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Generative Design Effectivity on Belt Conveyor for Additive Manufacturing Using Finite Element Method

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ABSTRACT

This research focuses on the optimization of belt conveyor brackets using generative design and finite element method in compliance with industrial needs toward efficiency, economic viability, and sustainability in material handling. Although an indispensable element in conveying bulk materials within industries, belt conveyors still face some problems, including material demand and high manufacturing costs. The following design utilizes generative design technology with Autodesk Fusion 360 2024 and FEM using software ANSYS 2023 R2 for presenting an optimized bracket design in aluminium 6061, which has a good strength-to-weight ratio and is very common. The research methodology was hence a combination of algorithmic design exploration with structural analysis, in pursuit of optimum material distribution with required load-carrying capacities maintained. Using generative design, a great number of iterations of designs were tested against pre-defined performance parameters and constraints. FEM validation was thereafter necessary to check for stress distribution, strain pattern, and deformation character under different loading conditions. The optimized design resulted in an 86.4% volume reduction from 89,317.58mm² to 12,172.8mm², while mass reductions ranged from 0.198 kg to 0.033 kg. The maximum equivalent Von-Mises stress, when a minimum and maximum applied load of 5-30 kg, was 109.95 MPa, way below the yield strength for aluminium 6061, at 276 MPa. The equivalent strain under these increasing loads varied between 0.00029559 to 0.0017735 mm and shear strain from 0.00039804 mm to 0.0023882 mm, which is relatively controlled deformation. Buckling analysis has been done showing good stability with two major modes at 1.0844 mm and 1.0523 mm, while keeping the high load multiplier in first mode from 2085.1 at 5 kg to 347.52 at 30 kg and 3332.3 at 5 kg to 555.38 at 30 kg in second mode. The safety factor of the design was between 13.385 and 2.2308 within the test load confines and thus is reliable for industrial use. These results confirm that generative design optimization can achieve significant material savings with absolutely no compromise on the structural integrity of the industrial conveyor system. That is a good representation of the feasibility of sustainable design for industrial applications without compromising performance and safety.

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1. Introduction

Businesses nowadays must compete on several factors, including product quality, production cost, and efficiency [1]. It is quite unpleasant for the organization's complex and unique equipment systems to experience issues or malfunctions, mostly because of the possible financial losses that could result, as well as worries about employee safety and environmental effects [2]. The demand for mineral raw resources has increased globally because of the growth of the global economy [3]. The need to increase supply can sometimes have negative socio-environmental effects and increase the number of accidents in the sector [4]. It is now essential for all businesses to compete with other market players in the modern business environment, concentrating on elements like manufacturing costs, product quality, and operational efficiency [5]. It is quite undesired for the company's complex and unique machinery systems to malfunction because this can lead to monetary losses, endanger worker safety, and raise environmental issues [6,7]. Although overall accident rates have been gradually declining, the extraction of basic raw materials continues to be one of the industrial activities linked to the highest rates of accidents and diseases worldwide [8], even with technological developments. The development of modern industry is characterized by exponential expansion in production, which calls for the methodical improvement of organizational and mechanized components of production processes [9]. This idea also applies to the development of in-plant systems, transportation techniques, and organizational structure. These elements are essential to ensuring that raw materials, semi-finished goods, and final goods continue to flow uninterruptedly throughout all production, control, and storage facilities [10]. They are also essential in making sure that the auxiliary material production process runs well. Palletization and concrete procedures are used in the first step, when mobility is facilitated using mechanical equipment operated under an operator's supervision [11]. Materials that are continually transported without the operator's assistance are referred to as the latter. Among the many techniques used in continuous transportation is the use of conveyors.

Belt conveyors are becoming more intelligent, long-distance, and energy-efficient as technical specifications and technology advance [12-17]. Raw materials in the conveyor belt must be thoroughly understood and properly controlled to stop them from sliding off. Belt conveyors can move a lot of raw materials across great distances with little energy usage, especially when it comes to efficiency. Raw materials used in industrial settings must be delivered to their destination without slipping off the conveyor belt. In addition to decreasing transportation efficiency, the risks and costs of recovering and collecting raw materials that fall off the conveyor belt are increased. To prevent them from sliding off, raw materials in the conveyor belt need to be fully understood and managed. However, because raw material physical properties and operating conditions greatly influence how raw materials behave in belt conveyors and other powder/particle operations, the conveying operation has not yet been thoroughly described [18–20].

Developing design methods that cut down on time, increase efficiency, and improve cost-effectiveness and sustainability in the built environment is a critical task for the structural engineering and building design industries. One example of this is the conveyor belt. Given how crucial it is to streamline design processes, cut costs and time, and boost productivity, research and development centered on integrating automation to speed up the design process is desperately needed [21]. Generative design (GD) is currently a major component of automated building design techniques. These techniques provide the capacity to build structures that are optimal and make use of materials exactly where they are required. Therefore, finding and improving appropriate GD techniques is essential to increasing their effectiveness in a range of computing applications. By adjusting material distribution and evaluating achievable outcomes, GD facilitates the exploration of design possibilities

[22-26]. Due to the rapid development of additive manufacturing technologies, GD is now widely used in the sector. Artificial intelligence-powered software creates various product designs and geometric structures according to load and boundary conditions. Significant advantages are offered by this component in terms of weight loss and production cost efficiency [27,28].

One of the main areas of study for finite element methods (FEM) is high-performance finite element analysis (FEA) [29]. Non-conforming elements and extended finite element methods are two examples of the components that numerous academics have suggested to get around the drawbacks and restrictions of traditional FEM [30]. Study by Wang *et al.,* [31] integrated approach that uses FEM to optimize joint structures in treelike column systems by fusing additive manufacturing and generative design. The focus is on designing a three-branch joint that enhances structural integrity while minimizing weight. The generatively designed joints exhibited superior static behavior and more uniform stress distribution compared to traditional joints, such as topologically optimized joints and bionic designs. The study concludes that integrating generative design with additive manufacturing not only enhances production accuracy but also addresses challenges associated with traditional casting methods, thus offering a promising approach for future joint designs in engineering applications. Lin *et al.,* [32] introduces a novel approach to improving the design of large-diameter tunnels constructed beneath existing ones, focusing on addressing the inherent uncertainties in geotechnical conditions. To address these challenges, they suggest an ensemble generative design system based on fuzzy robust multi-objective optimization (FRMOO).

Ming-Yuan Zhang *et al.,* [33] focuses on the structural analysis and optimization of a triangle bracket used in belt conveyors using FEM to assess the stress, strain, and displacement of the bracket under operational loads. The study focuses solely on one type of triangle bracket without considering variations in design or materials that may be used in different industrial applications. Leopold Hrabovský *et al.,* [34] investigates the effectiveness of a modified design of impact rollers used in conveyor systems to reduce vibrations caused by the impact of falling material. The experiments are conducted in a controlled laboratory setting, which may not fully replicate real-world operational conditions such as varying load sizes, speeds, or environmental factors. The research focuses solely on one type of impact roller design; further studies could explore various configurations and materials to establish more generalized conclusions applicable across different conveyor systems. In another research, Leopold Hrabovský *et al.,* [41] investigates the impact of using plastic brackets in conveyor roller designs to mitigate vibrations transmitted to the conveyor structure. The research does not explore other materials or bracket designs that might offer further improvements or benefits, limiting the scope of potential solutions for vibration reduction. Not many industries have implemented generative design to provide efficiency in its use, including brackets on conveyor belts.

The present research proposes new belt conveyor bracket designs using generative design algorithms and suggests a number of quite different variants. For that purpose, aluminum 6061 was selected due to its good balance of strength and light-weight characteristics. It also involves the extended use of FEM in ANSYS 2023 R2 for simulate load in designed, whereby the structural integrity, distribution of stresses, deformations, and performance at load for each model are scrutinized in detail under varying operational conditions. Aim of the current research will be to establish whether generative design can offer structural optimization for conveyors that are resilient yet highly efficient in their material use, lighter, and of less mass-and therefore with less energy consumption-without sacrificing strength or durability. The current study, therefore, seeks to establish, through a systematic analysis of FEM results, the potential of generative design to realize weight reductions that could enhance the energy efficiency, cost-effectiveness, and sustainability of belt conveyor systems applicable in industries.

2. Methodology

2.1 Required Software for Generative Design

The domains of engineering, architecture, and construction have all received help from the use of generative AI, because of the strength and relative maturity of the underlying algorithms. The Autodesk Fusion 360 2024 Generative Design Extension program, which offers the following features to increase design efficiency and reduce unscary of weight, was used to create this article.

2.2 Input of Model Geometry and Material

The experiment's design (DOE) can be used to statistically write down the link between input parameters and output responses, it is possible to optimize process parameters in design [35]. Figure 1 shows the placement of bracket conveyor belt as holder between conveyor and the table, design of bracket should be able to resist any force from conveyor and the load itself. This figure also shows design space for computation generative design. Table 1 Illustrated the on-detail dimension of initial design or space to optimize with generative design.

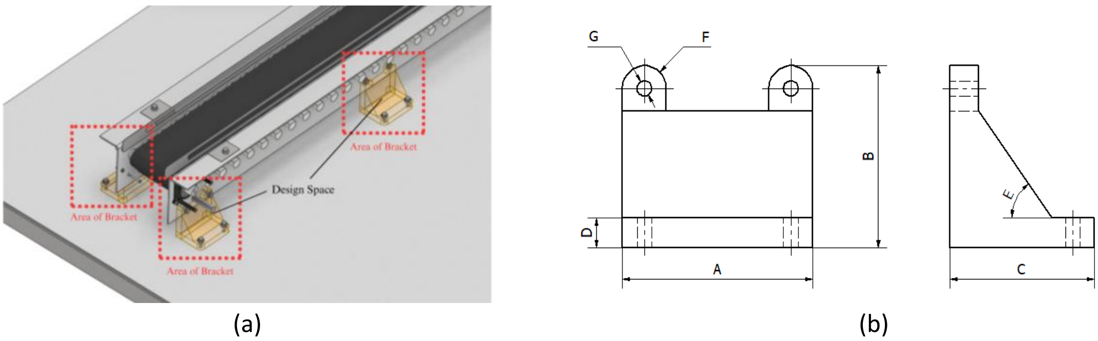


Fig. 1. Geometry (a) placement of bracket on conveyor belt and design space for computation, and (b) detail dimension of initial design for optimising

Table 1
Dimension of initial parameter design

Parameters	Value	Units
A	65	mm
B	60	mm
C	49,5	mm
D	10	mm
E	4,5	°
F	7,5	mm
G	5	mm

In engineering, the geometric design parameters significantly affect the performance and durability of components, especially about fatigue failure and material stresses [36]. In additive manufacturing (AM), the interaction between design geometry and manufacturing limitations is also crucial. Different tools, such as CAD software and manufacturability assessment tools, help engineers navigate these interactions by visualizing and refining geometry to minimize potential weaknesses [37]. The automotive, aerospace, and other sectors make extensive use of wrought aluminum Al 6061 because of its favorable qualities, which include high strength, superior corrosion resistance, and exceptional weldability [38]. Al 6061 is the material employed in this study, then Table 2 displays the material's mechanical properties.

Table 2
Mechanical properties of material Al 6061

Property	Value	Units
Density	2,700	kg/m^3
Ultimate Tensile Strength	310	MPa
Tensile Yield Strength	276	MPa
Elongation at Break	17	%
Modulus of Elasticity	68,900	MPa
Poisson's Ratio	0.33	
Shear Modulus	26,000	MPa
Shear Strength	207	MPa

2.3 Generative design process

The structure of the material reduces to a collection of topological properties that can be effectively refined by machine learning techniques. In the third category, high-dimensional topological design is the main focus. This entails segmenting the topology into pixels (or voxels) and generating pixelized topological matrices using generative models like generative adversarial networks and variational auto encoders in order to shape design [39]. For multi-scale design, developments in generative models have made it possible to accurately translate elastic characteristics to intricate structures like triply periodic smallest surfaces [40]. The first step in generative design is setting up parameters including obstacle geometry, keep geometry, and initial form. This is considerably basic in describing the design algorithm for creating the best solutions within set boundaries. This happens when limitations are set to guide the algorithm on a path to generate ideal solutions as shown in Figure 2 and Table 3.

