International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-12 Issue-2, July 2023

Structural Topology Optimization of Headphone

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Abstract*: Topology optimization is a mathematical strategy enhancing a system's performance by figuring out the best arrangement of materials for a certain set of loads, boundary conditions, and constraints. In basic terms, it builds a design space from a model (3D model). To make the design more efficient, it then eliminates or displaces material inside it. By defining cavities in continuous design domains, topology optimization is an excellent technique for generating lightweight, high-performance, and cost-effective structures. Like every other optimization problem, it needs some boundary conditions, constraints, an objective function, and criteria to attain optimality, which must be decided by the type of design we are making, material costs, mechanical performance, and resistance to failure. Since there are several iterations in the optimization rounds which allow us to play with variables within the boundary conditions to come up with an aesthetically pleasing, mechanically optimized design. We are in hope that the proper implementation of this would lead to the betterment of society.

***Keywords*: Material distribution, Mechanical performance Topology optimization.**

I. INTRODUCTION

To generate efficient structures, topology optimization techniques are usually implemented in the area of design with predetermined support conditions. The ability of the optimizer to design supports and topologies simultaneously opens new design possibilities for greater structural performance and decreased support costs. Existing simultaneous optimization approaches, on the other hand, are limited and involve time-consuming procedures to establish support conditions in advance; end-users may find this difficult [1]. This paper investigates the factors of a new element-based simultaneous effective optimization approach that can be easily adopted in finite element (FE) models by adding a multilayer of elements to the boundaries where supports are expected [2]. Structural engineers are responsible for carrying out finite element analysis of the existing structures by playing with variables, constraints, and other boundary conditions. Topology optimization can be thought of as a data-driven tool that will add a third layer to this analysis.

Manuscript received on 02 February 2023 | Revised Manuscript received on 11 July 2023 | Manuscript Accepted on 15 July 2023 | Manuscript published on 30 July 2023.
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Currently, due to low data set availability, it is in its early stages, and subsequent progress must be made before this particular optimization can be brought into mainstream scientific analysis. There is a lot of research that has been going on at this moment around the globe, mainly to do a structural analysis of soft and simple structures. Recently, the University of California, Berkeley, has made a substantial contribution to the development of software named OptiStruct, which can take finite element data and come up with highly relevant structural results. Other significant design elements were shown to have an impact on this investigation. Because of the slow formation feature of support components, it is discovered that using the artificial material model is acceptable; by penalizing the material model of support elements [4]. Despite these benefits, AM has its own set of constraints that must be considered while creating topology optimization methods. The absence of AM-friendly topology optimization techniques, as described in [15], was a major barrier. The review work by Brackett et al. [15] was released more than six years ago. Some issues have been solved since then, while others have been chosen, for example, self-support design [18–21], topology optimization using material anisotropy [16,17], and porous infill design. Simultaneously, other issues have surfaced that are still being looked into. The present state of topology optimization for AM is discussed in this viewpoint essay, but of greater significance, it delves into the remaining challenges and provides viable solutions. We hope that this study will motivate scholars and engineers. I hope that this study will motivate scholars and engineers.

A. Background

Topology optimization is a method for creating more efficient designs with fewer priority options. Additive manufacturing allows for a wide range of design shapes and complexity, and it is currently transitioning to new materials, greater accuracy, and larger body types [1]. The proposed framework may be used in a range of fields, including medicine, architecture, and engineering. The goal of mass-based topology iterative optimization is to find a solution to the following question: "What is the optimal material distribution within a defined domain?" The design domain is often discretized, and the density variables for each discretized element are optimized [2]. The method's popularity stems from the fact that it uses an Eulerian approach, which eliminates the need to re-mesh the domain to account for the new material-void or material-material boundary. Additive manufacturing allows us to take the lead with respect to traditional manufacturing, mainly because the cost and time are drastically reduced.

However, the amount of research that has gone into rapid prototyping using additive manufacturing is quite small compared to the number of things that can be manufactured using additive manufacturing. We are still not aware of how diverse the platform can be in additive manufacturing technologies, but if we extrapolate current development with respect to time, it can be assumed to have a bright future. Still, new relevant information is popping out every day about the sheer possibility of this technology. Augmentation of artificial intelligence with additive manufacturing is where topology optimization has a future [4]. A device to consider and a post-method 3-dimensional density-primarily based topology optimization outcomes are mentioned. Examples and packages for each technique are mentioned and shown in the project report. Additive manufacturing is the final and missing piece of a whole structural optimization framework. Two optimization approaches were investigated, and designs were developed and fabricated using them [2]. A three-dimensional, systematic, computer-attenuated model can be used to swiftly express design ideas and revisions, making it easier to create new (optimal) structures.

B. Motivation

Shape optimization has become a prominent method for improving design and performance. The necessity for several finite element analysis iterations to measure the component's effectiveness makes current state-of-the-art topology optimization approaches computationally expensive. Topology Optimization is a relatively new field in the Mechanical Design Engineering domain that has applications in producing optimised counter-intuitive design solutions based on mathematical models [2]. It is hoped that the sheer understanding gained from this project, as well as gaining more expertise in the domain through the project, and then carrying on the knowledge in higher education, will result in a positive change at the societal level. After reviewing the literature, it was realized that because of the recent advent of 3-D Printing and Additive Manufacturing, Topology Optimization has been utilized to optimize current designs in the automotive and aerospace industries, and it is slowly making its way into the mainstream industrial sector. However, not much hard-core research has gone into Headphone design using Topology Optimization.

C. Objective

- To learn how designers and engineers use structural topology optimization and generative design technologies during the concept creation phase of the iterative product design cycle.
- To generate a headphone design having the highest stiffness-to-structural mass ratio using computational methods and software tools.

D. Scope

To help overcome this difficulty, researchers have recently looked into machine learning (ML)-based topology optimization algorithms. Previous machine learning algorithms, on the other hand, were mostly demonstrated in two-dimensional applications using basic low-resolution geometry. Additionally, prior systems relied on a single machine learning model for end-to-end prediction, requiring a large training dataset [2]. Because of these challenges, extending current approaches to greater resolutions is difficult. We present deep learning-based frameworks for 3D topology optimization with a sufficiently fine (high) resolution that are compatible with existing topology optimization methods in this paper. This is done by training many networks [1], each of which learns a different stage of the entire topology optimization process, resulting in a more consistent framework with the topology optimization method. Our system has been demonstrated to work with both 2D and 3D geometry. The results show that our algorithm correctly predicts the ultimate best design. The structural design of a system can be thought of as a multi-variable analysis in which the loads and constraints form the variables of the equation. Topology optimization is handy here mainly because it has an enormous ability to withstand several data-driven failures that we observe in normal parametric evaluation. The structural stiffness to material mass ratio must be balanced in structural design. Subsequent amounts of research have been done to show that the strength of a structure is directly proportional to its material mass, as the structure would be able to hold the load and the efficiency of the distribution of the load would also increase drastically. But our goal is to achieve the highest structural stiffness to material mass ratio; hence, material mass has to be reduced to achieve this. Again, the balance between reducing the material mass to the point where it increases the optimality criterion while not jeopardizing the strength to the point where it is prone to failure is a major concern.

II. LITERATURE REVIEW

The literature review is divided in three sections:

- **First section dealing with**

What is Topology Optimization and what kind of techniques are involved in topology optimization that can be used for headphone designing?

- **Second section dealing with**

Recent Headphone Design Techniques, how to ensure the best material utilization, what is the stress distribution across a headphone chassis, what are the faults with current design of headphones

- **Third section dealing with**

Relating Topology optimization techniques with headphone designing and manufacturing.

Bendse and Kikuchi (1988) created the phrase "optimal topology," which encompasses a variety of methodologies; density, level set, topological derivative, phase field, and evolutionary techniques are examples of these [4]. How should various methods be classified? [1] What are the advantages and disadvantages of different approaches? [1] What is their efficiency? [2,3] The goal of this study is not to do a full evaluation but rather to notice and highlight trends and tendencies in the industry, as well as to apply those approaches to the creation of a new headphone idea. One of the most common pieces of electrical equipment is headphones.

