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Employing topology optimization method to create optimum telecommunication tower design structure

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Abstract
Recently, the employment of topology optimization (TO) in structural engineering design has gained a significant structural performance, also, TO is employed by designers for developing aesthetically and efficient buildings. In this work, TO is employed to design novel and rigged structures of communication towers. The way that the TO algorithm works is to intelligently create the 3D model by preserving architectural features with tradeoffs between the stiffness and weight ratio. The present work focuses on the investigation of creating optimal self-supported communication towers. Results concerning the prime observation of optimization analyses and the potential benefits of TO in designing telecommunication tower lattices are drawn.

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Keywords: Telecommunication structure, Topology optimization, Finite elements (FEM)

1. Introduction

Modernization and essential upgrades of the current telecommunication tours network continue to take place as the communication sector growth is sustained by the public's ongoing craving for new and improved services, as well as for replacements and better infrastructure. This calls for the creation of cutting-edge equipment that can be installed on substantial lattice structures for communication and broadcasting. In contrast to them, it involves antennas and dish-reflectors that are varied in size, shape, and weight. Developed technologies are now installed on the towers that already exist, albeit at variant heights than before, altering the possibilities for load carrying in the design and, Consequently, the functionalities of each structural element individually, occasionally with an uneven force distribution inside the skeleton of the structures [1]. Additionally, new technology increases the towers' surface area and solidity, which intensifies wind drag. However, it is important to emphasize that current towers for telecommunication have not been sufficiently engineered to withstand such increased lateral and gravitational stresses. As a result, it's likely that current towers with recently added apparatus sustain damage or possibly fall apart since they can't support the new, increased forces.

The study presented by [2] argued that both the social and financial ramifications of the collapse of such constructions can be viewed as being just as detrimental as those occurring from bridge collapses or other similar infrastructure failures. Therefore, it is sometimes thought necessary to build new towers and repair or completely

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replace the outdated lattice towers in order to improve and modernize the current broadcasting services [3]. It is also extremely possible that these tall, flexible constructions may sustain fatigue damage because they are frequently subjected to changing loads brought on by dynamic wind forces. It may be necessary to replace aging telecommunications masts and towers that have fatigue damage [4].

In general, there has been an increase in demand for large lattice telecommunication tower and mast installations worldwide. Guyed masts and self-supporting lattice structures entered a bright new age as a result of the mobile telecommunications industry's explosive growth. Andersen [5] explains that a certain sort of towers was developed for Connect Austria in a short amount of time to give you an idea of the impact the telecom business has on the installation of new towers or masts. This significant demand for the construction of new buildings necessitates building licenses, which are exceedingly challenging to get if the concerned structure's aesthetic value is insufficient [6]. Additionally, the growing number of masts and towers may obstruct the view of the surrounding area, making the procedure of obtaining a building permit much more challenging [7].

Given this, it is regrettable that skyscrapers with greater solidity stand out even more, which is clearly to their detriment in terms of aesthetics. As a result, it is necessary to create lattice telecommunication towers that can meet all structural requirements and practical utility criteria while also having an enhanced architectural appearance and reduced solidity. Through an innovative computational TO technique, the aim of this work is to create a configuration for a lattice telecom tower that meets the aforementioned conditions. TO is a computational method employed to find the best possible distribution of materials in a particular design space, subject to specified constraints and performance criteria. This innovative design approach has revolutionized the fields of engineering and materials science by enabling the creation of highly efficient and lightweight structures that were previously unattainable through traditional design methods [8–12]. By iteratively adjusting the material layout, topology optimization can address complex challenges such as weight reduction, structural integrity, and cost efficiency [10, 13–16]. This method leverages advanced algorithms and high-performance computing to explore a vast design space, uncovering novel configurations that maximize performance while minimizing resource use.

Consequently, topology optimization has become instrumental in solving challenging problems across various domains, including aerospace, automotive, civil engineering, and biomechanics, fostering advancements in sustainable and high-performance engineering solutions. Topology optimization methods encompass a range of computational techniques designed to best distribute materials inside a specific design area. These methods typically involve the use of numerical methods to simulate and evaluate the structural performance of different configurations. Common approaches include density-based methods, where material density is varied across the design domain; level-set methods, which evolve the shape boundaries through implicit functions; and evolutionary algorithms, which mimic natural selection processes to iteratively improve design candidates. These methods facilitate the creation of innovative and efficient designs, enabling significant advancements in engineering applications by optimizing structures for strength, weight, and other performance criteria. Topology optimization involves several methods, including solid isotropic material with penalization (SIMP) [17–19], Evolutionary Structural Optimization (ESO) [20–22], Metaheuristic Structural Binary-Distribution Method (MSB) [15,23,24], and the H1 Gradient Method [25]. In this research, we are implementing the SIMP method for our design methodology.

2. Previous work

Since 1971, Beck [26] described the possible role that computers could play in tower design, there has been interest in applying computational techniques to improve tower lattice design. This vision has partially come to fruition, as there are now several commercial software programs available to assist with the geometrical and structural design of tower steel structures. These programs include optimization of tower spotting, which involves positioning of towers, and selection of member sections for specific towers. Picard et al. [27] use an expert system technique to construct a system for a preliminary design that predicts line costs of alternatives based on electrical and environmental concerns as well as costs of steel towers, whereas most commercial programs concentrate on detail design.

Steel tower design has also benefited from the use of computer-aided methods. For example, a blackboard architecture knowledge system that combines communication and structural knowledge, as well as common design practices, has been developed [28]. Given the site and the structural and communication requirements, conventional tower designs are developed based on well-known configuration types. Rudolph et al. [29] present a rule-based system that uses genetic programming to generate novel tower configurations; practical design limitations are excluded, and structural analysis is not carried out. The section sizes and form junction positions of steel lattice towers have been optimized through studies to improve the design of the towers themselves. In the work presented by [30], an object-oriented strategy utilizing evolutionary algorithms has been utilized to enhance optimization outcomes for a tower with 85 discrete size variables while taking a number of practical restrictions into account. A technique for optimizing a small number of crucial shape control variables that affect tower designs is presented by [31] using fuzzy logic inside structural optimization to describe uncertainty connected to constraint bounds. Additionally, a minimum mass radio tower design that is modeled using five continuous shape variables and seventeen discrete size variables has been investigated utilizing a parallel evolution optimization technique [32]. A parallel approach has been utilized to optimize towers with up to 77 sizes and form variations by modeling a broader set of design factors. An examination of the dependability of steel lattice towers has focused on optimizing the structure for both maximum reliability index and minimum mass. Additionally, research has been done to maximize lattice towers' dynamic response to loads from earthquakes and winds [33].

