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REVIEW ARTICLE

Effect of vibration analysis towards dynamic properties in dissimilar joining materials: A review

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ABSTRACT - This paper presents a comprehensive overview of vibration analysis in structures comprising dissimilar materials, highlighting the challenges and opportunities associated with various joining techniques and material selection. By exploring the impact of different joining methods on vibration performance, including factors such as structural design and dynamic characteristics, it synthesizes diverse methodologies employed in research on vibration analysis for jointed structures. Additionally, it explores the factors influencing the vibration performance of dynamic structures, focusing on structural joining techniques, material properties, and analytical methods. Through a systematic review, the study categorizes dissimilar joints into mechanical, thermal, and chemical joining processes, offering insights into their impact on vibration behavior and microstructural dynamics. By synthesizing research findings and methodologies, the paper underscores the significance of integrating experimental and numerical analyses to optimize the vibrational performance and reliability of joint structures, especially when dealing with dissimilar materials. This collaborative approach not only enhances predictive accuracy but also offers a deeper understanding of the intricate dynamics of jointed systems, fostering advancements in structural engineering and materials science. The paper also discusses the application of Finite Element Model Updating (FEMU) methods in vibration analysis to reduce uncertainties in model assumptions and enhance accuracy. FEMU involves iteratively refining numerical models to align with actual structural behavior, crucial for design, construction, and engineering applications. Various FEMU methods, including sensitivity-based approaches, iterative optimization, Bayesian techniques, and computational intelligence algorithms, offer effective means to update finite element models and minimize discrepancies between predicted and observed structural behavior. Despite computational challenges, these methods provide valuable tools for optimizing design and operational parameters in vibration analysis, advancing structural reliability and precision.

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1. INTRODUCTION

In the modern era, the escalating demands for efficiency and specific vibrational properties in structures composed of dissimilar materials have garnered considerable attention in the automotive, aerospace, and civil engineering fields. The study of vibration analysis has evolved into a substantial subject within the realm of research, as manufacturers strive to enhance structural integrity, performance, and reliability for joining materials. Vibration analysis emerges as a powerful tool in unraveling the intricate symphony of forces and interactions within joined materials, providing crucial insights into the performance and durability of designed structures. The study of vibration analysis in dissimilar materials poses challenges and opportunities that necessitate a profound understanding of their dynamic properties.

Vibration analysis is the study of mechanical oscillations of an object about its rest position, and it has long played an important role in early-stage optimization, engineering testing, and structural evaluations [1, 2]. These vibrations initiate from external environmental forces or internal mechanical collisions and subsequently manifested as the dynamic response of various structure components [3-5]. According to [6, 7], a comprehensive dynamic analysis system consists of three fundamental elements: excitation, the mechanical system, and response. Among these, response is the most easily measurable in practical applications, as it provides valuable insights into dynamic loads and structural characteristics. Consequently, the identification of desired vibration characteristics is often hindered by the materials of structures and the challenges associated with effective joining, leading to difficulties in analysis.

In the pursuit of lightweight structures, the joining of different structural components serves a dual purpose: meeting weight reduction demands and contributing to vibration damping. According to references [8] and [9], joining involves connecting multiple components using various techniques to create a functional assembly. Additionally, the review paper cited in references [10-12], explores the challenges, advancements, and practical considerations associated with joining dissimilar materials in the context of automotive lightweight technology. In dynamic structures, the choice of joining technique significantly impacts overall stability and strength. Whether it's plates, beams, trusses, or columns, the

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components must form a cohesive system capable of withstanding external loads and forces. Dynamic structures commonly utilize mechanical fastening methods including welding, riveting, bolting, and adhesive bonding. The choice of a suitable joining method depends on material properties and dynamic characteristics such as damping ratios, natural frequencies, and mode shapes play a crucial role in joint design [13]. Structural joints have the potential to alter dynamic properties, offering opportunities for enhancing overall performance.

Apart from enhancing structural joining and conducting performance studies, researchers have evaluated the suitability of various materials for use in structural design and their pivotal role in improving dynamic vibration performance [14, 15]. Numerous alternatives to traditional metals have been investigated as engineered manufacturers' trend toward lightweight structures continues. These studies aim to understand the reliability of lightweight materials and provide insights into overall structural behavior, ultimately contributing to better dynamic performance in structures [16]. The utilization of dissimilar lightweight alloys, including different series of aluminum [17] and aluminum-magnesium [18, 19], has also been thoroughly reviewed to comprehend their significance in optimizing structural performance.

While this study primarily focuses on the vibration analysis of dissimilar materials joined together, researchers have also delved into other areas such as modeling techniques for structural tests. These studies aim to enhance the design and application of structural tests, with reliable simulations playing a crucial role in advancing the manufacturing industry within the structural domain. Although the main emphasis has been on the vibration analysis of joined dissimilar materials, the optimization of dynamic performance in test structures has been scrutinized from various perspectives and criteria. Experimental testing, along with analytical and numerical modelling, is commonly used to comprehend the impact of different joining methods towards structural vibrations. Experimental analysis enables the acquisition of data that would otherwise be unattainable and is vital for validation. In numerical studies of test structures, modeling issues related to various structures, such as plate structures with different types of joining and uncertainties in metal structures, are of significant concern. Optimization strategies for test structures, including joining models and structural configurations, have been extensively discussed by researchers, as covered in Topic 3.

In recent times, research on vibration has gained significant popularity among scholars, with a specific focus on its performance influenced by structural geometry, material composition, and structural analysis. According to the Web of Science database, a substantial amount of research has been conducted in vibration analysis for joint structures over the five years from 2019 to 2023. Figure 1 illustrates that approximately 1000 publications have emerged in this area, with 17 of them identified as review papers. Additionally, Figure 2 indicates a noteworthy influx of new researchers entering this field, as evidenced by the increasing number of citations. The trend suggests heightened interest in this research, particularly in the years 2022 and 2023, as depicted in Figures 1 and 2.

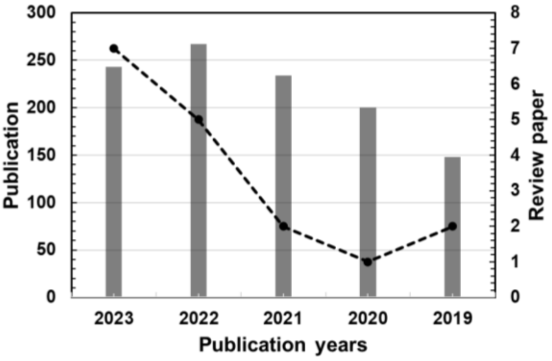


Figure 1. Total of publications versus review paper

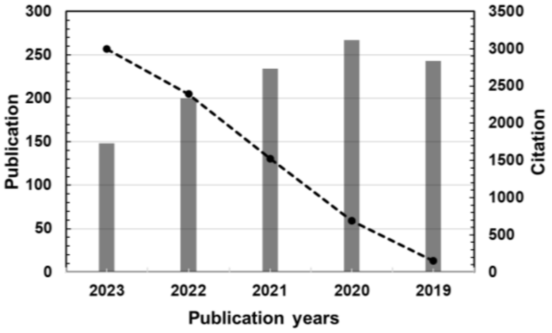


Figure 2. Total of research publications versus citations

This paper provides an overview of research on vibration analysis in joint structures consisting of dissimilar materials. The review examines various factors influencing the vibration performance of dynamic structures, including structural design, advancements in joining techniques, and materials selection. Additionally, the paper briefly explores other relevant aspects, such as experimental and numerical modeling, along with a brief discussion on optimization approach to enhance the accuracy of dynamic behavior analysis. The primary objective is to summarize the diverse approaches and perspectives researchers have undertaken in studying vibration analysis for joint structures.

2. FACTORS AFFECTED THE VIBRATION PERFORMANCE

This section presents a review of published works that explore factors affecting vibration performance on dynamic properties, with a focus on structural joining, structural materials, and structural analysis. Vibration analysis, a technique that has been utilized for decades across various industries, aims to enhance the dynamic properties of structures. The literature survey reveals that most studies on vibration performance concentrate on the dynamic properties of dissimilar joint structures. In this study, a classification system for dissimilar joints is proposed by the researchers based on the joining techniques and underlying joining mechanisms:

Group I – Dissimilar joints with different base materials for the mechanical joining process

Group II – Dissimilar joints with different base materials for the thermal joining process

Group III – Dissimilar joints with different base materials for the chemical joining process

The works are categorized based on base materials and joining techniques for dissimilar structures, as proposed in this study as shown in Table 1. The literature review encompasses dissimilar materials with different joining methods, including Aluminum alloys, Magnesium alloys, various steel grades, and, Copper as well as carbon-fiber-reinforced polymers (CFRP) and other composite materials. The review primarily focuses on the vibration behavior concerning the natural frequency and damping mode of dissimilar joints, along with the microstructural behavior, including fatigue, failure, and corrosion behavior of the structure. Earlier studies have identified three key factors that affect the effectiveness of vibration analysis to enhance the accuracy of dynamic properties, as depicted in Figure 3.

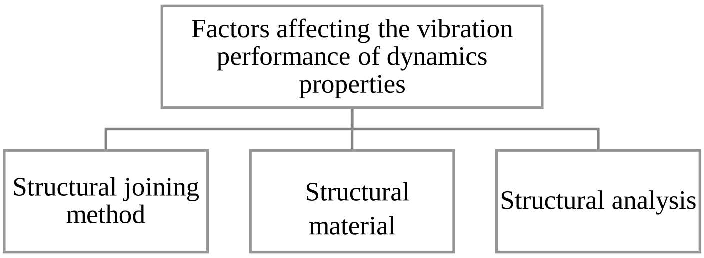


Figure 3. Factors affecting vibration performance of dynamic properties

2.1 Structural Joining Method of the Test Structure

The exploration of vibration analysis in structural joining has emerged as a focal point in contemporary research within the fields of engineering and materials science. The review of structural joining, based on materials and types of joining, has been divided into three (3) groups, as discussed in Topics 2.1.1 to 2.1.3, with the summary presented in Table 1. The necessity to join novel and dissimilar materials in the transportation industry requires alternative joining methods to meet functional demands and overcome technological limitations. Indeed, it is typically impossible to manufacture a product without some form of joining. The joining process is essential in manufacturing to ensure product functionality and increase the efficiency of the manufacturing process. The development of advanced materials and the pursuit of lighter, more reliable structures are key strategies to address the challenges associated with joining [20, 21]. Both studies emphasize the importance of selecting suitable welding techniques and optimizing process parameters to effectively address the challenges of joining dissimilar materials like aluminum and steel, particularly in the context of advancing material development and achieving lightweight, reliable structures. The selection of a joining process for dissimilar materials is more complex compared to similar materials due to differing chemical and physical characteristics. Mechanical fastening, primarily bolting and riveting, has been widely utilized in dissimilar structures. However, these methods contribute to increases in weight and limitations in the structure’s geometry, primarily due to the accessibility of the fasteners [22, 23]. Consequently, alternative structural joining methods can be employed to overcome conventional limitations, including various solid-state welding techniques such as friction stir welding [24], chemical joining methods like adhesive bonding [25], and hybrid joints that strategically combine mechanical, thermal, and chemical approaches to enhance joint performance and reliability [26].

Dynamic excitations frequently influence the operating performance of mechanisms and structures,particularly in the vibration of structures. As integral and essential components of structures, it is crucial to understand the role of structural joints in overall dynamic behavior. These joints can change key dynamic properties, such as, natural frequencies, damping, and mode shapes, which can significantly enhance structure performance. Among the various types of structural joints examined in this study, bolted joints, rivet joints, friction stir welded joints and adhesively bonded joints have been widely investigated over the last three decades [27, 28].

In recent years, the focus of many studies has been on the analytical and numerical modeling of the effects of joining properties on the vibration behavior of structures. Qin *et al.* [29] were among the first to develop an analytical model for a bolted joint structure within a simple rotor systems connected via disc-drum joints. Another significant contribution to the development of an analytical model of bolted joints in transient excitation was made by Xin *et al.* and Jamia *et al.*[30, 31] Specifically, Kim *et al.* [32] discussed the application of four different bolt models in finite element simulations to analyzed the vibration behavior of bolted structures. Wang *et al.* [33] developed, investigated, and validated the vibration characteristics of bolted joints using both experimental and theoretical models. Additionaly, Liu *et al.* [23] introduced a semi-analytical model to study the impact of bolt loosening on the natural frequencies of bolted composite plates, while Hammami [34] developed an analytical approach to investigate the behavior of bolted joints in designing structures. In addition to these, significant research has been conducted on modeling welded joints for vibration analysis. Zahari *et al.* [35, 36] studied the vibration behavior of friction stir welded plates and refined finite element models through model updating. Gharehbaghi *et al.* [37] discussed the influence of residual stresses on the natural frequencies of welded structures. Additionally, Shah *et al.* [38] studied the structural properties of laser stitch welded joints, focusing on natural frequencies and mode shapes. This body of work collectively advances our understanding of the complex dynamics of joined structures.

The influence of structural joints in enhancing the damping of structures is a significant aspect of modern joining techniques. Extensive research has been conducted on how various joint types, including bolting, riveting, welding, and adhesive bonding, affect structural damping. Al-Habibi *et al.* have discussed various methods and apparatus for measuring damping [39], studied the estimation of damping in different materials [40], and investigated the damping behavior of hollow beams connected through bolts, rivets, adhesives, and brazing using flexural vibration analysis [41]. Similarly, Ansari *et al.* [42] have studied the effect of rivets on the damping of layered cantilever beams, while other researchers have contributed valuable insights into the vibration and damping characteristics of bolted structures [43-45]. Researchers have categorized the details of their findings into specific groups to gain a comprehensive understanding of the aforementioned effects.

2.1.1 Group I - Mechanical joining process

The practice of joining using threaded fasteners or screws for one-sided joining has been widely used. However, when used with dissimilar base materials, this process presents certain limitations and problems compared to those with similar materials. These issues can be mitigated through the use of combinations of bolts and nuts, as well as riveting. These methods allow access to the joint from both sides of the components being joined. The mechanical joining process between dissimilar materials can help reduce vibration amplitude and maintain the structure’s strength and shape during vibrations. This group is further categorized into two: vibration behavior, which includes natural frequencies and mode shapes, and microstructural behavior, which covers fatigue, failure, and corrosion.

In their research, Rani *et al.* [46] employed bolts to join two Al6061 plates. They proposed a simplified finite element model for the bolted structure and used an optimization method to enhance the accuracy of dynamic behavior predictions. The study yielded a 95% accuracy in predicting dynamic behavior. In a subsequent study by the same author, the same materials were used for both plates, but with different geometrical shapes - an oblong hole and a bar shape. Thin Layer Elements (TLE) were utilized as a contact surface of the bolted structure. The differences in the geometrical shape of the structure are illustrated in Figure 4. The study concluded that the model and TLE effectively represent the bolted joints of the assembled structure [47]. Meanwhile, Xing *et al.* [48] used bolted flange joints to analyze vibrations in structures composed of multiple steel plates. They proposed a mathematical model for analyzing the results, using the Rayleigh-Ritz method and the Newmark-beta method to study the characteristics and vibration response. The model was validated through experimental studies under both bolt looseness and no-looseness conditions. Suman *et al.* [49] investigated the shear strength analysis of bolted joints involving dissimilar materials: Mild Steel-Aluminum and Mild Steel-Glass fiber-reinforced plastics (GFRP). The analysis of single-bolted joints as shown in Figure 6 using experimental and numerical methods revealed that the combination of metal and composite (Mild Steel-GFRP) exhibited better strength compared to the metal-metal joint (Mild Steel-Aluminum). Additionally, the study demonstrated that finite element (FE) results closely matched experimental results with minimal error.

Aluminum alloy, in both similar and dissimilar forms, is among the most commonly used materials in joint structures. In a study involving similar materials, Wu *et al.* [50] utilized a Self-Piercing Riveted (SPR)-bonded aluminum joint composed of 2.0 mm AA6111-TA aluminum sheets to examine the fatigue behavior of hybrid joints. These hybrid joints combine cold-formed mechanical fastening with adhesive bonding. The study tested SPR joints, adhesive-bonded joints, and SPR-bonded joints under two types of loading conditions: lap shear and 45^0 loading. The findings revealed that adhesive bonding played a dominant role and exhibited comparable fatigue life to SPR-bonded joints. Additionally, other researchers have also studied the static and fatigue behavior of SPR joints using 2.0 mm AL5052 sheets with two different overlap areas. Their test results indicated that by increasing the overlap area enhanced both the static strength and ductility of the joint [51].