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The elements that influence their use, however, are poorly understood [5]. Patrick Reinelt et al. claim that headphones can serve various purposes depending on the context in which they are used. It can be used only for pleasure seeking, creative output, and to distract ourselves from the current reality, which is boring. The Berkeley School of Music claims that headphones or any other music interaction devices are a part and parcel of communication and the effective straying or intermixing of creative ideas. Furthermore, through perceived satisfaction, perceived design aesthetics have an indirect influence on actual system use [6]. These findings suggest that headphone makers should emphasise their goods' hedonic qualities and design them carefully [6]. A headphone simulator has been proposed that enables the simultaneous evaluation of headphones' frequency response and ambient noise isolation properties, which together comprise the entire headphone listening experience [7]. The simulator is based on measurements of frequency responsiveness and ambient noise isolation taken using a standardised dummy head [8]. The music signals used as test sample are filtered using the headphones' modelled frequency response [8]. Furthermore, when integrating the reliability analysis into the optimization of geometrical form variables in the shape optimization example, a CAD model update is required during the design process. The parametrization phase then allows the optimization process's search directions to be defined. Among the design variables that determine points and directions are the domain boundary's geometry. The information relating to the geometrical boundary perturbation guides the shape optimization procedure. Several descriptions can be used to specify the structural geometry that will be adjusted throughout the optimization process, such as Bezier, B-spline, and NURBS (Kharmanda et al. 2002 a, b). Reliability-Based Shape is the name of this model Enhancement (RBSO). The designer of deterministic topology optimization tries to get the solution without taking into consideration the impacts of deterministic variables' uncertainty about geometry and loading. Reliability-Based Topology Optimization (RBTO) is a novel style of optimization that incorporates reliability or safety factors into topology optimization (Kharmanda and Olhoff 2001b). The goal of RBTO is to account for the unpredictability of the applied loads as well as the geometrical description. It also gives the designer a variety of options. In comparison to the deterministic topology optimization technique, we find distinct topologies using the RBTO model. The topologies that arise are determined by the target dependability levels. The shape optimization algorithm can be used to improve the solution's control.

III. METHODOLOGY

A. Planning Phase (Phase 0)

New product design and development is frequently a crucial component of an organization's long-term strategy and is typically evaluated at the strategic planning level. The planning activity connected with the complex product design process differs from other planning activities within the business in several ways. There is a desire to learn how larger planning focuses, such as planning theory, have informed planning activities on such complex design projects. An industry survey was utilized to create a tool that could be used to examine a population's planning activities. The goal of administering PMAST (Planning Management Assessment Survey Tool) to a large group of people was to get enough replies so that the data could be analysed. The survey's data uniformity and quantitative character made it easy to determine qualitative patterns of planning practice among the participants [12]. Organizations, according to Kast and Rozenzweig, are similar to organisms in that they may be thought of as a collection of interconnected subsystems. Product design, according to Maier, is an autopoietic social system that is receptive to information but is based on its own inner structure and operating logic. This research investigates how much of the complicated product design process's individual expression of interaction is accomplished through the planning system.

1) Mission Statement

a) Product Description:

A flexible, cost-effective, functionally efficient, topologically optimized headset that is marketable, customizable, and sustainably producible.

b) Benefit Proposition:

Drastically cost-effective solution and has higher flexibility.

c) Key Business Goals:

First and foremost, it's critical to get started early and create a powerful online sales funnel. It is the necessary basis for long-term and scalable success. And as the number of smart devices such as smartphones, TVs, and laptops increases, so will our headphone and earphone sales. It becomes much more lucrative when you consider the large opportunity of new goods entering the market with gesture recognition features, hands-free calling, and other features.

d) Primary Market:

Primary use at home, with primary users being people with middle-to-low incomes because the product's cost is less than the normalized market range.

e) Secondary Market:

The global earbuds and headphones market was valued at USD 25.1 billion in 2019, with a CAGR of 20.3 percent forecast from 2020 to 2027. Customer demand is expected to boom in the near future due to subsequent progress in music interaction devices and other communication tools to make music more relevant and relatable.

f) Assumptions:

Near Field Communication (NFC) system, disintegrated battery-charging circuit to ensure headphones work even when charging.

g) Stakeholders:

Key suppliers rely heavily on robust distribution channels, such as multi-brand distributors and earphone and headset shops, to achieve a competitive edge in the earphone and headset industry.

Retrieval Number: 100.1/ijrte.F74620311623
DOI: 10.35940/ijrte.F7462.0712223
Journal Website: www.ijrte.org

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Stakeholders include employees' families, customers, shareholders, various types of suppliers, communities, and in some cases, the government.

2) Target Market

A targeting strategy is one that seeks to narrow down the target market for a company's product. Topologically tailored noise-canceling headphones are designed to appeal to people of various ages, genders, races, socioeconomic levels, and educational levels in this situation. According to Elliot and Smith [3, 4], the choice of marketing strategy and the goal of having the lowest marketing and production expenses It has been noticed that headphones are particularly used by young adults who are working professionals and college students. Maybe the emotional and mental development required at this age requires the aid of music, and human beings at this age are unconsciously attracted to that. Another reason might be the technological fluke associated with it. This means that it is more likely for a young professional to know about music than it would be for, say, a person whose age is above 60 years. Due to these factors, it can be estimated that the target customers would have an age range of 15–35 years. The upper limit is set higher than usual for young adults because of the working-professional factor. If topology optimization is used in the headphones, of course the cost would go high, so a working professional can afford it more, and later on when the market increases, the cost would slide down, making the product more affordable for the masses. Headphones are one of the best noise-canceling headphones when compared to other brands, but they are also more costly. Benjamin A. Bose, the creator of Bose, was on an aircraft in 1978 and noticed that he couldn't appreciate the music due to the jet's high-volume noise. Furthermore, the Bose emblem has its own unique typeface, allowing customers to recognize the brand more quickly [2]. According to Cansu, Bose compromises on "consistency, aesthetic, and branding."

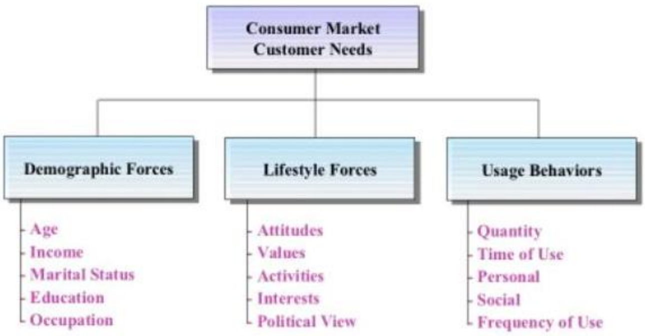

Fig. 1. Customer need chart

3) Customer Needs

a) Expected Needs

At this point, thoroughly pleasing the client is merely a means of entering the market. Topology optimization is a tool that can be used in the iterative cycle of concept generation in the product development process. It can be used to generate exciting and feasible concepts. To enter the market initially, financially independent customers are necessary to target. In later marketing iterations, when the product can be made mass-marketable, other customers can be brought into the account. Among the musts are customer assumptions, anticipated qualities, expected functions, and other implicit expectations [20].

b) Normal Needs

These basically refer to certain parameters that can make the product competitive with respect to other headphones on the market. Of course, the cost reduction is a big plus in this aspect; however, other things like quality, likability, future assurance, and delight are other aspects that can be taken into consideration while thinking about normal needs. The result of the multivariate analysis is a successful and impressive normal distribution. Customer needs and other communicated expectations are examples of wants [11].

c) Exciting Needs

These are the features and traits that set the benchmark for the product we are marketing. Kano defines "wow-level" features, traits, or attributes as the highest degree of consumer expectations [14]. These implicit expectations are known as "delighters," and they are extremely important in terms of a customer's memory or sheer trust in the company. To leave a lasting and sustainable mark, the product must deeply penetrate their conscience. Scalability is another important factor in this regard, which would require paradigmatic technological shifts like topology optimization to make the product seem feasible and marketable. Examples include a heads-up display in the front windshield, forward- and rear-facing radars, and a 100,000-mile warranty.

B. Ideation Phase (Phase 1)

An off-the-shelf headphone shell was utilized to construct the earpad sensor. Soft foam cushions might be used to secure the housing to the ear canal. To produce a housing, the original headphones' speaker and cabling were removed. A Knowles omnidirectional tiny electret microphone (type: FG23329) was employed as an acoustic transducer. This model had a consistent sensitivity across the frequency range of 100 Hz to 10 kHz, which was predicted to include the necessary signal information [13]. A modelling material compatible with human skin was used to insert the transducer into the headphone shell. The active sensing portion of the transducer and housing were aligned so that it faced centrally outward from the housing. This structure might catch noises propagating in the ear canal while worn.

a) Virtual Concept Generation Network (VCGN)

We try to capture the essence of the thought-creation process by identifying an effective creative thinking pattern. We look at a space made up of chain processes of concepts that are both openly invoked in the concept production process and implicitly depicted as a thinking space, focusing on two aspects: structure and latent sensitivity. The former relates to the structure of the thinking space, while the latter refers to the latent notions that are implicitly depicted in it [9]. We offer a way for modelling a virtual thinking environment using a semantic network based on various perspectives, and we statistically assess its pattern.