Currently, continuous or discrete representations are used for structural layout. Continuous approaches are useful for the designing of monolithic parts since they discretize a defined space of material and optimize its distribution.

3. Method

3.1. Concept of topology optimization

The finite element method (FEM) is used to optimize discretized structures. There is a single design variable associated with every finite element that is part of the optimization, and these design variables are gathered in a vector x and are scale factors of the elemental attributes. Although the literature frequently interprets the design variables—such as thickness, porosity, or describing a composite material—in different ways, we prefer to think of them as mathematical scale factors devoid of any physical meaning. There is no requirement for a physical interpretation of the intermediate design variable values because the optimization aims for a final design where the scale factor is either zero or one. How such final designs are accomplished is explained in Section 4. Section 3 explains how the design variables x are filtered and how they relate to the variables ρ, i.e. ρ = ρ(x). The latter variables, which specify stiffness and are included in the mass computation, will be referred to as the filtered variables and are regarded as physical variables. For a given design ρ(x), the equilibrium equation becomes:

$$K\big(\rho(x)\big)u = F \ldots \text{(1)}$$

Where u is the vector of global nodal displacements, F is a vector of known external loads, and $K\big(\rho(x)\big)$is the structure's global stiffness matrix.

3.2. Formulations of problems

In this section, a method for applying TO for lattice structure design will be briefly discussed. If we consider the design challenge of minimizing or maximizing objective functions to find the boundary of the design domainξ_d. The introduction of a fixed, extended design domain R that comprises the original design domain ξ_d

is the central concept of the topology optimization approach. The utilization of the following characteristic functions, such concepts are introduced in several publications [34, 35].

$$y_{\zeta}(x) = \begin{cases} 1\, if\ \ x\ \in\ \xi_d \\ 0\, if\ x\ \in\ D \backslash \xi_d \end{cases} \ldots\ldots\ldots (2)$$

Where x represents the specific point position in the design domain. When designing steel structures, the original structural design problem is swapped out for a material distribution problem that takes relative Young's modulus (E_0,) into account. Given that this characteristic function can be extremely discontinuous, meaning it lies in $L^{\infty}D$, the numerical treatment will require the introduction of a regularization or smoothing technique. By incorporating microstructures that represent the composite material, a homogenization method [36] has been employed to perform the relaxing of the solution space in the structural design problems. As an alternative, solid mechanics problems have also employed the density approach, often known as the SIMP method (Solid Isotropic Material with Penalization) [37-51]. Using a hypothetical isotropic material whose elasticity tensor is thought to be a function of penalized and normalized material density, which is given by an exponent parameter, is the fundamental principle behind the density approach. The relaxation in this study is carried out using the density strategy idea. In other words, the artificial density, ρ_{design}, which serves as a control variable in the optimization problem, and the genuine Young's modulus, E_0, are thought to be the functions that determine the stress tensor:

$$E(x) = \rho_{design}(x)^p E_0 \quad \ldots\ldots\ldots\ldots.. (3)$$

$$x \in \mathrm{D}$$

Where ρ is the normalized density meets the following conditions:

$$0 < \rho < 1 \quad \ldots\ldots. (4)$$

And p represents the penalization factor. The link between the normalized density and the physical parameters is used to determine this penalization parameter. Since the relationship between the material property and the goal function is monotonic, setting p bigger than 1, for example to 2 or 3, tends to promote design variables to either 0 or 1. This is especially true for static solid mechanics problems like minimizing the mean compliance. As previously explained in the SIMP approach, the density, ρ_{design}, which serves as a control variable in the optimization problem, and the genuine Young's modulus is regarded to be a functions of the stress tensor see Equation 3. Given that the stiffness cannot entirely disappear in any part of the model due to numerical constraints, the density parameter is limited so that $10^{-9} \leq \rho^p \leq 1$. Because of the penalty factor, exponent p ≥ 1, intermediate densities offer reduced stiffness relative to their weight cost. When any design that is deemed acceptable has a minimum level of stiffness, which can be represented similarly as a maximum amount of total strain energy:

$$0 \leq \int_{\Omega} w_s(x) d\Omega \leq w_s^{max} \quad \ldots\ldots\ldots (5)$$

Where w_s: strain energy

The SIMP penalization pushes design in one of two directions. Thus, increasing p results in a more precise solution. As calculated for the entirely solid architecture in Figure 1, the maximum strain energy w_s^{max} readily stated as a factor times the lowest feasible strain energy. The optimization challenge can be conceptualized as merely minimizing the amount of material used, which is expressed as the solid fraction of the original design domain:

$$\frac{1}{A} \int_{\Omega} \rho_{design}(x) d\Omega \ldots\ldots. (6)$$

Where A is the area of the designed domain, without going against the constraint on rigidity in Equation 5. On the other hand, excessive fine detail in the solution might undermine the final design's dependability.

Additionally, the solution should be as independent of the mesh resolution as feasible. In order to do this, some form of regularization is required. Based on a series of mesh revisions and a penalty imposed on the gradient of the design variable, this regularization is among the simplest to apply. The gradient of the design variable's integral of its squared norm in a way, design measures all of the design variables' variations combined. The amplitude of the gradient for a sharp topology solution represented by linear shape functions is inversely related to the size of the mesh elements. The area of the zone of intermediate densities is proportionate to the size of the mesh element because it is simultaneously one element thick. Consequently, a reasonable mesh- and problem-independent penalty term has the form:

$$\frac{l_0\, l_{max}}{A}\int_{\Omega} |\, \rho_{design}(x)|^2 d\Omega$$

Where l_{max} is the current mesh size at a specific stage of the process and l_0 is the beginning mesh size that determines the size of details in the solution.

In the worst-case scenario, this penalty term is dimensionless and on the order of 1. To produce a final composite objective function, the penalty term and the existing dimensionless objective, Equation 6, must be balanced against one another, maybe as a linear combination controlled by a parameter, q:

$$F= \frac{1-N}{A}\int_{\Omega} \rho_{design}(x) d\Omega + N\frac{l_0\, l_{max}}{A}\int_{\Omega} |\, \rho_{design}(x)|^2 d\Omega$$

This is the final objective function that controls the overall design domain.