Dissimilar Aluminum (Al) alloys were studied by Moraes *et al.*[52], who used an SPR lap-shear coupon to join AM60B and AA6082. They investigated the performance of the joint as shown in Figure 5, focusing on how deformation history affects the performance by incorporating residual stress and strain hardening into the simulation process. The results revealed that strain hardening was the dominant role in joint strength, while the formation of residual stress and plastic strains contributed to improved accuracy in simulation predictions. In addition, a dissimilar structure between AA5052 and high-strength steel HSS DP590 was joined by Electromagnetic High-Speed Nailing (E-HSN) to study the fatigue behavior. The Basquin equation was applied to fit the fatigue data, revealing that cyclic stress of 253 MPa marked the critical point between two failure modes, as determined by analysis of fracture characteristics in the rivet joints. The predicted results of fatigue life showed good accuracy and consistency [53].

In previous studies, both similar and dissimilar base materials, specifically aluminum alloy and composite, have been examined. Extensive research has been conducted on the microstructural behavior of these dissimilar materials compared to their vibration behavior. Most of these studies utilized Self-Piercing Riveting (SPR) single-shear lap, single-bolted, and clinching techniques to investigate microstructural behavior. Wang *et al.*[54] and Kam et al [55] carried out an analysis of fatigue behavior using Aluminum alloy combined with carbon fiber-reinforced plastics (CFRPs) to enhance the performance of joints. They employed riveted single-shear lap and SPR to evaluate the fatigue behavior and to investigate the quality of SPR about vibration damping. Wang's results indicated that higher load amplitudes resulted in changes in the failure mode. On the other hand, Kam's results suggested the optimal position of the vibration-damping Al panel during riveting.

In addition to that, both similar and dissimilar base materials, such as GFRP and CFRP, have been the subject of study. The summary of this paper suggests that prior research has been conducted on vibration and microstructural behavior. The failure behavior of hybrid bonded and GFRP single-lap joints was examined through experimental and numerical tests to comprehend the failure mechanism and enhance the performance and reliability of the joint. The study discovered that the interface-fit size significantly impacts the joints [56]. In the vibration analysis, bolted variable angle tow (VAT) plates from CFRP materials were used to analyze the coupled vibrations in the structures. The study concentrated on the effects of bolt tightening and material nonlinearity on the vibration characteristics. In this study, a semi-analytical dynamic model was established to validate the results of the natural characteristics and nonlinear vibration behavior of the joints.

In summary, this group used similar and dissimilar base materials to conduct experimental and numerical testing to determine the results in vibration behavior and microstructural behavior. This was done to improve and increase the accuracy of the joint structure.

2.1.2 Group II - Thermal joining process

Thermal joining processes involve the creation of bonds through the application of heat, typically leading to the melting and fusion of base materials. This category traditionally includes techniques such as gas tungsten arc welding (GTAW), tungsten inert gas welding (TIG), laser welding, and dimple spot welding. However, in this study, Friction Stir Welding (FSW) is also included in this group due to its increasing importance in structural joining research, particularly in the context of dissimilar and lightweight materials. Although FSW is technically a solid-state welding method, where bonding occurs through frictional heat below the melting point, it is discussed here for its functional relevance and growing industrial application in place of conventional thermal welding methods. This study reveals that the majority of researchers focus on studying the microstructural behavior rather than the vibration behavior in this category of joining. This is primarily because they are interested in studying the metallurgical properties, melting points, and thermal properties. In contrast, vibration studies aim to determine the dynamic properties of welded joints, including damping, mode shapes, and natural frequencies.

In this study, it is evident that one of the most popular joining methods used in the thermal joining process is FSW. It is important to note that FSW differs from traditional fusion-based welding methods, as it joins materials through localized frictional heat and mechanical stirring, without melting the base materials. FSW is favored because it avoids material melting during the joining process, preserving the material's original characteristics [57]. Moreover, FSW finds widespread application in joining high-strength aluminum alloys and other challenging-to-weld metals across various industries. By preventing defects related to material melting and solidification, FSW results in high-quality welds and improves the overall joining process [58]. A study by Wang *et al.* [59] investigated a study on the microstructure and mechanical properties of FSW joints between dissimilar materials, specifically 304 austenitic stainless steel and Q235 low carbon steel. The analysis revealed that the temperature distribution during the FSW process played an important role in affecting structural changes within the joint area.

Other researchers have also explored FSW techniques for dissimilar materials. For instance, a study focused on the influence of grain orientation on the corrosion behavior of thermo-mechanically affected dissimilar aluminum alloys, specifically AA6082 and AA7024 [60]. The findings indicated that structures with grain orientations close to the brass texture (110<112>) exhibited excellent corrosion resistance. Additionally, Rodriguez's [61] studied the effect of corrosion defects on the fatigue behavior in dissimilar FSW joints using high-strength aluminum alloys AA6061 and AA7050. Despite the presence of corrosion defects, the findings showed that fatigue life remained largely unaffected by exposure time, with crack initiation occurring at the defect sites.

Furthermore, Sadoun *et al.* [62] focused on enhancing the strength and ductility of dissimilar aluminum joints. Their study involved adding an interlayer strip of AA7075 to the base metal AA2024 using FSW. The presence of this compensation layer resulted in the precipitation of new intermetallic phases, specifically Al^2Cu and Mg^2Zn which developed along the grain boundaries of the aluminum structure. The results demonstrated an 18% improvement in strength and a 54.4% increase in failure strain compared to joints without the compensation layer. In addition, Rana *et al.* [63] and Prabarahan *et al.* [64] explored the impact of microstructure evolution and mechanical properties in dissimilar aluminum alloy joints through FSW. Rana studied AA7075/AA6061, while Prabarahan examined AA5051/AA6061, both using FSW. Their analyses indicated as a tool traverse rate increased, the grain size within the nugget zone decreased, significantly impacting the mechanical behaviour of the welded joints. While conventional thermal welding techniques rely on high temperatures to melt and fuse materials, FSW offers a solid-state alternative that reduces welding defects and improves joint integrity, especially in dissimilar metal combinations.

Chukwuneke *et al.* [65] analyzed transient temperature distribution in twin mild steel plates joined in a butt configuration using gas tungsten arc welding (GTAW). The authors specifically investigated operational parameters such as welding speed and power, which significantly influence the temperature profile during welding. The study's findings contribute to minimizing excessive heat accumulation in the base metal and improving stress distribution along the welding line. Furthermore, the study addresses the prevention of tensile strength degradation and other mechanical property deterioration. In a related context, other researchers have also explored GTAW for joining dissimilar aluminum plates. Their investigations encompassed discussions on the microstructural, mechanical, and corrosion behavior of dissimilar metal welds between Hastelloy C-276 nickel-based super-alloy and UNS S31803 duplex stainless steel [66]. These joints were created using the GTAW process, employing different filler metals such as ERNiCR-3 and ERNiCrMo-3. The resulting weld metals exhibited a dendritic or cellular solidification structure, which evolved due to thermal effects. Additionally, molybdenum (Mo) in the weld influenced toughness, hardness, and corrosion resistance within the joint structure.

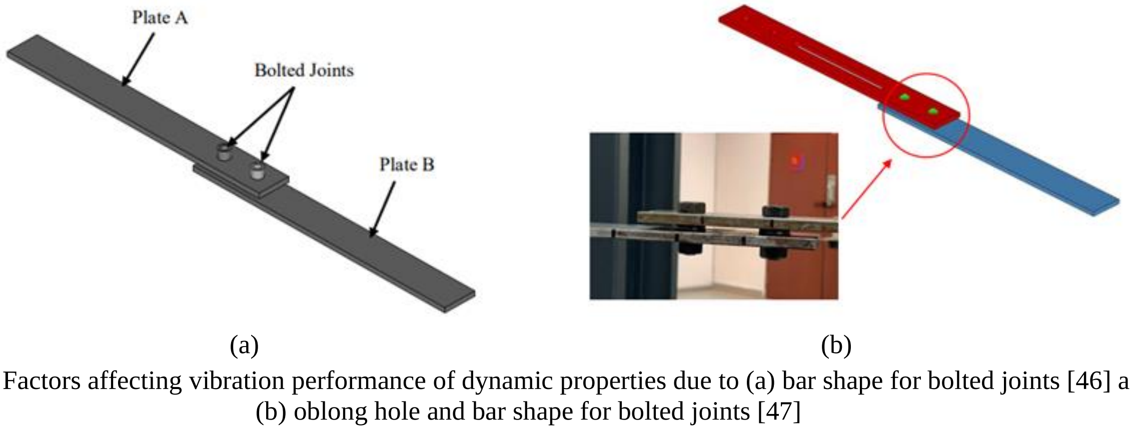
2.1.3 Group III - Chemical joining process

Adhesive bonding refers to joining two elements using an adhesive, a method that has gained significant traction in contemporary manufacturing applications. This bonding procedure can involve specific surfaces, diverse mechanisms, or a combination of both, forming a connection between the adhesive and the adherent. Ideally, the adhesive should fully saturate the bonding region, but the irregularities and potential voids on material surfaces may pose challenges. The characteristics of the bond, the adhesive's viscosity, and the substance's surface energy are determined by the adhesive's composition and the contact area [67].

The design of the joint is pivotal in the selection of adhesive and curing methods [68, 69]. Furthermore, the quality of the joint is significantly influenced by the preparation of the adherent surface. The design of the joint also affects stress distribution and vibration reduction, which are more uniformly distributed in adhesive joints compared to traditional joining methods. There is extensive research on adhesive joining, particularly for lightweight structures, as it offers less stress distribution without the need for bolt holes. Presently, research primarily focuses on adhesive type selection [70], joint design [71], surface pre-treatment [72, 73], optimization of the joining process [74], joining mechanisms, joint strength, failure mechanism, and fatigue life [75] based on FEM simulations.

The most common method of joining Carbon Fiber Reinforced Polymers (CFRPs) with aluminum alloys or high-strength steel is through adhesive bonding. This method not only seals the joints but also prevents crevices and galvanic corrosion between dissimilar materials [76]. Numerous studies have shown that temperature changes affect the mechanical properties of adhesive epoxy and thermal stresses are induced in the joints due to the significant difference in the coefficients of thermal expansion between CFRP and aluminum or steel [77, 78].

Lye *et al.* [79] discovered that as the temperature approaches the adhesive's glass transition temperature, there is a significant decrease in the adhesive's strength and stiffness, accompanied by nonlinear behavior. Experimental and numerical simulation results suggest that it is feasible to prevent the debonding of CFRP/steel plates at extreme temperatures by utilizing thinner and longer CFRP plates with a high modulus. A. Pramanik *et al.*[80] analyzed the joining mechanism in CFRP/aluminum alloy bonding. They concluded that the strength of adhesive joints is attributed to the adsorption theory, which is based on diffusion and mechanical keying or interlocking. Additionally, hybrid joints created by combining mechanical fastening or spot welding with adhesive bonding can effectively enhance the fatigue strength and torsional stiffness of lightweight components and body structures [77, 81].



(a) (b)

Figure 4. Factors affecting vibration performance of dynamic properties due to (a) bar shape for bolted joints [46] and (b) oblong hole and bar shape for bolted joints [47]

Table 1. Summary of comparative study with Base Materials, classification of group and joint configurations

Base Materials	Topic	Group	Joint	Reference
Steel - Steel	Vibration behavior	I	Bolted flange	[33, 48]
Aluminum - Aluminum	Vibration behavior	1	Bolted lap	[46, 47]
Aluminum - Aluminum	Vibration behavior	I	bolted	[82]
Aluminum - Aluminum	Fatigue behavior	I	SPR	[50, 51]
Aluminum - Magnesium	Microstructural behavior	I	SPR	[52]
Aluminum - Steel	Fatigue behavior	I	rivet	[53]
Aluminum - GFRP	Microstructural behavior	I	Single-bolted	[49]
Aluminum - CFRP	Fatigue behavior	I	single-shear lap	[54]
Aluminum - CFRP	Vibration behavior	I	SPR	[55]
GFRP - GFRP	Failure behavior	I	Hybrid bonded/bolted	[56]
CFRP- CFRP	Vibration behavior	I	Bolted	[83]
Steel – Steel	Microstructure behavior	II	GTAW	[65]
Steel – Steel	Microstructure behavior	II	FSW	[59]
Nickel – steel	Corrosion behavior	II	GTAW	[66]
Aluminum - Aluminum	Corrosion behavior	II	FSW	[60, 61]
Aluminum - Aluminum	Microstructural behavior	II	FSW	[17, 62-64]
Aluminum – Aluminum	Vibration behavior	II	FSW	[36]
Aluminum - Aluminum	Microstructural behavior	II	GTAW	[84, 85]
Aluminum -Aluminium	Microstructural behavior	II	TIGW	[86]
Aluminum - Magnesium	Microstructural behavior	II	FSW	[87-89]
Aluminum - Magnesium	Corrosion behavior	II	FSW	[90]
Aluminum - Magnesium	Ultrasonic Vibration	II	FSW	[91-93]
Aluminum - Magnesium	Vibration behavior	II	FSW	[94]
Aluminum - steel	Corrosion behavior	II	FSW	[95]
Aluminum - Steel	Microstructural behavior	II	Dimple spot welding	[96]
Aluminum - Polymer	Microstructural behavior	II	FSW	[97]
Aluminum - Copper	Microstructural behavior	II	FSW	[98, 99]
Magnesium - Magnesium	Microstructural behavior	II	TIG welding	[100]
Titanium - CFRP	Microstructural behavior	II	Laser weld	[101, 102]
Steel-CFRP	Dynamic behavior	III	Adhesive bonded	[103, 104]
Aluminum - Steel	Energy absorption	III	Adhesive bonded & bolted	[77]
Aluminum - Steel	Microstructural behavior	III	Adhesive bonded & welded	[81]
Aluminum - CFRP	Microstructural behavior	III	Single-lap adhesive joint	[76, 78, 80, 105]
Galvanized – Non-galvanized steel	Microstructural behavior	III	Adhesive bonded	[106]

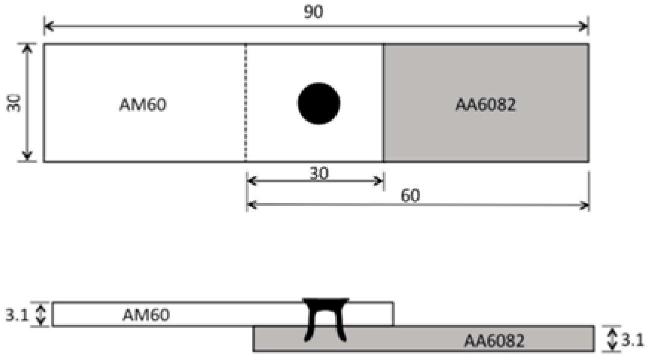


Figure 5. SPR lap-shear coupon joint using Aluminum and Magnesium sheets [52]

Figure 6. Specimen test using single-bolted joints [49]

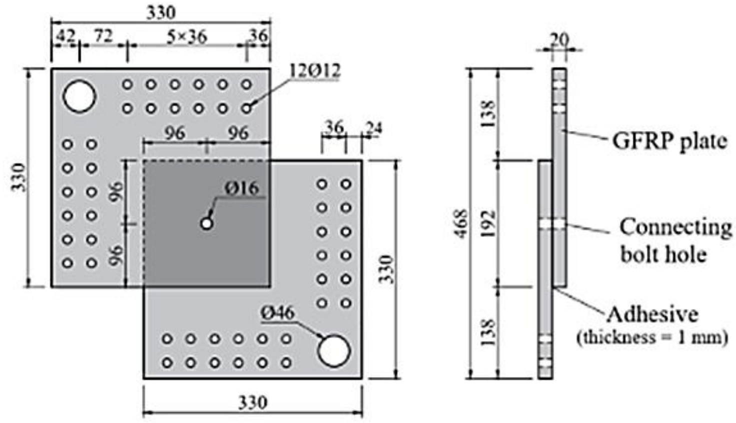


Figure 7. Bolted joint using a composite plate with an adhesive joint [56]

2.2 Structural Materials of the Test Structure

In the manufacturing sector, the demand for weight reduction has led engineering manufacturers to prioritize the design and materials of test structures and assembly components [107]. Numerous prior research has evaluated the effects of different materials on vibration performance, considering both microstructural and dynamic vibration contexts. As the production of test structures is consistently geared towards lightweight yet exceptional materials to mitigate dynamic and mechanical properties, various material categories have been scrutinized for this purpose. The materials utilized for fabricating a test structure specimen can generally be classified into two groups: metal/alloy and hybrid composite-metal/alloy combinations.