Retrieval Number: 100.1/ijrte.F74620311623
DOI: 10.35940/ijrte.F7462.0712223
Journal Website: www.ijrte.org

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As a consequence, we discovered that there is a strong link between structure and creativity and that the model can help explain the why of the design iteration.

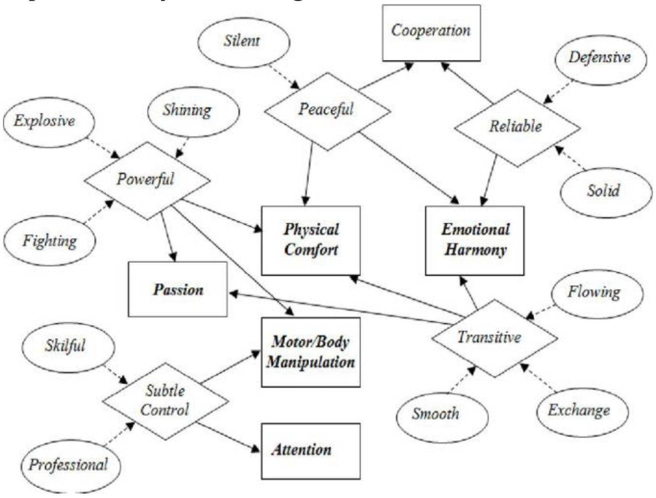

Fig. 2. VCGN graph analysis for headphone design

Four keywords: a) Physical Comfort b) Motor/Body Manipulation c) Attention d) Emotional Harmony

As a consequence, we discovered that there is a strong link between structure and creativity and that the model can help define the nature of design creativity in the concept generation process [14]. These data imply that the structure of the thinking space has a strong influence on the rated creativity score for design ideas. This suggests that an effective thought pattern for creativity exists and that this model might be applied to improve design inventiveness.

b) Brainwriting Sheets and Affinity Diagrams

Brainwriting is a great approach to communicating fresh ideas, boosting creativity, and producing novel ideas, similar to brainstorming. Bernd Rohrbach, a German marketing strategist, invented it in 1969. In group brainstorming meetings, shy or introverted team members may be hesitant to speak up. By allowing people to write down their thoughts, brainwriting removes these barriers, allowing everyone to engage equally. It also encourages people to spend more time reflecting on their own thoughts and expanding on those of others. 6-3-5 is a popular and colorful brainwriting style. During a 6-3-5 session, brainwriting activities are divided into several rounds [2]. Six people are given five minutes per round to jot down three ideas. These could be whole new concepts or variants on old ones. After six rounds, the pieces of paper are gathered, and most of the submitted ideas are carefully and consciously examined, as well as potential future activities. Although this example includes six participants, your brainstorming session can include any number of people. Other settings, such as the number of rounds, can be changed to suit your needs.

C. Concept Development Phase (Phase 2)

As a structural topology optimizer, our aim is to achieve optimal material distribution in a given space. It is hoped that this will not jeopardise the overall structural stiffness, which is inversely related to compliance. As a result, in order to achieve the highest stiffness to material mass ratio for isotropic material composition, one thing to keep in mind here is that we should not be concerned about material variation during initial iterative cycles. After optimising for isotropic materials, the focus would shift to material optimization, which would assume anisotropic material composition, and the final prototype would be a combination of material and structural topology optimization.

There has been a significant amount of research on stress density distribution across a headphone chassis. This dataset is fed into Topology Optimizer 3-D (TopOpt 3-D), developed by the engineers at TU Delft. The software essentially generates material distribution with the least volume by considering the constraints given by Finite Element Analysis datasets. The problem perceived with TopOpt 3D is its inability to achieve structural topology optimization when the net material is complex. In light of the aforementioned interpolation requirements, a model that is similar to the logistic regression function is chosen: where b and h denote the goodness of fit during interpolation in this mathematical model, respectively in the finite-element model, multiple materials are introduced to make the model more realistic. Various types of penalising can be augmented with artificial intelligence tools to make sure the output is as creative as possible. Many frameworks have been taken into consideration while thinking about it. The main among them would be the interpolation matrix of static structural system. Again, some assumptions are made on the basis of the penalising parameter of the material and the stability or load distribution of the material. At this stage, we are not bothered about the artificial intelligence algorithm that is necessary to come up with a possible solution, but the structural (static) part to ensure the material is free of any failure possibilities. After the engineering filter, it gives a great deal of room for the designer to ensure that the parametric properties correlate to the design requirements possessed by the system in the system design phase. There are various advantages when various materials are taken into consideration while doing topology optimization; not only does it make the model more realistic, but the iteration time is reduced if the boundary conditions are properly defined [10]. In the case of a pseudo-single material simulation optimization design (containing one solid surface and space), the interpolation between segment elemental density and the engineering parameter (Young's modulus) may be expressed as follows: (Eq. 3.2) Material 1 and material 2 have Young's moduli of E1 and E2, respectively. xi2 and xi1 represent the design variables of element in Figure 3 depicts the schematic distribution of three solid materials in the design domain. Three design variables are employed in this interpolation model to discriminate between solid materials and emptiness. Material 1 (red areas) is designated by the variables xi3, xi2, and xi1; material 2 (green regions) is distinguished from material 1 by the 0/1 value of xi1; and material 3 (blue region) is distinguished from material 2 by the 0/1 value of xi2. Alternatively, all materials can be differentiated by determining the 0/1 value of each design variable [18].

As previously stated, the subject of least compliance under volume constraints has been intensively investigated as a typical topology optimization project. Each material's maximal structural stiffness or minimum [17].

In multi-material topology optimization, compliance is utilised to find the ideal distribution.

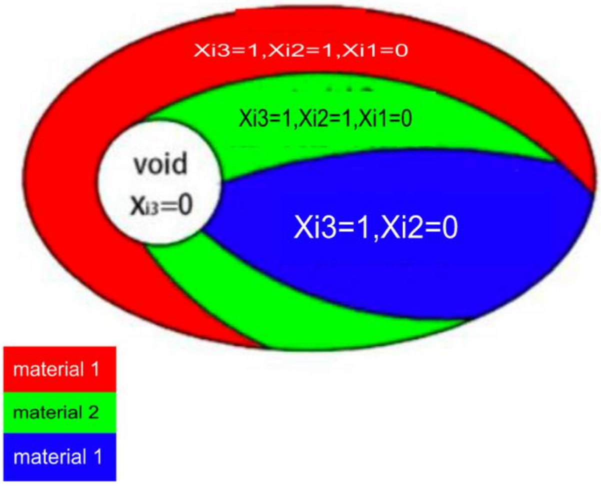

Fig. 3. In the design space, the distribution of three solid materials is shown.

Altair OptiStruct and Altair Inspire come into the picture in such scenarios. The assembled structure is optimised in Altair Inspire, which took approximately 17 minutes to complete the first 20 iterations, and 27 minutes to achieve 50 iterations. The computational time can be reduced if Machine Learning Algorithms are brought into the picture to analyse, learn, create, and thus replicate the pattern of codes. The database is constantly updated using the information from each piece of relevant literature. The future of topology optimization is expected to look like a distributed, self-updating dataset connected to the internet. The subject of least compliance under volume constraints has been actively investigated as a classic topology optimization project since it was first proposed. In multi-material topology optimization, the goal is to find the best distribution of each material with the highest structural stiffness or minimal compliance. For maximizing the flexibility and minimizing our objective function, the model with m candidate solid materials can be specified as follows: where C is the term for compliance, K is the structure's stiffness matrix, u is the displacement of the mode, which is a time-variant tool, and F stands for effective force vectors, basically the loads and their effective distribution in the specified system of consideration. The volume of element i is vi; the volume fraction of the solid material j is denoted by vj; and the density of the ith element for the jth material is denoted by xij. K (Stiffness matrix) is normalized using u*T* and u to make the solution multiband. After the normalization, depolarized outputs are found out which are generated in the optistruct software, and the depolarized outputs are given to do finite element analysis to take into account the engineering load and shear strength properties. Some overlaps may exist at the solid-materials junction because the new interpolation approach cannot completely eliminate the intermediate-density element. Since this a discrete analysis, to make it continuous a interpolation matrix would necessary which can be obtained from the volume elemental data-sets received after setting the boundary parameters of the system. Resistance to non-sensitivity properties can reduce computing costs by lowering the number of sophisticated sensitivity calculations required, while also increasing iteration speed