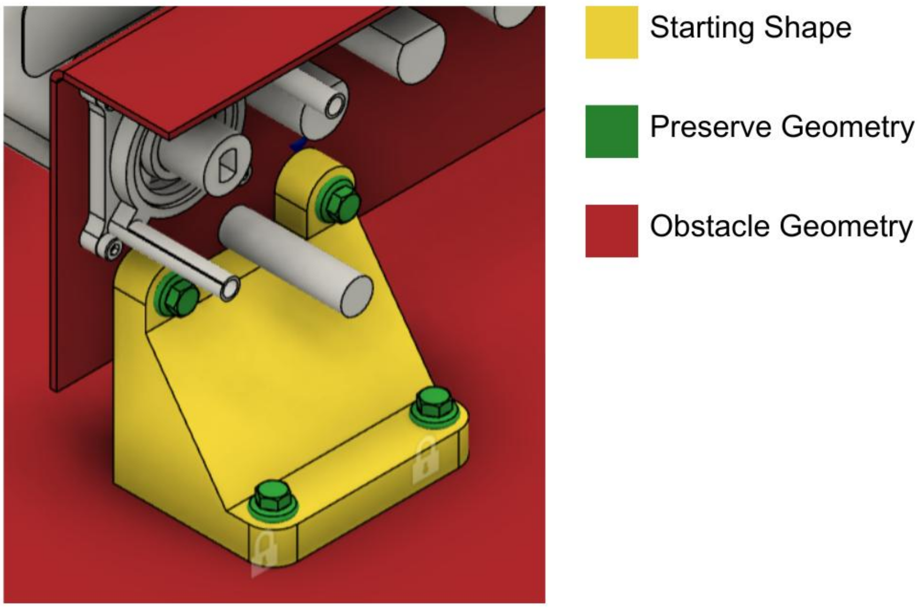


Fig. 2. Preserve and obstacle geometry area

Table 3
Parameters set for computation

Parameters	Selected Value
Manufacturing method	additive
Orientation	Z
Material	Al 6061

Calculative operations can be run using the set parameters in generative design algorithms, optimizing the design itself to meet the expectations. Going through numerous design configurations, the process of optimization includes iterative refinement in search of the greatest trade-off between functionality and efficiency as shown in Figure 3.

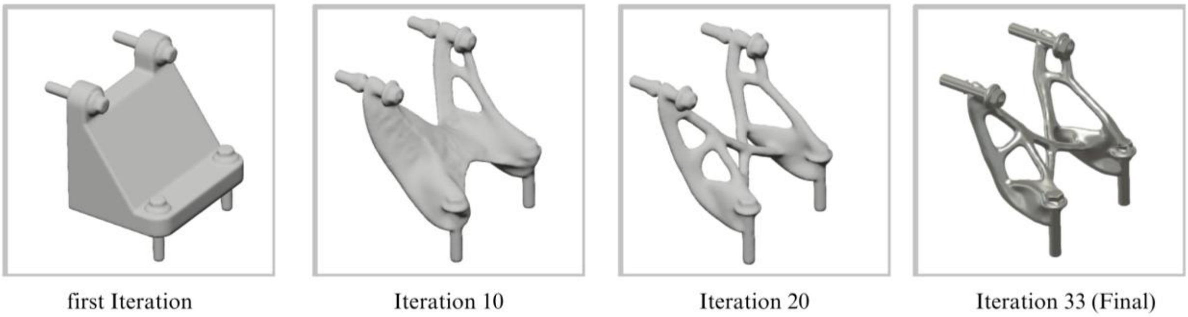


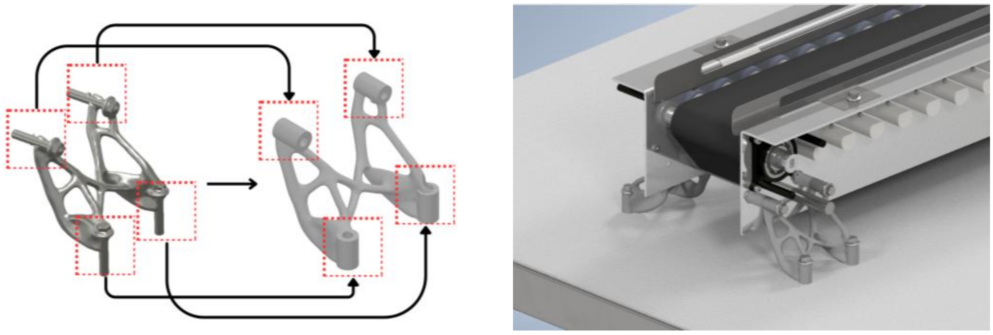
Fig. 3. Steps of computational iteration generative design

Figure 3 shows the process of generative design for a mechanical part. Algorithms run iteratively on computers to produce improved designs by minimizing material and maximizing strength as data highlighted in Table 4. The simple initial designs evolve into complex, efficient structures under the adaptation to the given loads and constraints.

Table 4
Iteration result

Iteration	Orientation	Volume (mm^2)	Mass (Kg)
First Iteration	Z+	89,317.58	0.198
Iteration 10	Z+	20,951.91	0.057
Iteration 20	Z+	12,439.07	0.034
Iteration 33 (Final)	Z+	12,172.8	0.033

After design computation, there must be a post-processing stage that refines the output to ensure integration into the current existing design. This includes adaptation to improve compatibility, and ensuring the generative results meet pre-set design parameters and functional requirements as revealed at Figure 4.



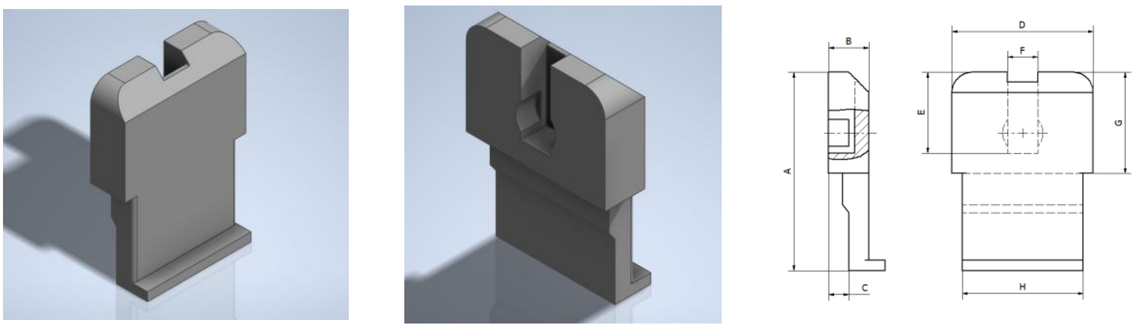
(a) (b)

Fig. 4. Post process feature for alignment assembly (a) feature add, (b) placement on conveyor belt

More than this implementation on the bracket conveyor belt, the generative design will bring many breakthroughs to sectors, starting with strong and lightweight parts in aerospace, innovative structurally sound designs in architecture, and personalized implants and prosthetics in healthcare-such application aspects prove that generative design is driving innovation and sustainability for diversified industries.

2.5 Comparation Geometry

Comparative analysis should be performed for completeness towards the evaluation of the efficiency of generative design in this study. The comparison will involve previous studies, especially those related to the reference model of a "plastic bracket" as displayed in Figure 5. This figure shows an isometric view and detailed dimensions of reference design geometry [41]. Table 5 shows the dimension of reference and comparison design.



(a) (b) (c)

Fig. 5 Geometry (a) isometric front view design, and (b) isometric back view design, and (c) detail dimension of design

Table 5
Dimension of reference and comparison design

Parameters	Value	Units
A	98	mm
B	20	mm
C	10	mm
D	70	mm
E	40	mm
F	15	mm
G	50	mm
H	60	mm

The baseline for such comparison's main metrics such as material, volume, cost, and weight as presented in Table 6. Different input geometry has come out showing enormous advantages of generative design. The result is a design that is often not only more cost-effective as get data from The JLC 3dp and JLC CNC who's manufacturing process vendor, due to better material use but is much lighter as well, hence guaranteeing better performance and even sustainability. This goes to show how it can disrupt older conventional methodologies of design while remaining responsive to both fiscal and considerations concurrently.

Table 6
Comparison main metrics of brackets

Input Geometry	Volume (mm^2)	Material	Mass (Kg)	Manufacturing method	Cost ($)	Ref
Before Generative Design	89,317.58	Al6061	0.198	CNC Milling	47.05	
After Generative Design	12,172.8	Al6061	0.033	Additive (SLM)	18.3	
Conventional Bracket design	92,033.93	Plastic	0.65	CNC Milling	32.37	[41]

In a previous study using a three-axis machining center (XH714D), the machine tool's energy consumption was 758,211 J (approximately 0.211 kWh) for a specific process and data includes the tool's operational energy but excludes additional exergy losses such as those from coolant dissipation or compressed air [42]. On an SLM 280HL facility by SLM Solutions (Lübeck, Germany) ahigh-power laser-based additive manufacturing system built for accuracy and energy efficiency is usually the SLM machine utilized for trials, devices frequently make use of fiber lasers with 400 watts of power and process consumes approximately 0.2 kWh and the process variables including scan speed, hatch spacing, and material type affect the precise laser power [43].

Table 7
Production energy consumption

Manufacturing method	Value	Units	Ref.
CNC Milling	0.211	Kw/h	[42]
Additive (SLM)	0.2	Kw/h	[43]

For find out the time of manufacturing methode with CNC milling Mastercam Learning Edition use for simulating the machining process, and for the Additive (Selective Leser Melting) RepliSLS3D Demo use for slicing design for manufacture SLM Methode as give data Table 8.

Table 8
Production time

Input Geometry	Manufacturing method	Value	Units
Before Generative Design	CNC Milling	3.3	h
After Generative Design	Additive (SLM)	2.1	h
Conventional Bracket design	CNC Milling	2.7	h

2.6 Governing Equation

Equations are essential in engineering for modeling, analysis, and perfecting designs. They offer quantitative insights into structural integrity and material properties under different conditions. Differential equations, in particular, are widely used for modeling systems and structural responses to external forces. By applying these equations, engineers can predict and enhance system stability and performance. Such mathematical modeling is foundational across engineering disciplines, enabling safe, efficient designs [44]. In material mechanics, it is termed strain, which involves the change or distortion of the materials' shape due to applied forces acting upon them. The percentage of deformation that the material underwent from its initial dimensions is displayed by comparing the measurement to the ratio of the material's length change to its initial length. The relationship between Cauchy stresses and strains for elastic behavior, as defined by Eq. (1) [45], is defined as follows where the Cauchy stress tensor σ = [σ_{11}, σ_{22}, σ_{33}, σ_{12}, σ_{23}, σ_{31}], and elastic strain tensor ε^e = [ε^e_{11}, ε^e_{22}, ε^e_{33}, ε^e_{12}, ε^e_{23}, ε^e_{31}] adhere to the Voigt notation, and *C* is the elastic stiffness matrix, which is dependent on the local relative density ρ for cellular materials with density changes.

$$\sigma = \varepsilon^e \tag{1}$$

The shear stress taking into consideration the accordion effect may be simply calculated using Eq. (2) by adding three angular displacement functions. The τ_w shear stress, as decided by the stress-strain relationship [46]. The deflection angle of the centroid line of the top and bottom flanges is indicated by the angle produced between the line segment and the z-axis, β*(x)*, *w'(x)*, and θ*(x).* These changes between different composite boxes are denoted by *α(x)*, where G_w is the effective shear modulus.

$$\tau_w = G_w\left(w' - \lambda\alpha + \zeta\beta\right) = G_w\left(w'(x) - \theta(x)\right) \tag{2}$$

For in-service applications, the quantity of applied loads and the stress levels that go along with them will always be unpredictable; load estimations are often simply approximations. Additionally, almost all engineering materials show diversity in their measured mechanical characteristics, as mentioned in the preceding section. As a result, design modifications are necessary to guard against unforeseen failure. An alternative to design stress is safe stress, often known as working stress σ_w. Based on the material's yield strength, this safe stress is calculated by dividing the yield strength by a safety factor ℕ, Displayed in Eq. (3) [47].

$$\sigma_w = \frac{\sigma_y}{\mathbb{N}} \tag{3}$$

The Euler buckling equation is often used in engineering applications to calculate the critical buckling load of a beam. The impact of the limitations at both ends of the compressed beam on the critical buckling load is measured by the coefficient of effective length, or k [49]. Eq. (4) is the equation for Euler buckling, where *L* is the unsupported length, *I* was the column's cross-sectional moment of inertia, and *E* is the material's Young's modulus [49].

$$F_{buckling} = \frac{4\pi^2 EI}{(2L)^2} \tag{4}$$

Equivalent stress by Von-Mises in solid mechanics is one important concept deduced from a maximum distortion energy theory, also called the fourth strength theory. This theory is used to predict the yielding of material under complicated loadings, considering the combined stresses in three-dimensional space. It is based explicitly on the assumption that yield initiation occurs at an energy of distortion per unit volume in a material equal to that reached in a uniaxial tensile test. This is expressed as Eq. (5) [50]. Where σ_1, σ_2, and σ_3 represent the stresses acting on the x, y, and z planes of a geometry, measured in MPa.