4. Formulation of FEM

These kinds of problems are essentially mesh-size dependent in the absence of regularization.
It was necessary to create a preliminary free triangular mesh for this model with a maximum element size of 15 mm. The mesh depicted in Figure 2 is relatively coarse and serves to restrict the least size of details that can be included in the topology solution. Proper scaling of the regularization term ensures that the updated solution maintains the same topology, only honing the details when the mesh is later refined and the optimization solver is resumed on the finer mesh.

5. Results

5.1. Top load design domain

Consider that you are creating a lattice tower that has to support a given load that is shifted to the top and down from its anchoring. You start with a completely solid building, similar to Figure 1.

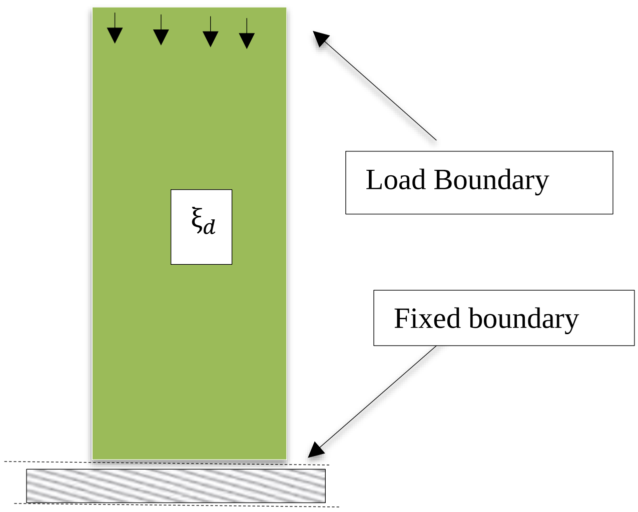


Figure 1. Structure's geometry under loads and constraints

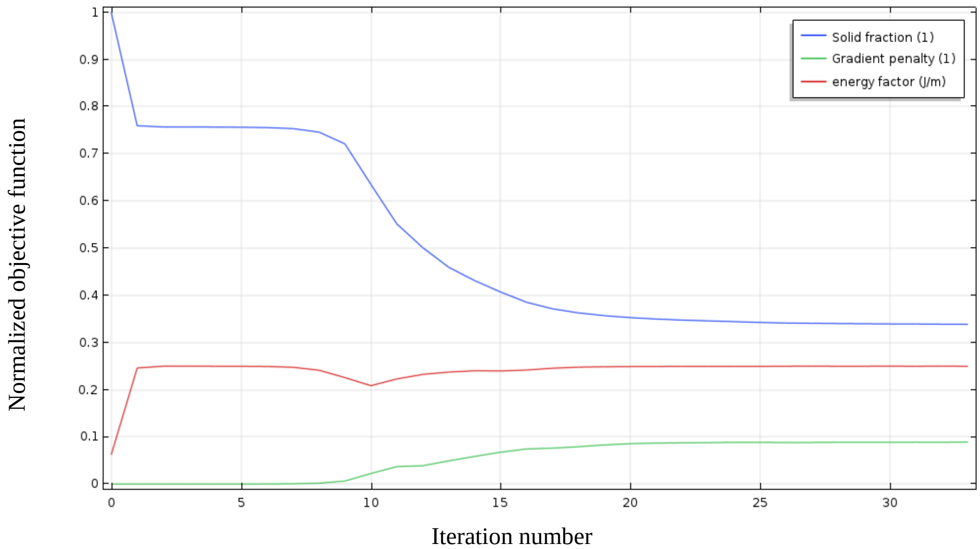
It is obvious that this design is overly complex and inefficient with materials. Stresses are unevenly distributed, as a direct simulation demonstrates, thus some parts bear noticeably less strain than others. It is tempting to eliminate some material in order to save weight and cost, provided that the stiffness of the part may be decreased to, say, 40% of the value estimated from the fully solid design without breaking the specification. However, how much material is required at the very least, and how should it be distributed that is the equation we try to answer in this work. This paper shows how to optimize structural topology using the Solid Isotropic Material with Penalization (SIMP) model. It should be noted that this example lowers the weight for a specified minimum stiffness rather than optimizing stiffness for a specified maximum weight, which is not how SIMP is often employed. The initial tower-like-shaped form defines the boundaries of the region that may include solid material see Figure 1. As seen in the illustration, the lowermost boundary of the structure is fixed, whereas the highest boundary is load-carried. The row material from which the construction was formed has the characteristics listed in Table 1.

Table 1. The properties of row material used in the experiments

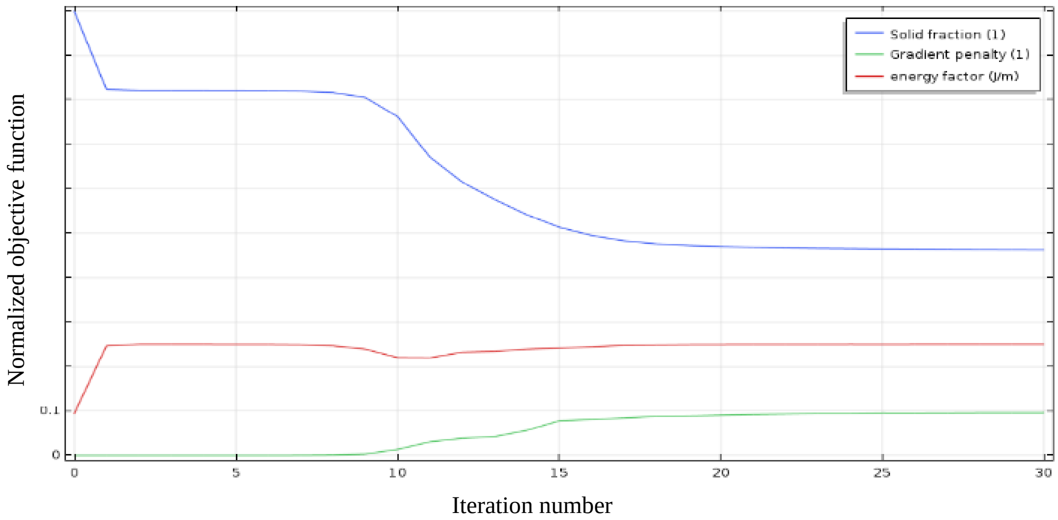
N	Property	Value	Unit
1	Density	7850	Kg/m^2
2	Poisson’s ratio	0.3	1
3	Relative permeability	1	
4	Heat capacity at constant pressure	475	J/(kg.K)
5	Thermal conductivity	44.5	W/(m.K)
6	Electrical conductivity	$4.032*10^6$	S/m
7	Relative permittivity	1	
8	Coefficient of thermal expansion	$12.3*10^{-6}$	1/K
9	Young’s modulus	$200*10^9$	Pa