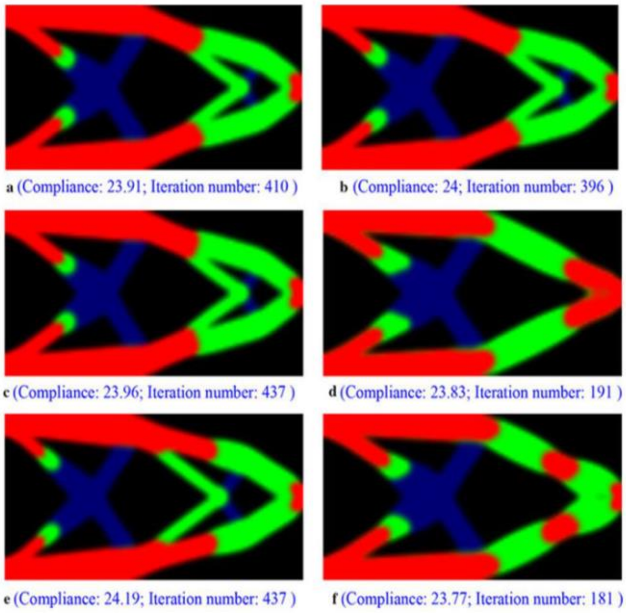

Fig. 4. Compliance vs Iteration number of simulations

Figure 4 displays portray the simulation results for a two-solid-material cantilever beam structure, where the intermediate-density components are suppressed by simply applying the better interpolation approach. Figure 4a–e shows topology optimization results after 437 iterations, and (f) shows the ultimate OptiStruct 2.9 simulation optimization result after 54 iterations, namely the ideal design with a structural compliance of 49.68 (stable state condition). The suggested technique, based on the data in Figure 6, may yield an appropriate distribution with a defined border. A sequential inner iteration is included in the suggested approach. As a result, the final outcomes may be influenced by the order in which design variables are solved. To investigate this topic, another example is topology optimization of a three-solid-material cantilever beam design. The parameter settings are the same as before, however this time a different solution sequence of design variables is applied. Figure 5 shows the case's ultimate topology design outcomes using several design variables solving sequences. The optimal design findings for the solution order design variables [xi1 xi2 xi3], [xi1 xi3 xi2], [xi2 xi1 xi3], [xi2 xi1 xi3], [xi2 xi1 xi3], [xi2 xi1 xi3], [xi2 xi1 xi3], [xi2 xi1 xi3]. It is only noticeable when the volume recursive design sequence is utilized. When the volume in a particular unit space of the iterative sequence of design variables is followed, the best design can only be achieved with higher flexibility and fewer iteration numbers. Following these numerical trials, it is clear that the final outcomes are dependent on the design variable solution sequence.

Steps performed:

The following sequence of activities are performed to come to the structurally optimized output:

a) Creating structural models using software.

b) Determining how structures react to stresses and loads.

Retrieval Number: 100.1/ijrte.F74620311623
DOI: 10.35940/ijrte.F7462.0712223
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-12 Issue-2, July 2023

c) Selecting the proper concrete materials for the project.
d) Estimating the project's budget.
e) Working with software variables to guarantee that freshly installed headphone chassis are structurally sound
f) Computers and computer-aided design technologies are used for simulation

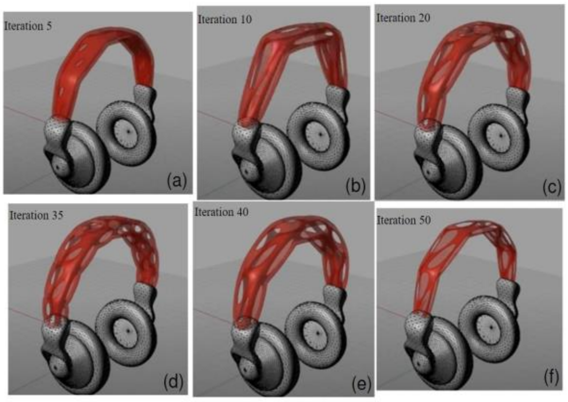

Fig. 5. Concept development using structural topology optimization

D. SYSTEM LEVEL DESIGN PHASE (PHASE 3)

To detect the opening and shutting of the case, the sensors primarily use Hall sensors in the signal chain. The device's aesthetic effect is enhanced with LED lights. The case information may be transmitted to the phone through Bluetooth, making it simple for the phone to verify the case's power. Some devices, such as the SN74LVC1G74, a D-trigger that translates the pulse of a key into a level flip for the MCU to capture key information, may be required for keystroke detection. In most cases, the input port is converted to a 5V micro-USB port in the power rail (the lighting interface on Apple's Airpods is likewise 5V). Given the variety of contemporary adapters that offer high-powered rapid charging, the charging case will require an overvoltage protection chip for misplacement protection as well as a lithium battery charger. Overvoltage protection is built into many chargers nowadays, although the overvoltage reaction time isn't optimal. For rapid protection, an overvoltage protection chip is advised. When the charging case's battery is low, putting in the adapter will immediately supply a greater system voltage, ensuring that the case can power low-battery headphones. When the rapid charging stream is set too low and the load demands a consistent load (such as an LED light), the load will be close to the charger's cut-off current. The charger may not be able to identify if the battery is fully charged without the power-path feature. Single-cell lithium batteries are commonly used in TWS charging cases and are normally supplied by the battery manufacturer. To provide more stable battery operation, the power meter and secondary protection IC package have already been incorporated. A single-cell lithium battery's power supply is split into two parts: one is boosted to 5V to power the headphones, while the other at 3V and lower to power the rest of the device.

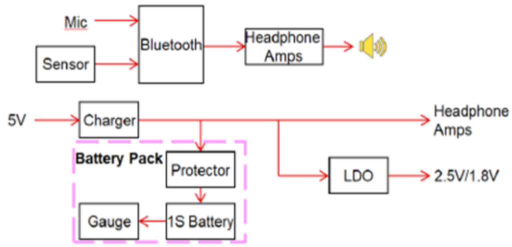

Fig. 6. Electrical product architecture of the headphone

1) Bluetooth Architecture/Protocol Stacks

The Bluetooth chip is in charge of receiving data provided by the phone in the signal chain and pushing it to the headphones through the earpiece. The sensors are mostly gravity sensors that detect signals like the headphones shaking. The headset can no longer be utilized as a power supply port for the micro-USB interface in the power rail due to its limited area. Typically, the headphone input is replaced by a metal contact patch. Because the 5V charging case provides power to the headphone input, there is no risk of overvoltage, and it may be used without overvoltage safety (we can charge a single lithium battery directly with the charger). Bluetooth is a very important technology in recent generations, spanning its importance in all sectors ranging from communication to hardware. At the heart of this standard procedure lies the possibility of innovation. The Bluetooth has a way in which it operates which is stated by the protocol it follows. A protocol stack's layers again communicate the possibility of a Near Field Communication (NFC) channel. From a low-level system engineering to a high-level output driven topology optimization is necessary to reduce error associated with such hardcore technological parameters. The lower aspects refer to the ease of efficiency in which Bluetooth works, that is, it has a certain efficiency and time to operate. The Bluetooth protocol stack's formulation is either in the radio layer, or in the preferred module. The radio layer describes the required physical characteristics of the transceiver.

2) Lower-layer Stacks

It is generally responsible for various kinds of modulation and demodulation for transmission and reception across 2.4 GHz radio bands. This is the general manifestation of physical output. It uses rapid frequency sinusoidal hopping (1600 hops/sec) to divide the transmission spectrum into 79 distributed channels for security. Above the aspect radio layer is the baseband and the link which attach to the hardware. The baseband is in charge of properly organizing the data for effective transmission, which is perhaps the most efficient way to think about the various levels mentioned earlier. It specifies the flow of information, timing and preciseness of signal, framing of stacks, and other packets of data. By translating the top stack's host controller interface (HCI) commands, the link, also responsible to parallel and perpendicular distribution flow, creates and maintains the link. It plays a big role for maintaining the connection, ensuring fairness among the piconet's slaves, and regulating power.

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3) Upper Stack Layers

The top stack tiers' profile requirements focus on what are the essential and required aspects to generate estimates that are required for proper iteration efficiency. The central processing system serves as a link between the software and hardware of the system (i.e., the control bus). The L2CAP (logical link control and adaptation protocol) layer is a very important component for smoothness of data transfer. It plays a crucial role in communication between the Bluetooth stack's higher and lower layers, among all other things. It keeps track of where data packets come from and where they should go. It's an integral part of any Bluetooth system irrespective of the system. Above the L2CAP layer, the central bus protocol layer is not as neatly organized. Nonetheless, the service of distributed networking exists.

