Dicle University
Journal of Engineering
https://dergipark.org.tr/tr/pub/dumf
duje.dicle.edu.tr

Research Article

Design and Development of Effective Furrower Mounting Bracket Using Topology Optimization

Hilmi Saygin SUCUOGLU[1*], Ismail BOGREKCI[2], Pinar DEMIRCIOGLU[3], Berkcan AKSOY[4]

[1]Aydin Adnan Menderes University, Mechanical Engineering Department, hilmisucuoglu@adu.edu.tr, Orcid No: 0000-0002-2136-6015
[2] Aydin Adnan Menderes University, Mechanical Engineering Department, ibogrekci@adu.edu.tr, Orcid No: 0000-0002-9494-5405
[3] Aydin Adnan Menderes University, Mechanical Engineering Department, pinar.demircioglu@adu.edu.tr, Orcid No: 0000-0003-1375-5616
[4] Aydın Adnan Menderes University, Graduate School of Natural and Applied Sciences, Department of Mechanical Engineering, berkcan637@hotmail.com, Orcid No: 0009-0001-4838-3077

ARTICLE INFO

Article history:

Received 14 November 2024
Received in revised form 25 March 2025
Accepted 17 May 2025
Available online 30 June 2025

Keywords:

Agricultural Machinery, Fatigue Analysis, Finite Element Analysis, Topology Optimization, Light Weight Structure Design, Structural Optimization, Weight Reduction, Topology Optimization Approaches

DOI: 10.24012/dumf.1584851

* Corresponding author

ABSTRACT

Structural and design improvements on the agricultural machinery using the engineering technology and tools are crucial in today world. It is possible to create the cost effective, structurally safe, and easy to manufacture components and parts using engineering tools such as topology optimization and Finite Element Analysis (FEA) methods. In this study it was aimed to create an optimized structure for the agricultural mounting bracket of the furrower. For those purposes, preliminary structure design was created, and FEA was conducted to observe the occurred stresses, deformations and total mass. Then topology optimization was conducted to reduce the excessive weights. The FEA and fatigue analysis were applied to the new optimized structure to check and validate the strength. It was observed from the results that the weight was reduced by 13.5%. The occurred stresses and deformations values were found as almost same 199,0 MPa with the preliminary structure. From all obtained results it was concluded that the mounting bracket was structurally optimized. It had similar structural strength with reduced weight.

Introduction

Furrowers are commonly used attachments in the agricultural machinery sector for soil cultivation. It's used to create channels called furrows in the field by cultivating the soil. The main purpose is to establish irrigation systems in the field or prepare preliminary groundwork for planting. These attachments aim to increase productivity by creating grooves of specific depth and width on the surface of the soil. They allow planting seeds and plants in these grooves or establishing irrigation channels, ensuring proper water distribution to the plants.

The importance of agricultural machinery has significantly increased in today's world. The labor costs and time can be tremendously decreased with the utilization of the machinery. In the conventional manufacturing methods of those machines, the structures might be too heavy causes to the usage of unnecessary material, time and laboring and unexpected energy consumption when they are operated. The lightening process of the agricultural machinery can provide the avoiding of excessive reinforcement, reducing the necessary pulling force, and thus decreasing the energy consumption by the tractor for the operation of soil cultivation [1]. There are studies on the lightening of agricultural machinery. These studies strongly emphasize that the determination of the effective loads on the soil cultivation machines have crucial effect on the design optimization [2,3].