Within the metal/alloy category, the primary focus of studies has been aluminum. The material combinations predominantly originate from different series of aluminum alloys, followed by combinations with magnesium and mild steel. As highlighted by Arunkumar *et al.* [108], aluminum alloy is widely used because of their excellent strength-to-weight ratio. Furthermore, this alloy is selected as the study material because it can enhance the microstructure and mechanical properties during joining techniques. Key attributes of aluminum alloys include non-heat treatability, high hardness, corrosion resistance, exceptional ductility, lightweight nature, high strength, flexibility, resilience, and excellent electrical and thermal conductivity. On the other hand, magnesium and steel alloys are chosen due to the availability of prior research on material combinations, enabling comparative analysis while reducing vibration effects. These alloys also find extensive application in the industry, are easily accessible, and are cost-effective.

The exploration of composite materials continues to be a focal point of research, driven by the increasing demand for alternatives to metallic materials. Despite comprehensive investigations into the performance of diverse composite materials in experimental structures, the inherent brittleness has driven the development of composite-metal/alloy hybrid materials to enhance structural durability and performance [109]. Interestingly, the application of these hybrid materials has given rise to innovative structural designs to mitigate the effects of structural vibrations. Moreover, the technique of hybrid joining has been shown to enhance the strength of adhesive joints, thereby reinforcing the overall structure. A summary of studies discussing the materials used in test structures is presented in Table 2.

Table 2. Material of test structure

Categories	Material	Findings	Potential Applications	Reference
Metal/alloy	Aluminum alloy • AA6061 • AA6082 • AA7075 • AA5051	Dissimilar Aluminum is selected as the material for the study due to several factors: it enhances microstructure and mechanical properties, including tensile strength and microhardness, and improves the techniques used for joining.	Automotive components: Frames, panels, and suspension parts Aerospace structures: Lightweight fuselage parts and wing elements	[108, 110-113]
	Aluminum - Magnesium alloy	The study indicates that dissimilar aluminum and magnesium alloys demonstrate higher resonant frequencies compared to equivalent aluminum structures. This contributes to improved stability and reduced vibrations. Additionally, these alloys help mitigate metal corrosion and enhance tensile strength, thereby reducing the weight of automotive devices.	Vibration-resistant electronic enclosures: Especially in vehicles or aircraft to reduce resonance issues Lightweight automotive components: Wheels, housings, or brackets that need corrosion resistance and lower weight.	[19, 90, 114]
	Aluminum - Mild-steel alloy	The use of these dissimilar materials aims to predict the behavior of joints in terms of crack initiation, fatigue reduction, and enhanced corrosion resistance. The study also concentrates on the impact of process parameters, tool geometry, joint type, and the composition of the interlayer to improve the properties of the joints.	Multi-material vehicle body structures: Enhancing crashworthiness while controlling weight.	[20, 96, 115]
	Advance high strength steel (AHSS)	This study shows that this material offers an optimal blend of mechanical properties for design considerations, including strength, fatigue resistance, fracture wear, and manufacturability. However, it also highlights the challenge in ensuring a prolonged lifespan for these alloys, particularly in a vibration environment. The study indicates that high-strength steel may undergo higher stress, leading to lower damping ratios during vibrations.	Structural components in vehicles: Crumple zones or pillars, where strength and fatigue resistance are vital.	[116-118]
A hybrid of composite and metal/alloy	Aluminum alloy - CFRP	Ultrasonic vibration is utilized to enhance the penetration of adhesive, thereby strengthening these bonding joints. The study further reveals that the amalgamation of materials can augment the lightweight and mechanical attributes of the structure, a factor of significant importance in today’s industry.	Aircraft interior panels: Lightweight with strong joints for safety and efficiency.	[54, 109, 119]
	Aluminum alloy - GFRP	In general, this study demonstrates that the strength of the Al/GFRP interface increases as the interface roughness decreases. Additionally, the study concentrates on identifying the natural frequencies and mode shapes of this structure. The findings indicate that an increase in the curvature radius for each mode results in a decrease in the frequency value.	Wind turbine blades: Where natural frequencies and joint strength are critical Automotive body panels: Lightweight with vibration control	[56, 120, 121]
	Titanium alloy - CFRP	The application of Longitudinal-Torsional Ultrasonic Vibration (LTUV) drilling can enhance the cutting quality in CFRP/Ti-alloy, resulting in a sharper cutting edge. Furthermore, it has been found to improve the machinability and assembly of joints.	Aerospace fasteners and joint assemblies	[122, 123]

2.3 Structural Analysis of the Test Structure

In recent years, the application of structural dynamics analysis has become increasingly prevalent in predictive engineering. The utilization of structural vibration analysis is crucial for saving engineering costs and time, and for making informed decisions about engineering design. This method has been implemented across various industries and has proven its effectiveness. Experimental and numerical methods have significantly propelled the advancement of vibration analysis. The Finite Element Method (FEM) provides precise estimation of mechanical properties in structures. However, accurately determining the mechanical characteristics of joints remains a challenge in modeling and understanding their overall mechanical properties. A comprehensive review of joint identification techniques is available in previous study [124-126]. Owing to the complexity of extracting dynamic characteristics of joints, researchers have proposed various techniques from diverse perspectives. From the viewpoint of [127-129], the focus is on comprehending the behaviors of joints, the impact of parameters on mechanical properties, and uncertainty in contact interfaces for joint structures. Conversely, from the perspective of others [46, 130], the researchers aim to enhance the accuracy in predicting dynamic behaviors by proposing simplified finite element methods and optimization approaches. In summary, these studies offer valuable insights into the complexities of joint dynamics, taking into account various materials, joining techniques, uncertainties, and modeling approaches. The primary objective of vibration analysis in joint identification is to determine the dynamic characteristics through analytical or numerical methods while minimizing discrepancies between the measured and predicted frequency response function (FRF) of an assembled structure [46, 131, 132].

In structural vibration analysis, two primary approaches are commonly used to identify joint dynamic properties. The first is the experimental approach, which relies solely on experimental data to identify the joint parameters. This method helps avoid errors associated with structural modeling. However, its accuracy is often affected by unavoidable noise in the measured FRFs [133], and conducting FRF measurements under multiple experimental conditions can be impractical. The second approach is the model-based method, which combines experimental data and the Finite Element Model (FEM) to identify joint parameters [48, 134]. The model-based approach in structural vibration analysis is of significant importance due to its comprehensive accuracy to get reliable results in research studies. Besides that, the model-based approach can provide a more complete and accurate analysis of structural vibration. It can help to identify potential issues early, optimize the design and maintenance of structures, and ultimately ensure the safety and longevity of structural design.

Vibration structural analysis in joint structures involving dissimilar materials is a multifaceted domain, demanding a comprehensive understanding of structural behavior. The integration of dissimilar materials poses unique challenges and opportunities, necessitating a combined approach of experimental and numerical structural analysis. This exploration delves into the significance of structural analysis, incorporating both experimental and numerical methodologies, in unraveling the dynamic intricacies of joint structures with dissimilar materials. By examining recent trends in research and methodologies, this study aims to underscore the synergies between experimental and numerical analyses, offering insights to optimize the vibrational performance and reliability of such complex jointed systems [83, 135].

Experimental data derived from real-world observations plays a crucial role in capturing complex behaviors and interactions, enabling the validation and verification of specific aspects of numerical simulation results. Meanwhile, numerical models are powerful modern tools for continuous structural monitoring, damage detection, service life prediction, and the formulation of optimal maintenance strategies. The advancement of numerical modeling techniques has increased the demand for models that meet stringent accuracy and reliability requirements. One of the key advantages of numerical simulations is their flexibility in structural modifications, which can be made instantly to meet specifications or desired outputs. Additionally, simulations can be rerun multiple times, allowing for iterative refinements until the optimal results are archived.

According to Li *et al.* [136], both the experimental test and numerical model exhibit consistency in dynamic characteristics, and structural differences do not necessarily result in discrepancies between experimental and simulated results. Table 4 highlights that most test structures have been analyzed to evaluate structural performance based on joining characteristics while comparing the results with experimental data. Despite advancements in computational simulation, researchers widely acknowledge that discrepancies between numerical and experimental results cannot remain unavoidable. Since numerical studies are based on assumption, numerous investigations have explored the sources of these inconsistencies. The primary challenges in numerical simulation extend beyond dissimilar structures to various other simulation fields. Zhang *et al.* [137], emphasized that optimization factors can help reduce these discrepancies, while other studies suggest improvements in computation techniques, material modeling, and accurate material property measurements. Precisely, the issue of discrepancies becomes more pronounced in complex test structures. Finite element simulation of the test structure requires not only basic properties such as density and Young’s modulus but also precise strain rate data. When dealing with dissimilar materials, assumed values are often used, potentially affecting the accuracy of FEMs [49]. Table 4 presents several examples of correlation between experiment testing and finite element simulations. As shown, if the test specimen includes joining elements such as bolts, the complexity of modeling increases, making it difficult to generate an accurate finite element model for comparison. However, based on most research findings in Table 4, discrepancies between real and predicted results have been progressively minimized.

The summary of recent studies underscores the complementary nature of experimental and numerical analyses. Researchers have utilized experimental data to validate and refine numerical models, ensuring accuracy and reliability in predicting the vibrational characteristics of joint structures. This synergy between experimental and numerical approaches becomes particularly vital in overcoming the challenges associated with dissimilar materials, leading to more robust design strategies and improved structural performance. The integration of experimental and numerical structural analyses proves to be a powerful and synergistic approach to comprehending the structural vibration analysis of joint structures involving dissimilar materials. The challenges posed by dissimilar materials are effectively addressed through a combined methodology, leveraging the strengths of both experimental and numerical analyses. This collaborative approach not only enhances the accuracy of predictions but also provides a more comprehensive understanding of the dynamic behavior of jointed systems

3. OPTIMIZATION APPROACH FOR VIBRATION ANALYSIS

Nowadays, the optimization approach has emerged as a potent tool in vibration analysis. It aims to identify the optimal design or operational parameters of a system to either minimize or maximize a specific objective function, typically associated with the system's vibrational performance. Previous research has underscored the need to quantify errors and uncertainties (such as stiffness, mass, and boundary conditions) linked with model assumptions, which often result in inaccuracies and uncertainties [138]. Evaluating these factors is crucial to ascertain the reliability of the numerical models. As a result, Finite Element Model Updating (FEMU) methods have been developed to refine numerical models by aligning them with the actual structural behavior observed in static and/or dynamic testing [139].

3.1 Finite Element Model Updating (FEMU)

Currently, FEMU has garnered significant attention and is of paramount importance in the realms of design [140, 141], construction [142, 143], and structural engineering [144-146]. The FEMU process introduces two primary sources of uncertainty: one related to the predicted FE model and the other to the experimentally obtained data. Uncertainties in the FE model arise from discrepancies between the predicted structural behavior in the numerical model and the actual behavior observed in physical testing.

Despite its widespread application, there is no universally accepted definition of FEMU in the literature. Ereiz *et al.* [147] describe it is a process designed to refine and enhance the FE model to be better reflect the actual structural behavior. Yang and Shahbaznia *et al.* [148] define FEMU as the procedure for adjusting the initial numerical model to more accurately match the measured structural response. Similarly, Schommer *et al.* [149] characterize model updating as an optimization technique in which the objective function minimizes deviations between the numerical model's predicted behavior and the actual structural performance. Mottershead and Friswell [150, 151] describe FEMU as a procedure that enhances numerical models to replicate the measured response of real structures more precisely. In a separate study [152], the same authors define it as an iterative process where the FE model is progressively refined to align with the actual structural response by updating its physical parameters. Although the definition of FEMU varies, the central concept remains consistent across studies which is for updating the numerical model using experimental data to achieve an accurate representation of real structural behavior.

In practical scenarios, while it is possible to minimize errors, they can never be eliminated. Uncertainties in modeling can be classified into three main categories: uncertainties in model parameters, model code, and model structure [153]. Uncertainties in model parameters typically stem from incorrect assumptions regarding material properties, geometry, boundary conditions, or the thickness of shell and plate elements [154]. Model structure uncertainties often result from inaccurate assumptions about a structure's mechanical properties and physical behavior. Factors such as incorrect load estimation, geometric shapes, and misclassification of structural behavior as linear or nonlinear contribute significantly to these uncertainties [155]. Discrepancies between a numerical model's predicted behavior and the actual structural response can be attributed to errors in model structure, model order, model parameter, and measurement inaccuracies [156]. These challenges highlight the complexities inherent in FEM and the need for continuous refinement to improve accuracy and reliability.

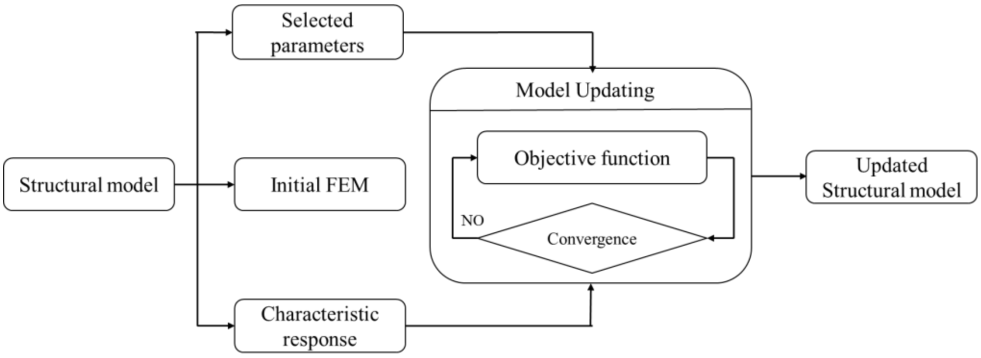


Figure 8. Flow of model updating technique [139]

Model structure errors typically arise from incorrect assumptions about a structure's mechanical properties and physical behavior [157, 158]. Model order errors, on the other hand, often arise due to the complexities and difficulty associated with modeling nonlinearity [159, 160]. Model parameter errors are usually a result of inaccurate assumptions regarding material properties, geometry, and other defining characteristics [161], all of which can significantly impact the accuracy of numerical predictions. Measurement errors can occur during the measurement process, influenced by various environmental effects and other factors [162, 163]. These errors can originate from uncertainties from variations in geometric parameters, physical and material properties, loading conditions, and even the model itself. Much research is primarily focused on updating finite element models using structural dynamic parameters such as mode shapes, damping ratio, and natural frequency. These parameters offer advantages in damage detection, particularly when numerical modeling inaccuracies are present, as they directly relate to the structure's topology and provide a comprehensive representation of its global behavior [164]. However, identifying structural dynamic properties remains computationally intensive and susceptible to noise. Furthermore, this approach is limited in its ability to extract modes across the entire frequency bandwidth and is primarily suitable for highly damped and linear structures [165].

The FEMU method is generally categorized into two main approaches: manual and automated [166]. These approaches are further divided into iterative (non-direct) and non-iterative (direct) methods [167]. The primary distinction between manual and automated FEMU lies in the number of selected updating parameters and the method used to model updating, which is FEMU relies on a trial-and-error approach, whereas automated FEMU is algorithm-driven. Notably, manual methods typically achieve a discrepancy of less than 5% between predicted and actual structural behavior, while automated methods reduce this difference to less than 1% [168]. The categorization of Model Updating (MU) methods into iterative and non-iterative approaches is more clearly defined. The key distinction lies in the updating process which is iterative methods that update the model through repeated adjustments, whereas non-iterative methods apply a direct approach. Iterative methods are further classified into deterministic and Bayesian methods. Deterministic methods, which update the numerical model based on targeted response data, can be classified into two groups: (1) methods that utilize eigenvectors and eigenvalues (eigenfrequencies, mode shapes, damping coefficient), and (2) methods that employ frequency response data. The primary goal of these methods is to quantify the uncertainties of the selected updating parameters [169]. This section provides an overview of the model updating procedure, which involves selecting numerical model updating, defining the discrepancy function between the predicted and actual behavior, and outlining commonly used techniques for minimizing these differences, as depicted in Figure 8.