5.2. Numerical implementation

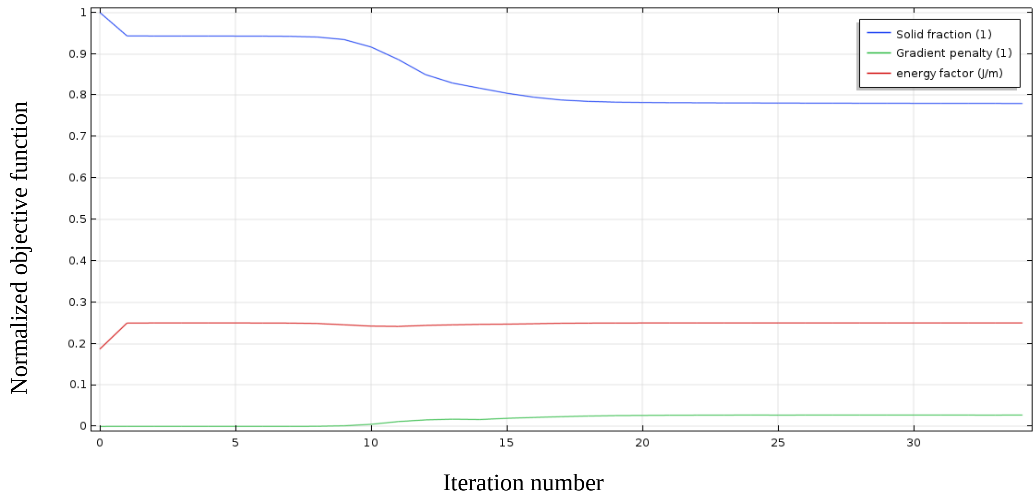
The rectangle closed box filled with row martial is considered as shown in Figure 1. To assess and explore the influence of the self-load effect on the acquired outcomes, three distinct applied loads are explored. The experiment was carried out on a Core i9 laptop on COMSOL version 6.1a. To accurately assess the final design, three different scenarios of applied load are considered. The characteristics including sold fraction, gradient penalty, and energy factor of the optimization analysis are summarized in Figure 2.



(a)



(b)

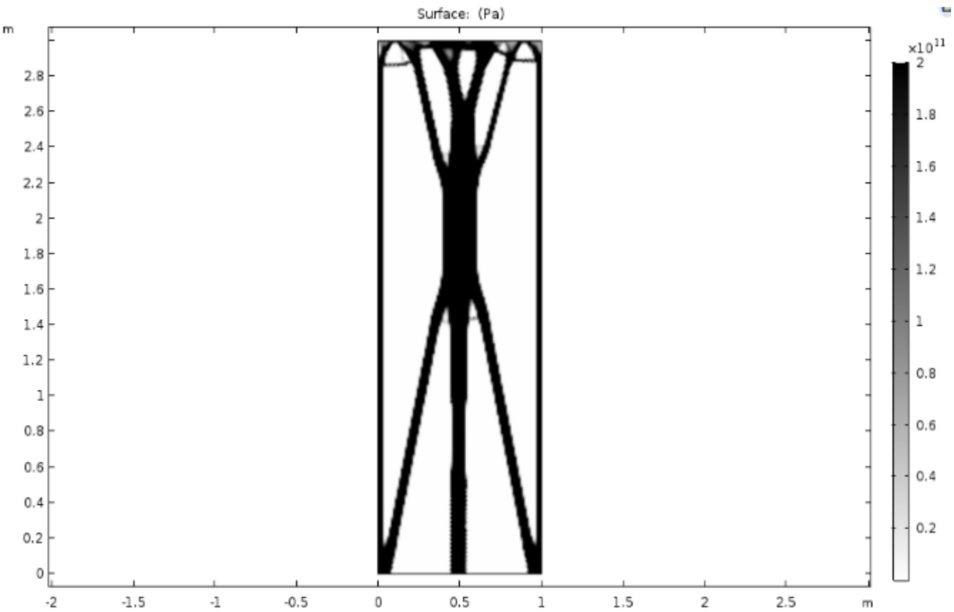


(c)

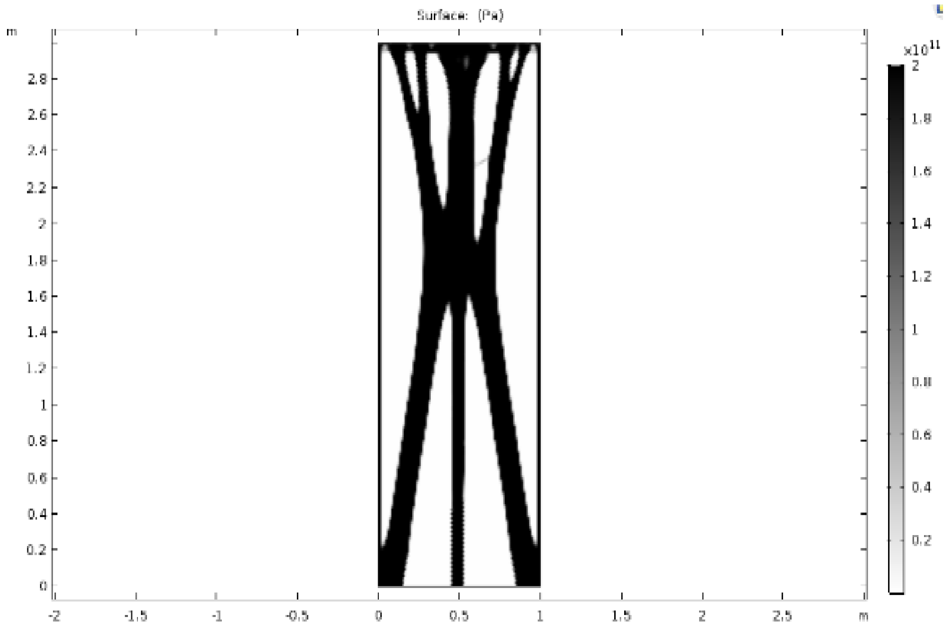
Figure 2. The characteristics including sold fraction, gradient penalty and energy with different applied load (a) self-load (b) medium load (c) high load