Topology optimization is frequently used in product design processes and utilized in various industries such as automotive and aerospace. Its applications have been expanded with the development of the additive manufacturing technologies. The aim of topology optimization is to optimize material distribution within a designated design space considering the specific loads, boundary conditions, and constraints. The goal is to reduce the weight of the design while enhancing its strength and natural frequencies. The objective of optimization is to determine the appropriate material usage within the specified design area to achieve the desired structural performance while meeting strength criteria. In the process, designed volume is divided into smaller elements, FEA model is created, and boundary conditions are applied to perform the FEA; respectively. During the analysis, the elements exhibit intermediate density values. These values approach close to 1 or 0 by employing penalization techniques such as the power law to penalize higher-density elements. This process encourages convergence toward solid and void regions to build the final structure. Throughout the optimization process, the optimization algorithm iteratively updates the material density and converges to a solution to achieve the best performance and design volume. It determines the final structure by ensuring a smooth transition between solid and void regions to create optimized and manufacturable parts. Isotropic Material Penalization (SIMP) is commonly preferred method for determining the distribution of elements in topology optimization. The SIMP method prescribes an optimal material distribution within a given design space for specific load cases, boundary conditions, manufacturing constraints and performance requirements. The density distribution of material within a design space, denoted by ρ, is discrete, with each element assigned a binary value. For each element, the assigned relative density can vary between the minimum value, denoted as ρ_{min}, and 1, thereby enabling the allocation of intermediate densities for elements that are characterized as porous elements. Given the continuous nature of the relative density of the material, the material Young's modulus in each element is also subject to continuous variation. For each element e, the relationship between the material relative density factor ρ_e and the Young's modulus of elasticity of the assigned isotropic material model E_0 is calculated by the power law [4-6].

$$E(\rho_e) = \rho_e^{\rho} E_0 \quad (1)$$

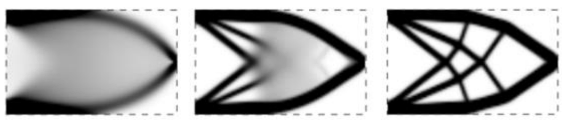
Where:

ρ: The density distribution of material

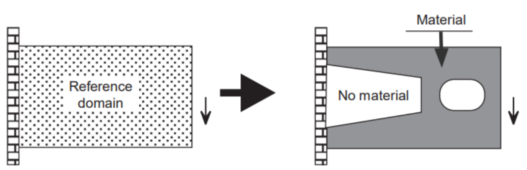
ρ_e: For each element "e" the relation between the material relative density factor

E_0: Young modulus of elasticity of the isotropic material

The SIMP interpolation and generalized schemes are shown in Figure 1.



(a)Interpolation



(b) Generalized scheme

Figure 1. The SIMP interpolation and generalized schemes [7]

There are some commercial and academic topology optimization tools. Most of those tools utilize the SIMP method. A list of commonly used commercial software and academic tools are given in Table 1.

Table 1. Topology optimization tools

Commercial Software	Educational tools
Ansys	SmartDO
Altair OptiStruct	META4ABQ
Solidworks Topology Study	TopOpt
Autodesk Fusion 360	BESO3D
Simulia Tosca	CATOPTO
Abaqus Atom	ProTOp
MSC Nastran	ToPy
Fem Tools Optimization	TRINTAS
OPTISHAPE-TS	ParetoWorks
Vanderplaats Genesis	Topostruct

(Barbieri et al. [8]), carried out a comparative study for the mechanical performance results of topology optimized and generatively designed rocker arm and brake pedal for the Formula Student race car. They obtained from the results that both optimized and generatively designed structures can provide effective results and there is no significant difference. (Meng et al. [9]), provided a detailed exploration of the entire process of a bracket for aviation industry from topology optimization to additive manufacturing. They offered a useful roadmap for researchers in the field of topology optimization. (Cavazzuti et al. [10]), conducted studies involve optimization techniques for automotive chassis design. The objective of the optimization process was the chassis weight reduction, yet in fulfilment of structural performance constraints as required by Ferrari standards. They tried to create the optimum chassis configuration by combining topology, size optimizations, and FEA. They used the structural performance of the Ferrari F458 as reference. Their numerical results showed that they obtained a significant weight reduction and optimized chassis structure.

(Lu et al. [11]) proposed a study of the investigation of the optimization process of the self-propelled sprayer chassis frame. They designed a freestanding longitudinal beam frame with an X-shaped reinforcing beam. The static mechanical properties of the structure under bending, torsion, emergency breaking and emergency turning conditions were analyzed with the finite element analysis methods. The topology optimization method was applied to optimize the cross beam and reinforcing beam locations. Their optimization processes had resulted in a 2.2% reduction in the total mass of the frame, a 19.4% reduction in the maximum deformation while maintaining a small change in the maximum stress under bending condition, and a 4.1% and 15.1% reduction in the maximum deformation and maximum stress of the frame under torsion conditions, respectively.