3.1.1 Selection of the updating parameters

Selecting the appropriate parameters for the numerical model updating is a complex process. The chosen parameters should accurately represent the unknown structural properties of the model while remaining limited in number to prevent ill-conditioned problems. The effectiveness of FEMU largely depends on the careful selection of these updating parameters. Precisely defining model parameterization and estimating unknown parameters from ill-conditioned equations are critical steps in ensuring accuracy. Incorporating sensitivity analysis into model parameterization provides a key advantage by identifying the most influential parameters and addressing potential inadequacies. However, regardless of the parameterization approach used, challenges during the updating process may lead to non-unique solutions.

Insufficient measured data can constrain parameter estimation, resulting in an underdetermined system of equations in deterministic methods or unidentified parameters in stochastic iterative approaches [170]. Beyond parameterization, other critical considerations include the uniqueness of the updating parameters, computational efficiency, handling of ill-conditioned equations, and the utilization of incomplete data. The selected parameters for updating the numerical model should effectively account for the uncertainties or inaccuracies, provided that the output data remain sensitive to the model's input parameters [171]. Various methods for selecting updating parameters are represented in Figure 9.

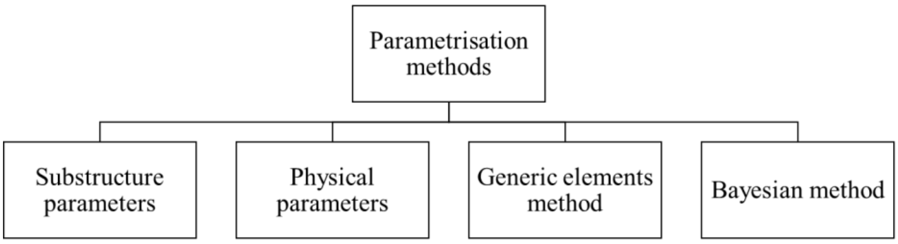


Figure 9. Parametrization methods for FEMU [139]

One approach involves defining scalar multipliers for damping, stiffness, and mass matrices [172, 173], which are derived from collected data. Another parameterization approach directly integrates the geometrical and material properties of structures [174], a technique commonly applied in structural model updating. A third approach, known as the generic method [175, 176], updates the mass and stiffness matrices by altering the eigenvalues and eigenvectors of specific sub-structures or elements. The fourth method, referred to as the Bayesian method, treats numerical modeling as a statistical problem to develop multiple models that accurately depict the actual structure behavior [177]. Regardless of the selected parameterization method, minimizing the number of updating parameters is essential to eliminate redundant variables and optimize computational efficiency. Furthermore, parameter selection is constrained by the availability of measurement data within a limited frequency range.

3.1.2 Definition of the FEMU problem and the objective function

The FEMU challenge is primarily defined by the discrepancy between the predicted structural behavior from the numerical model and the actual observed response. The nature of this problem, whether it's an optimization or statistical problem, hinges on the method employed, which could be either iterative stochastic, or deterministic. In the realm of practical engineering applications, FEMU is commonly executed using the Maximum Likelihood Method (MLM). This method essentially converts the model updating problem into an optimization process [178]. As part of this transformation process, an objective function is formulated based on the residuals between various types of data sets obtained both numerically and experimentally, as illustrated in Table 3.

The datasets analyzed in these studies encompass dynamic properties [179-181], static datasets [182-184], or a combination of both [149, 185, 186]. Among these, the primary metrics often utilized are the structural dynamic properties, specifically mode shapes and natural frequencies. These datasets are considered the most reliable indicators of the structure's actual behavior. This is because any alterations to the structure result in changes to its stiffness (or flexibility), which in turn influence its dynamic properties. Although these changes may be subtle, they are highly significant, highlighting the high precision during field experimental testing. In addition to mode shapes and natural frequencies, the Frequency Response Function (FRF) is frequently used in formulating the objective in FEMU [180, 187, 188]. This approach has certain advantages, primarily because the FRF can accurately replicate dynamic properties. Moreover, the use of FRF in FEMU eliminates errors associated with modal fitting and removes the need for any fitting between predicted and measured mode shapes [180]. Another widely used and effective form of the objective function in FEMU is Modal Flexibility Residuals (MF) [181, 189, 190]. Comparative studies evaluating the impact of different potential residuals (mode shapes, natural frequency, and modal flexibility and their combination), it has been concluded that the objective function that takes into account all three residuals exhibits the best performance in model updating [191]. Beyond these dynamic properties and their derivatives, the objective function can also be formulated using the Modal Strain Energy (MSE) [192-194].

The FEMU problem's objective function formulation requires the inclusion of two residual types that are sensitive to the updating parameters chosen. The first residual type is associated to the natural frequencies, r_i^f (where i represents the considered natural frequency), and the second type pertains to the corresponding mode shapes, r_i^m (where i represents the considered mode shapes). Additionally, the damping ratio's residual can also be considered when defining the objective function [195]. In FEMU, the objective function is defined by the residuals, which represent the differences between the numerical model's prediction and the actual structural behavior. The effect of these residuals on the objective function can be assessed through two methods: the Single Objective Function (SOF) approach and the Multi Objective Function (MOF) approach.

Table 3. Example of objective function defined using statics and dynamics data sets

Category	Data sets	Example of an objective function	Reference
Statics	ε	$\sum_{i=1}^{n_\epsilon}\left(1-\frac{\Vert \varepsilon_i^{exp}-\varepsilon_i^{num}\Vert}{\Vert \varepsilon_i^{exp}-\varepsilon_i^{\overline{num}}\Vert}\right)$	[182, 196]
	Influence Line (IL)	$\sum_{k=1}^{N}\omega_k\sum_{i=1}^{M}\left(\frac{Z_{Ci}-\mu Z_{Ti}}{Z_{Ti}}\right)^2$	[183, 197]
	δ, ε	$\sum_{i=1}^{n_\delta}\left(1-\frac{\Vert \delta_i^{exp}-\delta_i^{num}\Vert}{\Vert \delta_i^{exp}-\delta_i^{\overline{num}}\Vert}\right)\sum_{i=1}^{n_\epsilon}\left(-\frac{\Vert \varepsilon_i^{exp}-\varepsilon_i^{num}\Vert}{\Vert \varepsilon_i^{exp}-\varepsilon_i^{\overline{num}}\Vert}\right)$	[198, 199]
Dynamics	$f_i, \emptyset_i$	Single Objective $f(\theta)=\frac{1}{2}\left[\sum_i^{n_f} w_i^f \times r_i^f\ (\theta)^2\right]^{\frac{1}{2}}+\frac{1}{2}[\sum_i^{n_m} w_i^m \times r_i^m\ (\theta)^2]^{\frac{1}{2}}$ $\theta \in [\theta_1, \theta_2]\ \&\ \sum w_i = \sum w_i^f + \sum w_i^m = 1\ w_i\ \geq 0$ Multi-Objective $min\ f\ (\theta) = min\ (f_1(\theta)\ \&\ f_2(\theta)) \begin{cases} f_1(\theta)=\frac{1}{2}\left[\sum_i^{n_f} r_i^f\ (\theta)^2\right]^{\frac{1}{2}} \\ f_2(\theta)=\frac{1}{2}\left[\sum_i^{n_m} r_i^m\ (\theta)^2\right]^{\frac{1}{2}} \end{cases}$	[200-202]
	FRF	$H_{exp}\ (f) - \ H_{num}\ (f)$	[187, 203]
	MF	$\frac{\Vert MF_{num}\ (\theta) - MF_{exp}(\theta_{ref})\Vert_{fro}^2}{\Vert MF_{num}\ (\theta_{ini}) - MF_{exp}(\theta_{ref})\Vert_{fro}^2}$	[204]
	MSE	$\sum_{i=1}^{n_m}\left(\frac{MSE_{num,i}}{MSE_{exp,i}}-1\right)^2$	[192, 205]

The SOF approach formulates the objective function by incorporating weighted residuals that represents the discrepancies between the numerical model's predicted modal properties and the experimentally measured ones. These weights are assigned to reflect the relative contributions and uncertainties with experimental estimates of a dynamic or static structural parameter in the objective function. Weighting the residuals is a critical step for obtaining more precise

FEMU results, with higher weighting factors being assigned to them. Mode shapes, unlike natural frequencies, show less sensitive to changes in structural stiffness and are approximately ten times affected by noise [206]. To establish a meaningful correlation between experimentally and numerically derived datasets, the weighting factors for mode shapes must be optimized through careful analysis [207, 208]. These values can be establish using a statistical criterion or a trial-and-error approach [201, 209]. According to the statistical criterion, the weights are determined based on the uncertainty linked to the experimental modal properties of the structure. Conversely, the trial-and-error criterion involves an iterative process to define the weights, ensuring the best possible agreement between the numerical model's predicted modal properties and the experimentally observed ones.

The MOF approach defines the objective function through multiple functional components. In real-world engineering contexts, this objective function typically consists of two functional components based on two residual types. One advantage of this approach is that it eliminates the determine residuals weights. However, it also presents a distinct disadvantage: a subsequent decision-making problem arises, involving the identification of the best solution from a range of potential solutions (known as the Pareto front) provided by the optimization algorithm [210]. To address this decision-making challenge, the study has utilized the Normal Boundary Intersection (NBI) method [211], which is among the various criteria discussed in the literature for solving such issues [212].

Most researchers typically employ both single and multi-objective functions in FEMU to evaluate their efficacy. Jiménez-Alonso *et al.* [200] conducted a study on a laboratory footbridge model using both approaches to address issues such as computational cost and the dependency between the updated model and the selected objective function. Their results demonstrated that the multi-objective approach is more advantageous for FEMU, as it allows for a larger search space, reduces computational time, and ensures a balanced influence of residuals related to natural frequencies and mode shapes. In another study, Naranjo-Pérez *et al.* [213] validated the performance of a new hybrid algorithm by comparing it with three computational intelligence algorithms applied to the same real structure used in the prior study [200]. This comparison focused on convergence speed and matching accuracy, utilizing both single and multi-objective functions, and similarly concluded that the multi-objective approach outperforms the single-objective approach. FRom a review of the literature defining the FEMU problem as an optimization problem, it is evident that the multi-objective method performs more effectively in resolving the updating problem.

3.2 FEMU Methods

3.2.1 Matrix update methods

The matrix update method focuses on modifying structural mass, stiffness, or damping matrices to minimize discrepancies between analytical and experimental matrices. This techniques aims to update numerical models by adjusting global stiffness, mass, or damping matrices to better align with experimental results [214, 215]. The application of this method directly reduces the differences between the structural dynamic parameters obtained experimentally and numerically. However, these methods are recognized for their computational intensity and the challenge of identifying a global minimum through optimization techniques due to the presence of multiple stationary points [216]. Moreover, it is challenging to derive a solution with a physical interpretation. Fundamentally, the matrix update method strives to enhance the precision of numerical models by adjusting crucial structural parameters based on experimental data. Nevertheless, the computational complexity, the difficulty in identifying a global minimum, and deriving a solution with physical significance pose significant challenges to this approach [217].

3.2.2 Sensitivity-based methods

Sensitivity-based methods have proven to be highly effective, with numerous applications in Model Updating (MU) problems. These methods utilize experimentally derived structural dynamics parameters, such as natural frequencies and mode shapes, to update the initial numerical model. They offer a broad selection of parameters for model updating and allow for the weighting of measured outputs. However, determining the sensitivity of the measurements is computationally demanding, and only an approximation of the sensitivity may be achievable. The sensitivity is often a non-linear function of the updating parameters, necessitating an iterative procedure [139, 218]. This iterative process is linked with the convergence problem when solving for the chosen parameters [219]. Despite its effectiveness, the sensitivity-based method has certain limitations. It requires the existence of a sensitivity matrix to all updating parameters, leading to high computational costs. Furthermore, this method may not be suitable for structures that have sustained significant damage [220].

3.2.3 Iterative optimization methods

The FEMU process is converted into an optimization problem through iterative optimization methods. In this context, the objective function is established by the relative differences, referred to as residuals, between the numerical model's predicted structural behavior and the actual behavior observed. These residuals can be approached in two ways: the first treats the problem as a single-objective optimization problem, and the other as a multi-objective optimization problem [213]. The single-objective optimization problem, as the name suggests, is defined by a single objective function expressed as the sum of the weighted residuals. Typically, the final values of these weighted residuals are determined using a trial-and-error approach.

3.2.4 Bayesian methods

Bayesian FEMU is a statistical methods aims at estimating the probabilistic density function of a numerical model's physical parameters. It applies Bayesian probability theory, as cited in references [221, 222], to compute the posterior probability density function of these parameters. The density function is derived from the likelihood and prior probability density functions, as discussed in [207]. The likelihood function measures the discrepancies between the structure's numerical and experimental dynamic properties, whereas the prior probability density function reflects pre-existing assumptions about the statistical behavior of the FE model's physical parameters. Despite its benefits, this method has a drawback when applied to complex numerical models. It can be time-consuming and computationally intensive, which restricts its use in large real-world structures.

3.2.5 Computational intelligence algorithms

FEMU is an optimization technique where the uncertain parameters of the model serve as the design variables, as referenced in [200]. The goal is to reduce the discrepancies between the numerical model's predicted structural behavior and the experimentally observed behavior. Computational intelligence algorithms, shown in Figure 10, are employed to address the optimization challenge in FEMU. These techniques encompass a wide range of algorithms including, but not limited to, the genetic algorithm [223, 224], sequential programming technique [138, 225], particle swarm optimization [184, 226], Nelder-Mead simplex method [227], response surface method [228, 229], hybrid optimization [230], multi objective optimization [231, 232], and simulated annealing [233, 234].

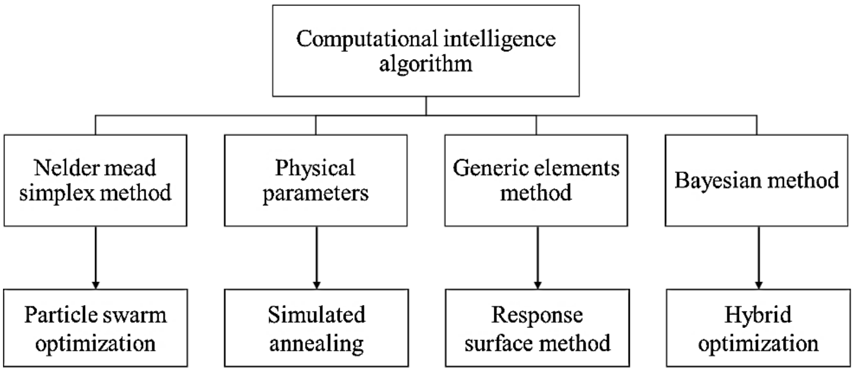


Figure 10. Computational Intelligence Algorithms for Model Updating [139]

4. CONCLUSIONS

Previous research has extensively investigated vibration analysis through various approaches, including experimental and computational methods. However, the primary focus of these studies has been on understanding the factors influencing the vibration performance of structural systems, particularly those involving dissimilar materials and joining techniques. These factors are typically categorized into mechanical, thermal, and chemical joining processes, each introducing specific challenges. In computational modeling, assumptions are especially important due to the complexity of joining techniques such as bolting, riveting, welding, and adhesive bonding. Each category encompasses numerous studies aimed at exploring the vibration behavior and microstructural characteristics of joints, with an emphasis on enhancing dynamic properties like natural frequencies and damping. Moreover, this research underscores the importance of integrating both experimental and numerical methodologies in structural analysis to grasp the intricacies of joint structures involving dissimilar materials. It also highlights the ongoing efforts to reconcile experimental and numerical outputs, aiming to improve accuracy and bridge the gap between real-world observations and simulated results.