$$\sigma = \sqrt{\frac{\left[(\sigma_1 - \sigma_2) + (\sigma_2 - \sigma_3) + (\sigma_3 - \sigma_1)\right]}{2}} \tag{5}$$

Eq. (6), which was linked to the Von-Mises equivalent strain equations and the Chakrabarty membrane stretching model, demonstrated the relationship between equivalent strain and thickness change [50].

$$\varepsilon_{eq} = \sqrt{\frac{2}{3}\varepsilon_{ij}.\varepsilon_{ij}} = \sqrt{\frac{2}{3}\left(\varepsilon_\theta^2 + \varepsilon_\varphi^2 + \varepsilon_T^2\right)} = |\varepsilon_T| = \ln\frac{T_0}{T(\delta)} \tag{6}$$

The center deflection is denoted by ε, the circumferential strain is denoted by ε_θ, the meridional strain by ε_φ, the radial strain by ε_T, the equivalent strain by ε_{eq}, the deviatoric strain tensor by ε_{ij}, the first specimen thickness by T_0, the specimen thickness when the deflection is δ, and the center deflection by δ [51,52].

$$\lambda = \frac{z_s + z_x}{h_s + h_x} = \frac{h_u}{h_w} \tag{7}$$

The distances between the section centroid, the top surface of the top flange, and the top surface of the bottom flange are denoted by h_s and h_x respectively in Eq. (7), which defines a load multiplexer. The distances between the top and bottom flange centers and the section centroid, which represent the net distance between the top and bottom flanges, are denoted by the letters z_s and z_x respectively [49].

$$E_l = (P_l + P_b)t_l \tag{8}$$

Power calculations also need to account for the efficiency of the machinery. This may be further calculated as a linear function of laser output power consumption E_l Eq. (8), energy consumed during the laser exposure process is calculated where P_l the laser's power consumption is. The laser exposure time is denoted by t_l [43].

2.7 Load Variation Testing

The finite element method (FEM) incorporates the suggested contact concept. Only contact between two bodies—one malleable and the other stiff and solid—will be considered for the first phase. Since the contact's structural behavior is solved using FEM, a geometrical discretization using finite elements (FE) must be performed. The structure under discussion is spatially decomposed into nodal points and finite elements as part of this discretization [48]. Only when the change in load is considered in FEM analysis will the changing rule of elastic modulus and supporting deviation concur with actual conditions. Different load intensities and distributions, for example-a point load versus a surface load-can be simulated by FEM on the variation in elastic modulus and support behavior [46]. In this study, FEM loading simulations will be varied in such a way, as shown in Table 9, with different mass values in order to know the strength of the design itself.

Table 9
Value load variation for FEM analysis

Variation	Mass (Kg)
1	5
2	7.5
3	10
4	12.5
5	15
6	17.5
7	20
8	22.5
9	25
10	27.5
11	30

2.8 FEM Modelling Procedure

This study's modelling uses ANSYS 2023 R2 with the combination of Static Structural and Eigenvalue Buckling tools for the finite element analysis procedure present in Figure 6. By considering the first state in Static Structural, the Eigenvalue Buckling analysis provides a more exact prediction of the structure's buckling behavior. The combined approach offers a deeper understanding of the structure's response under various loading conditions, including its potential for instability.

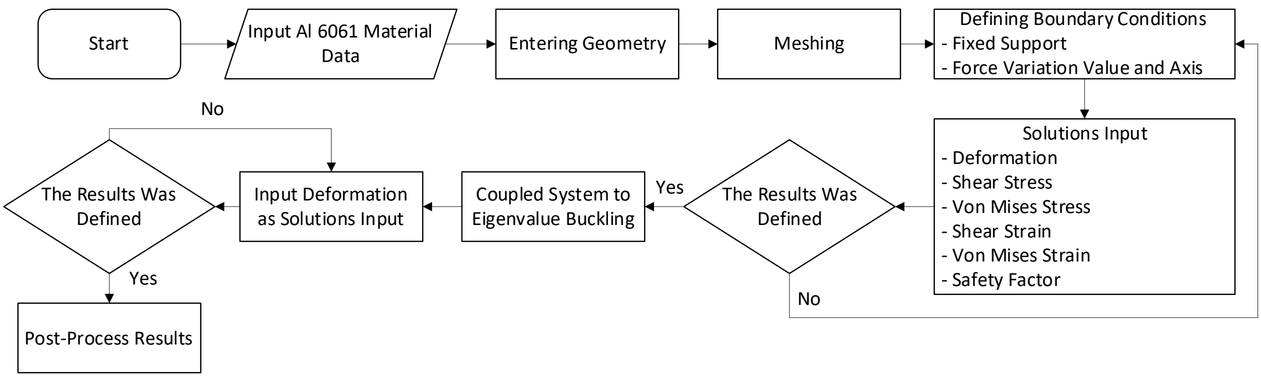


Fig. 6. Modelling procedure for finite element analysis on the research

The first step on this study is input the data material of Al 6061 as present Table 2 to the computational system at Static Structural, then the geometry of generative design could be entered. Next step, the geometry must be meshed before inputting the boundary conditions for the geometry. The meshing size in this study is 1 mm which the result from this meshing size is 0.39069 of average skewness quality, 54,081 nodes, and 30,123 elements as shown at Figure 7.

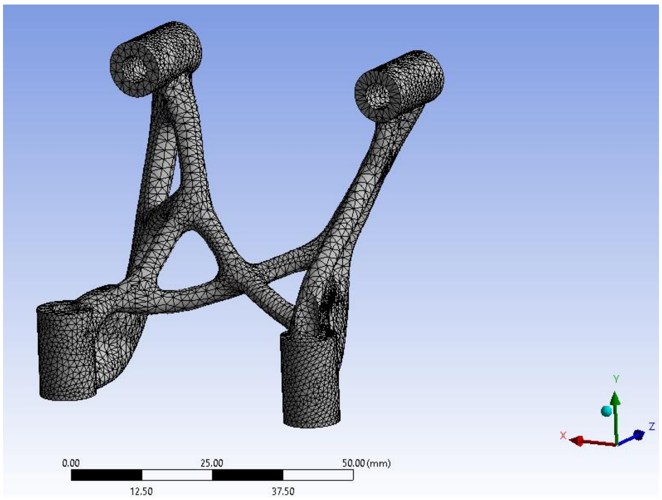


Fig. 7. Generative design meshing

The boundary conditions of the generative design were decided by inputting the force axis shown in Figure 8(a). This force axis is applied based on the direction of motion of the conveyor belt which moves when carrying a load on it. The bolt holes, which hold the generative design in place so that it can function properly when the conveyor belt is operating, were subjected to strain. As seen in Figure 8(b), fixed support is applied to the bolt holes that are fastened to the conveyor belt wall.

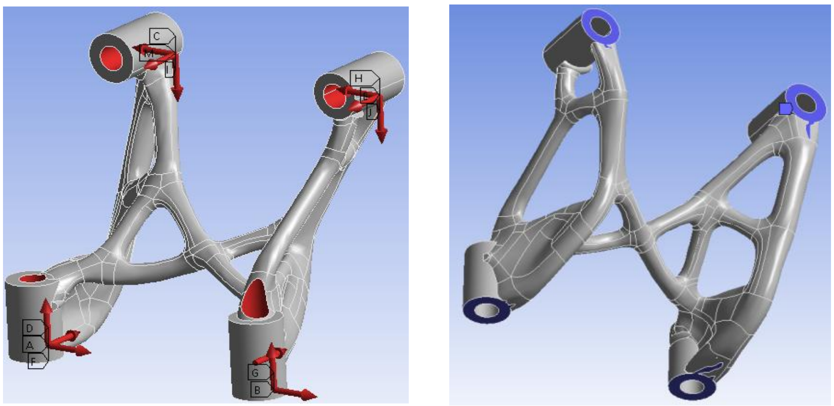


Fig. 8. Boundary conditions of generative design (a) applied force axis, and (b) applied fixed support

After the boundary conditions are defined in the generative design's geometry, the simulation in ANSYS can be done by inputting the solution which will be displayed after the simulation is complete. Total deformation, shear stress, equivalent (Von-Mises) stress, shear strain, equivalent (Von-Mises) strain, and safety factor are the simulation's displayed data.

3. Results and Discussions

3.1 Total Deformation

Figure 9 shows the results of the deformation from the simulation of generative design cause various of load. The value of deformation has increase cause of the higher load. The connector between bolt holes has a greater deformation that present on Figure 9(k) cause of the force from the load that applied on the generative design.

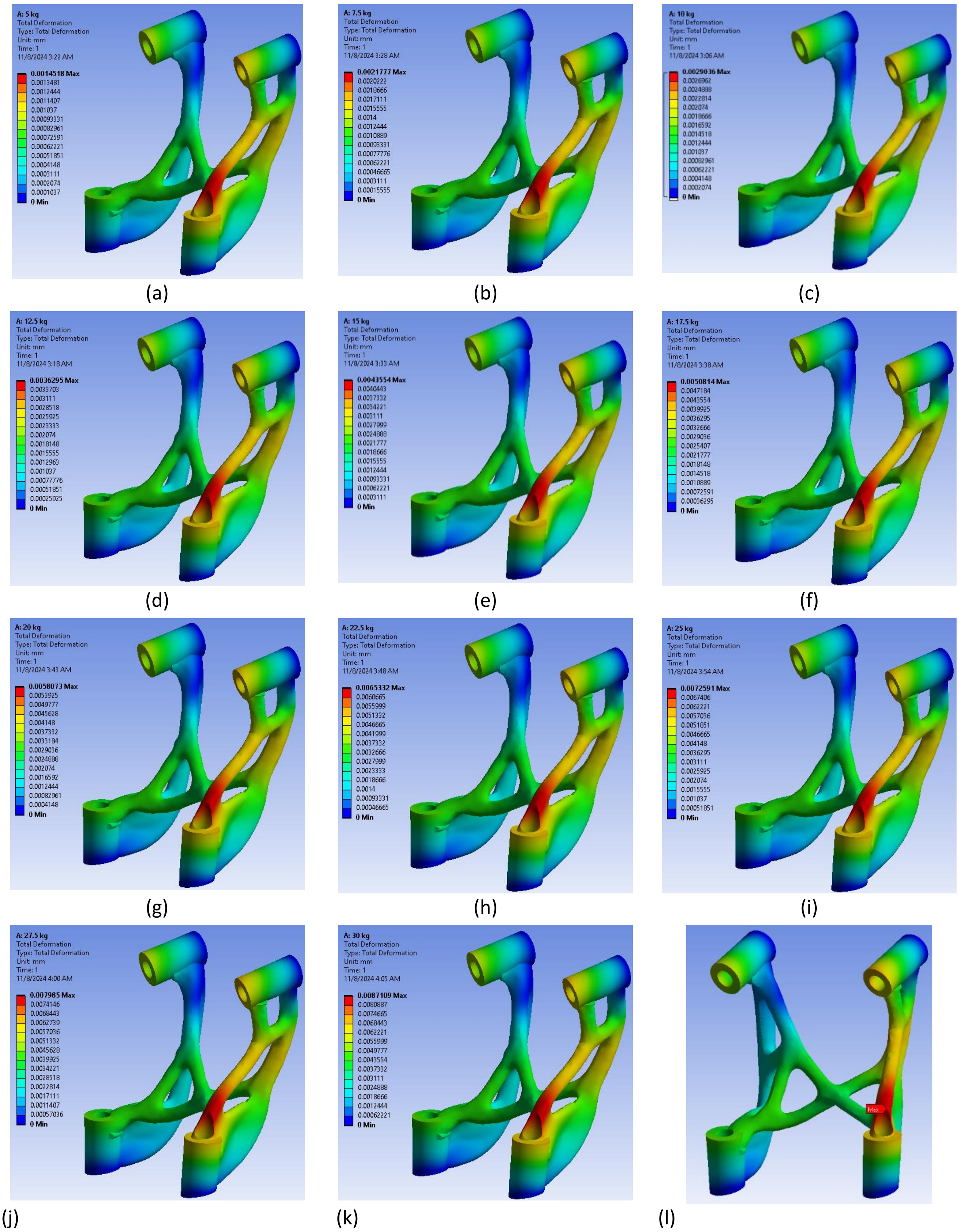


Fig. 9. Total deformation of the generative design at various load (a) 5 kg; (b) 7.5 kg; (c) 10 kg; (d) 12.5 kg; (e) 15 kg; (f) 17.5 kg; (g) 20 kg; (h) 22.5 kg; (i) 25 kg; (j) 27.5 kg; (k) 30 kg; and (l) the greater deformation location on generative design

The generative design deformed at 0.0014518 mm at a load of 5 kg, 0.0021777 mm at a load of 7.5 kg, 0.0029036 mm at a load of 10 kg, 0.0036295 mm at a load of 12.5 kg, 0.0043554 mm at a load of 15 kg, 0.0050814 mm at a load of 17.5 kg, 0.0058073 mm at a load of 20 kg, 0.0065332 mm at a load of 22.5 kg, 0.0072591 mm at a load of 25 kg, 0.007985 mm at a load of 27.5 kg, and 0.0087109 mm at a load of 30 kg.