(Yao et al. [12]) presented a paper for the statical structural analysis of the transporter frame. They have also applied topology optimization processes to enhance the frame design for the parameters of the deformation and uniform stress distribution. The optimization design results demonstrate that the total mass of the frame increased by 8.7%, while the deformation was reduced by 88.2% and the maximum stress decreased by 11.7%.

(Sobocki et al. [13]) studied an industrial application example of the topology optimization for the spray tank bracket. They used the solid isotropic punishing material (SIMP) method under static loads. They obtained lighter and more durable structure with the application of the FEA and topology optimization processes.

In the contemporary era, a plethora of computer-based tools were developed to facilitate the design and analysis cycle of structures. Solid modelling, utilizing CAD methodologies, facilitates the definition of system components and assemblies by designers, with the geometry subsequently employed in applications such as simulation, analysis and prototyping. CAE methods facilitate the execution of virtual prototype simulations, static, kinematic and dynamic analyses. [14-16].

Comprehensive topology optimization process was conducted in this study to lighten the furrower mounting brackets to create structural-cost effective and easy manufacturable structures. The loads on the mounting bracket were determined specified in the American Society of Agricultural and Biological Engineers ASAE 497.5 Standards [17]. Autodesk Fusion 360 software utilizes the SIMP method used for topology optimization process. The structural strengths of the preliminary and final structures were also calculated and compared using FEA.

Material and Method

Draft Forces Calculation

Draft forces calculation is crucial to conducting the successful topology optimization study for the furrower mounting bracket. In the literature; (Godwin et al. [18]), proposed a method to calculate the draft forces of plows. (Askari et al. [19]), conducted a study to determine the draft force values obtained from different machines. (Patuk et al. [20]), performed a topology optimization study for the shank of a subsoil tillage machine used for fertilizing. All those studies obtained draft force results were consistent with ASAE 497.5 standard [17].

$$D = F_i[A + B(S) + C(S)^2]WT \quad (2)$$

Where:

F: A dimensionless soil texture adjustment parameter

i: 1 for fine, 2 for medium and 3 for coarse textured soils

A, B, C: Machine-specific parameters

S: Field speed, km/h

W: Machine width, m

T: Tillage depth, cm for major tools, 1 (dimensionless) for minor tillage tools and seeding implements

D: Implement draft

The parameters and values were used as;

A :273, B:13.3, C: 0, F_i : 0.65

Machine operating conditions.

S: 8 km/h

W:1.8 m

T = 8 cm

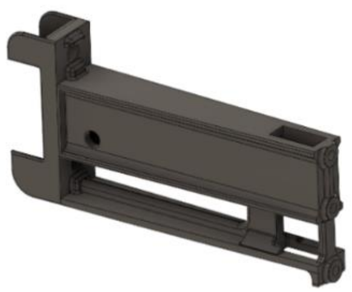
D = $0.65[273 + 13.3(8) + 0]$ (1.8) (8)

according to ASAE 497.5 standard.

To determine the forces acting on the furrower bracket, tensile force applied to the component was found, then using this data, force on the furrower shank was calculated. Draft forces can be affected by the environmental and operation conditions such as machine working depth and tractor speed. For the draft force calculations, all those effects were taken into consideration. The equation from the ASAE 497.5 standard and literature studies were considered [17-20]. The average draft force on the mounting bracket was calculated as 2,828.0 N.

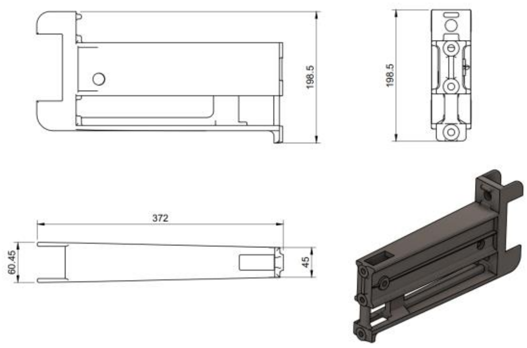
Design of the Mounting Bracket

The designed furrower mounting bracket is actively used to connect the furrower leg to the main frame of the machine. Five pieces of mounting brackets are used in the assembly of one machine. All the 3d cad models and engineering drawings were created using Autodesk Fusion 360 software. 3d cad model, location and engineering drawing of the bracket is shown in Figure 2.