The topology output of the domain is made up of successive "high-waisted" bracings closer to the middle of the tower's face, as the results shown in Figure 3, this is because bending and shear forces are coupled. The instigation of optimum shape with respect to our hypothesis is accepted where with the lowest load the result shows less material in Figure 3(a) without violating the stiffness curve in Figure 2(a). So, topology optimization data often involve analyzing the behavior and performance of various design variables over iterative processes to achieve an optimal structure. The provided graph depicts three key variables—solid fraction (f1), gradient penalty (l2), and energy factor (J/m)—plotted against iteration number. Initially, the solid fraction (blue line) sharply decreases from near 1, stabilizing around 0.8, indicating substantial early adjustments followed by convergence. The gradient penalty (red line) starts just above 0.2, displaying minor fluctuations but remains largely stable, showing insensitivity to iterative changes. The energy factor (green line) remains nearly constant, slightly below 0.4, throughout the iterations, suggesting negligible impact from the iterative process. This convergence behavior is crucial for material science and engineering researchers, providing insights into the stability and efficiency of the optimization process.

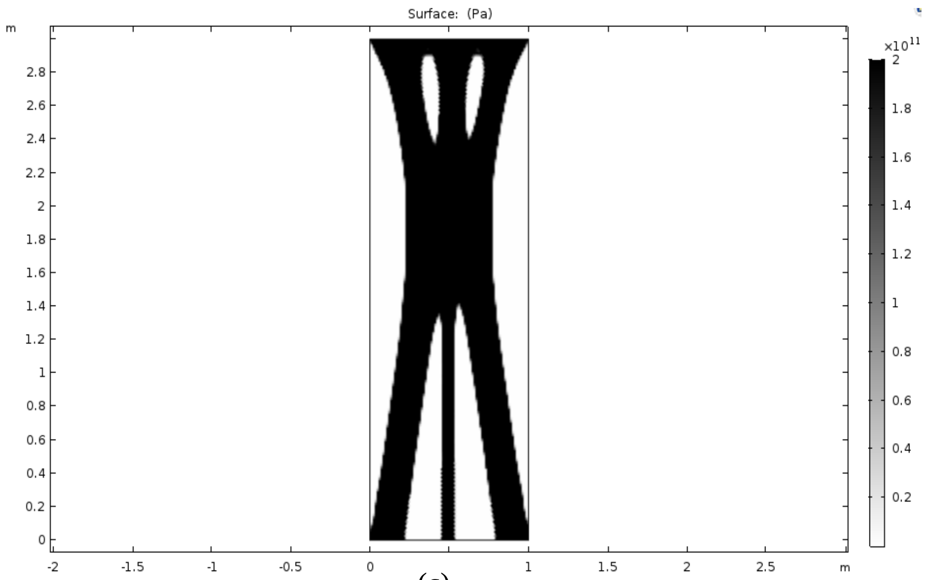
While as load increases the output shows thick optimum topology Figure 3(b) and Figure 3(c) also without the violet stiffness curve in Figure 2(b) and Figure 2(c). In Figure 2(b), the graph illustrates the convergence behavior of three critical variables—solid fraction (f1), gradient penalty (l2), and energy factor (J/m)—plotted against iteration number during a topology optimization process. The solid fraction (blue line) starts near unity, exhibiting a steep decline in the initial iterations before stabilizing around 0.8, indicative of significant early changes followed by convergence. The gradient penalty (red line) commences slightly above 0.2, maintaining relative constancy with minor fluctuations throughout the iterations, suggesting minimal sensitivity to iterative changes. The energy factor (green line) remains nearly constant just below 0.4, indicating its insensitivity to the iterative process. This analysis provides valuable insights into the dynamic adjustment and stabilization of these variables, pertinent to researchers in materials science and engineering engaged in optimization studies. Additionally, the material is less dense at the top and bottom, signifying a shift in the tower's cross-section size from the bottom to the top. This idea has previously been used in the design of tall structures and traditional lattice communications towers.



(a)



(b)



(c)

Figure 3. The output optimum result by the applied load on the top design domain with different load scenarios (a) self-load (b) medium load (c) high load

In the next load scenario, a force is applied on the design domain from left toward the positive x direction as shown in Figure 4 in the top and left side load design domain.

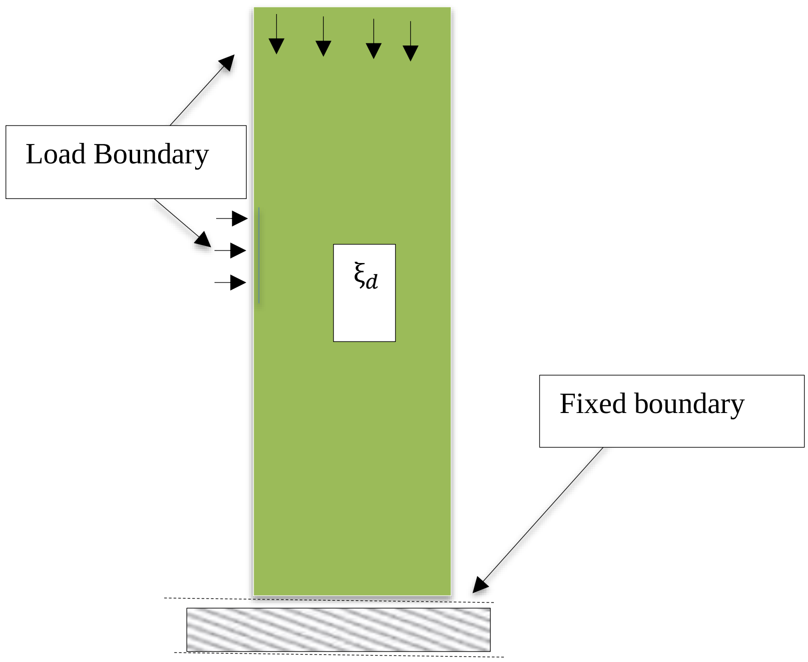


Figure 4. Design domain with applied load on the top and left side

Microstrip filters, cloud computing, amplifiers, antennas, cybersecurity and diplexer can be engaged to augment potential telecommunication tower design and performance [52-65].