3.2 Equivalent (Von-Mises) Strain and Shear Strain

Figure 10 and 11 show the equivalent (Von-Mises) strain and shear strain of the generative design at various loads. However, the equivalent (Von-Mises) strain and shear strain values in the generative design using Al 6061 material experience changes in length that are not too large due to the force obtained under the load. The mechanical properties of the Al 6061 material are reliable in resisting elongation when the material receives a large load. The equivalent (Von-Mises) strain that experienced on the generative design has a value of 0.00029559 mm at a load of 5 kg, 0.00044338 mm at a load of 7.5 kg, 0.00059118 mm at a load of 10 kg, 0.00073897 mm at a load of 12.5 kg, 0.00088677 mm at a load of 15 kg, 0.0010346 mm at a load of 17.5 kg, 0.0011824 mm at a load of 20 kg, 0.0013302 mm at a load of 22.5 kg, 0.0014779 mm at a load of 25 kg, 0.0016257 mm at a load of 27.5 kg, and 0.0017735 mm at a load of 30 kg. The shear strain of generative design from this simulation was defined as 0.00039804 mm at a load of 5 kg, 0.00059705 mm at a load of 7.5 kg, 0.00079607 mm at a load of 10 kg, 0.00099509 mm at a load of 12.5 kg, 0.0011941 mm at a load of 15 kg, 0.0013931 mm at a load of 17.5 kg, 0.0015921 mm at a load of 20 kg, 0.0017912 mm at a load of 22.5 kg, 0.0019902 mm at a load of 25 kg, 0.0021892 mm at a load of 27.5 kg, and 0.0023882 mm at a load of 30 kg.

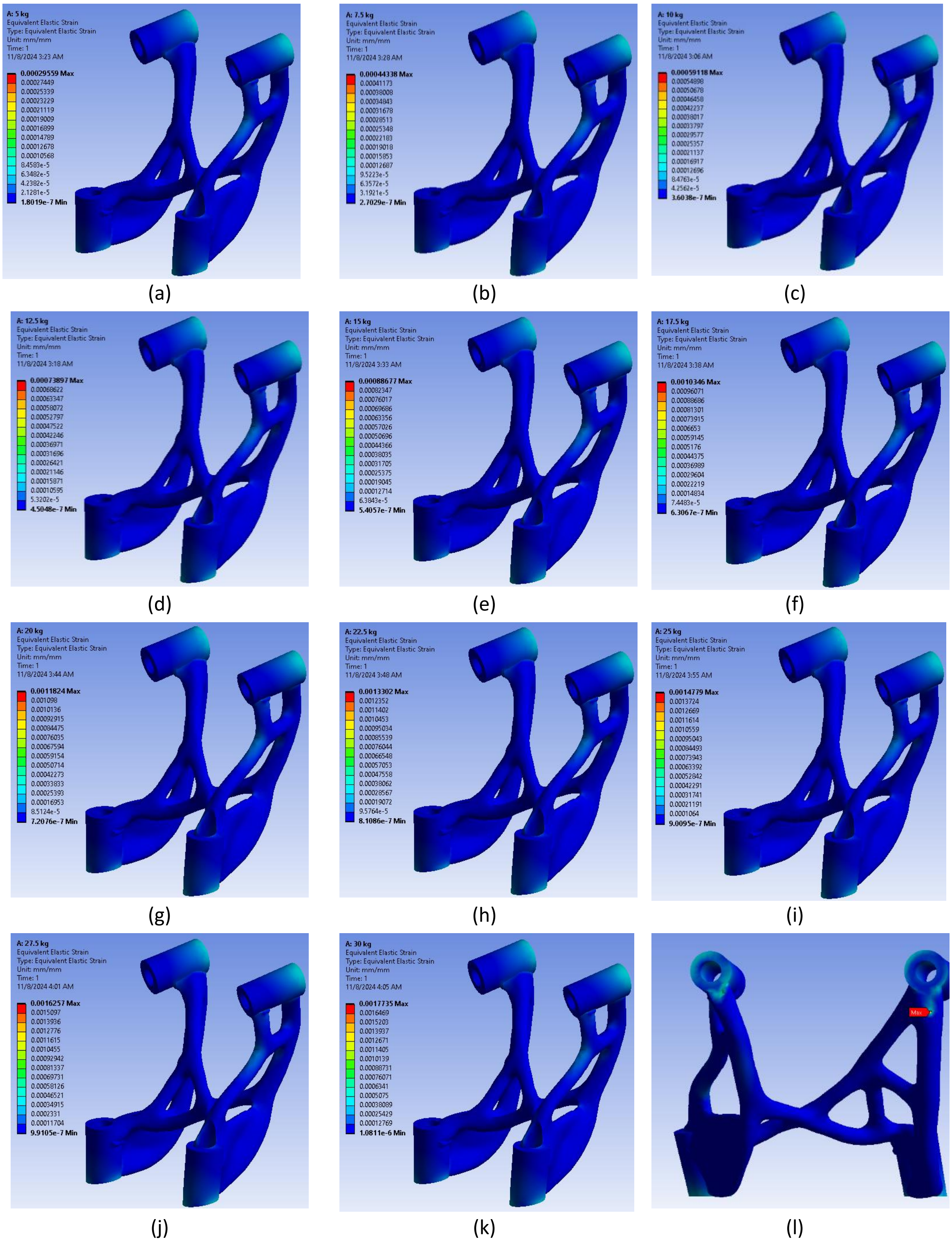


Fig. 10. Equivalent strain of the generative design at various load (a) 5 kg; (b) 7.5 kg; (c) 10 kg; (d) 12.5 kg; (e) 15 kg; (f) 17.5 kg; (g) 20 kg; (h) 22.5 kg; (i) 25 kg; (j) 27.5 kg; (k) 30 kg; and (l) the greater equivalent (von-mises) strain location on generative design

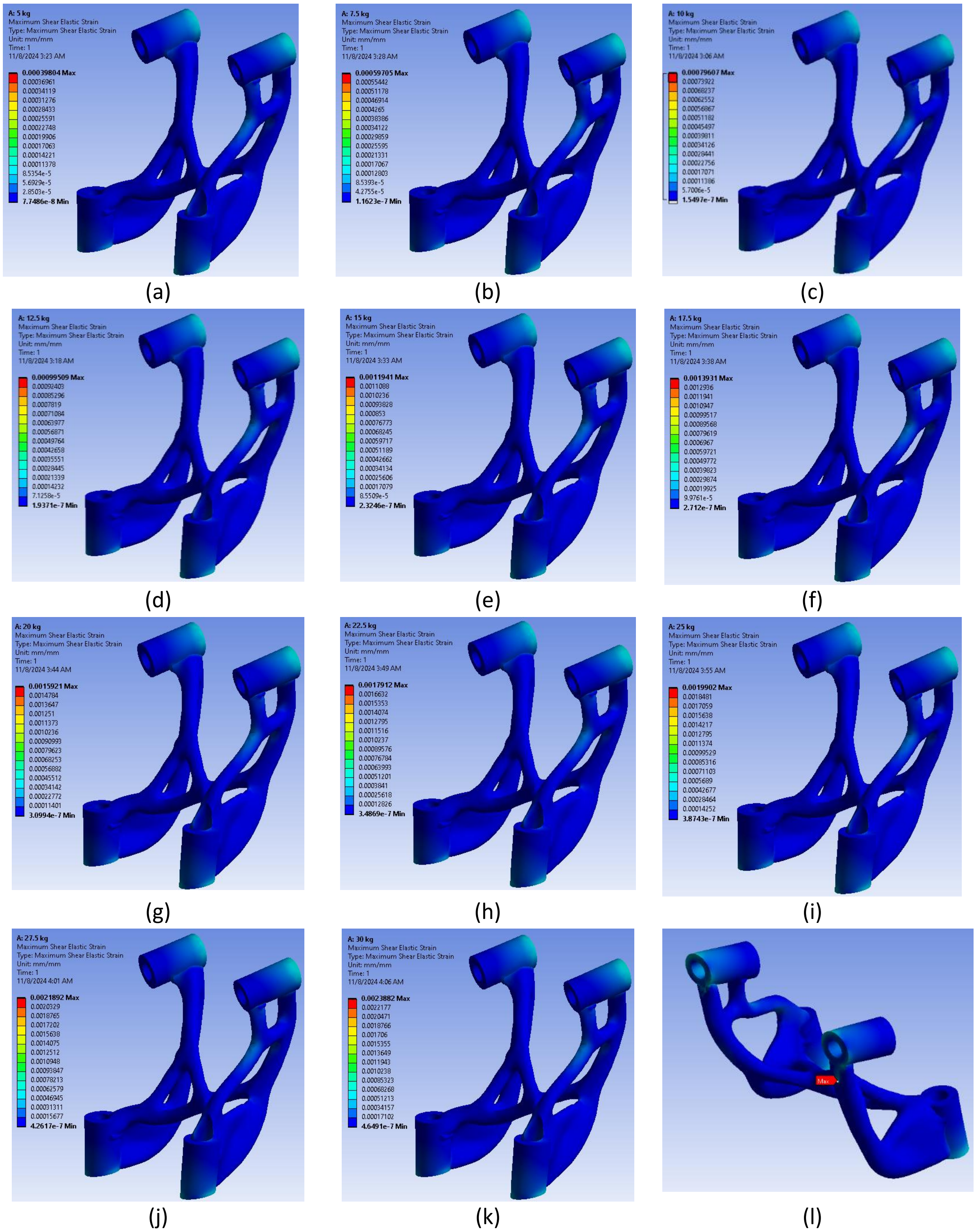


Fig. 11. Shear strain of the generative design at various load (a) 5 kg; (b) 7.5 kg; (c) 10 kg; (d) 12.5 kg; (e) 15 kg; (f) 17.5 kg; (g) 20 kg; (h) 22.5 kg; (i) 25 kg; (j) 27.5 kg; (k) 30 kg; and (l) the greater shear strain location on generative design

Figure 12 presents the comparison between equivalent (Von-Mises) strain and shear strain that applied on the generative design cause of the various load.

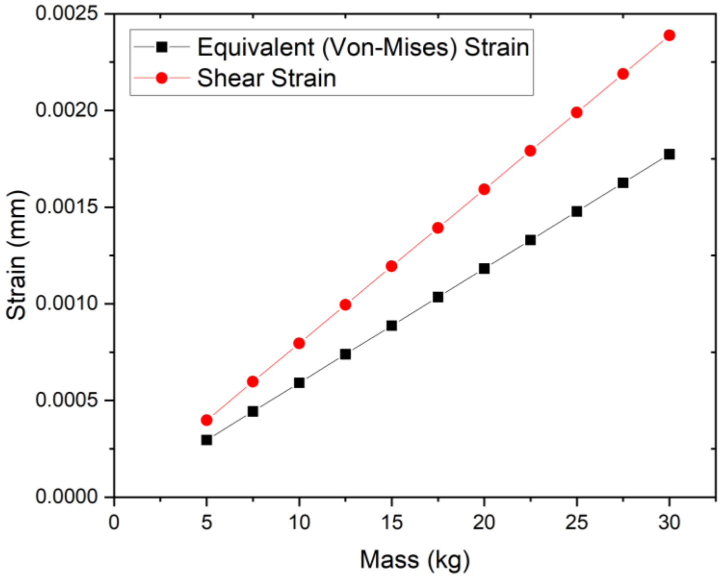


Fig. 12. Comparison between equivalent (von-mises) and shear strain at each various load

3.3 Equivalent (Von-Mises) Stress and Shear Stress

The equivalent (Von-Mises) stress and shear stress of the generative design at various loads has been shown at Figure 13 and 14. The stress caused by the various loads on the generative design has various values too. Equivalent (Von-Mises) stress of this generative design is 18.325 MPa at a load of 5 kg, 27.487 MPa at a load of 7.5 kg, 36.65 MPa at a load of 10 kg, 45.812 MPa at a load of 12.5 kg, 54.974 MPa at a load of 15 kg, 64.137 MPa at a load of 17.5 kg, 73.299 MPa at a load of 20 kg, 82.461 MPa at a load of 22.5 kg, 91.624 MPa at a load of 25 kg, 100.79 MPa at a load of 27.5 kg, 109.95 MPa at a load of 30 kg. For the shear stress that applied on the generative design is 10.31 MPa at a load of 5 kg, 15.465 MPa at a load of 7.5 kg, 20.62 at a load of 10 kg, 25.775 MPa at a load of 12.5 kg, 30.93 MPa at a load of 15 kg, 36.085 at a load of 17.5 kg, 41.24 at a load of 20 kg, 46.395 MPa at a load of 22.5 kg, 51.55 MPa at a load of 25 kg, 56.705 MPa at a load of 27.5 kg, 61.86 MPa at a load of 30 kg. The comparison of the equivalent (Von-Mises) stress and shear stress at various load shown at Figure 15.

