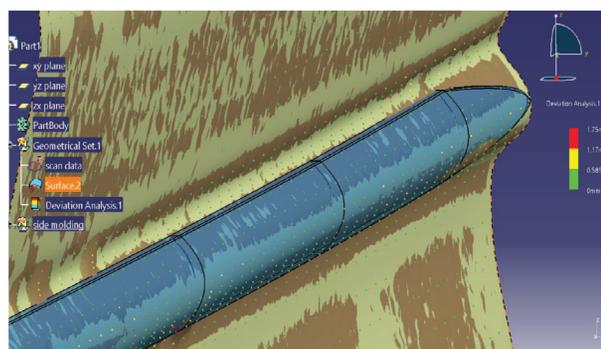


FIGURE 4. Deviation Analysis for fitting the side molding prototype component to carryover part.

For the 3D printing process, an FDM 3D printer was utilized to produce the prototype, as illustrated in Figure 5. Once the prototype was printed, it underwent a series of post-processing steps to achieve a smooth and polished finish. These steps included manual sanding to remove rough edges, followed by priming and painting to ensure a high-quality and durable surface.

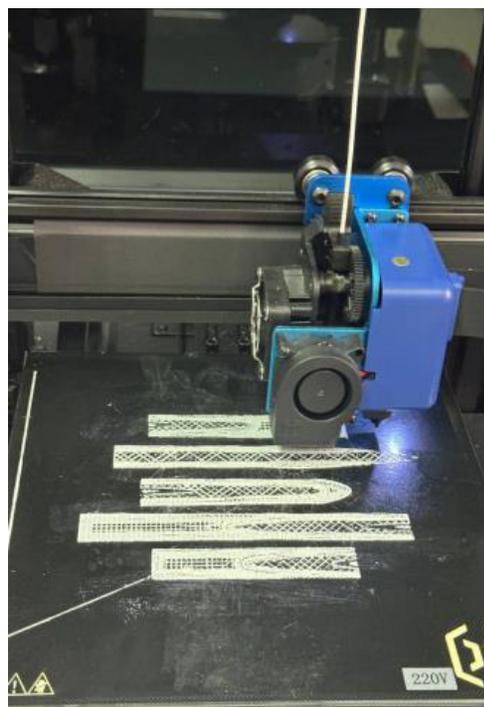


FIGURE 5. Prototyping component using 3D printing process.

Then, the finished prototype will be assembled on the existing carryover part which is the location of the side molding is located. Figure 6 shows the fitting process where the 3D printed prototype perfectly matches with the surface of the targeted area. Figure 6 (a) shows the image before the vehicle does not have any side molding and Figure 6(b) shows the prototype of the side molding after installation.

This result reflects the CAD design process which went through the deviation analysis which provides a good fitting to the surface area of the carryover part and the development of the prototype components. The prototype then assembles with a double-sided adhesive foam tape to match the carryover part.



(a) Before development of side molding



(b) After side molding prototype installation

FIGURE 6: Fitting a finished prototype component to the car.

However, certain limitations in 3D printing for this study such as the need for larger printing machine volume and engineering filament material for further research. As indicated by previous research, prototyping with additive manufacturing can significantly reduce costs before mold making (Tamaşag et al. 2021). This approach allows for direct evaluation of component fitting and tolerance in the specific target area (Milburn & Timmers, 2018). Any necessary changes can be thoroughly addressed before finalizing the new concept design (Milburn & Timmers, 2018; Sansoni & Docchio, 2004; Tamaşag et al. 2021).

CONCLUSION

This study confirms the potential of integration of 3D scanning and 3D printing technologies in automotive retrofitting. The integrated workflow enhances design accuracy, reduces production time, and offers a flexible

solution for creating complex components. Future research should focus on optimizing the integration process and exploring broader applications within the automotive industry. In terms of material used by FDM technology for the prototyping, future research on end used components printed directly can be explored which are capable of withstanding harsh weather conditions. This may be beneficial to enhance the usability of FDM process that can be used as final customized component.

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DECLARATION OF COMPETING INTEREST

None.