6. Conclusion

A method of optimizing topology through the distribution of isotropic material has been presented, which involves identifying structures with the lowest volume while taking into account numerous displacement limitations. Fixed point or distributed loads and forces with many places of application can be handled by the same problem. It has been demonstrated that optimal design with numerous displacement limitations can be elaborated by numerical simulations. Two approaches to creating deflection-related enforcements have been tested. The optimal solution of telecommunication design shows more rigidity and less material consumption. It need for more practically investigation for employing the suggested design for improve the classical fix load structure.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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Author contributions

In this study, the authors Amjad Yousif Sahib, Ali Assad, Osamah Malik Mohammed, and Haider TH. Salim ALRikabi collaboratively employed topology optimization methods to develop an optimal design structure for telecommunication towers. Amjad Yousif Sahib led the conceptual framework and methodology, while Ali Assad focused on the computational analysis and simulations. Osamah Malik Mohammed contributed to the interpretation of results and design validation and Haider TH. Salim ALRikabi provided insights into practical applications and structural integrity assessments. Together, their combined expertise facilitated the creation of an innovative and efficient telecommunication tower design that addresses both performance and material efficiency.

References

[1] K.D. Tsavdaridis, A. Nicolaou, A.D. Mistry, E. Efthymiou, Topology optimisation of lattice telecommunication tower and performance-based design considering wind and ice loads, Structures 27 (2020) 2379–2399. https://doi.org/10.1016/j.istruc.2020.08.010.

[2] Efthymiou, E., D. N. Kaziolas, and C. C. Baniotopoulos. “On the response of steel lattice telecommunication masts under environmental actions and seismic loading.” Nordic Steel Construction Conference NSCC 2009. 2009., in: n.d.

[3] S. Roy, C.K. Kundu, State of the art review of wind induced vibration and its control on transmission towers, Structures 29 (2021) 254–264. https://doi.org/10.1016/j.istruc.2020.11.015.

[4] S. Chowdhury, V. Zabel, Influence of loading sequence on wind-induced fatigue assessment of bolts in TV-tower connection block, Results in Engineering 16 (2022) 100603. https://doi.org/10.1016/j.rineng.2022.100603.

[5] Støttrup-Andersen, Ulrik. “Masts and towers.” Journal of the international association for shell and spatial structures 55.2 (2014): 69-78., (n.d.).

[6] Nielsen, M. G., and U. Støttrup-Andersen. “Advantages of using tubular profiles for telecommunication structures.” Tubular Structures XI. Taylor & Francis Group, 6000 Broken Sound Parkway NW, Suite 300, Boca Raton, FL 33487-2742: CRC Press, 2017. 45-50., (n.d.).

[7] Nicolaou, Andreas, Konstantinos Daniel Tsavdaridis, and Evangelos Efthymiou. “Topology optimisation study for the design of lattice towers.” 9th Hellenic National Conference of Steel Structures: proceedings. Steel Structures Research Society, 2017., in: n.d.

[8] M.S. Musaddiq Al Ali, Toward Concurrent Multiscale Topology Optimization for High Heat Conductive and Light Weight Structure, in: 15th World Congress on Computational Mechanics (WCCM-XV) and 8th Asian Pacific Congress on Computational Mechanics (APCOM-VIII), 2022: pp. 1–12. https://doi.org/10.23967/wccm-apcom.2022.118.

[9] M. Torisaki, M. Shimoda, M. Al Ali, Shape optimization method for strength design problem of microstructures in a multiscale structure, International Journal for Numerical Methods in Engineering (2022).

[10] M. Al Ali, M. Shimoda, Designing piezoelectric stretcher through multiphysics topology for enhanced photodynamic therapy in cancer treatment, Advances in Engineering Software 191 (2024) 103621. https://doi.org/https://doi.org/10.1016/j.advengsoft.2024.103621.

[11] M. Al Ali, M. Shimoda, Exploring the influence of initial design domain dependencies in concurrent multiscale topology optimization for heat conductivity maximization, Computer Physics Communications 295 (2024) 108968. https://doi.org/10.1016/j.cpc.2023.108968.

[12] M. Shimoda, M. Hikasa, M. Al Ali, Micropore shape optimization of porous laminated shell structures, Additive Manufacturing 69 (2023) 103530. https://doi.org/10.1016/j.addma.2023.103530.

[13] M. Al Ali, M. Shimoda, Hygrally activated displacement inverter using a multiphysics multiscale topology optimization with considering evaporation, Structural and Multidisciplinary Optimization 66 (2023) 1–16. https://doi.org/10.1007/s00158-023-03679-6.

[14] M. Fujioka, M. Shimoda, M. Al Ali, Concurrent shape optimization of a multiscale structure for controlling macrostructural stiffness, Structural and Multidisciplinary Optimization 65 (2022) 1–27. https://doi.org/10.1007/s00158-022-03304-y.

[15] M. Al Ali, M. Shimoda, B. Benaissa, M. Kobayashi, T. Takeuchi, A. Al-Shawk, S. Ranjbar, Metaheuristic aided structural topology optimization method for heat sink design with low electromagnetic interference, Scientific Reports 14 (2024) 3431. https://doi.org/10.1038/s41598-024-54083-z.

[16] M. Torisaki, M. Shimoda, M. Al Ali, Shape optimization method for strength design problem of microstructures in a multiscale structure, International Journal for Numerical Methods in Engineering 124 (2023) 1748–1772. https://doi.org/10.1002/nme.7186.

[17] A. Ferrer, SIMP-ALL: A generalized SIMP method based on the topological derivative concept, International Journal for Numerical Methods in Engineering 120 (2019) 361–381.

[18] W. Zuo, K. Saitou, Multi-material topology optimization using ordered SIMP interpolation, Structural and Multidisciplinary Optimization 55 (2017) 477–491. https://doi.org/10.1007/s00158-016-1513-3.