Furthermore, optimization approaches, particularly Finite Element Model Updating (FEMU) methods, have emerged as powerful tools in vibration analysis. FEMU focuses on refining numerical models to better capture the actual behavior of structures, addressing uncertainties and errors inherent in modeling assumptions. This process involves selecting and updating parameters, defining objective functions based on differences between predicted and observed behaviors, and applying various methods such as sensitivity-based approaches, iterative optimization procedures, Bayesian methods, and computational intelligence algorithms. Despite computational challenges, including intensity and convergence issues, FEMU methods offer significant benefits in enhancing the accuracy of numerical models. By leveraging experimental data and computational techniques, FEMU enables engineers to gain deeper insights into structural behavior, make informed design decisions, and ensure the reliability and safety of engineering systems. As research in this field continues to advance, further innovations and refinements in FEMU methods are anticipated, bolstering their applicability and effectiveness in real-world engineering applications.

Table 4. Summary of study on experimental and numerical analysis in a test structure

Type/joining of structures	Geometric parameter	Experimental analysis	Numerical analysis	Finding data	Number of modes	Result: Trends	Error	Findings	Reference
2 Plates / Bolted flange	Plates: 100mm x 120mm x 2.2mm Flange: 15mm x 2.2mm Bolt: M10	Force hammer	FEM	Natural frequency, mode shapes	6 modes	Experiment ↓, Model ↑	0.077%-mode5 (10 N.m) 0.032%-mode5 (6 N.m) 0.029%-mode5 (2 N.m)	• The decrease of the tightening torque will increase the structural modal damping ratio and reduce the vibration amplitude.	[48]
2 Plates / Hybrid bonded/bolted	Plates: 330mm x 330mm x 20mm Overlap region: 192mm x 192mm Bolt: M16	Structural loading system: ST PL-630	Three-dimensional Hashin-type Criteria	Failure mode, load-displacement curve	N/A	Experiment ↓, Model ↑	N/A	• Joint rigidity increases by 98.9%~133.1% comparing the second loading stage to the first stage. • Failure loads of 4-bolt and 9-bolt joints are respectively 14.5 % and 22.9 % higher than the single-bolt specimen.	[56]
Plate / bolted	Plates: 120mm x 120mm Overlap region: 30mm	Hammering and sweeping frequency testing	ANYSS	Natural frequency, mode shapes	10 modes	VAT plate: Experiment ↑, Model ↓ Bolted CFRC plate: Experiment ↓, Model ↑	0.86%- mode3 4.98%- mode1	• The frequency veering behavior of the VAT plate is caused by variations in boundary stiffness, connection stiffness, and fiber orientation.	[83]
Dual rotor / bolted	Rotor: Length of LP shaft – 1m Outer radius – 0.0401m Length of HP shaft – 0.36m Outer radius – 0.36m	Bolted joint dual-rotor test rig	FEM	Amplitude, Natural frequency, Rotational speed	N/A	N/A	N/A	• Rubbing stiffness increases and the impact force imparts more energy to the rotor system leading to an increase in system vibration amplitude. • The amplitude of self-excited vibration frequency increases with the rubbing stiffness, which contributes to the occurrence of the beating phenomenon.	[136]

Table 4. Summary of study on experimental and numerical analysis in a test structure

Type/joining of structures	Geometric parameter	Experimental analysis	Numerical analysis	Finding data	Number of modes	Result: Trends	Error	Findings	Reference
Double-hat / adhesive bonding and bolted	Hat: 400mm x 60mm x 1mm	Three-point bending test	ABAQUS	Energy absorption (EA)	N/A	Experiment ↓, Model ↑	N/A	• EA and SEA increased by an average of 23.19 % and 18.61 % respectively once the joining from bolt to a bolt-adhesive hybrid is changed. • Adhesive bond reduces the stiffness of the structure.	[77]
Plates/ Adhesive single-lap joint	Plates: 100mm x 25mm x 2.5mm Adhesive layer thickness: 0.2mm	Quasi-static shear test and fatigue test	N/A	Stress level, amplitude, load	N/A	N/A	N/A	• The increase of aluminum alloy bonding area length improves the bonding strength of the adhesive joint.	[235]
Plates/ Ultrasonic Vibration enhanced FSW (UVeFSW)	Plates: 200mm x 65mm x 3mm Welding parameter: 800rpm – 50mm/min Weld length: 70mm	FSW and UVeFSW	DEFORM - 3D	Temperature, strain rate, dislocation density	N/A	Experiment ↓, Model ↑	N/A	• Ultrasonic-induced dislocation-annihilation and decrease of dislocation density in UVeFSW cause declining of the atomic diffusion coefficients.	[91]
L-shaped Pipeline system	Pipe: 1800mm x 1200mm	• Fixed-end pipeline • Spring-damper shock absorber	Optimization: NSGA-II	Natural frequency, mode shapes	4 modes	Experiment ↓, Model ↑	0.74%- mode1 0.29%- mode2	• Miminize the discrepancies between before and after optimization around 89.29 % and 55.56% for excitation frequencies 38 Hz and 47 Hz respectively	[137]
Plates/ bolted flange	Plates: 100mm x 120mm x 2.2mm Flange: 15mm x 2.2mm Bolt: M6 and M8	Force hammer	FEM	Natural frequency, mode shapes	5 modes	Without BJAR: 3 modes - Experiment ↑, Model ↓ With BJAR: 4 modes - Experiment ↓, Model ↑	Without BJAR: 0.6% -mode4 26.5%- mode1 With BJAR: 1.1% - mode1 4.2%- mode5	• The accuracy of the model results improved by considering the pressure distribution in the bolted joint affected region (BJAR). • Flange geometry has a significant effect on the resonance frequency and amplitude of bolted joints.	[33]

Table 4. (cont.)

Type/joining of structures	Geometric parameter	Experimental analysis	Numerical analysis	Finding data	Number of modes	Result: Trends	Error	Findings	Reference
Beam	Beam: 469mm x 20.4mm x 3.98mm	Impact hammer	FEM	Damage location, natural frequency, mode shapes	4 modes	Experiment ↓, Model ↑	Predicted locations: 0.19 – 2.66% Predicted severities: 1 – 2.6%	• Predicted locations are close to the real locations for damage detection. • Experimental mode shapes show the error is larger due to the noise affected.	[236]
Plate and beam/ welded	Plate: 350mm x 177mm x 10mm Beam: 350mm x 10mm x 20mm	Impact hammer	FEM Model updating	Natural frequency, mode shapes	5 modes	Plate: Experiment ↑, Model ↓ Beam: Experiment ↓, Model ↑	FE model: 6.16%-mode1 1.77%-mode2 Updated model: 0.09%-mode1 0.13%-mode2	• The updating procedure reduced errors between the updated numerical model and the experimental natural frequencies. • Damping identification techniques produced a good fit between the experimental and numerical FRFs	[237]
Frame/ bolted	Frame: Height – 66.75cm Length – 2.75cm Cross-sectional: 3.81cm & 0.95cm	Impact hammer	FEM Model updating	Natural frequency, damping ratio, mode shapes	8 modes	Experiment ↑, Model ↓	FE model: 3.07%-mode2 11.78%-mode4 Updated model: 0%-mode7 0.51%-mode2 0.32%-mode4	• The closer value of closeness index (CI) indicates more accurate structural parameters. • The existing sensitivity methods in the time domain are only applicable for damage with low severities.	[238]

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CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

AUTHORS' CONTRIBUTION

R.M. Yaacob (Conceptualisation; Investigation; Writing – original draft)
J.M. Zikri (Validation; Writing – review & editing)
N.A.Z. Abdullah (Validation; Writing – review & editing)
M.S.M. Sani (Supervision; Conceptualisation; Writing – review & editing)

AVAILABILITY OF DATA AND MATERIALS

Data sharing is not applicable to this article as no new data were created or analysed in this study.

ETHICS STATEMENT

This study did not involve human participants or animals.

REFERENCES

[1] X. Wang, J. Jiang, L. Hong, J.-Q. Sun, "Random vibration analysis with radial basis function neural networks," *International Journal of Dynamics and Control*, vol. 10, no. 5, pp. 1385–1394, 2022.

[2] M. H. Mohd Ghazali, W. Rahiman, "Vibration analysis for machine monitoring and diagnosis: A systematic review," *Shock and Vibration*, vol. 2021, p. 9469318, 2021.

[3] V. V. Mikheyev, "New type of vibration generator with vibratory force oriented in preferred direction," *Journal of Vibration Engineering & Technologies*, vol. 6, no. 2, pp. 149–154, 2018.

[4] E. A. Van der Zee, "The biology of vibration," in *Manual of Vibration Exercise and Vibration Therapy*, J. Rittweger, Ed. Cham: Springer International Publishing, 2020, pp. 23–38.

[5] P. Ragauskas, R. Jasevičius, "Objective function distortion reduction in identification technique of composite material elastic properties," *Vibration*, vol. 7, no. 1, pp. 177–195, 2024.

[6] Y. Yang, R. Xie, M. Li, M. Li, W. Cheng, "A review on the application of blind source separation in vibration analysis of mechanical systems," *Measurement*, vol. 227, p. 114241, 2024.

[7] R. Jinfeng, W. Lin, L. Pei, "Summary of research on supporting facilities and structure vibration and noise reduction of high-rise buildings," in *IOP Conference Series: Earth and Environmental Science*, IOP Publishing, 2021.

[8] J. Bai, W. Zuo, "Hollow structural design in topology optimization via moving morphable component method," *Structural and Multidisciplinary Optimization*, vol. 61, no. 1, pp. 187–205, 2020.

[9] Y. Liu, J. Su, G. Ma, X. Han, C. F. Tan, L. Wu, et al., "Effect of the laser texturing width on hot-pressing joining of AZ31B and CFRTP," *Optics & Laser Technology*, vol. 143, p. 107350, 2021.

[10] A. Gullino, P. Matteis, F. D'Aiuto, "Review of aluminum-to-steel welding technologies for car-body applications," *Metals*, vol. 9, no. 3, p. 315, 2019.

[11] O. Kayode, E. T. Akinlabi, "An overview on joining of aluminium and magnesium alloys using friction stir welding (FSW) for automotive lightweight applications," *Materials Research Express*, vol. 6, no. 11, p. 112005, 2019.

[12] H. Zhao, R. Zhang, Z. Bin, "A review of automotive lightweight technology," in *2018 International Conference on Mechanical, Electronic, Control and Automation Engineering (MECAE 2018)*. Atlantis Press, 2018.

[13] T. Guo, L. Li, L. Cai, Y. Zhao, "Alternative method for identification of the dynamic properties of bolted joints," *Journal of Mechanical Science and Technology*, vol. 26, no. 10, pp. 3017–3027, 2012.

[14] H. Wang, Q. Ge, D. Zeng, Z. Zhang, J. Chen, "Human-induced vibration serviceability: From dynamic load measurement towards the performance-based structural design," *Buildings*, vol. 13, no. 8, p. 1977, 2023.

[15] Y. H. Elmoghazy, B. Safaei, M. Asmael, S. Sahmani, Q. Zeeshan, Z. Qin, "Computational modelling and analysis of effect of viscoelastic materials on damping and vibrational behaviors of composite structures—An extensive review," *Archives of Computational Methods in Engineering*, vol. 31, pp. 2611–2662, 2024.

[16] Y. Chevalier, "Damping in materials and structures: An overview," in *Generalized Models and Non-classical Approaches in Complex Materials 2*, H. Altenbach, J. Pouget, M. Rousseau, B. Collet, T. Michelitsch, Eds. Cham: Springer International Publishing, 2018, pp. 1–27.

[17] S. Varunraj, M. Ruban, "Investigation of the microstructure and mechanical properties of AA6063 and AA7075 dissimilar aluminium alloys by friction stir welding process," *Materials Today: Proceedings*, vol. 68, pp. 1654–1657, 2022.

[18] H. Chen, Z. Zhu, Y. Zhu, L. Sun, Y. Guo, "Solid-state welding of aluminum to magnesium alloys: A review," *Metals*, vol. 13, no. 8, p. 1410, 2023.

[19] Z. Hao, Y. Ju, L. Chen, "The use of aluminium and magnesium alloys in automotive lightweight technologies," *Journal of Mechanical Science and Technology*, vol. 37, no. 9, pp. 4615–4622, 2023.

[20] Y. Yang, Z. Luo, Y. Zhang, and J. Su, "Dissimilar welding of aluminium to steel: A review," *Journal of Manufacturing Processes*, vol. 110, pp. 376–397, 2024.

[21] S. T. Selvamani, "Various welding processes for joining aluminium alloy with steel: Effect of process parameters and observations – A review," *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, vol. 236, no. 10, pp. 5428–5454, 2022.

[22] U. A. Khaliq, M. R. Muhamad, F. Yusof, S. Ibrahim, M. S. M. Isa, Z. Chen et al., "A review on friction stir butt welding of aluminum with magnesium: A new insight on joining mechanisms by interfacial enhancement," *Journal of Materials Research and Technology,* 2023.

[23] H. Liu, W. Sun, D. Du, X. Liu, "Modeling and free vibration analysis for bolted composite plate under inconsistent pre-tightening condition," *Composite Structures*, vol. 292, p. 115634, 2022.

[24] M. M. El-Sayed, A. Y. Shash, M. Abd-Rabou, M. G. ElSherbiny, "Welding and processing of metallic materials by using friction stir technique: A review," *Journal of Advanced Joining Processes*, vol. 3, p. 100059, 2021.

[25] E. J. Kellar, "Joining similar and dissimilar materials," in *Adhesive Bonding*. Elsevier, 2021, pp. 385–405.

[26] T. Nonnenmann, R. Beygi, R. J. C. Carbas, L. F. M. da Silva, A. Öchsner, "Synergetic effect of adhesive bonding and welding on fracture load in hybrid joints," *Journal of Advanced Joining Processes*, vol. 6, p. 100122, 2022.

[27] L. D. C. Ramalho, I. J. Sánchez-Arce, D. C. Gonçalves, J. Belinha, R. D. S. G. Campilho, "Numerical analysis of the dynamic behavior of adhesive joints: A review," *International Journal of Adhesion and Adhesives*, vol. 118, p. 103219, 2022.

[28] L. D. C. Ramalho, R. D. S. G. Campilho, J. Belinha, L. F. M. da Silva, "Static strength prediction of adhesive joints: A review," *International Journal of Adhesion and Adhesives*, vol. 96, p. 102451, 2020.

[29] Z. Qin, Q. Han, F. Chu, "Analytical model of bolted disk–drum joints and its application to dynamic analysis of jointed rotor," *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, vol. 228, no. 4, pp. 646–663, 2014.

[30] X. Liao, J. Zhang, X. Xu, "Analytical model of bolted joint structure and its nonlinear dynamic characteristics in transient excitation," *Shock and Vibration*, vol. 2016, p. 1–11, 2016.

[31] N. Jamia, H. Jalali, J. Taghipour, M. I. Friswell, H. H. Khodaparast, "Nonlinear dynamic analysis of bolted joints: Detailed and equivalent modelling," in *Nonlinear Structures & Systems, Volume 1*. Cham: Springer International Publishing, 2021.

[32] J. Kim, J.-C. Yoon, B.-S. Kang, "Finite element analysis and modeling of structure with bolted joints," *Applied Mathematical Modelling*, vol. 31, no. 5, pp. 895–911, 2007.

[33] Y. Q. Wang, W. C. Xing, J. Wang, Q. Chai., "Theoretical and experimental studies on vibration characteristics of bolted joint multi-plate structures," *International Journal of Mechanical Sciences*, vol. 252, p. 108348, 2023.

[34] C. Hammami, "Numerical investigation of static behavior of bolted joints," *Journal of Theoretical and Applied Mechanics*, vol. 60, 2022.

[35] N. A. Nazri, M. S. M. Sani, M. N. Mansor, S. N. Zahari, "Model updating of friction stir welding for aluminium and magnesium plate structure," in *MATEC Web of Conferences*. EDP Sciences, 2018.

[36] S. N. Zahari, M. S. M. Sani, N. A. Husain, M. Ishak, I. Zaman, "Dynamic analysis of friction stir welding joints in dissimilar material plate structure," *Jurnal Teknologi*, vol. 78, nos. 6–9, 2016.

[37] H. Gharehbaghi, S. Hosseini, R. Hosseini, "Investigation of the effect of welding residual stress on natural frequencies: Experimental and numerical study," *Iranian Journal of Science and Technology, Transactions of Mechanical Engineering*, vol. 47, no. 4, pp. 1777–1785, 2023.