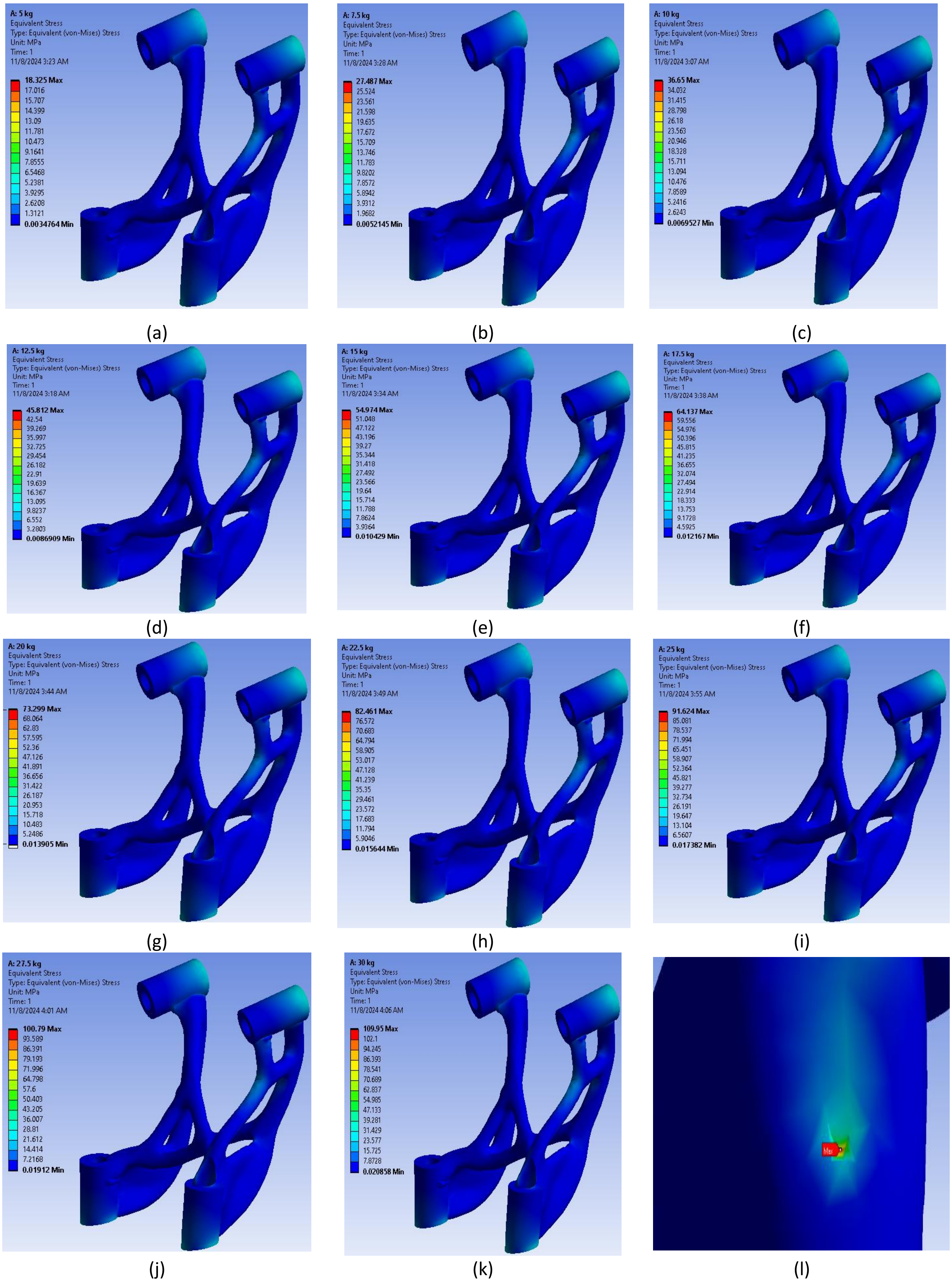


Fig. 13. Equivalent (von-mises) stress of the generative design at various load (a) 5 kg; (b) 7.5 kg; (c) 10 kg; (d) 12.5 kg; (e) 15 kg; (f) 17.5 kg; (g) 20 kg; (h) 22.5 kg; (i) 25 kg; (j) 27.5 kg; (k) 30 kg; and (l) the greater equivalent (von-mises) stress location on generative design

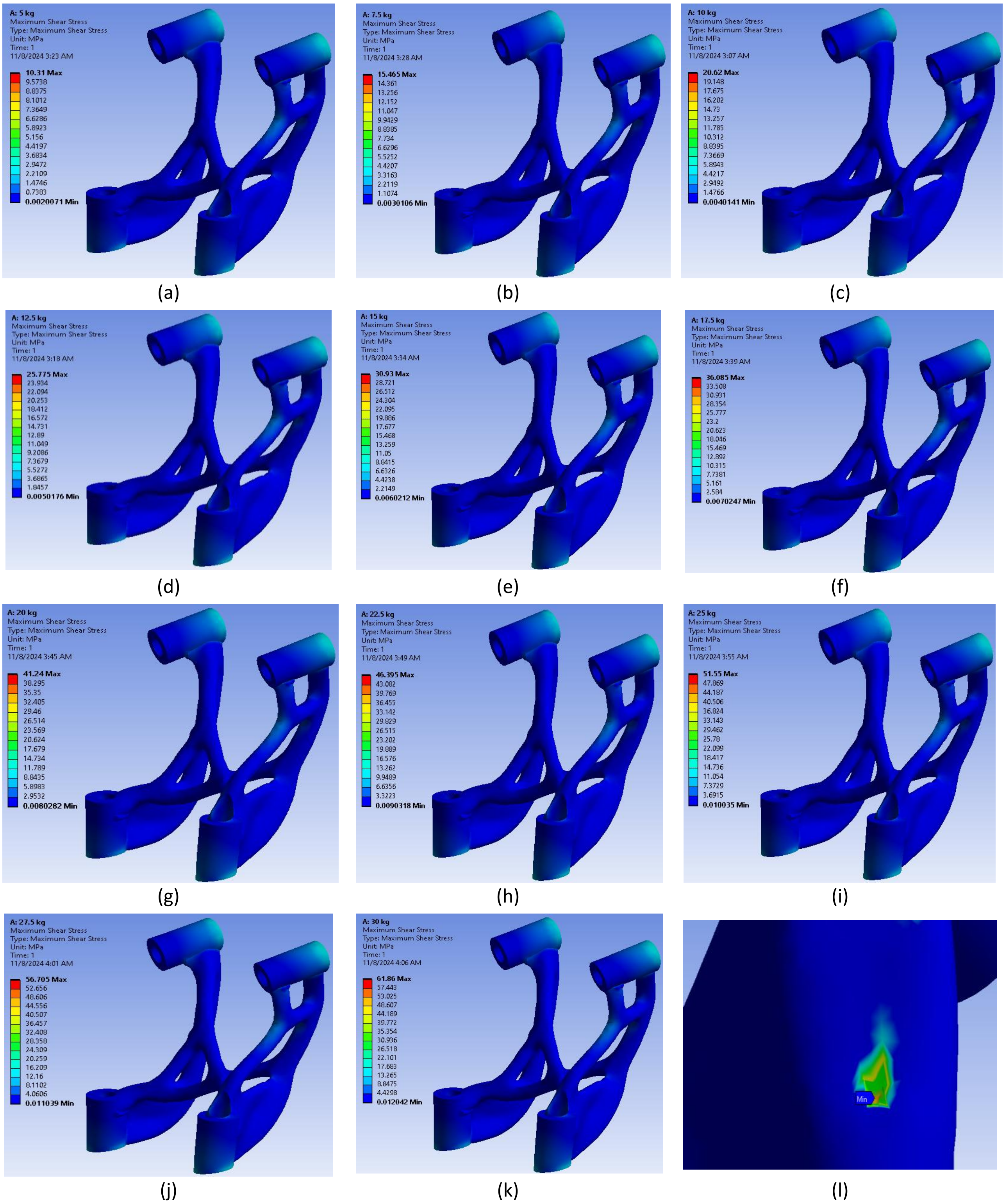


Fig. 14. Shear stress of the generative design at various load (a) 5 kg; (b) 7.5 kg; (c) 10 kg; (d) 12.5 kg; (e) 15 kg; (f) 17.5 kg; (g) 20 kg; (h) 22.5 kg; (i) 25 kg; (j) 27.5 kg; (k) 30 kg; and (l) the minimum shear stress location on generative design

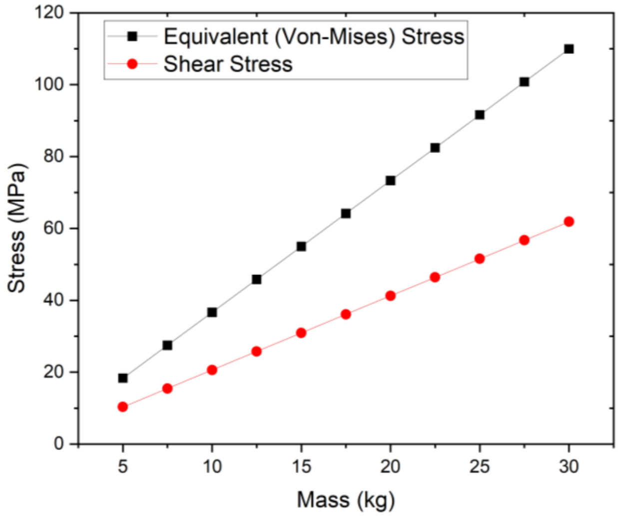
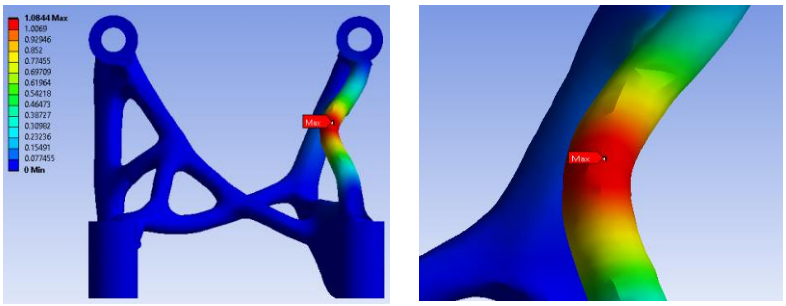


Fig. 15. Comparison between equivalent (von-mises) and shear stress at each various load

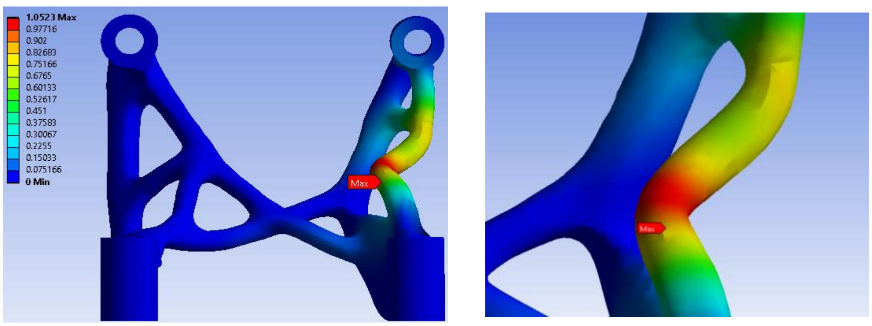
3.4 Buckling Phenomenon

The buckling phenomenon for the generative design was present in Figure 16 and 17, the buckling shows two modes from the ANSYS Eigenvalue Buckling. For the first mode, the value of buckling is 1.0844 mm, and at the second mode the value of buckling is 1.0523 mm. On this research, the load multiplier on each various load at first and second mode of the buckling has a different value caused increase by load that applied on the generative design which shown at Table 6. Figure 18 shows the load multiplier value at each various load on the generative design.