(a) 3d cad model

(b)Location



(c) Engineering drawing

Figure 2. 3d cad model, placement and engineering drawing of furrower mounting bracket

Structural Analysis

Structural analysis was conducted using Ansys Workbench Static Structural tool based on the calculated draft forces. Boundary conditions in the analysis are shown in Figure 3.

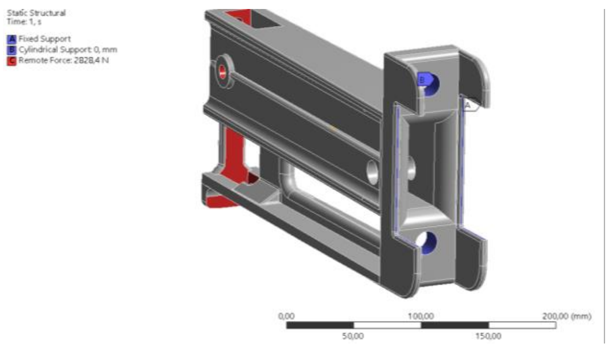


Figure 3. Boundary conditions in structural analysis environment

The draft forces were applied as remote force as 1,750.0 N as vertical and 2,220.0 N as horizontal in the analysis environment (Figure 4).

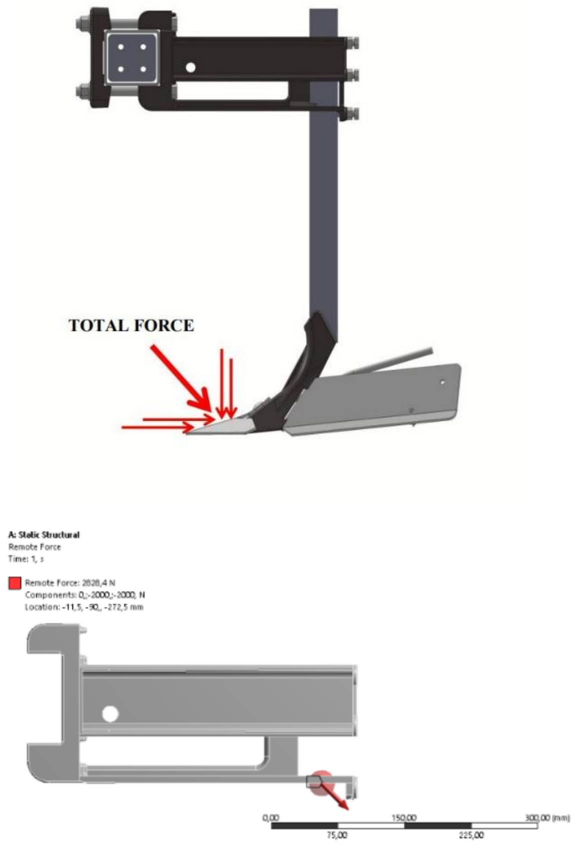


Figure 4. Draft force application in structural analysis environment

The hex dominant mesh method was used, material was assigned as GS-45 cast steel. The mechanical properties of the GS-45 cast steel are given in Table 2.

Table 2. Mechanical properties of material [7]

Properties	GS-45 Cast Steel
Young Module	200.0 MPa
Poisson Ratio	0.3
Tensile Strength	450.0 MPa
Yield Strength	260.0 MPa
Fatigue Strength (10^6For Cycle)	200.0 MPa

Topology Optimization and Design Validation

Topology optimization was performed to remove non-load bearing and unnecessary regions within defined boundaries in a volume. Those topology optimization studies were conducted in Autodesk Fusion 360 software. Different mass ratio values were applied to structure. The geometry remove regions were observed in the design. 65% mass ratio was selected as the optimum safe distance to the critical edges obtained with this ratio. The original weight of the bracket was 7.4 kg. This weight was reduced to 6.4 kg (13.5%). Weight decrease on the structure was obtained with the topology optimization process. The stages of topology optimization are shown in Figure 5.