[38] M. A. S. Aziz Shah, M. A. Yunus, M. N. Abdul Rani, M. S. Mohd Zin, W. I. I. Wan Iskandar Mirza, "Finite element modelling of laser stitch welding joints for structural dynamic predictions," *International Journal of Automotive and Mechanical Engineering*, vol. 16, no. 2, pp. 6556–6567, 2019.

[39] T. Al-hababi, M. Cao, B. Saleh, N. F. Alkayem, H. Xu., "A critical review of nonlinear damping identification in structural dynamics: Methods, applications, and challenges," *Sensors*, vol. 20, no. 24, p. 7303, 2020.

[40] H. Mevada, D. Patel, "Experimental determination of structural damping of different materials," *Procedia Engineering*, vol. 144, pp. 110–115, 2016.

[41] Adams, R., *et al.*, "Frictional damping in hollow beam structures joined by bolts, rivets, and adhesive," *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*, vol. 235, no. 6, pp. 1477–1487, 2021.

[42] Ansari, M.S.P., A. Jain, "Experimental analysis of damping on layered and riveted joint beam: A review," *International Journal of Engineering Sciences & Research Technology*, vol. 3, no. 6, pp. 219–223, 2014.

[43] Brøns, M., *et al.*, "Coupling effects with vibration-based estimation of individual bolt tension in multi-bolt structures," *Journal of Sound and Vibration*, vol. 528, p. 116873, 2022.

[44] A. Pirdayr, M. Mohammadi, M. J. Kazemzadeh-Parsi, M. Rajabi, "Self-loosening effects on vibration characteristics of plates with bolted joints: An experimental and finite element analysis," *Measurement*, vol. 185, p. 109922, 2021.

[45] K. Lingfei, H. Jiang, A. H. Ghasemi, Y. Li, "Condensation modeling of the bolted joint structure with the effect of nonlinear dynamics," *Journal of Sound and Vibration*, vol. 442, pp. 657–676, 2019.

[46] R. Omar, M. N. A. Rani, M. A. Yunus, W. I. I. Wan Iskandar Mirza, "Improvement in the accuracy of the dynamic behavior prediction of a bolted structure using a simplified finite element model and model updating," in *IOP Conference Series: Materials Science and Engineering*. IOP Publishing, 2021.

[47] M. N. Abdul Rani, M. A. Yunus, Z. Yahya, M. Rusli, A. R. Bahari, "Model updating of a bolted joint contact surface using thin layer element parameters," in *AIP Conference Proceedings*. AIP Publishing, 2024.

[48] W. C. Xing, J. Wang, Y. Q. Wang, "An effective model for bolted flange joints and its application in vibrations of bolted flange joint multiple-plate structures: Theory with experiment verification," *Applied Mathematical Modelling*, vol. 126, pp. 482–505, 2024.

[49] S. Gajendra, S. Suman, K. Mahesha, "Shear strength analysis of dissimilar materials bolted joint," *International Journal for Modern Trends in Science and Technology*, vol. 8, pp. 87–90, 2022.

[50] G. Wu, D. Li, W.-J. Lai, Y. Shi, H. Kang, Y. Peng, et al., "Fatigue behaviors and mechanism-based life evaluation on SPR-bonded aluminum joint," *International Journal of Fatigue*, vol. 142, p. 105948, 2021.

[51] B. Xing, F. Tang, C. Song, X. He, "Static and fatigue behavior of self-piercing riveted joints with two overlap areas," *Journal of Materials Research and Technology*, vol. 14, pp. 1333–1338, 2021.

[52] J. F. C. Moraes, R. A. S. Moreira, B. Ralph, S. A. M. Tavares., "Effect of process deformation history on mechanical performance of AM60B to AA6082 self-pierce riveted joints," *Engineering Fracture Mechanics*, vol. 209, pp. 92–104, 2019.

[53] H. Jiang, M. Zhang, C.-H. Lee, Y. Jiang, "Failure behavior of electromagnetic driven nailing riveted joint for Al/steel structures subjected to fatigue loading," *Engineering Failure Analysis*, vol. 132, p. 105941, 2022.

[54] H. Wang, X. Li, Y. Zhao, F. Liu, "Numerical analysis of dynamic response: Fatigue behavior analysis of Al alloy–CFRP riveted single-shear lap joints," *International Journal of Fatigue*, vol. 170, p. 107515, 2023.

[55] D.-H. Kam, T. E. Jeong, J. Kim, "A quality study of a self-piercing riveted joint between vibration-damping aluminum alloy and dissimilar materials," *Applied Sciences*, vol. 10, no. 17, p. 5947, 2020.

[56] S. Xiang, Y. Zhang, Q. Li, X. Sun, "Experimental and numerical investigation on failure behavior of hybrid bonded/bolted GFRP single-lap joints under static shear loading," *Engineering Failure Analysis*, vol. 158, p. 107969, 2024.

[57] B. Meyghani, C. Wu, "Progress in thermomechanical analysis of friction stir welding," *Chinese Journal of Mechanical Engineering*, vol. 33, no. 1, p. 12, 2020.

[58] M. Verma, S. Ahmed, P. Saha, "Challenges, process requisites/inputs, mechanics and weld performance of dissimilar micro-friction stir welding (dissimilar µFSW): A comprehensive review," *Journal of Manufacturing Processes*, vol. 68, pp. 249–276, 2021.

[59] H. Wang, J. Liu, X. Zhang, F. Chen, "Microstructure and mechanical properties of dissimilar friction stir welded type 304 austenitic stainless steel to Q235 low carbon steel," *Materials Characterization*, vol. 155, p. 109803, 2019.

[60] L. Guan, H. Zhao, M. Liu, W. Chen, "Texture-induced corrosion resistance of dissimilar AA7204/AA6082 friction stir welded joints," *Materials*, vol. 16, no. 18, p. 6183, 2023.

[61] R. I. Rodriguez, J. B. Jordon, P. G. Allison, T. W. Rushing, L. Garcia, “Corrosion effects on fatigue behavior of dissimilar friction stir welding of high-strength aluminum alloys,” *Materials Science and Engineering A*, vol. 742, pp. 255–268, 2019.

[62] A. M. Sadoun, A. F. Meselhy, A. W. Deabs, “Improved strength and ductility of friction stir tailor-welded blanks of base metal AA2024 reinforced with interlayer strip of AA7075,” *Results in Physics*, vol. 16, p. 102911, 2020.

[63] R. Rana, A. Karmakar, and D. B. Karunakar, “Effect of tool travel rate on microstructure evolution and mechanical properties of dissimilar friction stir welded joints of AA7075 and AA6061 aluminium alloys,” *Journal of Materials Engineering and Performance*, 2023.

[64] T. Prabaharan, M. B. S. Sreekara Reddy, A. B. Herbert, B. Ramanan, P. K. Jenaris, “Strain-cum-deformation analysis of friction stir welded AA5052 and AA6061 samples with microstructural analysis,” *Journal of Mines, Metals & Fuels*, vol. 70, 2022.

[65] J. L. Chukwuneke, C. A. Okafor, S. N. Obike, A. U. Onwuzulike, “Numerical and thermal analysis of mechanical properties degradations and distortions in steel weld joint,” *Cleaner Materials*, vol. 6, p. 100150, 2022.

[66] Ş. H. Atapek, M. Tümer, E. Çelikkol, A. Kısasöz, M. Z. Kerimak, “Microstructural, mechanical and corrosion behavior of UNS S31803/Hastelloy C-276 dissimilar metal welds,” *CIRP Journal of Manufacturing Science and Technology*, vol. 40, pp. 129–141, 2023.

[67] Y. Y. Jang, J. C. Ha, D. Lee, Y. Lee, S.-Y. Nam, S. B. Yang, D.-J. Kwon, “Dissimilar material bonding technology for lightweight future mobility: A review,” *Polymer Testing*, p. 108281, 2023.

[68] L. F. M. da Silva, E. A. S. Marques, R. D. S. G. Campilho, “Design rules and methods to improve joint strength,” in *Handbook of Adhesion Technology*. Cham: Springer International Publishing, 2018, pp. 773–810.

[69] D. K. Dwivedi, “Adhesive joining of dissimilar metals,” in *Dissimilar Metal Joining*. Singapore: Springer Nature Singapore, 2023, pp. 287–305.

[70] E. J. C. Kellar, “Selection of adhesives,” in *Handbook of Adhesion Technology*. Cham: Springer International Publishing, 2018, pp. 409–430.

[71] H. A. Waqas, M. Sahil, M. M. Khan, A. W. Anwar, M. U. Shah, and M. Usman., “Optimizing reinforcement strategies for robust beam-column joints in seismic-resistant structures,” *Arabian Journal for Science and Engineering*, vol. 49, no. 4, pp. 6107–6124, 2024.

[72] J. Pietschmann, “Surface pretreatment of metals,” in *Industrial Powder Coating: Basics, Methods, Practical Application*. Wiesbaden: Springer Fachmedien Wiesbaden, 2023, pp. 209–275.

[73] Groche, P., A. Kleemann, S. Köhler, “Surface pre-treatment and its influence on electric functionality and the formability of screen-printed steel sheet,” *Production Engineering*, vol. 12, no. 6, pp. 789–795, 2018.

[74] J. P. A. Valente, R. D. S. G. Campilho, E. A. S. Marques, J. J. M. Machado, L. F. M. da Silva, “Geometrical optimization of adhesive joints under tensile impact loads using cohesive zone modelling,” *International Journal of Adhesion and Adhesives*, vol. 97, p. 102492, 2020.

[75] S. Maggiore, M. D. Banea, P. Stagnaro, G. Luciano, “A review of structural adhesive joints in hybrid joining processes,” *Polymers*, vol. 13, no. 22, p. 3961, 2021.

[76] S. Safaei, M. R. Ayatollahi, A. Akhavan-Safar, M. Moazzami, L. F. M. da Silva, “Effect of residual strains on the static strength of dissimilar single lap adhesive joints,” *The Journal of Adhesion*, vol. 97, no. 11, pp. 1052–1071, 2021.

[77] H. Golivari, H. S. Googarchin, A. Zaeri, A. Keshavarzi, “Experimental and numerical investigation of the energy absorption in hybrid double-hat thin-walled structures reinforced by adhesive bonding under three-point bending,” *International Journal of Adhesion and Adhesives*, vol. 128, p. 103543, 2024.

[78] H. Li, X. S. Liu, Y. S. Zhang, M. T. Ma, G. Y. Li, J. Senkara, “Current research and challenges in innovative technology of joining dissimilar materials for electric vehicles,” in *Advanced High Strength Steel and Press Hardening: Proc. 4th Int. Conf. on Advanced High Strength Steel and Press Hardening (ICHSU2018)*. World Scientific, 2019.

[79] H. L. Lye, M. H. Jaafar, M. H. Osman, A. R. Baharom, “Bond relationship of carbon fiber-reinforced polymer (CFRP) strengthened steel plates exposed to service temperature,” *Materials*, vol. 14, no. 13, p. 3761, 2021.

[80] A. Pramanik, A. K. Basak, Y. Dong, P. K. Sarker, M. S. Uddin, G. Littlefair et al., “Joining of carbon fibre reinforced polymer (CFRP) composites and aluminium alloys – A review,” *Composites Part A: Applied Science and Manufacturing*, vol. 101, pp. 1–29, 2017.

[81] A. Zvorykina, O. Sherepenko, M. Neubauer, S. Jüttner, “Dissimilar metal joining of aluminum to steel by hybrid process of adhesive bonding and projection welding using a novel insert element,” *Journal of Materials Processing Technology*, vol. 282, p. 116680, 2020.

[82] P. Langer, K. Sepahvand, C. Guist, S. Marburg, “Finite element modeling for structural dynamic analysis of bolted joints under uncertainty,” *Procedia Engineering*, vol. 199, pp. 954–959, 2017.

[83] X. Liu, W. Sun, H. Liu, D. Du, H. Ma, H. Li, "Coupled vibration analysis of bolted variable angle tow plates under combined nonlinear effects," *Composite Structures*, vol. 330, p. 117847, 2024.

[84] Yürük, A., B. Çevik, N. Kahraman, "Analysis of mechanical and microstructural properties of gas metal arc welded dissimilar aluminum alloys (AA5754/AA6013)," *Materials Chemistry and Physics*, vol. 273, p. 125117, 2021.

[85] A. Yürük, B. Çevik, N. Kahraman, "Numerical simulation and experimental residual stress analyses of dissimilar GTA weldments of AA5083 and AA6082," *International Journal on Interactive Design and Manufacturing (IJIDeM)*, pp. 1–11, 2023.

[86] M. J. H. Prasad, I. Sudhakar, S. Adinarayana, D. V. N. J. Jagannadha Rao, "Simulation and validation of experimental residual stresses of dissimilar AA2124 and AA7075 TIG weld joint using ANSYS APDL," *International Journal on Interactive Design and Manufacturing (IJIDeM)*, vol. 18, no. 1, pp. 71–82, 2024.

[87] R. Hynes, S. N. Khamis, A. R. Anath, "An experimental insight of friction stir welding of dissimilar AA6061/Mg AZ31B joints," *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, vol. 236, p. 095440542110434, 2021.

[88] R. S. Sidhu, R. Kumar, R. Kumar, P. Goel, S. Singh, D. Y. Pimenov, et al., "Joining of dissimilar Al and Mg metal alloys by friction stir welding," *Materials (Basel)*, vol. 15, no. 17, p. 5901, 2022.

[89] M. M. Z. Ahmed, M. M. El-Sayed Seleman, D. Fydrych, G. Çam, "Review on friction stir welding of dissimilar magnesium and aluminum alloys: Scientometric analysis and strategies for achieving high-quality joints," *Journal of Magnesium and Alloys*, vol. 11, no. 11, pp. 4082–4127, 2023.

[90] M. Kumar, A. Das, R. Ballav, "Influence of the Zn interlayer on the mechanical strength, corrosion and microstructural behavior of friction stir-welded 6061-T6 aluminium alloy and AZ61 magnesium alloy dissimilar joints," *Materials Today Communications*, vol. 35, p. 105509, 2023.

[91] Z. Chen, L. Shi, H. Su, C. Wu, "Numerical and experimental investigation on intermetallic compounds formation in ultrasonic vibration-enhanced friction stir welding of dissimilar Al/Mg alloys," *Journal of Alloys and Compounds*, vol. 977, p. 173426, 2024.

[92] Z. Liu, X. Meng, S. Ji, Z. Li, L. Wang, "Improving tensile properties of Al/Mg joint by smashing intermetallic compounds via ultrasonic-assisted stationary shoulder friction stir welding," *Journal of Manufacturing Processes*, vol. 31, pp. 552–559, 2018.

[93] C. Yang, C. Wu, "Numerical simulation of ultrasonic vibration-enhanced friction stir welding process of dissimilar Al/Mg alloys," *The International Journal of Advanced Manufacturing Technology*, vol. 120, no. 3, pp. 2277–2289, 2022.

[94] S. A. Aljunid, N. A. Nazri, M. S. M. Sani, M. N. Mansor, S. N. Zahari, "Model updating of friction stir welding for aluminium and magnesium plate structure," *MATEC Web of Conferences*, vol. 150, 2018.

[95] S. Y. Anaman, H. H. Cho, H. Das, J. S. Lee, S. T. Hong, "Microstructure and mechanical/electrochemical properties of friction stir butt welded joint of dissimilar aluminum and steel alloys," *Materials Characterization*, vol. 154, pp. 67–79, 2019.

[96] M. Sakaguchi, Y. Kurokawa, F. Nakamura, T. Hashimura, "Fatigue strength of steel–aluminum alloy dissimilar lap joints fabricated by dimple spot welding for automotive application," *Fatigue & Fracture of Engineering Materials & Structures*, 2024.

[97] A. N. Correia, D. F. O. Braga, P. M. G. P. Moreira, V. Infante, "Review on dissimilar structures joints failure," *Engineering Failure Analysis*, vol. 129, p. 105652, 2021.

[98] K. Raja, A. Bovas Herbert Bejaxhin, G. Jayaprakash, P. Gopi Krishnan, N. Ramanan, "Microstructural and mechanical analysis of achieving crack-free joints in high-speed friction stir spot welding of Cu–Al dissimilar material," *International Journal on Interactive Design and Manufacturing (IJIDeM)*, pp. 1–12, 2024.