(a) (b)

Fig. 16. (a) Buckling phenomenon at first mode and (b) the detail of bucking phenomenon



(a) (b)

Fig. 17. (a) Buckling phenomenon at second mode and (b) the detail of bucking phenomenon

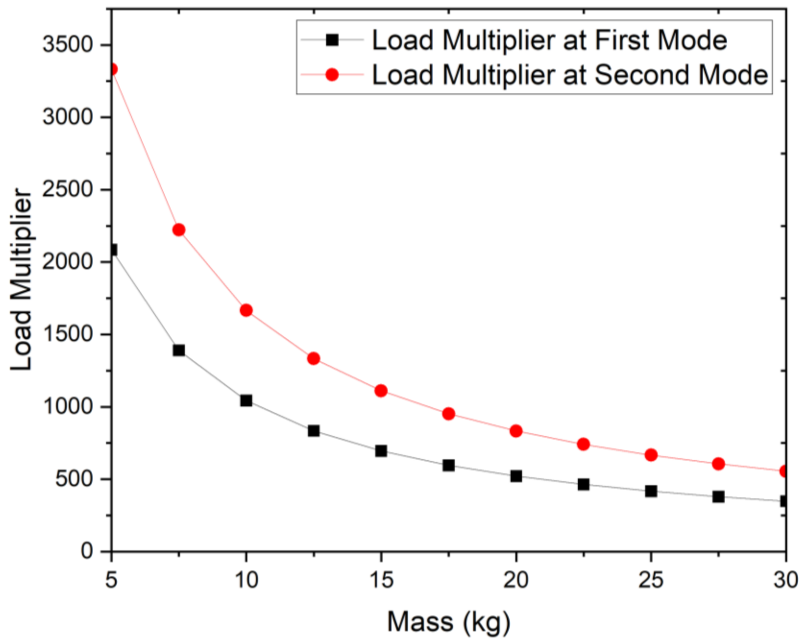


Fig. 18. Load multiplier at each various load

Table 10
Load multiplier at first and two modes at each various load

Mass (kg)	Deformation Load Multiplier at First Mode	Deformation Load Multiplier at Second Mode
5	2085.1	3332.3
7.5	1390.1	2221.5
10	1042.6	1666.1
12.5	834.06	1332.9
15	695.05	1110.8
17.5	595.76	952.08
20	521.29	833.07
22.5	463.37	740.51
25	417.03	666.46
27.5	379.12	605.87
30	347.52	555.38

3.5 Safety Factor

Figure 19 presents the value of the safety factor for generative design at each various load. The safety factor value decreased by the load value that applied on the generative design shown at Figure 20. If the safety factor value is below zero, then the geometry couldn't be able to withstand the load well. Table 6 shows the minimum safety factor of the generative design.

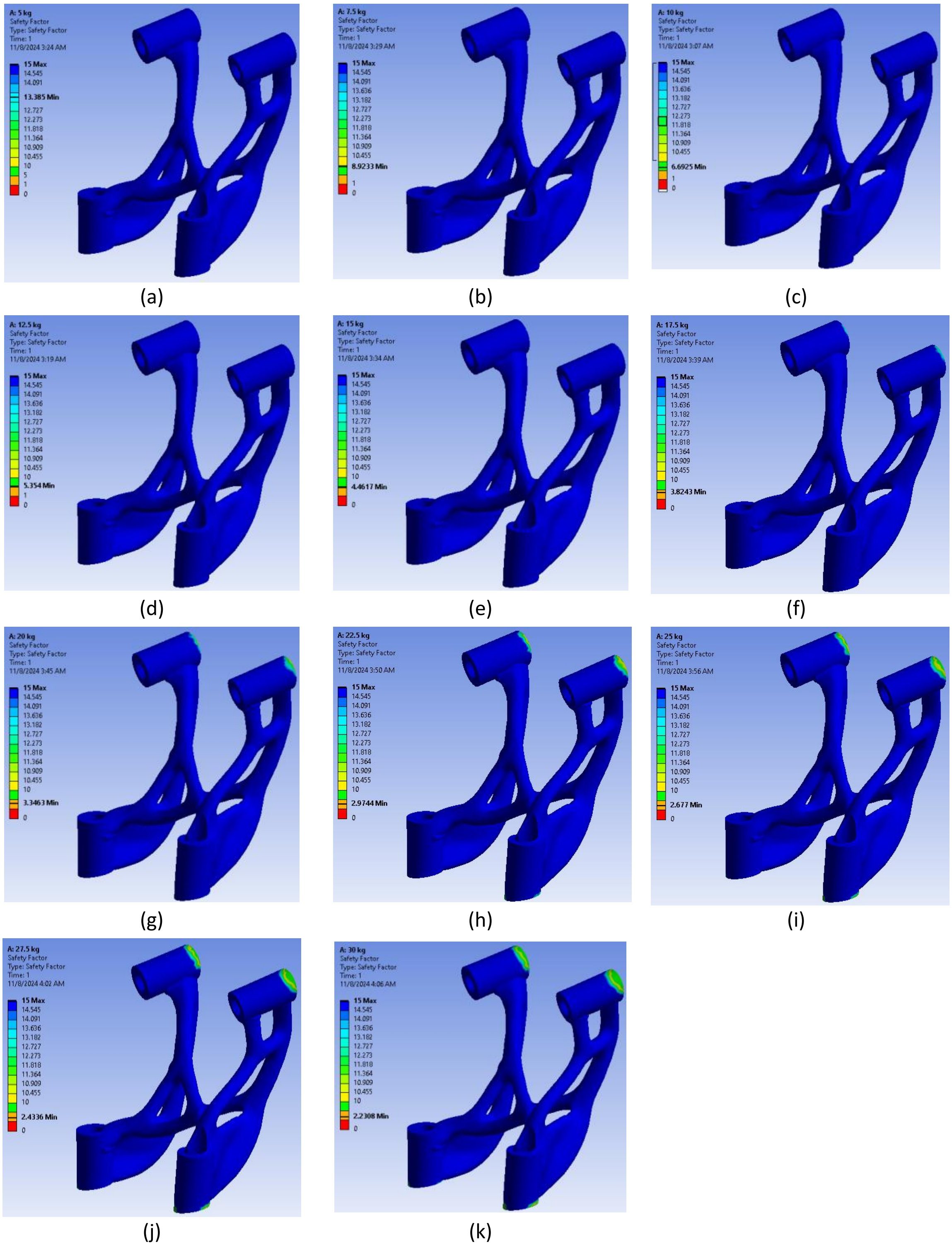


Fig. 19. Safety factor of the generative design at various load (a) 5 kg; (b) 7.5 kg; (c) 10 kg; (d) 12.5 kg; (e) 15 kg; (f) 17.5 kg; (g) 20 kg; (h) 22.5 kg; (i) 25 kg; (j) 27.5 kg; and (k) 30 kg

Table 11
Minimum safety factor of generative design at various load

Mass (kg)	Minimum Safety Factor
5	13.385
7.5	8.9233
10	6.6925
12.5	5.354
15	4.4617
17.5	3.8243
20	3.3463
22.5	2.9744
25	2.677
27.5	2.4336
30	2.2308

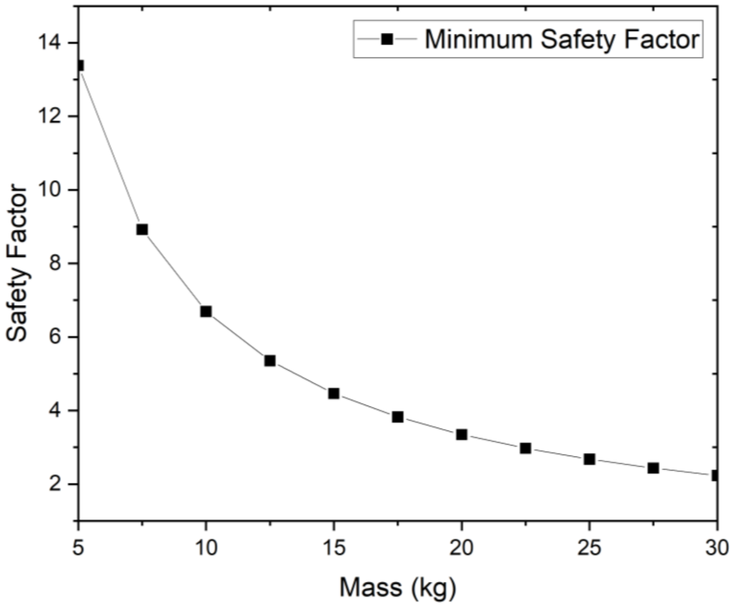


Fig. 20. Minimum safety factor on various load

The results of the safety factor shown in Figure 21 show that the most susceptible to fracture are the bolt holes because they grip the generative design from the load received. However, the minimum safety factor from the largest load on this research (30 kg) is 2.2308, than the generative design can be said to be safe in accepting quite large loads while the belt conveyor was working.

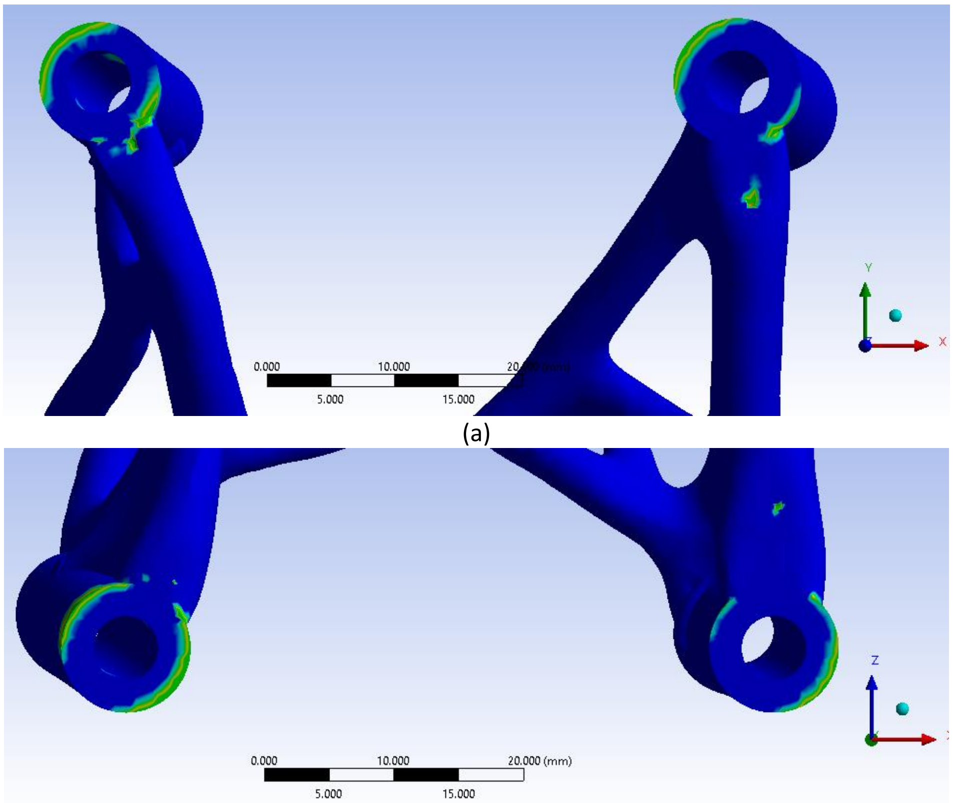


Fig. 21. The highest risk of fracture on generative design at (a) +z axis and (b) -y axis

3.6 Geometry comparation

This study of bracket conveyor also provides an analysis of comparation between design before being generative design and design that already in generative design also design with conventional design and manufacture. This study shows that generative design and additive manufacture are way more effective than conventional design and conventional manufacture as given Table 12.

Table 12
Comparison brackets output

Input Geometry	Material	Mass (Kg)	Manufacturing method	Cost ($)	Time Production (h)	Energy Consumption (kW)	Ref
Before Generative Design	Al 6061	0.198	CNC Milling	47.05	3.3	0.73	[39]
After Generative Design	Al 6061	0.033	Additive (SLM)	18.3	2.1	0.42	
Conventional Bracket design	Plastic	0.65	CNC Milling	32.37	2.7	0.59	

This study also shows generative design with additive manufacture will be enchained great efficiency in many aspects and parameters, this collaborates give the best results compared to conventional design and manufacturing Methode. Generative design with Additive (SLM) manufacture can give way less mass without compromising the ability to stand with force with low deformation as give Table 13, with less material to build generative design also give cheaper cost for manufacturing also lower energy consumption. Figure 22 show the comparation of the bracket design deformation and Figure 23 presents the cost and energy consumption comparation from the bracket designs.