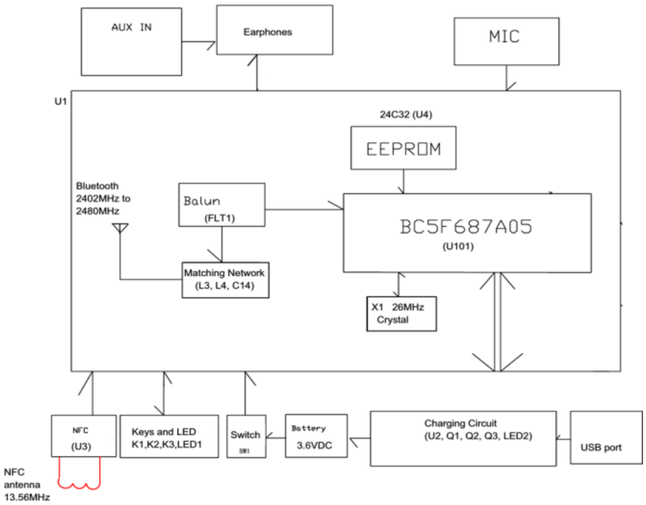

Fig. 7. Bluetooth protocol block diagram of headphone system

4) Profiles for Bluetooth Protocol

A protocol is set a relevant standard information that can used to generate a data architecture suitable for Bluetooth design. Depending on the types of devices linked and their objectives, many profiles exist. Various protocols are followed to implement the kind of Bluetooth technology we want to implement. It has an enormous possibility when Near Field Communication (NFC) is taken into consideration. Charging box is separated from the battery mainly because to eliminate the scenario in which the device is unable to play music while it is in charge condition. Bluetooth system designed is connected to the common bus through multiparous portal where there can be two-way flow of signal. This is a basic protocol feature of Bluetooth assessor. The chipset forms the heart of the common bus controlling and modulating various parameters like- streaming, cordless phones, wireless controllers for game stations, in-car calls & audio and others.

E. Detail Design Phase (Phase 4)

Over-the-head and Behind-the-head are two popular headband structures. For the Over-the-Head type, which again comes to the fact that for something to be design, either the solution space or the solution criteria (or both) must be ill defined. The structural shift causes a biannual knob deficiency which can be optimized by taking into account a lot of other factors like parametric attenuations, causal issue error and structural effective void. The chassis forms the holding arm which holds both the earcups in positions. Through topology optimization a prismatic shape of the chassis can be obtained which would minimize compliance and maximize flexibility of the structure. The criteria are unambiguous, if the egg is uncracked, the design is good.

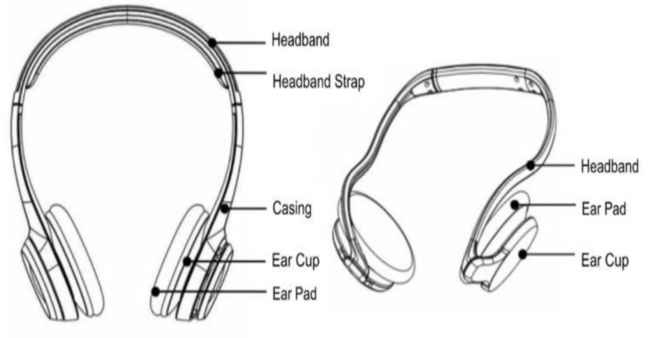

Fig. 8. Detail design of headphone chassis (left- overhead style, right- behind-the-head style)

The headband of a Behind-the-Head headphone (Figure 10 (b)) is shaped to encircle the back of the user's head. As a result, the headband does not exert any force on the user's head. This style of headset has the potential to enhance your experience. However, this style of headset might put a strain on the user's temples 2. Regardless of headband design, the burden on the user's head should be adequately divided or reduced so that listeners do not experience excessive weight or strain when wearing the headphones. As a result, the headphones' design should allow listeners to use them comfortably and easily for a lengthy amount of time.

(1) Functional Decomposition

Customers are increasingly demanding high-quality, dependable headphones from businesses. Manufacturers are finding it more challenging to maintain quality and dependability while reaching cost targets as headphones' capabilities and usefulness grow. Reliability has traditionally been accomplished by thorough testing and the application of approaches like probabilistic reliability modelling. These are, nevertheless, approaches used in the latter phases of development. It may be difficult to evaluate a product early in the development cycle.

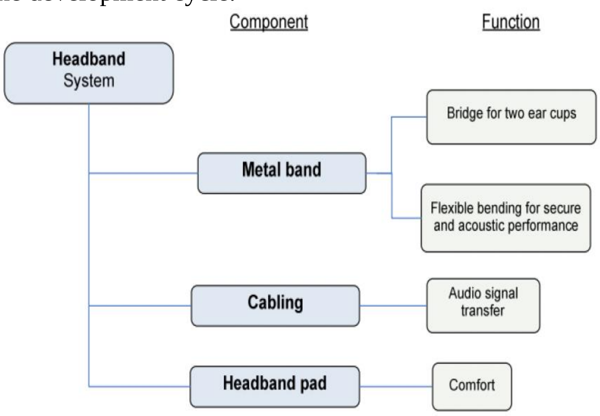

Fig. 9. Functional decomposition of headphone

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Attenuation control in headphones is affected by the constriction and details used in various components of the assembly, such as the ear cup, foam lining, and headband force. It depends on our needs and what type of headbands we are looking for. It can be recommended the ones used for active sports and physical fitness. Research have found the best selection and price comparison is using the internet. We can skim through Amazon or eBay to pick the best ones that match our choice of size, style, pattern, color, and material. We can also take into account the local sports shops or larger known franchised department stores, but our selection may be more limited. However, at least you can try them on and see what they look or feel like in person. Users will want to reduce this force in real-world situations, making the protection more comfortable while simultaneously driving the headband outwards. It appears that determining the end user's comfort level based on headband clamping force is always a challenge. Because "comfort" is a subjective and difficult to quantify concept, the footwear industry has created a number of pressure mapping algorithms to aid in the prediction of optimal comfort levels [9]. That is very subjective. Everyone has a different preference. Some people like fluffy but squishy like down. Some like firmer. Some people like hard slabs. So, there is no one best. However, an overwhelming latex pillow earbud technology mainly because of the cost associated with firmness fiberfill. It uses sleep modules with one pillow for earbud. I sleep with two. In line with EN352-1, the headband force is measured using a traditional head frame [16]

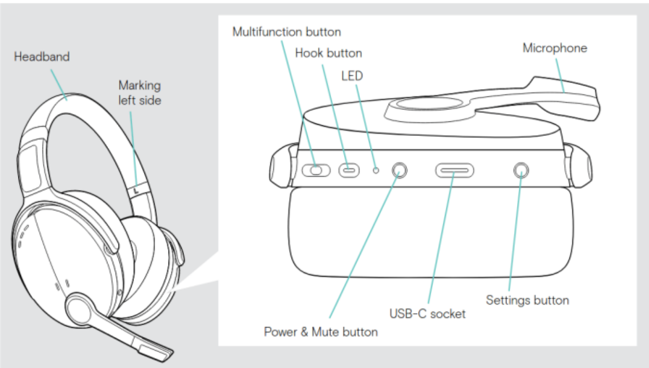
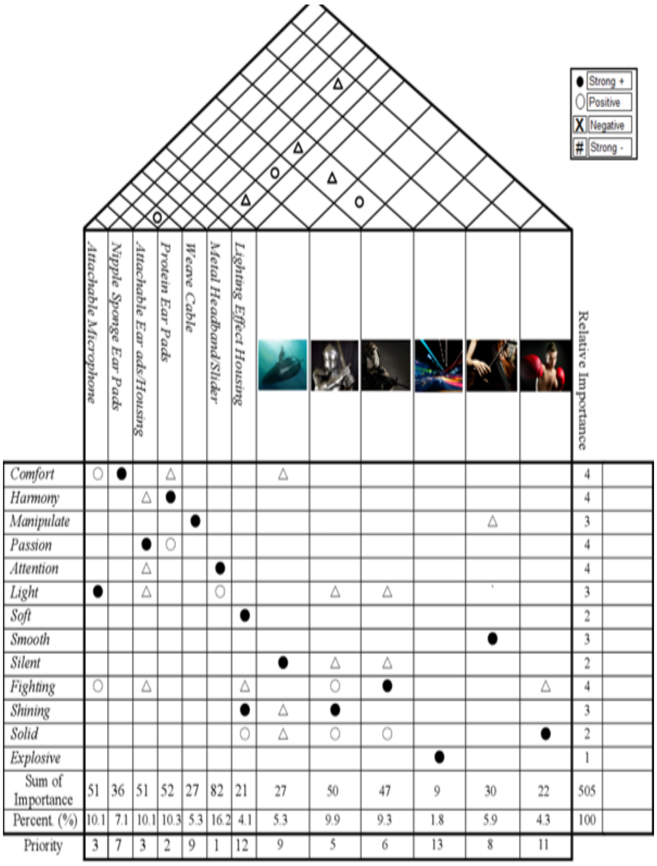