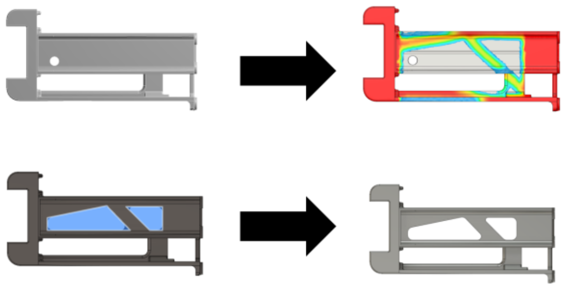


Figure 5. Stages of topology optimization

FEA was applied to the optimized structure by using the same procedure applied to the original preliminary structure. By this way the occurred stresses and deformations on the structure were observed and compared. Fatigue analysis was also applied to check the damage regions and values using Goodman Diagram in Ansys Workbench environment. Stress range values according to the cycle numbers are given in Table 3.

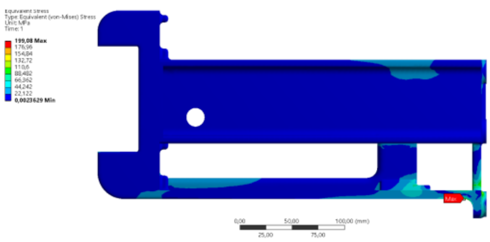
Table 3. Stress range values according to cycle numbers [21]

Cycles	Alternating Stress (MPa)
10	424.9
20	404.2
10	378.3
100	359.9
200	342.3
2,000.0	290.0
10,000.0	258.2
20,000.0	245.6
100,000.0	218.7
200,000.0	208.0
1,000,000.0	185.2

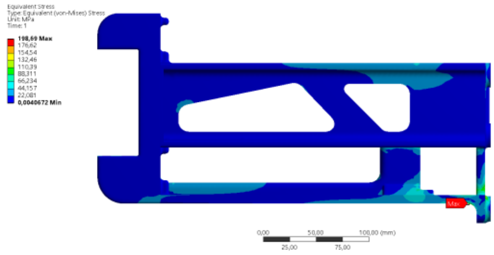
Results And Discussion

Structural Analysis Results

Structural analyses were applied to both preliminary and optimized brackets using the same procedures and boundary conditions to compare and check the topology optimization results. Equivalent von Misses stresses results of two structures are presented in Figure 6.



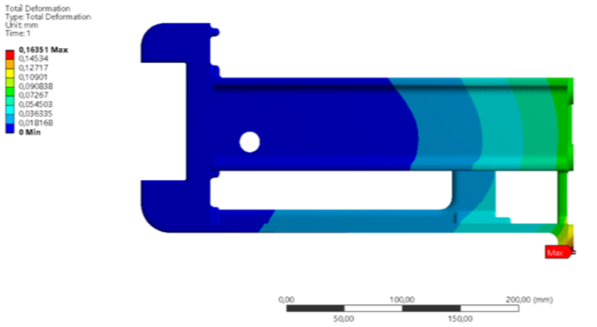
(a) Equivalent von Misses stresses of preliminary structure



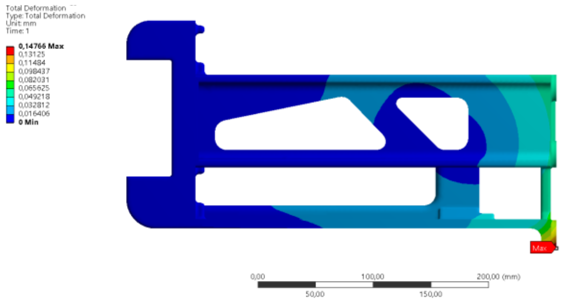
(b) Equivalent von Misses stresses of optimized structure

Figure 6. Equivalent von Misses stresses results

It was obtained from the results that there was not any increase in the maximum stress on the optimized structure. The observed maximum stress values were about 199.0 MPa in both structures.
Deformation results are shown in Figure 7.