[99] G. Li, L. Zhou, W. Zhou, X. Song, Y. Huang, "Influence of dwell time on microstructure evolution and mechanical properties of dissimilar friction stir spot welded aluminum–copper metals," *Journal of Materials Research and Technology*, vol. 8, no. 3, pp. 2613–2624, 2019.

[100] B. Qin, R. Qu, Y. Xie, S. Liu, "Numerical simulation and experimental study on the TIG (A-TIG) welding of dissimilar magnesium alloys," *Materials*, vol. 15, no. 14, p. 4922, 2022.

[101] Y. Xu, H. Bu, F. Wang, W. Ma, X. Zhan, "Numerical simulation and experimental investigation of laser joining Ti6Al4V alloy and CFRTP with embedded Ti6Al4V alloy," *Optics & Laser Technology*, vol. 156, p. 108433, 2022.

[102] H. Bu, X. Zhan, H. Yang, F. Wang, W. Ma, "Numerical simulation of thermal distribution and residual stress characteristic for laser wobble joining of CFRTP and Ti-6Al-4V alloy," *Journal of Manufacturing Processes*, vol. 79, pp. 562–575, 2022.

[103] A. Li, S. Xu, H. Wang, H. Zhang, Y. Wang, "Bond behavior between CFRP plates and corroded steel plates," *Composite Structures*, vol. 220, pp. 221–235, 2019.

[104] H. Tang, X. Deng, Z. Lin, X. Zhou, “Analytical and experimental investigation on bond behavior of CFRP-to-stainless steel interface,” *Composite Structures*, vol. 212, pp. 94–105, 2019.

[105] K. Zhang, Z. Yang, Y. Li, “A method for predicting the curing residual stress for CFRP/Al adhesive single-lap joints,” *International Journal of Adhesion and Adhesives*, vol. 46, pp. 7–13, 2013.

[106] E. Janoško, A. Guzanová, D. Draganovská, M. Tomáš, “Adhesive bonding of dissimilar materials,” *Machines. Technologies. Materials.*, vol. 14, no. 4, pp. 159–162, 2020.

[107] F. Czerwinski, “Current trends in automotive lightweighting strategies and materials,” *Materials*, vol. 14, no. 21, p. 6631, 2021.

[108] S. Arunkumar, V. P. M. Baskaralal, V. Muthuraman, “Comparative investigation on modal analysis of LM25 aluminium alloy with other aluminium alloys using finite element analysis software,” in *IOP Conference Series: Materials Science and Engineering*. IOP Publishing, 2017.

[109] H. Wang, C. Gao, Y. Chen, M. Wu, L. Hua, “Ultrasonic vibration-strengthened adhesive bonding of CFRP/aluminum alloy joints with anodizing pretreatment,” *JOM*, vol. 72, no. 10, pp. 3472–3482, 2020.

[110] Y. Koli, N. Yuvaraj, S. Aravindan, Vipin, “Enhancement of mechanical properties of 6061/6082 dissimilar aluminium alloys through ultrasonic-assisted cold metal transfer welding,” *Arabian Journal for Science and Engineering*, vol. 46, no. 12, pp. 12089–12104, 2021.

[111] S. Cui, X. Zhang, Y. Wang, L. Liu, “Numerical simulation and mechanical properties of 6063/6082 dissimilar joints by laser welding,” *Coatings*, vol. 13, no. 12, p. 2049, 2023.

[112] P. Kaewkham, W. Nakkiew, A. Baisukhan, “Mechanical properties enhancement of dissimilar AA6061-T6 and AA7075-T651 friction stir welds coupled with deep rolling process,” *Materials*, vol. 15, no. 18, p. 6275, 2022.

[113] N. Çömez, H. Durmuş, “Cold metal transfer welding of AA6061 to AA7075: Mechanical properties and corrosion,” *Journal of Engineering Materials and Technology*, vol. 141, no. 3, 2019.

[114] J. Korpysa, I. Zagórski, “Vibration analysis during AZ31 magnesium alloy milling with the use of different toolholder types,” *Eksploatacja i Niezawodność*, vol. 24, no. 3, 2022.

[115] M. Thomä, F. Haupt, D. Löwenstein, M. Zaeh, M. Schmidt, “Analysis of the oscillation behavior of hybrid aluminum/steel joints realized by ultrasound enhanced friction stir welding,” *Metals*, vol. 10, no. 8, p. 1079, 2020.

[116] R. Branco, F. Berto, A. Kotousov, “Special issue on recent trends in advanced high-strength steels,” *Applied Sciences*, vol. 11, no. 15, p. 6914, 2021.

[117] M. S. Gümüş, M. Kalyoncu, “Fatigue failure of high strength steels under extreme vibrations of military standards: A comparative study,” *Journal of Mechanical Science and Technology*, vol. 38, no. 3, pp. 1059–1068, 2024.

[118] M. Hamza, K. Akhtar, M. A. Khan, “Modal and dynamic analysis of damaged steel column-beam frame structure subjected to seismic vibrations using experimental and finite element analysis approach,” *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, vol. 46, no. 2, p. 94, 2024.

[119] F. Bleicher, P. Heindl, H. Kopsch, F. Kuster, “Vibration assisted drilling of CFRP/metal stacks at low frequencies and high amplitudes,” *Production Engineering*, vol. 12, no. 2, pp. 289–296, 2018.

[120] S. Sooriyan, U. Madhusudhanan, R. Kitey, “Al/GFRP interface strength under quasi-static and dynamic loading conditions,” in *Advances in Structural Integrity*. Singapore: Springer Singapore, 2022.

[121] A. Jafari, A. H. Kazemian, H. Rahmani, “Investigating vibration properties of aluminum plates in radii of different curvatures reinforced with glass fibers by modal analysis method experimentally and numerically,” *Fibers and Polymers*, vol. 25, no. 4, pp. 1457–1478, 2024.

[122] D. Wang, Z. Li, S. Tian, T. Li, “Study on dynamic drilling forces of CFRP/Ti stacks during longitudinal-torsional ultrasonic vibration drilling,” *The International Journal of Advanced Manufacturing Technology*, vol. 126, no. 7, pp. 2989–3004, 2023.

[123] R. Hussein, A. Sadek, M. A. Elbestawi, M. H. Attia, “Low-frequency vibration-assisted drilling of hybrid CFRP/Ti6Al4V stacked material,” *The International Journal of Advanced Manufacturing Technology*, vol. 98, no. 9, pp. 2801–2817, 2018.

[124] F. Delzendehrooy, A. Akhavan-Safar, A. Q. Barbosa, R. Beygi, D. Cardoso, R. J. C. Carbas, et al., “A comprehensive review on structural joining techniques in the marine industry,” *Composite Structures*, vol. 289, p. 115490, 2022.

[125] K. Martinsen, S. J. Hu, B. E. Carlson, “Joining of dissimilar materials,” *CIRP Annals*, vol. 64, no. 2, pp. 679–699, 2015.

[126] G. Phanikumar, K. Chattopadhyay, P. Dutta, “Joining of dissimilar metals: Issues and modelling techniques,” *Science and Technology of Welding and Joining*, vol. 16, no. 4, pp. 313–317, 2011.

[127] G. Sathishkumar, P. Sethuraman, C. Chanakyan, S. Sundaraselvan, A. Joseph Arockiam, S. V. Alagarsamy et al., “Friction welding of similar and dissimilar materials: A review,” *Materials Today: Proceedings*, 2021, vol. 81, pp. 208-211.

[128] S. Kuryntsev, “Laser welding of dissimilar materials (Al/Fe, Al/Ti, Al/Cu)—Methods and techniques, microstructure and properties: A review,” *Materials*, vol. 15, p. 122, 2021.

[129] M. A. S. Aziz Shah, M. A. Yunus, M. N. Abdul Rani, R. Omar, A. Mora, “Stochastic model updating of bolt-jointed structure for structural dynamics applications,” *International Journal of Automotive and Mechanical Engineering*, vol. 18, no. 2, pp. 8760–8771, 2021.

[130] R. Omar, M. N. H. Abdul Rani, W. I. I. W. I. Mirza, M. A. Yunus, M. H. Othman, “Finite element modelling and updating for bolted lap joints,” *Journal of Mechanical Engineering*, vol. SI 4, no. 3, pp. 202–222, 2017.

[131] A. Sharma, A. K. Bagha, D. K. Shukla, S. Bahl, “Finite element model updating of metallic and composite structures – A state of the art review,” *AIMS Materials Science*, vol. 8, no. 3, pp. 390–415, 2021.

[132] M. Girardi, C. Padovani, D. Pellegrini, L. Robol, “A finite element model updating method based on global optimization,” *Mechanical Systems and Signal Processing*, vol. 152, p. 107372, 2021.

[133] W. I. I. W. I. Mirza, A. Kyprianou, T. A. N. da Silva, M. N. A. Rani, “Frequency based substructuring and coupling enhancement using estimated rotational frequency response functions,” *Experimental Techniques*, vol. 48, no. 3, pp. 423-437, 2023.

[134] K. Charoensuk, T. Sethaput, “The vibration analysis based on experimental and finite element modeling for investigating the effect of a multi-notch location of a steel plate,” *Applied Sciences*, vol. 13, no. 21, p. 12073, 2023.

[135] J. X. Wei, N. A. Z. Abdullah, M. N. A. M. Asri, M. S. M. Sani, “Investigation on vibration analysis of beam structure with different types of joints,” *AIP Conference Proceedings*, vol. 2545, no. 1, p. 020016, 2022.

[136] Y. Li, Z. Zhu, C. Wen, K. Liu, Z. Luo, T. Long, “Rub-impact dynamic analysis of a dual-rotor system with bolted joint structure: Theoretical and experimental investigations,” *Mechanical Systems and Signal Processing*, vol. 209, p. 111144, 2024.

[137] L. Zhang, T. Zhang, H. Ouyang, T. Li, M. You, “Natural frequency assignment of a pipeline through structural modification in layout optimization of elastic supports,” *Journal of Sound and Vibration*, vol. 561, p. 117702, 2023.

[138] Y. Bai, Z. Peng, Z. Wang, “A finite element model updating method based on the trust region and adaptive surrogate model,” *Journal of Sound and Vibration*, vol. 555, p. 117701, 2023.

[139] S. Ereiz, I. Duvnjak, J. F. Jimenez-Alonso, “Finite element model updating methods for structural applications,” *Annals of DAAAM & Proceedings*, 2021.

[140] Z.-X. Guan, D.-H. Yang, T.-H. Yi, W.-J. Li, C. Li, “Bridge finite element model updating using stochastic vehicle-induced static response monitoring data,” *Engineering Structures*, vol. 301, p. 117280, 2024.

[141] U. Sinha, S. Das, S. Chakraborty, “Enhancing damping estimation accuracy of exponential windowed responses of a GFRP plate through finite element model updating approach,” *Ocean Engineering*, vol. 303, p. 117710, 2024.

[142] Z. Xia, A. Li, D. Feng, J. Li, X. Chen, G. Zhou., “Comparative analysis of typical mathematical modelling methods through model updating of a real-life bridge structure with measured data,” *Measurement*, vol. 174, p. 108987, 2021.

[143] D. A. Sequera-Gutierrez, L. F. Solano-Rodríguez, E. E. Muñoz-Díaz, Y. A. Alvarado, J. D. Villalba, I. Gasch, “Updating the finite element model of a Colombian bridge with ANSYS,” *Dyna (Medellin, Colombia)*, vol. 87, pp. 209–218, 2020.

[144] T. Sharry, H. Guan, A. Nguyen, E. Oh, N. Hoang, “Latest advances in finite element modelling and model updating of cable-stayed bridges,” *Infrastructures*, vol. 7, p. 8, 2022.

[145] S. Ereiz, I. Duvnjak, D. Damjanović, M. Bartolac, “Analysis of seismic action on the tie rod system in historic buildings using finite element model updating,” *Buildings*, vol. 11, 2021.

[146] G. Park, J. Jung, H. Yoon, “Structural finite element model updating considering soil-structure interaction using LS-DYNA in loop,” *Scientific Reports*, vol. 13, no. 1, p. 4753, 2023.

[147] S. Ereiz, I. Duvnjak, J. F. Jiménez-Alonso, “Review of finite element model updating methods for structural applications,” *Structures*, vol. 41, pp. 684–723, 2022.

[148] T. Yang, K. Liu, G. Nie, “Improved time domain substructural damage identification method on large-span spatial structure,” *Shock and Vibration*, vol. 2021, p. 1–19, 2021.

[149] S. Schommer, V. H. Nguyen, S. Maas, A. Zürbes, “Model updating for structural health monitoring using static and dynamic measurements,” *Procedia Engineering*, vol. 199, pp. 2146–2153, 2017.

[150] M. I. Friswell, J. E. Mottershead, *Finite Element Model Updating in Structural Dynamics*. Dordrecht: Kluwer Academic Publishers, 1995.

[151] M. Friswell, J. E. Mottershead, *Finite Element Model Updating in Structural Dynamics*. Springer Science & Business Media, 2013.

[152] J. E. Mottershead, M. Link, M. I. Friswell, “Erratum to ‘The sensitivity method in finite element model updating: A tutorial’,” *Mechanical Systems and Signal Processing*, vol. 99, pp. 946–947, 2018.

[153] E. Simoen, G. De Roeck, G. Lombaert, “Dealing with uncertainty in model updating for damage assessment: A review,” *Mechanical Systems and Signal Processing*, vol. 56–57, pp. 123–149, 2015.

[154] X. Ye, B. Chen, “Model updating and variability analysis of modal parameters for super high-rise structure,” *Concurrency and Computation: Practice and Experience*, vol. 31, no. 12, p. e4712, 2019.

[155] L. Sun, Y. Li, W. Zhu, W. Zhang, “Structural response reconstruction in physical coordinate from deficient measurements,” *Engineering Structures*, vol. 212, p. 110484, 2020.

[156] G. Dessena, D. I. Ignatyev, J. F. Whidborne, L. Zanotti Fragonara, “A Kriging approach to model updating for damage detection,” 2023, pp. 245–255.

[157] L. Sun, Y. Li, W. Zhang, “Experimental study on continuous bridge-deflection estimation through inclination and strain,” *Journal of Bridge Engineering*, vol. 25, no. 5, p. 04020020, 2020.

[158] S.-W. Lin, Y.-L. Du, T.-H. Yi, D.-H. Yang, “Model updating using bridge influence lines based on an adaptive metamodel global optimization method,” *Journal of Bridge Engineering*, vol. 27, no. 3, p. 04022003, 2022.

[159] C. Touzé, A. Vizzaccaro, O. Thomas, “Model order reduction methods for geometrically nonlinear structures: A review of nonlinear techniques,” *Nonlinear Dynamics*, vol. 105, no. 2, pp. 1141–1190, 2021.

[160] Q. Aumann, P. Benner, J. Saak, J. Vettermann, “Model order reduction via substructuring for a nonlinear, differential-algebraic machine tool model with moving loads,” *PAMM*, vol. 23, no. 1, p. e202200286, 2023.

[161] G. Sun, F. Peng, M. Mu, “Uncertainty assessment and sensitivity analysis of soil moisture based on model parameter errors – Results from four regions in China,” *Journal of Hydrology*, vol. 555, pp. 347–360, 2017.

[162] M. Misawa, H. Kawasoe, “Effects of errors in finite element models on component modal tests,” in *Topics in Modal Analysis II, Volume 8*. Springer, 2014.

[163] R. N. Coppolino, “Reconciliation of finite element models and modal test data,” in *The Integrated Test Analysis Process for Structural Dynamic Systems*. Springer, 2020, pp. 123–146.

[164] D. J. Ewins, B. Weekes, A. delli Carri, “Modal testing for model validation of structures with discrete nonlinearities,” *Philosophical Transactions of the Royal Society A*, vol. 373, no. 2051, p. 20140410, 2015.

[165] F. Vestroni, A. Morassi, “Structural dynamic identification and damage detection,” in *50+ Years of AIMETA: A Journey Through Theoretical and Applied Mechanics in Italy*. Springer, 2022, pp. 287–303.

[166] A. C. Altunişik, M. Günaydin, E. Ertürk Atmaca, A. F. Genç, F. Y. Okur, B. Sevim, “Experimental measurement-based FE model updating and seismic response of Santa Maria Church and its guesthouse building,” *Journal of Civil Structural Health Monitoring*, pp. 1–30, 2024.