Fig. 10. Incorporating electronic circuit system to the structure

The latter was one of the crucial photos in the Replication ZMET, and it appeared at stage 3. As shown in Figure 6, the HOQ results give helpful information for the industrial designer to rank both functional and cosmetic characteristics in a simple yet systematic manner. Because industrial design is a visual rather than a verbal or mathematical profession. Visual metaphor may help a designer produce an acceptable form for conveying the functions and meanings that e-sports headphones users require and desire when using the product. The designer can use the HOQ to assist them prepare for design standards. Image quality of connected items is critical in conveying key values and meanings in usage situations. Because their major task is to generate acceptable shape for products, industrial designers want helpful visual tools to listen to the VOC. The Replication ZMET and QFD were combined in this study to capture what the e-sports gamer desired and required through a series of visual-oriented processes. As an example, product planning for an e-sports headset was shown.

(2) Quality Function Deployment (QFD)

Relates the customer's voice to the engineering characteristics of the headphone. Metal Headband/Slider (16.2 percent) was ranked #1 among non-visual design features, followed by Protein Ear Pads (10.3 percent), Attachable Ear Pads/Housing (10.1 percent), and Attachable Microphone (10.1 percent), all of which were equally significant. The Armoured is one of the visual design characteristics. The Warrior (9.9%) had the highest priority, followed by the Modern Armoured Soldier (9.3%). As these two pictures have a medium inner connection (+3), as shown in the Roof Matrix. Furthermore, the intrinsic link between Protein Ear Pads and Attachable Ear Pads/Housing was moderate. Visual features of the Armoured Warrior were good metaphors since they shared a medium inner relationship. Metal Headband/Slider has several sources. Light Beams (1.8%) and Lighting Effect (1.8%) are noteworthy. The final two priority (4.1 percent) were housing and education, but the former was a novel notion.



	Attachable Microphone	Nipple Sponge Ear Pads	Attachable Ear ads/Housing	Protein Ear Pads	Weave Cable	Metal Headband/Slider	Lighting Effect Housing							Relative Importance	
Comfort	○	●		△				△						4	
Harmony			△	●										4	
Manipulate					●							△		3	
Passion			●	○										4	
Attention			△			●								4	
Light	●		△			○			△	△				3	
Soft							●							2	
Smooth												●		3	
Silent								●	△	△				2	
Fighting	○		△				△		○	●			△	4	
Shining							●	△	●					3	
Solid							○	△	○	○			●	2	
Explosive											●			1	
Sum of Importance	51	36	51	52	27	82	21	27	50	47	9	30	22	505	
Percent (%)	10.1	7.1	10.1	10.3	5.3	16.2	4.1	5.3	9.9	9.3	1.8	5.9	4.3	100	
Priority	3	7	3	2	9	1	12	9	5	6	13	8	11		

Fig. 11 Quality Function Deployment (QFD) of headphone

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DOI: 10.35940/ijrte.F7462.0712223
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F. Testing Phase (Phase 5)

1) Simulation Test Results

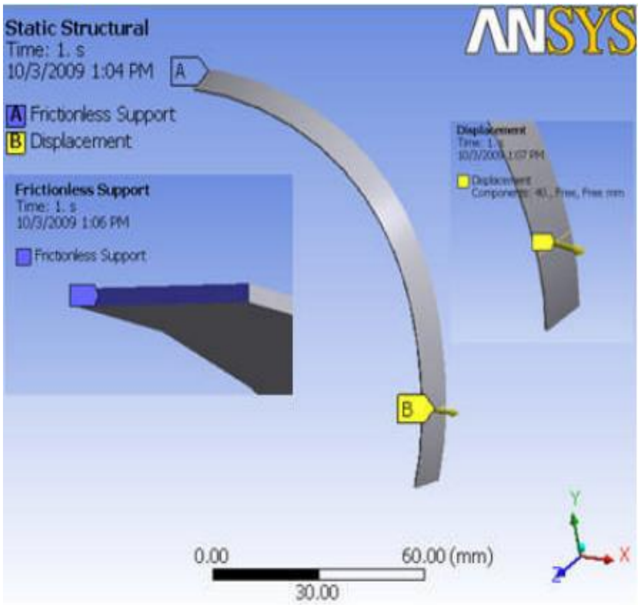

Fig. 12. Ansys static structural boundary condition

Table. 3.1 Clamping forces for each set

Set	Thickness (mm)	Tensile strength (Mpa)	Clamping force (N)
1	0.7293	1040	6.42
2	0.8	1040	8.47
3	0.87293	1040	10.913
4	0.8	804	9.14
5	0.8	1276	7.96
6	0.75	873	7.28
7	0.75	1207	6.71
8	0.85	873	10.59
9	0.85	1207	9.77
10	0.8	1207	8.15

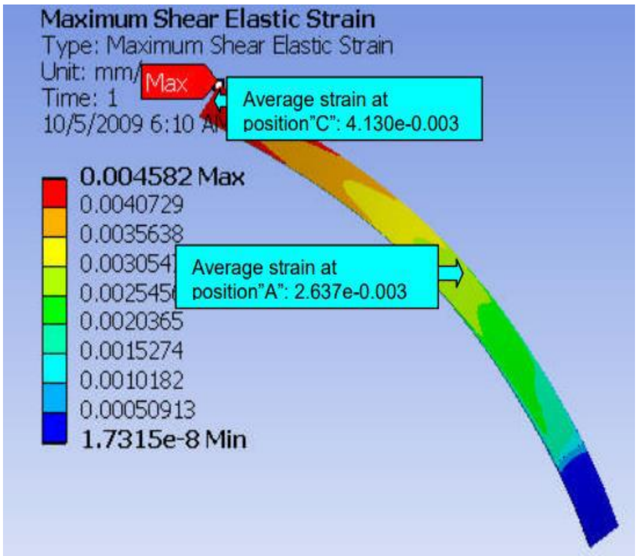

Fig. 13. Maximum shear stress (top side of chassis)

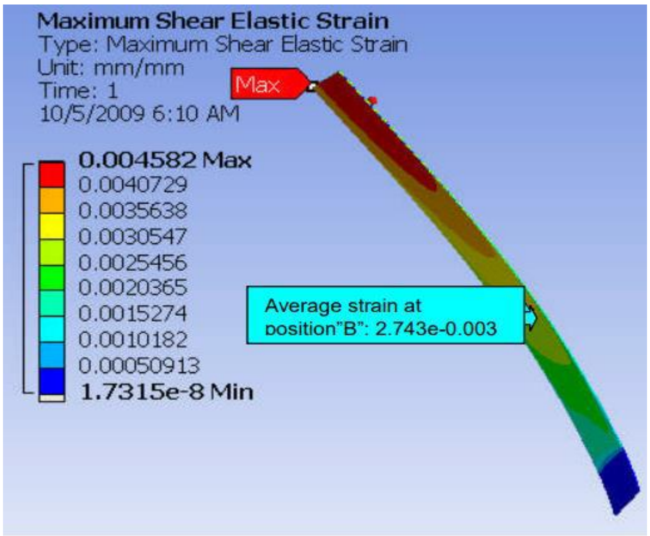

Fig. 14. Von-misses stress distribution

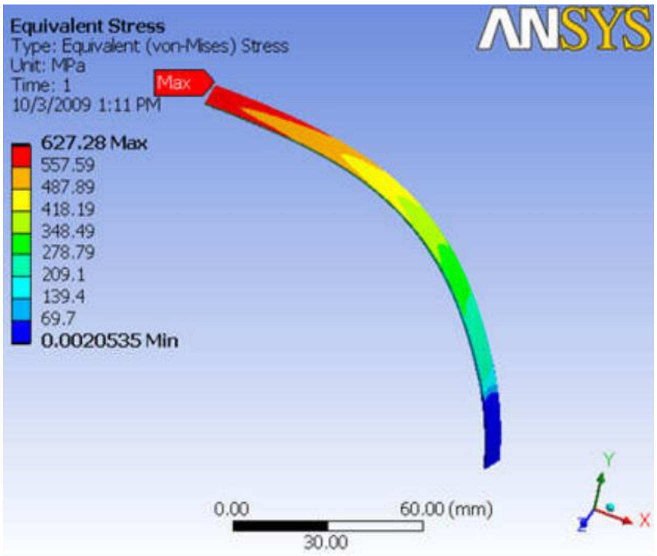

Fig. 15. Maximum shear stress (bottom side of chassis)