(a) Deformations of preliminary structure



(b) Deformations of optimized structure

Figure 7. Deformations result

While deformation was 0.16 mm in the preliminary structure it was observed as 0.14 mm in the optimized. It can be understood from these values that optimization had a slight positive effect on deformation as it provided decrease in weight and increase in stiffness. The results of the fatigue analysis of the optimized structure are shown in Figure 8.

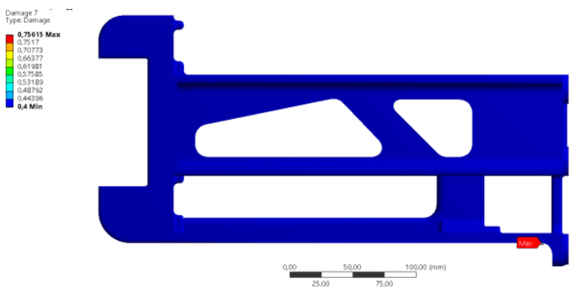


Figure 8. Fatigue analysis results

It was observed from the analyses that the damage in the critical region was attributed to high stress. The highest damage in the critical region was 0.76. As the maximum damage occurring on the bracket was less than one, it can be resulted that the optimized bracket structure could meet the intended number of cycles. All the results obtained from the analyses of the preliminary and optimized structures are given in Table 4 for comparison.

Table 4. Obtained results for preliminary and optimized structures

Results	Preliminary Structure	Optimized Structure
Stress (MPa)	199,0	199,0
Deformation (mm)	0.16	0.14
Damage	0.73	0.76
Weight(kg)	7.4	6.4

From all the analysis and validation results, with the optimized structure the weight of the mounting bracket decreased as 1 kg (13.5%) while keeping structurally integrity.

Conclusion

In this study a comprehensive topology optimization process was applied to furrower mounting brackets to decrease the weight while keeping the rigidity, stiffness, and structural integrity. It was aimed at decreasing the manufacturing costs, time, and operational energy consumption. FEA was applied to preliminary and optimized structures to compare the results and validate the topology optimization.

It was aimed at decreasing weight while keeping the stress and deformations at the same levels. (Lu et al. [9]) applied FEA and topology optimization processes self-propelled sprayer chassis frame. They obtained notable enhancements for the parameters of the total mass and deformation reduction under static loads with the values of 2.2% and 19.4%, respectively. (Yao et al. [10]) studied the statical structural analysis of the transporter frame. They obtained reductions in the total mass and stresses occurred as 8.7% and 11.7%, respectively. In our study, we have conducted optimization and FEA processes with the converted dynamic draft forces related to the interaction of the tool and soil. Furthermore, we analyzed the fatigue behavior of the optimized structure. The weight of the one mounting bracket decreased by 1kg (13.5%). As there are five pieces of mounting brackets used for one machine, important weight, material, manufacturing, and operational energy gain were obtained.

Topology optimization is a valuable tool that enables designers to swiftly create structures that are optimal in specific respects. The usage of topology optimization methods has been demonstrated to markedly reduce the duration of the design process, thereby significantly diminishing the engineering costs associated with the development of new components and products. This process has capacity to engineer significantly superior components in a substantially reduced timeframe when compared with that of a team of experienced designers. It is a great numerical tool to create mass reduction and to increase energy efficiency. However, it should be noted that this process has its own limitations, such as neglecting the environmental effects such as temperature changes and corrosion. Therefore, the results obtained should be compared and analyzed with the real application tests.

References

[1] H. Yurdem, A. Degirmencioglu, E. Cakir and E. Gulsoylu, "Measurement of strains induced on a three-bottom moldboard plough under load and comparisons with finite element simulations," Measurement, 2019, pp.594-602.

[2] S.J. Smyth, P.W. Phillips and D. Castle, "Handbook on agriculture, biotechnology, and development", Edward Elgar Publishing, 2014.

[3] W.R. Gill and G.E. Berg, "Soil dynamics in tillage and traction. Agricultural Research Service", US Department of Agriculture, 1967.