[19] G. Rozvany, The SIMP method in topology optimization-theoretical background, advantages and new applications, in: 8th Symposium on Multidisciplinary Analysis and Optimization, 2000: p. 4738. https://doi.org/10.2514/6.2000-4738.

[20] M. Al Ali, M. Shimoda, Investigation of concurrent multiscale topology optimization for designing lightweight macrostructure with high thermal conductivity, International Journal of Thermal Sciences 179 (2022) 107653. https://doi.org/10.1016/j.ijthermalsci.2022.107653.

[21] M. Zhou, G.I.N. Rozvany, On the validity of ESO type methods in topology optimization, Structural and Multidisciplinary Optimization 21 (2001) 80–83. https://doi.org/10.1007/s001580050170.

[22] X. Huang, Y.-M. Xie, A further review of ESO type methods for topology optimization, Structural and Multidisciplinary Optimization 41 (2010) 671–683. https://doi.org/10.1007/s00158-010-0487-9.

[23] M. Al Ali, M. Shimoda, B. Benaissa, M. Kobayashi, Non-parametric optimization for lightweight and high heat conductive structures under convection using metaheuristic structure binary-distribution method, Applied Thermal Engineering 233 (2023) 121124. https://doi.org/10.1016/J.APPLTHERMALENG.2023.121124.

[24] M. Al Ali, M. Shimoda, B. Benaissa, M. Kobayashi, Concurrent Multiscale Hybrid Topology Optimization for Light Weight Porous Soft Robotic Hand with High Cellular Stiffness, in: Proceedings of the International Conference of Steel and Composite for Engineering Structures: ICSCES 2022, 2023: pp. 265–278. https://doi.org/10.1007/978-3-031-24041-6_22.

[25] M. Fujioka, M. Shimoda, M. Al Ali, Shape optimization of periodic-microstructures for stiffness maximization of a macrostructure, Composite Structures 268 (2021) 113873. https://doi.org/10.1016/j.compstruct.2021.113873.

[26] C.F. Beck, Computer’s Role in Transmission Line Design, Journal of the Structural Division 97 (1971) 63–79. https://doi.org/10.1061/JSDEAG.0002810.

[27] B. Picard, F.D. Galiana, D. McGillis, A knowledge-based system for the structural design of high-voltage lines, in: Engineering Solutions for the Next Millennium. 1999 IEEE Canadian Conference on Electrical and Computer Engineering (Cat. No.99TH8411), IEEE, n.d.: pp. 1229–1233. https://doi.org/10.1109/CCECE.1999.804866.

[28] H.B. Aravind, T.L. Murlidharan, P. Sivakumar, N. V. Raman, A Knowledge-Based System for Synthesis and Design of Transmission Towers Using Blackboard Architecture, Computer-Aided Civil and Infrastructure Engineering 6 (1991) 191–203. https://doi.org/10.1111/j.1467-8667.1991.tb00403.x.

[29] A. Bielecki, B. Strug, An Evolutionary Algorithm for Solving the Inverse Problem for Iterated Function Systems for a Two Dimensional Image, in: n.d.: pp. 347–354. https://doi.org/10.1007/3-540-32390-2_40.

[30] P. Sivakumar, A. Rajaraman, G.M. Samuel Knight, D.S. Ramachandramurthy, Object-Oriented Optimization Approach Using Genetic Algorithms for Lattice Towers, Journal of Computing in Civil Engineering 18 (2004) 162–171. https://doi.org/10.1061/(ASCE)0887-3801(2004)18:2(162).

[31] G.V. Rao, Optimum designs for transmission line towers, Comput Struct 57 (1995) 81–92. https://doi.org/10.1016/0045-7949(94)00597-V.

[32] J. Cheng, T. Shi, Structural optimization of transmission line tower based on improved fruit fly optimization algorithm, Computers and Electrical Engineering 103 (2022) 108320. https://doi.org/10.1016/j.compeleceng.2022.108320.

[33] H.J. Zhu, K. Nakagawa, S.J. Duan, A study on optimization of power transmission pylons by minimization of the square sum of the natural periods, Comput Struct 59 (1996) 805–812. https://doi.org/10.1016/0045-7949(95)00327-4.

[34] T. Belytschko, S.P. Xiao, C. Parimi, Topology optimization with implicit functions and regularization, Int J Numer Methods Eng 57 (2003) 1177–1196. https://doi.org/10.1002/nme.824.

[35] J. Norato, R. Haber, D. Tortorelli, M.P. Bendsøe, A geometry projection method for shape optimization, Int J Numer Methods Eng 60 (2004) 2289–2312.

[36] F. T. A. Haider TH. Salim ALRikabi Nisreen Khalil Abed, Hamdalla F. Al-Yasriy, "Detection of power transmission lines faults based on voltages and currents values using K-nearest neighbors," International Journal of Power Electronics and Drive Systems (IJPEDS), vol. 14, no. 02, pp. 1033-1043, 2023.

[37] G. A. Al-Rubaye and H. T. Hazim, "Optimization of capacity in non-Gaussian noise models with and without fading channels for sustainable communication systems," Heritage and Sustainable Development, vol. 5, no. 2, pp. 239-252, 2023.

[38] M. J. Al-Dujaili, A. Rikabi, H. T. Salim, G. A. Al-Rubaye, and I. R. N. ALRubeei, "Enhancement of the Fifth Generation of Wireless Communication by Using a Search Optimization Algorithm," International Journal of Online & Biomedical Engineering, vol. 19, no. 11, 2023.

[39] I. M. Jawad, A. Q. Abdulrasool, A. Q. Mohammed, W. S. Majeed, and H. T. Salim ALRikabi, "The optimal allocation of thyristor-controlled series compensators for enhancement HVAC transmission lines Iraqi super grid by using seeker optimization algorithm," Open Engineering, vol. 14, no. 1, p. 20220499, 2024.

[40] N. A. Hussien, A. A. Daleh Al-Magsoosi, H. T. AlRikabi, and F. T. Abed, "Monitoring the Consumption of Electrical Energy Based on the Internet of Things Applications," *International Journal of Interactive Mobile Technologies*, vol. 15, no. 7, pp. 17-29, 2021.