2) Optimal Solution Analysis

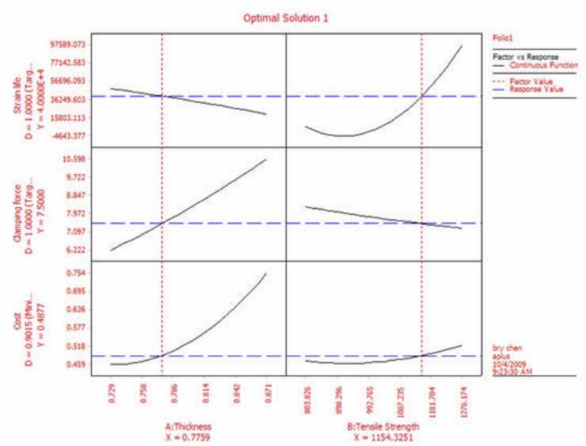

Fig. 16. Headband design with optimal weight of 0.2 for clamping force and 0.4 for fatigue life

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There are a number of analysis methods, procedures, processes that should be realized. Different methods are applied to certain loading conditions and structural systems. Depending on the load type and the configuration of the structure, a static linear analysis procedure, for instance, is applied to simple, stationary, and ordinary structural systems. Loads can be static, dynamic, or instantaneous. The reactions take different forms: shear, moment, stress, etc. It takes a long time to figure out an analysis model of a system to provide these demands in a simple form that depicts the structural system. The values of the demands cannot be arrived at by simple analysis for complicated multi-story, indeterminate, and critically weak structures. Computer software based on the matrix method of analysis or finite element analysis produces thousands of output values that need to be validated for correctness. The RBTO concept is beneficial for reducing construction weight in similar scenarios. Both deterministic and reliability-based design optimizations can benefit from this weight reduction. The optimum topologies that emerge from the RBTO model are more trustworthy than deterministic topologies for the same structural weight (but associated with larger compliance values). The second benefit is that RBTO introduces a novel technique. The second benefit is that RBTO introduces a novel technique for creating various topologies with varying goal dependability levels. This study can be used for a number of topology optimization procedures, including the homogenization strategy. In order to account for the unpredictability of compliance, densities, and element dimensions, additional limit state functions can be implemented. After completing this tedious and complicated part of analysis, the design stage follows. It is so tiresome but innovative that lead to selection of member cross sections of the structural system. Different design methods are utilized. Depending on the limit state of the material strength and behaviour, the design method is selected. The limit states include: working, crack, yield, nonlinear, and ultimate. Each structural system is designed according to its maximum and desired limit [2 3, 5]. A wood member is designed to its working stress state; a swimming pool is designed to its crack limit; a parking lot slab is designed to its working stress limit; and concrete and steel are designed to develop their ultimate states. Depending on the member strength capacity, the design is intended to utilize its ductile behaviour. In reinforced concrete, the design requires that you look at the moment-curvature relationship to evaluate its limit states and the development of plastic hinges that are needed to dissipate seismic and large forces. These relationships can be obtained by computer software but require extensive experience to interpret.

IV. RESULTS

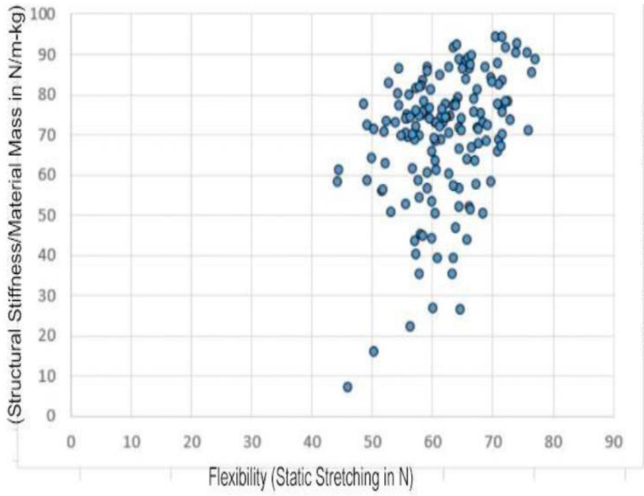

Fig. 17. Structural Stiffness/Material Mass vs Flexibility

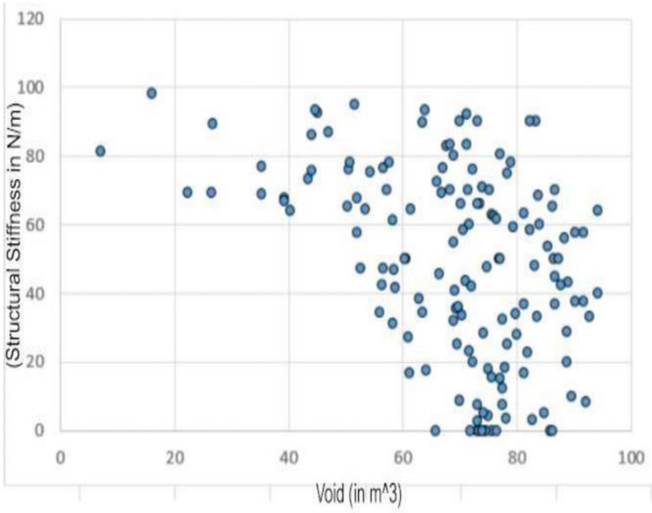

Fig. 18. Structural Stiffness vs Void Space

Scatter plots were generated, as shown in Fig 19, between Structural Stiffness/Material Mass ((measured in N/m-kg), and along Y-Axis) and Flexibility, as in Static Stretching ((measured in Newton), and along X- Axis) which reflects that an increase in Structural Stiffness/Material Mass ration increases the flexibility of the design. An intuitive explanation of this could be, with increase in Structural Stiffness/Material Mass ratio, the void space increases and subsequently an increase in void space gives the overall structure greater bending space contributing to increase in flexibility Another scatter plot (Fig.20) was drawn between Structural Stiffness ((measured in N/m), and along Y-Axis) and Void Space ((measured in m^3), and along the X-axis) which states that as the void space is increased the structural stiffness gets reduced if the amount of mass is kept constant. An intuitive explanation could be, if the mass is kept constant, the net material remains constant. With an increase in void space, the overall spread of the material would be high which would increase the likelihood of failure at far away radial distances, making the material prone to lower structural stiffness.

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It was interesting to realize that Structural Stiffness/Material Mass (measured in N/m-kg) increases with Void Space (measured in m^3), and along the X-axis) to a certain level and then starts decreasing as shown in Fig 4 basically bursting the myth that higher the Structural Stiffness/Material Mass ratio higher the Void Space. In reality, the maximum Void Space for highest Structural Stiffness/Material Mass ratio is 23% and one percent change (increase or decrease) tends to reduce the Structural Stiffness/Material Mass ratio by 3% (relevant for headphone design).

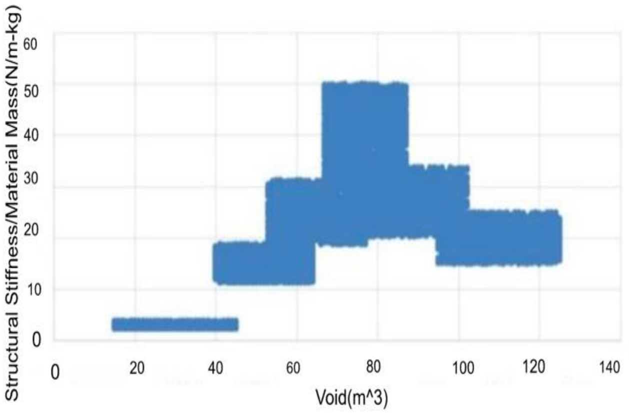

Fig. 19. Plot of Structural Stiffness/Material Mass vs Void Space

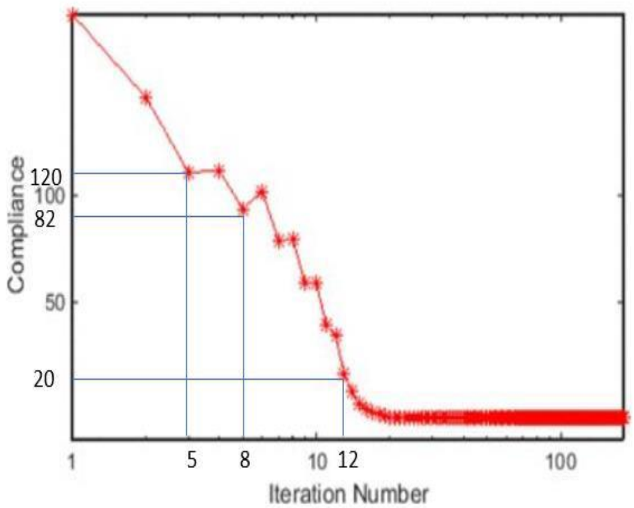

Fig. 20. Plot of Compliance vs Iteration Number

Two important points from the compliance vs iteration number table:

- As the iterations are progressed, the compliance of the system is reduced which directly minimizes the objective function in the question
- As the compliance reduces, the structure's flexibility increases (flexibility is inversely proportional to compliance) which enhances the load handling capability of the structure.