REFERENCES

- Alami, A. H., Ghani Olabi, A., Alashkar, A., Alasad, S., Aljaghoub, H., Rezk, H., & Abdelkareem, M. A. 2023. Additive manufacturing in the aerospace and automotive industries: Recent trends and role in achieving sustainable development goals. *Ain Shams Engineering Journal* 14(11).
- Ameen, W., Al-Ahmari, A. M., & Mian, S. H. 2018. Evaluation of handheld scanners for automotive applications. *Applied Sciences (Switzerland)* 8(2).
- Cano-Vicent, A., Tambuwala, M. M., Hassan, S. S., Barh, D., Aljabali, A. A. A., Birkett, M., Arjunan, A., & Serrano-Aroca, Á. 2021. Fused deposition modelling: Current status, methodology, applications and future prospects. *Additive Manufacturing* 47.
- Dana, K. U., Ladislav, Č. E. K., & Vítězslav, N. E. 2023. Data preparing for reverse engineering. *Advances in Science and Technology* 132 AST.
- Fabian, M., Huňady, R., & Kupec, F. 2022. Reverse engineering and rapid prototyping in the process of developing prototypes of automotive parts. *Manufacturing Technology* 22(6).

- Fabian, M., & Kupec, F. 2021. Use of 3D parametric models in the automotive component design process. *Advances in Science and Technology Research Journal* 15(1).
- Gechev, T. 2021. A short review of 3D printing methods used in the automotive industry. *Bulgarian Journal for Engineering Design* 44.
- Kuş, A. 2009. Implementation of 3D optical scanning technology for automotive applications. *Sensors* 9(3).
- Milburn, A., & Timmers, N. 2018. Efficient reverse engineering of automotive firmware. *6th ESCAR USA*.
- Mohseni, Y., Mohseni, M., Suresh, S., Riotto, M., Jaggessar, A., Little, J. P., Wille, M.-L., & Yarlagadda, P. K. 2023. Investigating impacts of FDM printing parameters and geometrical features on void formation in 3D printed automotive components. *Materials Today: Proceedings*.
- Nayeem, A. M., & Hossain, M. M. N. 2023. Usage of additive manufacturing in the automotive industry: A review. *Bangladesh Journal of Multidisciplinary Scientific Research* 8(1).
- Othman, S. A. T., Azman, A. H., Wahid, Z., & Azman, M. A. 2024. Reverse engineering of brake calliper design via integration of topology optimisation and lattice structure for additive manufacturing. *Jurnal Kejuruteraan* 36(2); 439–446.
- Rud, V. D., Zaika, O. M., Samchuk, L. M., & Povstyana, Y. S. 2023. Improvement of the quality of 3D printing in the mass production of parts. *Journal of Engineering Sciences (Ukraine)*; 10(2).
- Sansoni, G., & Docchio, F. 2004. Three-dimensional optical measurements and reverse engineering for automotive applications. *Robotics and Computer-Integrated Manufacturing* 20(5).
- Sarma, A., & Srivastava, R. 2024. Prospects of additive manufacturing technology in mass customization of automotive parts: A case study. *Journal of The Institution of Engineers (India): Series C*.
- Setyanto, D., Soewono, A. D., Wibowo, A., & Liong, R. T. 2020. Design of a motorcycle frame at an automotive company in Indonesia. *International Journal of Engineering Research and Technology* 13(4).
- Shahrubudin, N., Lee, T. C., & Ramlan, R. 2019. An overview on 3D printing technology: Technological, materials, and applications. *Procedia Manufacturing* 35.
- Sreehitha, V. 2017. Impact of 3D printing in automotive industries. *International Journal of Mechanical and Production Engineering* 5.
- Tamaşag, I., Beşliu, I., & Amaranđei, D. 2021. Application of Reverse Engineering for Automotive Plastic Components – Case Study. *Macromolecular Symposia* 395(1).
- Tuazon, B. J., Custodio, N. A. V., Basuel, R. B., Reyes, L. A. D., & Dizon, J. R. C. 2022. 3D printing technology and materials for automotive application: A mini-review. *Key Engineering Materials: Vol. 913 KEM*.
- Yahaya, M. I., Samsuddin, Z., Mohd Rodzi, A. S., Hemdi, Abd. R., Othman, M., & Mohamed Noor, R. 2023. Manufacture of automotive component using reverse engineering and manufacturing additive techniques. *ESTEEM Academic Journal* 19(September).