Table 13
Comparison of deformation

Load Mass (Kg)	Bracket After Generative Design	Bracket Before Generative Design	Conventional Bracket Design
5	0.0014518	159.97	0.0024427
7.5	0.0021777	239.96	0.0036641
10	0.0029036	319.94	0.0048855
12.5	0.0036295	399.93	0.0061069
15	0.0043554	479.91	0.0073282
17.5	0.0050814	559.9	0.0085496
20	0.0058073	639.88	0.009771
22.5	0.0065332	719.87	0.010992
25	0.0072591	799.85	0.012208
27.5	0.007985	879.84	0.013435
30	0.0087109	959.83	0.014656

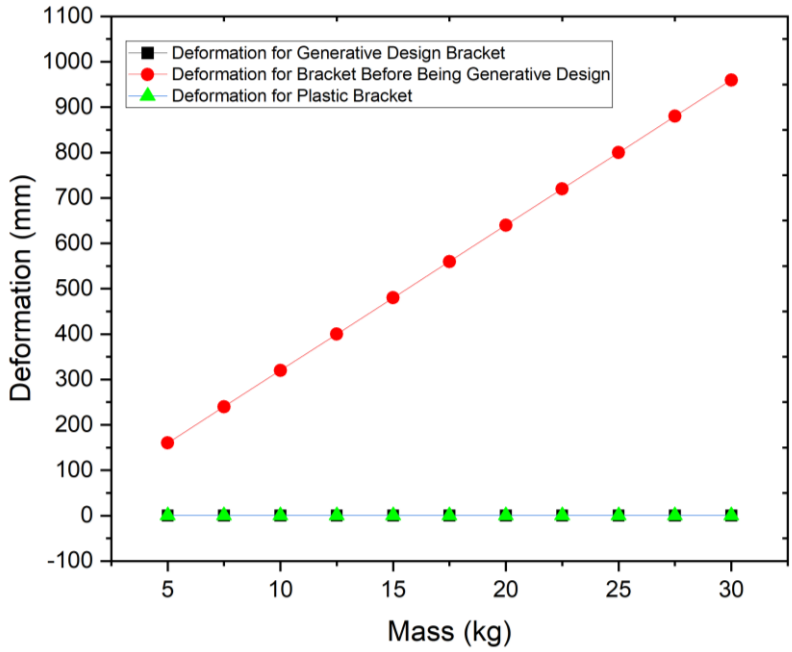
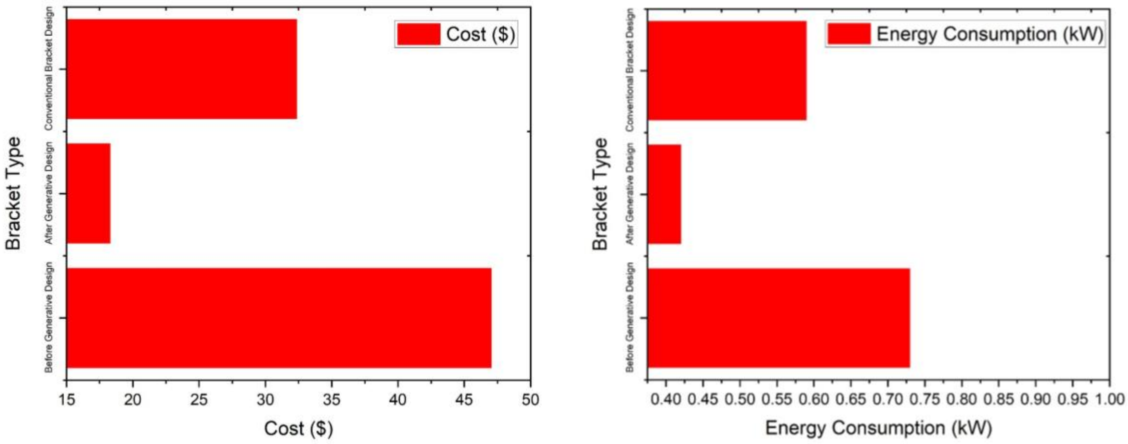


Fig. 22. Graphic comparation results of deformation



(a) (b)

Fig. 23. Comparation results; (a) manufacture cost comparation; (b) energy consumption comparation

4. Conclusion

This study provides a study on the application of generative design for improving belt conveyor systems in view of additive manufacturing about structure, weight, and energy consumption. It pointed out from the results that adding generative design coupled with FEM significantly increased efficiency in performance for the conveyor brackets made from Aluminum 6061. Precisely, the paper indicated that the final design was associated with volume reduction by about 86.4%, from an initial volume of 89,317.58mm^2 to as low as 12,172.8mm^2, and with a corresponding mass reduction from 0.198 kg to 0.033kg. It does not only contribute to cost-cutting by using minimal material but also helps save energy when in use.

The test results provided fundamental information on the Equivalent (Von-Mises) Stress and Shear Stress developed in the optimized design, the equivalent stresses have increased with the load from 18.325 MPa at 5 kg to a maximum of 109.95 MPa at 30 kg, which remains quite below aluminum 6061's yield strength of 276 MPa. This means that the bracket can support even the highest tested load without any compromise in the structure and shows how strong the material is and suitable it is for industry use. Like equivalent stress, shear stress material resistance to sliding forces and rising with load started from 10.31 MPa under load of 5 kg, to reach 61.86 MPa at 30 kg. These have consistently remained within safe limits, confirming that the bracket can manage lateral stresses without yielding, something quite important in moving conveyor applications for stability.

Further analysis focused on the whole structure concerning Equivalent Strain (Von-Mises) and Shear Strain. The equivalent strain gives the magnitude of deformation produced in the bracket structure. As the increase in application of load increases, there is a progressive increase in equivalent strain that expresses the material deformation. Recorded equivalent strain as the application of 5 kg load up to 30 kg was 0.00029559 to 0.0017735 mm, respectively. This means that for the structure to deform, it will be under increased loading. Also shear strain showed progressive increase with the increase in applied load as the material would allow lateral or sliding forces. Correspondingly, at 5 kg load, it was 0.00039804 mm and increases to 0.0023882 mm when the load increases to 30 kg. Therefore, it shows that the lateral strain of the material, like equivalent strain, is within control and falls comfortably within acceptable limits of deformation.

The buckling analysis gives the capability of the bracket to resist sudden buckling arising from compressive loading. From the use of ANSYS Eigenvalue Buckling, it could be observed that there are two major buckling modes, with the first mode at 1.0844 mm and the second mode at 1.0523 mm.

Under increasing load, the design remained stable through all applied loads, indicating very high buckling resistance and rather a suitable amount of operational reliability in the conveyor application. The load multiplier defines the amount at which the loads can be multiplied before critical buckling load is achieved. It decreased with an increase in loads. At 5 kg, the first mode was 2085.1, while for 30 kg, it was 347.52. This shows that the bracket will be able to carry very high loads but still retain a large factor of safety due to buckling.

The final calculated safety factor, this safety factor means structure strength compared to intended load requirement. From 13.385 at a load of 5 kg, it reduced to 2.2308 at 30 kg. This safety factor is supposed to mean that throughout, a bracket design is reliably safe to use even for high loads but with an adequate margin against failure, making use of generative design in enhancing performance and safety within conveyor systems.

This research serves to illustrate that generative design coupled with FEM tends to make a big difference in weight and material consumption with no compromise in structural integrity. All the equivalent and shear strains remained within the allowable for all the applied loads continuously, hence proving the strength and suitability of the material for the intended industrial conveyor applications. The values of equivalent and shear stresses were very small compared to the yield strength; thus, it was verified that the optimized bracket can support high loads without failure. Buckling factor suggests the strength of a design that is able to sustain high compressive load without exhibiting instability. Similarly, with a safety factor always greater than the limit, the optimized design for brackets ensures better energy efficiency, material saving, and structural reliability, serving as one of the best solutions for industrial sustainable conveyor systems.

Results from the research also show that generative design in combination with additive manufacturing, especially by SLM, increases efficiency significantly in cost and energy consumption when compared to traditional techniques of manufacture and other design methodologies void of generation. The manufacturing cost was drastically cut down to $18.3, as opposed to $47.05 for the pre-generative design using CNC milling and $32.37 for the conventional bracket design. Energy consumption was also reduced to 0.42 kW from the pre-generative design of 0.73 kW and from the conventional design at 0.59 kW. Again, this asserts the value of generative design and additive manufacturing regarding material efficiency and optimization of resources, making them more sustainable and economically viable.

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References

[1] Permana, Adrian, Humiras Hardi Purba, and Nyimas Desy Rizkiyah. "A systematic literature review of Total Quality Management (TQM) implementation in the organization." *International Journal of Production Management and Engineering* 9, no. 1 (2021): 25-36. https://doi.org/10.4995/ijpme.2021.13765.

[2] Dhutekar, Prashant, Girish Mehta, Jayant Modak, Sagar Shelare, and Pramod Belkhode. "Establishment of mathematical model for minimization of human energy in a plastic moulding operation." *Materials Today: Proceedings* 47 (2021): 4502-4507. https://doi.org/10.1016/j.matpr.2021.05.330.

[3] Litvinenko, V. S. "Digital Economy as a Factor in the Technological Development of the Mineral Sector." *Natural Resources Research* 29, no. 3 (2019): 1521–41. https://doi.org/10.1007/s11053-019-09568-4.

[4] Buniya, Mohanad K., Idris Othman, Riza Yosia Sunindijo, Ahmed Farouk Kineber, Eveline Mussi, and Hayroman Ahmad. "Barriers to Safety Program Implementation in the Construction Industry." *Ain Shams Engineering Journal* 12, no. 1 (2020): 65–72. https://doi.org/10.1016/j.asej.2020.08.002.

[5] De Oliveira, Rui Torres, Morteza Ghobakhloo, and Sandra Figueira. "Industry 4.0 Towards Social and Environmental Sustainability in Multinationals: Enabling Circular Economy, Organizational Social Practices, and Corporate Purpose." *Journal of Cleaner Production* 430 (2023): 139712. https://doi.org/10.1016/j.jclepro.2023.139712.

[6] Waghmare, S. N., Sagar D. Shelare, C. K. Tembhurkar, and S. B. Jawalekar. "Development of a Model for the Number of Bends During Stirrup Making Process." In *Lecture Notes in Mechanical Engineering*, 69–78, 2020. https://doi.org/10.1007/978-981-15-5151-2_7.

[7] Shelare, Sagar, Ravinder Kumar, Trupti Gajbhiye, and Sumit Kanchan. "Role of Geothermal Energy in Sustainable Water Desalination—A Review on Current Status, Parameters, and Challenges." *Energies* 16, no. 6 (2023): 2901. https://doi.org/10.3390/en16062901.

[8] Yu, Zhang, Asif Razzaq, Abdul Rehman, Adeel Shah, Kiran Jameel, and Rahul S Mor. "Disruption in Global Supply Chain and Socio-economic Shocks: A Lesson From COVID-19 for Sustainable Production and Consumption." *Operations Management Research* 15, no. 1–2 (2021): 233–48. https://doi.org/10.1007/s12063-021-00179-y.

[9] Rathi, Rajeev, Chander Prakash, Sunpreet Singh, Grzegorz Krolczyk, and Catalin I. Pruncu. "Measurement and Analysis of Wind Energy Potential Using Fuzzy Based Hybrid MADM Approach." *Energy Reports* 6 (2020): 228–37. https://doi.org/10.1016/j.egyr.2019.12.026.

[10] Perkumienė, Dalia, Kristina Ratautaitė, and Rasa Pranskūnienė. "Innovative Solutions and Challenges for the Improvement of Storage Processes." *Sustainability* 14, no. 17 (2022): 10616. https://doi.org/10.3390/su141710616.

[11] Ramteke, Amrapali L., Shubash N. Waghmare, Sagar D. Shelare, and Piyush M. Sirsat. "Development of Sheet Metal Die by Using CAD and Simulation Technology to Improvement of Quality." In *Lecture Notes on Multidisciplinary Industrial Engineering*, 687–701, 2021. https://doi.org/10.1007/978-3-030-73495-4_47.