V. CONCLUSION

To produce next-generation high-performance, multi-functional, and lightweight structures, topology optimization and additive manufacturing are coupled in a powerful approach. While developing a new headphone design, structural optimization design approaches for Additive Manufacturing and related applications have been researched in recent years. Topologically optimised structures can meet Additive Manufacturing design guidelines without requiring additional structural adjustments during the reconstruction process. Additive Manufacturing structural optimization is and will continue to be a prominent topic. In addition, more study is needed to optimize and build practical industrial structures. The influence of the Additive Manufacturing technique on material anisotropy and fatigue performance, as well as the design and fabrication of FGM and sophisticated multi-material functional systems, are all research concerns.

FUTURE PERSPECTIVE

In the future, it can be hoped that we will achieve material optimization where the material properties will be brought into the constraint parameters. Some data-driven methodologies suited for additive manufacturing would be the best choice to ensure optimal material optimization, as the computing speed of using traditional tools is not suitable for this purpose. In this research, recent progress in applying data-driven methodologies to Additive Manufacturing design is explored from several angles. In cases of topology optimization, the structure can be considered to be made up of structural members and joints. The forces in the individual members (generally axial loads, bending moments, and shear forces) are worked out by carrying out structural analysis, considering intended loads and load combinations. The structural analysis is based on different theories of physics, experimental analysis, and the properties of materials. Now a days excellent computer programs are available for structural analysis. Different countries have adopted different codes of practise for the design of structures. Such codes specify safety standards (maximum permissible stresses, factors of safety, etc.) and standards for serviceability (maximum permissible deflections, etc.). The design involves the selection of the right material (like concrete, steel, carbon fibre, etc.) and working out the optimum cross section for all the members involved in the system so that the cost of the entire structure is the least. The members are designed for the forces on them as per the structural analysis. The cross sections of the members are made optimal by using shapes and dimensions efficiently. The members can be prefabricated or fabricated at site, or cast as per the shape and size at site (like members of concrete). It also involves the design of joints where the members are connected.

DECLARATION

Funding/ Grants/ Financial Support	No, I did not receive any financial support for this article.
Conflicts of Interest/ Competing Interests	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	No, this article does not require ethical approval and consent to participate with evidence.

Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	All authors having equal contribution for this article.

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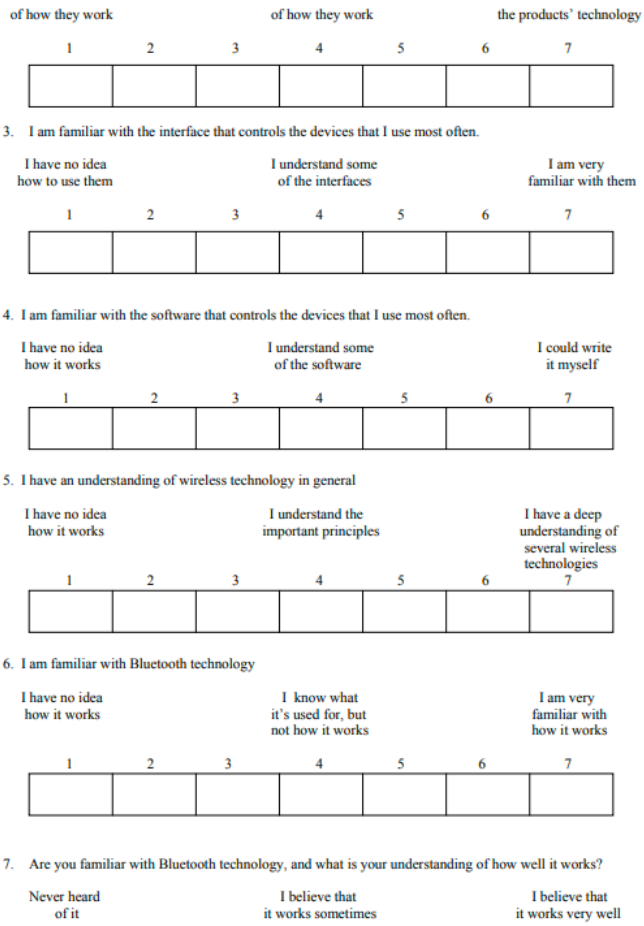
APPENDIX 1.

	The Computer System Usability Questionnaire Version 3	1 (Strongly agree)	2	3	4	5	6	7 (Strongly disagree)	NA
1	Overall, I am satisfied with how easy it is to use this system.	○	○	○	○	○	○	○	○
2	It is simple to use this system.	○	○	○	○	○	○	○	○
3	I am able to complete my work quickly using this system.	○	○	○	○	○	○	○	○
4	I feel comfortable using this system.	○	○	○	○	○	○	○	○
5	It was easy to learn to use this system.	○	○	○	○	○	○	○	○
6	I believe I became productive quickly using this system.	○	○	○	○	○	○	○	○
7	The system gives error messages that clearly tell me how to fix problems.	○	○	○	○	○	○	○	○
8	Whenever I make a mistake using the system, I recover easily and quickly.	○	○	○	○	○	○	○	○
9	The information (such as online help, on-screen messages, and other documentation) provided with this system is clear.	○	○	○	○	○	○	○	○
10	It is easy to find the information I needed.	○	○	○	○	○	○	○	○
11	The information provided with the system is effective in helping me complete my work.	○	○	○	○	○	○	○	○
12	The organization of information on the system screens is clear.	○	○	○	○	○	○	○	○
13	The interface* of this system is pleasant.	○	○	○	○	○	○	○	○
14	I like using the interface of this system.	○	○	○	○	○	○	○	○
15	This system has all the functions and capabilities I expect it to have.	○	○	○	○	○	○	○	○
16	Overall, I am satisfied with this system.	○	○	○	○	○	○	○	○

Usability Testing Sample Questions (Standard Format

APPENDIX 2.



Usability Questions for Bluetooth Protocol

AUTHORS PROFILE

Soutrik Mukherjee, I'm a graduate student in the Mechanical Engineering and Applied Mechanics (MEAM) at the University of Pennsylvania, School of Engineering and Applied Sciences specializing in robotics. I have received several accolades for my academic endeavors including the Gold Medal of Academic Excellence for securing 1st position in my department. My passion lies in Design and Manufacturing, Solid Mechanics, Vibrational Analysis, and Structural Engineering and my research interests include Robotics, AI, and Computer Vision. I have gathered the required expertise in Vibrational Analysis, Modal Testing, and Finite Element Methods to analyze designs through research internships and industrial freelancing. I also had the golden opportunity to intern at IIST (Indian Institute of Space Science and Technology), the space-tech wing of ISRO, on "Numerical Studies of Laminar Fluid Flow".

Kadambari R Vaikkat, I'm a final-year bachelor's student in Industrial design at the National Institute of Technology Rourkela. My interest lies in mechanical design and analysis, and my passion is to provide and support the needed facilities in my country, which drives me to learn the complete engineering design aspects to formulate tools and environments for a faster and more sustainable community. I have worked at the Healthcare Innovation Technology Center at the Indian Institute of Technology Madras Research Park as a mechanical design intern, where I designed tools that assisted the robot in spine surgery procedures. Currently, I'm working on the Rotodynamic Analysis of Cryogenic Turbopumps Rotor Supported by Metal Foil Bearing in Ansys as my undergrad thesis. The study aims to comprehend the mode shape, critical speed, unbalanced response, and orbital plot of a rotor supported by a metal foil bearing to understand the impacts and effects of other parameters on vibration.