[41] H. T. S. Alrikabi, I. A. Aljazaery, and A. H. M. Alaidi, "Using a Chaotic Digital System to Generate Random Numbers for Secure Communication on 5G Networks," *Engineering, Technology & Applied Science Research,* vol. 14, no. 2, pp. 13598-13603, 2024.

[42] A. A. Haider TH. Salim ALRikabi, Mohammed Jawad Al Dujaili, Ibtihal Razaq Niama ALRubeei, "Automatic Human Age Estimation from Face Images Using MLP and RBF Neural Network Algorithms in Secure Communication Networks," *Sustainable Engineering and Innovation,* vol. 6, no. 2, 2024.

[43] M. H. Mthboob, S. A. Rikabi, T. Haider, and I. A. Aljazaery, "Design and analysis of a DC motor speed drive with generalized regression neural network (GRNN) and invasive weed optimization (IWO) algorithms," in *AIP Conference Proceedings*, 2023, vol. 2977, no. 1: AIP Publishing.

[44] H. T. S. ALRikabi, "Study the Matching of the Level of Electromagnetic Radiation Emitted by Communication Towers in the Kut City with the International Health organization criterion," *Wasit Journal of Engineering Sciences,* vol. 4, no. 1, pp. 101-111, 2016.

[45] I. A. Ibrahim, H. T. Salim, and H. F. Khazaal, "Investigating the Analysis of Power Saving Mode in IEEE 802.11 for Wi-Fi Communication," *Wasit Journal of Engineering Sciences,* vol. 6, no. 3, pp. 13-19, 2018.

[46] M.P. Bendsøe, N. Kikuchi, Generating optimal topologies in structural design using a homogenization method, Comput Methods Appl Mech Eng 71 (1988) 197–224. https://doi.org/10.1016/0045-7825(88)90086-2.

[47] M.P. Bendsøe, Optimal shape design as a material distribution problem, Structural Optimization 1 (1989) 193–202. https://doi.org/10.1007/BF01650949.

[48] S. Roshani *et al.*, "Design of a compact quad-channel microstrip diplexer for L and S band applications," *Micromachines (Basel)*, vol. 14, no. 3, 2023.

[49] S. I. Yahya *et al.*, "A New Design method for class-E power amplifiers using artificial intelligence modeling for wireless power transfer applications," *Electronics (Basel)*, vol. 11, no. 21, p. 3608, 2022.

[50] H. A. Hussein, Y. S. Mezaal, and B. M. Alameri, "Miniaturized microstrip diplexer based on FR4 substrate for wireless communications," *Elektron. Ir Elektrotech.*, 2021.

[51] S. Roshani, S. I. Yahya, B. M. Alameri, Y. S. Mezaal, L. W. Y. Liu, and S. Roshani, "Filtering power divider design using resonant LC branches for 5G low-band applications," *Sustainability*, vol. 14, no. 19, p. 12291, 2022.

[52] F. Abayaje, A. A. Alrawachy, Y. S. Mezaal C-Band, and -Max Wi, "Design of compact UWB monopole patch antenna with octagonal shape for C-band, Wi-MAX, and WLAN applications," *Optoelectronics and Advanced Materials-Rapid Communications*, vol. 17, no. 7–8, pp. 323–328, 2023.

[53] Y. S. Mezaal, K. Al-Majdi, A. Al-Hilalli, A. A. Al-Azzawi, and A. A. Almukhtar, "New miniature microstrip antenna for UWB wireless communications," *Proc. Estonian Acad. Sci.*, vol. 71, no. 2, p. 194, 2022.

[54] Y. S. Mezaal and J. K. Ali, "Investigation of dual-mode microstrip bandpass filter based on SIR technique," *PLoS One*, vol. 11, no. 10, p. e0164916, 2016.

[55] A. H. M. Alaidi and A. Mahmood, "Distributed hybrid method to solve multiple traveling salesman problems," presented at the 2018 International Conference on Advance of Sustainable Engineering and its Application (ICASEA), IEEE, 2018, pp. 74–78.

[56] A. H. Alaidi, C. S. Soong Der, and Y. Weng Leong, "Systematic Review of Enhancement of Artificial Bee Colony Algorithm Using Ant Colony Pheromone," *Int. J. Interact. Mob. Technol. IJIM*, vol. 15, no. 16, pp. 172–180, 2021.

[57] A. H. Alaidi, C. Soong Der, and Y. Weng Leong, "Increased Efficiency of the Artificial Bee Colony Algorithm Using the Pheromone Technique," *Eng. Technol. Appl. Sci. Res.*, vol. 12, no. 6, pp. 9732–9736, 2022.

[58] A. H. Alaidi, S. D. Chen, and Y. Weng Leong, “Artificial Bee Colony with Crossover Operations for Discrete Problems,” *Eng. Technol. Appl. Sci. Res.*, vol. 12, no. 6, pp. 9510–9514,2022.

[59] M. S. Shareef *et al.*, “Cloud of Things and fog computing in Iraq: Potential applications and sustainability,” *Heritage and Sustainable Development*, vol. 5, no. 2, pp. 339–350, 2023.

[60] M. S. Shareef, T. Abd, and Y. S. Mezaal, “Gender voice classification with huge accuracy rate,” *TELKOMNIKA*, vol. 18, no. 5, p. 2612, 2020.

[61] Y. S. Mezaal, D. A. Hammood, and M. H. Ali, “OTP encryption enhancement based on logical operations,” in *2016 Sixth International Conference on Digital Information Processing and Communications (ICDIPC)*, 2016.

[62] M. Q. Mohammed, *et al.*, “Harnessing cloud of thing and fog computing in Iraq: Administrative informatics sustainability,” *J. Mech. Contin. Math. Sci.*, vol. 19, no. 2, 2024.

[63] K. Al-Majdi and Y. S. Mezaal, “New miniature narrow band microstrip diplexer for recent wireless communications,” *Electronics (Basel)*, vol. 12, no. 3, p. 716, 2023.

[64] S. Roshani *et al.*, “A compact filtering coupler with unwanted harmonic rejection using LC composite lines for communication systems applications,” *Systems*, vol. 11, no. 1, p. 14, 2022.

[65] K. M. Tarrad *et al.*, “Cybercrime challenges in Iraqi Academia: creating digital awareness for preventing cybercrimes,” *International Journal of Cyber Criminology*, vol. 16, no. 2, pp. 15–31, 2022.