[12] Zhang, Mengchao, Hao Shi, Yan Yu, and Manshan Zhou. "A Computer Vision Based Conveyor Deviation Detection System." *Applied Sciences* 10, no. 7 (2020): 2402. https://doi.org/10.3390/app10072402.

[13] Homišin, Jaroslav, Robert Grega, Peter Kaššay, Gabriel Fedorko, and Vieroslav Molnár. "Removal of Systematic Failure of Belt Conveyor Drive by Reducing Vibrations." *Engineering Failure Analysis* 99 (2019): 192–202. https://doi.org/10.1016/j.engfailanal.2019.02.028.

[14] Zhang, Mengchao, Hao Shi, Yuan Zhang, Yan Yu, and Manshan Zhou. "Deep Learning-based Damage Detection of Mining Conveyor Belt." *Measurement* 175 (2021): 109130. https://doi.org/10.1016/j.measurement.2021.109130.

[15] Carr, Michael J., Craig A. Wheeler, Peter W. Robinson, and Bin Chen. "Reducing the Energy Intensity of Overland Conveying Using a Novel Rail-running Conveyor System." *International Journal of Mining Reclamation and Environment* 35, no. 3 (2020): 183–98. https://doi.org/10.1080/17480930.2020.1788199.

[16] Yao, Yanping, and Bisheng Zhang. "Influence of the Elastic Modulus of a Conveyor Belt on the Power Allocation of Multi-drive Conveyors." *PLoS ONE* 15, no. 7 (2020): e0235768. https://doi.org/10.1371/journal.pone.0235768.

[17] Zhang, Dongyue, Yuan Zhang, Yanbo Yue, Manshan Zhou, Chao Yuan, and Chenming Li. "Optimal Design of Robust Control for Belt Conveyor Systems Based on Fuzzy Dynamic Model and Nash Game." *Journal of the Franklin Institute* 361, no. 11 (2024): 106925. https://doi.org/10.1016/j.jfranklin.2024.106925.

[18] Bajda, Mirosław, Monika Hardygóra, and Daniela Marasová. "Energy Efficiency of Conveyor Belts in Raw Materials Industry." *Energies* 15, no. 9 (2022): 3080. https://doi.org/10.3390/en15093080.

[19] Mu, Yunfei, Taiang Yao, Hongjie Jia, Xiaodan Yu, Bo Zhao, Xuesong Zhang, Chouwei Ni, and Lijia Du. "Optimal Scheduling Method for Belt Conveyor System in Coal Mine Considering Silo Virtual Energy Storage." *Applied Energy* 275 (2020): 115368. https://doi.org/10.1016/j.apenergy.2020.115368.

[20] Tsunazawa, Yuki, Yoshihiro Kosaku, Ryuto Kamo, Ryo Miyazawa, Yoshiaki Nishina, and Chiharu Tokoro. "DEM Study on Investigation of Wet Particle Conveying Efficiency in an Inclined Belt Conveyor System." *Advanced Powder Technology* 35, no. 7 (2024): 104555. https://doi.org/10.1016/j.apt.2024.104555.

[21] Kookalani, Soheila, Erika Parn, Ioannis Brilakis, Samir Dirar, Marios Theofanous, Asaad Faramarzi, Mohammad Ali Mahdavipour, and Qixian Feng. "Trajectory of building and structural design automation from generative design towards the integration of deep generative models and optimization: A review." *Journal of Building Engineering* 97 (2024): 1–35. https://doi.org/10.1016/j.jobe.2024.110972.

[22] Kallioras, Nikos Ath., and Nikos D. Lagaros. "DzAIℕ: Deep Learning Based Generative Design." *Procedia Manufacturing* 44 (2020): 591–98. https://doi.org/10.1016/j.promfg.2020.02.251.

[23] Marinov, Martin, Marco Amagliani, Tristan Barback, Jean Flower, Stephen Barley, Suguru Furuta, Peter Charrot, et al. "Generative Design Conversion to Editable and Watertight Boundary Representation." *Computer-Aided Design* 115 (2019): 194–205. https://doi.org/10.1016/j.cad.2019.05.016.

[24] Krish, Sivam. "A Practical Generative Design Method." *Computer-Aided Design* 43, no. 1 (2010): 88–100. https://doi.org/10.1016/j.cad.2010.09.009.

[25] Aage, Niels, Erik Andreassen, Boyan S. Lazarov, and Ole Sigmund. "Giga-voxel Computational Morphogenesis for Structural Design." *Nature* 550, no. 7674 (2017): 84–86. https://doi.org/10.1038/nature23911.

[26] Pilagatti, Adriano Nicola, Giuseppe Vecchi, Eleonora Atzeni, Luca Iuliano, and Alessandro Salmi. "Generative Design and New Designers' Role in the Manufacturing Industry." *Procedia CIRP* 112 (2022): 364–69. https://doi.org/10.1016/j.procir.2022.09.010.

[27] Junk, Stefan, and Nils Rothe. "Lightweight Design of Automotive Components Using Generative Design With Fiber-reinforced Additive Manufacturing." *Procedia CIRP* 109 (2022): 119–24. https://doi.org/10.1016/j.procir.2022.05.224.

[28] Hartomacioğlu, Selim, Ersin Kaya, Beril Eker, Salih Dağlı, and Murat Sarıkaya. "Characterization, Generative Design, and Fabrication of a Carbon Fiber-Reinforced Industrial Robot Gripper via Additive Manufacturing." *Journal of Materials Research and Technology*, October 1, 2024. https://doi.org/10.1016/j.jmrt.2024.10.064.

[29] Sussman, Theodore, and Klaus-Jürgen Bathe. "Spurious Modes in Geometrically Nonlinear Small Displacement Finite Elements With Incompatible Modes." *Computers & Structures* 140 (2014): 14–22. https://doi.org/10.1016/j.compstruc.2014.04.004.

[30] Fries, Thomas-Peter, and Ted Belytschko. "The Extended/Generalized Finite Element Method: An Overview of the Method and Its Applications." *International Journal for Numerical Methods in Engineering* 84, no. 3 (2010): 253–304. https://doi.org/10.1002/nme.2914.

[31] Wang, H., W. Du, Y. Zhao, Y. Wang, R. Hao, and M. Yang. "Joints for Treelike Column Structures Based on Generative Design and Additive Manufacturing." *Journal of Constructional Steel Research* 184 (2021): 106794. https://doi.org/10.1016/j.jcsr.2021.106794.

[32] Lin, Penghui, Limao Zhang, and Robert L.K. Tiong. "Multi-objective Optimization Ensembled Generative Design for Large-diameter Tunnel Passing Underneath Existing Tunnels." *Applied Soft Computing* 144 (2023): 110448. https://doi.org/10.1016/j.asoc.2023.110448.

[33] Zhang, Ming-Yuan, Hai-Dong Zhu, and Wei Zhang. "Finite Element Analysis of Belt Conveyor Bracket." *Journal of Physics Conference Series* 1748, no. 6 (2021): 062047. https://doi.org/10.1088/1742-6596/1748/6/062047.

[34] Hrabovský, Leopold, Daniel Kurač, Štěpán Pravda, Eliška Nováková, and Tomáš Machálek. "Measuring Device Detecting Impact Forces on Impact Rollers." *Processes* 12, no. 5 (2024): 850. https://doi.org/10.3390/pr12050850.

[35] Hemenkumar H. Thakar. "Performance Optimization and Investigation of Metal-cored Filler Wires for High-strength Steel During Gas Metal Arc Welding." *High Temperature Materials and Processes* 42, no. 1 (2023). https://doi.org/10.1515/htmp-2022-0305.

[36] Budinoff, Hannah D., Sara McMains, and Sara Shonkwiler. "Exploring the Impact of Design Tool Usage on Design for Additive Manufacturing Processes and Outcomes." *Design Science* 10 (2024). https://doi.org/10.1017/dsj.2023.34

[37] Mohammad Awwad, "Studying the Effects of Roads Geometry and Design Parameters on the Pavement Drainage System," *Civil Engineering Journal* 7, no. 1 (2021): 49–58, https://doi.org/10.28991/cej-2021-03091636.

[38] Zheng, Tianqi, Changyu Ma, Alexander Killips, Bingbing Li, and Xiaochun Li. "Nanoparticle-enabled Additive Manufacturing of High Strength 6061 Aluminum Alloy via Laser Powder Bed Fusion." Manufacturing Letters 41 (2024): 753–57. https://doi.org/10.1016/j.mfglet.2024.09.093.

[39] Yang Hong "Designing Spongy-bone-like Cellular Materials: Matched Topology and Anisotropy." *International Journal of Mechanical Sciences*, (2024), 109788. https://doi.org/10.1016/j.ijmecsci.2024.109788.

[40] Jun Wang "IH-GAN: A Conditional Generative Model for Implicit Surface-based Inverse Design of Cellular Structures." *Computer Methods in Applied Mechanics and Engineering* 396 (2022): 115060. https://doi.org/10.1016/j.cma.2022.115060.

[41] Hrabovský, Leopold, Eliška Nováková, Štěpán Pravda, Daniel Kurač, and Tomáš Machálek. "The Reduction of Rotating Conveyor Roller Vibrations via the Use of Plastic Brackets." *Machines* 11, no. 12 (2023): 1070. https://doi.org/10.3390/machines11121070.

[42] Feng, Zhaohui, Hua Zhang, Wei Li, Yajian Yu, Youjia Guan, and Xinru Ding. "Exergy Loss Assessment Method for CNC Milling System Considering the Energy Consumption of the Operator." *Processes* 11, no. 9 (September 9, 2023): 2702. https://doi.org/10.3390/pr11092702.

[43] Zhu, Chengcheng, Xiaoming Chen, Honglin Wu, Jun Zhu, Tao Peng, Jingxiang Lv, and Yihang Wu. "Multi-Objective Optimization of Selective Laser Melting Processes for Minimizing Energy Consumption and Maximizing Product Tensile Strength." *Metals* 12, no. 11 (October 23, 2022): 1782. https://doi.org/10.3390/met12111782.

[44] Zahedi, Zahedi, A. N. T. O. N. Kamil, Irvan Irvan, Jelita Jelita, Harahap Amin, Affandi Marwan, and Sarmin Suparni. "Some Applications of Cubic Equations in Engineering." *Mathematical Modelling of Engineering Problems* 9, no. 1 (2022). https://doi.org/10.18280/mmep.090116

[45] Yuanyuan Ding and Shilon Wang ., "Density-graded Voronoi Honeycombs – a Local Transversely Isotropic Description." *International Journal of Solids and Structures* 285 (2023): 112555, https://doi.org/10.1016/j.ijsolstr.2023.112555.

[46] Liu, Hongbo, Zhifeng Yang, Ting Zhou, Longxuan Wang, and Zhihua Chen. "Study on Updating Finite Element Model of Steel Truss Structure Based on Knowledge-enhanced Deep Reinforcement Learning." *Engineering Structures* 316 (2024): 118576. https://doi.org/10.1016/j.engstruct.2024.118576.

[47] Callister Jr, William D., and David G. Rethwisch. *Fundamentals of materials science and engineering: an integrated approach*. John Wiley & Sons, 2020.

[48] S. Wang and C.M. Harvey., "Post-local Buckling-driven Delamination in Bilayer Composite Beams." *Composite Structures* 133 (2015): 1058–66, https://doi.org/10.1016/j.compstruct.2015.08.012.

[49] Patrascu, M., and S. Stramigioli. "Modeling and Simulating the Stick–slip Motion of the µWalker, a MEMS-based Device for µSPAM." *Microsystem Technologies* 13, no. 2 (2006): 181–88. https://doi.org/10.1007/s00542-006-0161-8.

[50] Lin Mu, Hu Zhang, and Jiale Cui ., "Numerical Study of Transient Supercooling Performance and Thermal Stress Analysis of Segmented Annular Thermoelectric Cooler." *Applied Thermal Engineering* 245 (2024): 122804. https://doi.org/10.1016/j.applthermaleng.2024.122804.

[51] Rahmi, Diah Puspita, Robert Fleischhauer, and Michael Kaliske. "A Displacement-driven Approach to Frictional Contact Mechanics." *International Journal for Numerical Methods in Engineering* 124, no. 24 (2023): 5471–5503. https://doi.org/10.1002/nme.7353.

[52] Zhu, Chengcheng, Xiaoming Chen, Honglin Wu, Jun Zhu, Tao Peng, Jingxiang Lv, and Yihang Wu. "Multi-Objective Optimization of Selective Laser Melting Processes for Minimizing Energy Consumption and Maximizing Product Tensile Strength." *Metals* 12, no. 11 (2022): 1782. https://doi.org/10.3390/met12111782.