[4] M. P. Bendsøe, N. Kikuchi, "Generating optimal topologies in structural design using a homogenization method", Computer methods in applied mechanics and engineering, 71(2), 197-224, 1988.

[5] G. I. Rozvany, M. Zhou, T. Birker, "Generalized shape optimization without homogenization", Structural optimization, 4, 250-252, 1992.

[6] J.H. Zhu, W.H. Zhang and L. Xia, "Topology optimization in aircraft and aerospace structures design", Archives of computational methods in engineering, 2016 Vol. 23, pp. 595-622.

[7] A. Bendsøe and O. Sigmund, "Material interpolation schemes in topology optimization", Archive of applied mechanics, 1999. Vol. 69, pp. 635-654,

[8] L. Barbieri and, M. Muzzupappa, "Performance-driven engineering design approaches based on generative design and topology optimization tools: a comparative study", Applied Sciences, 2022.

[9] L. Meng, W. Zhang, D. Quan, G. Shi, L. Tang, Y. Hou, P. Breitkopf, J. Zhu and T. Gao, "From topology optimization design to additive manufacturing: Today's success and tomorrow's roadmap", Archives of Computational Methods in Engineering, 2020.

[10] M. Cavazzuti, A. Baldini, E. Bertocchi, D. Costi, E. Torricelli and P. Moruzzi, "High performance automotive chassis design: a topology optimization-based approach. Structural and Multidisciplinary Optimization", 2020, pp. 45-56.

[11] L. Lu, B. Liu, E. Mao, Z. Song, J. Chen, Y. Chen, "Design and optimization of high ground clearance self-propelled sprayer chassis frame", Agriculture, 13(2), 233, 2023.

[12] M. A. Yao, S. U. Wei, L. A. I. Qinghui, Y. U. Qingxu, W. A. N. Yuan, "Finite element analysis and topology optimization design of lightweight Panax Notoginseng transplanting machine frame," Journal of Intelligent Agricultural Mechanization, 5(2), 51-60, 2024.

[13] S. Sobockı, S. Legutko, J. Wojcıechowskı, S. Szymczyk, "Topology Optimization as a Design Tool-An Industrial Example Of Spray Tank Bracket, Acta Technica Napocensis-Series: Applied Mathematics, Mechanics, and Engineering, 65(4s), 2023.

[14] H.S. Sucuoglu, I. Bogrekci, P. Demircioglu and O. Turhanlar, "Design & FEA and Multi Body System Analysis of Human Rescue Robot Arm", Advanced Mechatronics Solutions Springer International Publishing, 2016, pp. 651-656.

[15] N. Demir, H.S. Sucuoglu, I. Bogrekci and P. Demircioglu, "Topology optimization of mobile transportation robot", International Journal of 3D Printing Technologies and Digital Industry, 210-9, 2021.

[16] N. Demir, H.S. Sucuoglu, I. Bogrekci and P. Demircioglu, "Structural & dynamic analyses and simulation of mobile transportation robot", International Journal of 3D Printing Technologies and Digital Industry, 2021, 5(3): pp.587-595,

[17] "Agricultural machinery management data", American Society of Agricultural and Biological Engineers, 2011.

[18] R.J. Godwin, M.J. O'dogherty, C Saunders and A.T. Balafoutis, "A force prediction model for mouldboard ploughs incorporating the effects of soil characteristic properties, plough geometric factors and ploughing speed", Biosystems engineering, 2007, pp. 97-117.

[19] M. Askari and S. Khalifahamzehghasem, "Draft force inputs for primary and secondary tillage implements in a clay loam soil", World Applied Sciences Journal,2013. Vol.12, pp. 1789-1794.

[20] I. Patuk, P.F. Borowski, "Computer aided engineering design in the development of agricultural implements: a case study for a DPFA", In Journal of Physics: Conference Series 2020, Vol. 1679.

[21] T. Saraçyakupoğlu, "Usage of additive manufacturing and topology optimization process for weight reduction studies in the aviation industry", Advances in Science, Technology and Engineering Systems Journal, 2021.