[167] M. Tondi, M. Bovo, L. Vincenzi, “Efficient two-step procedure for parameter identification and uncertainty assessment in model updating problems,” *Frontiers in Built Environment*, vol. 9, pp. 1–18, 2023.

[168] A. C. Altunişik, E. Kalkan, F. Y. Okur, O. Ş. Karahasan, K. Ozgan, “Finite-element model updating and dynamic responses of reconstructed historical timber bridges using ambient vibration test results,” *Journal of Performance of Constructed Facilities*, vol. 34, no. 1, p. 04019085, 2020.

[169] Y. Huang, C. Shao, B. Wu, J. L. Beck, H. Li, “State-of-the-art review on Bayesian inference in structural system identification and damage assessment,” *Advances in Structural Engineering*, vol. 22, no. 6, pp. 1329–1351, 2019.

[170] D. Dinis, A. P. Teixeira, C. G. Soares, “Probabilistic approach for characterising the static risk of ships using Bayesian networks,” *Reliability Engineering & System Safety*, vol. 203, p. 107073, 2020.

[171] B. T. Svendsen, Ø. W. Petersen, G. T. Frøseth, A. Rønnquist, “Improved finite element model updating of a full-scale steel bridge using sensitivity analysis,” *Structure and Infrastructure Engineering*, vol. 19, no. 3, pp. 315–331, 2022.

[172] M. H. Richardson, C. Jamestown, *Modal Mass, Stiffness and Damping*. Vibrant Technology Inc., 2000.

[173] M. Aenlle, M. Juul, R. Brincker, “Modal mass and length of mode shapes in structural dynamics,” *Shock and Vibration*, vol. 2020, pp. 1–16, 2020.

[174] B. Fröhlich, J. Gade, F. Geiger, M. Bischoff, P. Eberhard, “Geometric element parameterization and parametric model order reduction in finite element based shape optimization,” *Computational Mechanics*, vol. 63, no. 5, pp. 853–868, 2019.

[175] C. Fei, H. Liu, S. Li, H. Li, L. An, C. Lu, “Dynamic parametric modeling-based model updating strategy of aeroengine casings,” *Chinese Journal of Aeronautics*, vol. 34, no. 12, pp. 1457–1673, 2021.

[176] Z. Yuan, P. Liang, T. Silva, K. Yu, J. E. Mottershead, "Parameter selection for model updating with global sensitivity analysis," *Mechanical Systems and Signal Processing*, vol. 115, pp. 483–496, 2019.

[177] Z. Taherkhani, H. Ahmadian, "Stochastic model updating of rotor support parameters using Bayesian approach," *Mechanical Systems and Signal Processing*, vol. 158, p. 107702, 2021.

[178] S. Ereiz, J. F. Jiménez-Alonso, I. Duvnjak, A. Pavić, "Game theory-based maximum likelihood method for finite-element-model updating of civil engineering structures," *Engineering Structures*, vol. 277, p. 115458, 2023.

[179] E. Durmazgezer, U. Yucel, O. Ozcelik, "Damage identification of a reinforced concrete frame at increasing damage levels by sensitivity-based finite element model updating," *Bulletin of Earthquake Engineering*, vol. 17, no. 11, pp. 6041–6060, 2019.

[180] Y. Wu, R. Zhu, Z. Cao, Y. Liu, D. Jiang, "Model updating using frequency response functions based on Sherman–Morrison formula," *Applied Sciences*, vol. 10, no. 14, p. 4985, 2020.

[181] M. Razavi, A. Hadidi, "Assessment of sensitivity-based FE model updating technique for damage detection in large space structures," *Structural Monitoring and Maintenance*, vol. 7, no. 3, pp. 261–281, 2020.

[182] S. P. Tchemodanova, J. F. Jiménez-Alonso, A. Pavić, "Strain predictions at unmeasured locations of a substructure using sparse response-only vibration measurements," *Journal of Civil Structural Health Monitoring*, vol. 11, no. 4, pp. 1113–1136, 2021.

[183] N.-B. Wang, B. Zhang, Y. Zhang, "A novel extraction method for the actual influence line of bridge structures," *Journal of Sound and Vibration*, vol. 553, p. 117605, 2023.

[184] M. Q. Tran, T. T. Nguyen, H. Lee, J. M. Lee, "Finite element model updating for composite plate structures using particle swarm optimization algorithm," *Applied Sciences*, vol. 13, no. 13, p. 7719, 2023.

[185] A. Ali, T. Y. Sandhu, M. Usman, "Ambient vibration testing of a pedestrian bridge using low-cost accelerometers for SHM applications," *Smart Cities*, vol. 2, no. 1, pp. 20–30, 2019.

[186] Y. Xin, Z. Zhou, X. Sun, "Load-carrying capacity assessment of an existing highway bridge based on hybrid finite-element model updating," *Journal of Performance of Constructed Facilities*, vol. 36, no. 3, p. 04022028, 2022.

[187] Q. Pu, Y. Chen, W. Zheng, "Model updating-based damage detection of a concrete beam utilizing experimental damped frequency response functions," *Advances in Structural Engineering*, vol. 22, no. 4, pp. 935–947, 2019.

[188] J. Wang, C. Wang, "Structural model updating of frequency response function based on Kriging model," in *Proc. 2016 3rd International Conference on Information Science and Control Engineering (ICISCE)*, 2016.

[189] D. Dinh-Cong, T. Nguyen-Thoi, D. T. Nguyen, "A FE model updating technique based on SAP2000-OAPI and enhanced SOS algorithm for damage assessment of full-scale structures," *Applied Soft Computing*, vol. 89, p. 106100, 2020.

[190] Z. Feng, W. Wang, J. Zhang, "Probabilistic structural model updating with modal flexibility using a modified firefly algorithm," *Materials*, vol. 15, no. 23, p. 8630, 2022.

[191] B. Jaishi, W.-X. Ren, "Structural finite element model updating using ambient vibration test results," *Journal of Structural Engineering*, vol. 131, pp. 617–628, 2005.

[192] M. I. Shirazi, M. H. Daneshvar, H. Sarmadi, "Damage assessment in laminated composite plates using modal strain energy and YUKI-ANN algorithm," *Composite Structures*, vol. 303, p. 116272, 2023.

[193] M. H. Daneshvar, M. I. Shirazi, H. Sarmadi, "Damage identification of structural systems by modal strain energy and an optimization-based iterative regularization method," *Engineering with Computers*, vol. 39, no. 3, pp. 2067–2087, 2023.

[194] M. Rezaiee-Pajand, A. Entezami, H. Sarmadi, "A sensitivity-based finite element model updating based on unconstrained optimization problem and regularized solution methods," *Structural Control and Health Monitoring*, vol. 27, no. 5, p. e2481, 2020.

[195] G. Biroli, A. Guionnet, "Large deviations for the largest eigenvalues and eigenvectors of spiked Gaussian random matrices," 2020.

[196] S. Kim, K. Y. Koo, J.-J. Lee, "Bridge finite model updating approach by static load input/deflection output measurements: Field experiment," in *Proc. 2016 Structures Congress (Structures 16)*, Jeju Island, 2016.

[197] J. Liao, X. Chen, Y. Xu, "Finite element model updating based on field quasi-static generalized influence line and its bridge engineering application," *Procedia Engineering*, vol. 31, pp. 348–353, 2012.

[198] C. Fei, H. Liu, S. Li, H. Li, L. An, C. Lu, "Hierarchical model updating strategy of complex assembled structures with uncorrelated dynamic modes," *Chinese Journal of Aeronautics*, vol. 35, no. 3, pp. 281–296, 2022.

[199] M. Sanayei, A. M. Imbaro, M. S. Mauro, P. S. Santini, "Structural model updating using experimental static measurements," *Journal of Structural Engineering*, vol. 123, no. 6, pp. 792–798, 1997.

[200] J. F. Jiménez-Alonso, S. Ereiz, I. Duvnjak, A. Pavić, "Maximum likelihood finite-element model updating of civil engineering structures using nature-inspired computational algorithms," *Structural Engineering International*, vol. 31, no. 3, pp. 326–338, 2021.

[201] S. Ereiz, J. F. Jiménez-Alonso, C. Gallegos-Calderón, I. Duvnjak, "Vibration based single-objective finite element model updating using cooperative game theory approach," *Mechanical Systems and Signal Processing*, vol. 212, p. 111316, 2024.

[202] S.-S. Jin, X.-Q. Zhu, Z.-L. Huang, "A new multi-objective approach to finite element model updating," *Journal of Sound and Vibration*, vol. 333, no. 11, pp. 2323–2338, 2014.

[203] Z. Niu, "Two-step structural damage detection method for shear frame structures using FRF and Neumann series expansion," *Mechanical Systems and Signal Processing*, vol. 149, p. 107185, 2021.

[204] S. Nadjafi, H. R. Noori, S. M. Seyedpoor, "An effective approach for damage identification in beam-like structures based on modal flexibility curvature and particle swarm optimization," *Journal of Rehabilitation in Civil Engineering*, vol. 8, no. 1, pp. 109–120, 2020.

[205] J. Pal, S. Banerjee, "A combined modal strain energy and particle swarm optimization for health monitoring of structures," *Journal of Civil Structural Health Monitoring*, vol. 5, pp. 353–363, 2015.

[206] E. L. Eskew, S. Jang, "Remaining stiffness estimation of buildings using incomplete measurements," *Structural Control and Health Monitoring*, vol. 24, no. 4, p. e1899, 2017.

[207] B. Goller, J. Beck, G. Schueller, "Evidence-based identification of weighting factors in Bayesian model updating using modal data," *Journal of Engineering Mechanics*, vol. 138, no. 5, pp. 430–440, 2012.

[208] X. Zhou, Y. Li, Y. Xia, "Vibration-based Bayesian model updating of an actual steel truss bridge subjected to incremental damage," *Engineering Structures*, vol. 260, p. 114226, 2022.

[209] R. Astroza, A. Alessandri, J. P. Conte, "A dual adaptive filtering approach for nonlinear finite element model updating accounting for modeling uncertainty," *Mechanical Systems and Signal Processing*, vol. 115, pp. 782–800, 2019.

[210] S. Petchrompo, K. Charoenpornpattana, S. Luangpaiboon, "A review of Pareto pruning methods for multi-objective optimization," *Computers & Industrial Engineering*, vol. 167, p. 108022, 2022.

[211] J. Cui, Y. Zhang, L. Wang, "Improved normal-boundary intersection algorithm: A method for energy optimization strategy in smart buildings," *Building and Environment*, vol. 212, p. 108846, 2022.

[212] S. Kim, D. M. Frangopol, B. Ge, "Probabilistic multi-objective optimum combined inspection and monitoring planning and decision making with updating," *Structure and Infrastructure Engineering*, vol. 18, no. 10–11, pp. 1487–1505, 2022.

[213] J. Naranjo-Pérez, E. Alarcón, P. A. Calderón, "Finite-element-model updating of civil engineering structures using a hybrid UKF-HS algorithm," *Structure and Infrastructure Engineering*, vol. 17, no. 5, pp. 620–637, 2021.

[214] M. Girardi, C. Padovani, D. Pellegrini, "Finite element model updating for structural applications," *Journal of Computational and Applied Mathematics*, vol. 370, p. 112675, 2020.

[215] S. Sehgal, H. Kumar, "Structural dynamic model updating techniques: A state of the art review," *Archives of Computational Methods in Engineering*, vol. 23, no. 3, pp. 515–533, 2016.

[216] G. Dessena, M. Balestrino, L. Senatore, "A global-local meta-modelling technique for model updating," *Computer Methods in Applied Mechanics and Engineering*, vol. 418, Part A, p. 116511, 2024.

[217] J. E. Mottershead, M. I. Friswell, S. Adhikari, "Model updating," in *Handbook of Experimental Structural Dynamics*. New York, NY: Springer, 2020, pp. 1–53.

[218] E. Patelli, K. Broggi, A. Gulezian, "Sensitivity or Bayesian model updating: A comparison of techniques using the DLR AIRMOD test data," *Archive of Applied Mechanics*, vol. 87, no. 5, pp. 905–925, 2017.

[219] Z. H. Maibed, A. M. AL-Hameedwi, "Study of convergence for a new iterative rate method," *AIP Conference Proceedings*, vol. 2834, no. 1, 2023.

[220] T. Marwala, *Finite-element-model updating using computational intelligence techniques: Applications to structural dynamics*. London: Springer London, 2010.

[221] K. Wang, Y. Kajita, Y. Yang, "Bayesian RC-frame finite element model updating and damage estimation using nested sampling with nonlinear time history," *Buildings*, vol. 13, no. 5, p. 1281, 2023.

[222] D. Raviolo, M. Civera, L. Zanotti Fragonara, "A Bayesian sampling optimisation strategy for finite element model updating," *Journal of Civil Structural Health Monitoring*, 2024.

[223] F. Salata, A. Golasi, M. Vollaro, A. Ferrante, "Effects of local conditions on the multi-variable and multi-objective energy optimization of residential buildings using genetic algorithms," *Applied Energy*, vol. 260, p. 114289, 2020.

[224] C. Kim, T. Han, S. Lee, "Polymer design using genetic algorithm and machine learning," *Computational Materials Science*, vol. 186, p. 110067, 2021.

[225] J. Qian, Z. Wang, D. Kang, “A sequential constraints updating approach for Kriging surrogate model-assisted engineering optimization design problem,” *Engineering with Computers*, vol. 36, pp. 993–1009, 2020.

[226] A. Thakkar, K. Chaudhari, “A comprehensive survey on portfolio optimization, stock price and trend prediction using particle swarm optimization,” *Archives of Computational Methods in Engineering*, vol. 28, no. 4, pp. 2133–2164, 2021.

[227] Y. Lee, J. Kim, S. Choi, “The optimization of machining parameters for milling operations by using the Nelder–Mead simplex method,” *Journal of Manufacturing and Materials Processing*, vol. 4, no. 3, p. 66, 2020.

[228] V. Panwar, P. Singh, R. K. Verma, “Experimental investigations and optimization of surface roughness in turning of EN36 alloy steel using response surface methodology and genetic algorithm,” *Materials Today: Proceedings*, vol. 46, pp. 6474–6481, 2021.

[229] A. J. Percy, M. Edwin, “Studies on the performance and emission characteristics of a dual fuel VCR engine using producer gas as secondary fuel: An optimization approach using response surface methodology,” *Energy*, vol. 263, p. 125685, 2023.

[230] W. Liu, J. Wang, S. Li., “A hybrid optimization framework for UAV reconnaissance mission planning,” *Computers & Industrial Engineering*, vol. 173, p. 108653, 2022.

[231] S. Karasu, H. Altan, C. Cevik, “A new forecasting model with wrapper-based feature selection approach using multi-objective optimization technique for chaotic crude oil time series,” *Energy*, vol. 212, p. 118750, 2020.

[232] Z. Qiao, X. Shu, “Coupled neurons with multi-objective optimization benefit incipient fault identification of machinery,” *Chaos, Solitons & Fractals*, vol. 145, p. 110813, 2021.

[233] Z. Wang, J. Tian, K. Feng, “Optimal allocation of regional water resources based on simulated annealing particle swarm optimization algorithm,” *Energy Reports*, vol. 8, pp. 9119–9126, 2022.

[234] R. B. Messaoud, “Extraction of uncertain parameters of single-diode model of a photovoltaic panel using simulated annealing optimization,” *Energy Reports*, vol. 6, pp. 350–357, 2020.

[235] L. Duan, Y. Li, X. Wang, “Investigation on shear and fatigue performance of CFRP/aluminum alloy single-lap adhesive joint,” *Thin-Walled Structures*, vol. 196, p. 111421, 2024.

[236] M. Dahak, N. Touat, M. Kharoubi, “Damage detection in beam through change in measured frequency and undamaged curvature mode shape,” *Inverse Problems in Science and Engineering*, vol. 27, no. 1, pp. 89–114, 2019.

[237] K. Shrivastava, K. Vijayan, V. Arora, “Experimental identification of dynamic characteristics of welded stiffened structures based on model updating,” *Thin-Walled Structures*, vol. 184, p. 110485, 2023.

[238] S. Baybordi, A. Esfandiari, “A novel damage identification method based on acceleration response sensitivity and finite element model updating: Numerical and experimental,” *Measurement*, p. 114732, 2024.