sustainability

Article

Earthquake Consideration in Architectural Design: Guidelines for Architects

Sardar S. Shareef

Department of Architectural Engineering, Tishk International University-Sulaimani, Sulaymaniyah 46001, Kurdistan Region, Iraq; sardar.shareef3@gmail.com

Abstract: Architectural planners must give due consideration to seismic events as they present substantial hazards to both critical infrastructure and human well-being. This research investigates the fundamental concepts and methodologies employed by architects to enhance seismic resilience in buildings and ensure the safety of occupants. It emphasizes the importance of seismic hazard assessment, design standards, structural systems, and cutting-edge technology in reducing earthquake-related dangers. A mixed method has been adopted: surveying the literature, applying inductive reasoning, and conducting a case study. This research highlights the value of interdisciplinary cooperation between structural engineers, geotechnical experts, and architects to design resilient built environments that can survive the pressures unleashed by seismic occurrences. The findings demonstrated that architectural design solutions and approaches might significantly impact earthquake risk reduction techniques in seismic and non-seismic locations. In the cases taken, different techniques—in some cases multiple techniques—had been applied based on the buildings' geographical locations, sizes, and shapes. Finally, we prepared a checklist for these strategies, including mass distribution, openings, rooftop structures, and other considerations to be applied by architects to make the solutions easier.

Keywords: earthquake; structural systems; design codes; architectural design; technological innovations; interdisciplinary collaboration; case studies

check for updates

Citation: Shareef, S.S. Earthquake Consideration in Architectural Design: Guidelines for Architects. *Sustainability* **2023**, *15*, 13760. https://doi.org/10.3390/su151813760

Academic Editor: Claudia Casapulla

Received: 28 August 2023
Revised: 11 September 2023
Accepted: 12 September 2023
Published: 15 September 2023

1. Introduction

Throughout human history, earthquakes have often caused great loss of life and material destruction [1]. The need for architects and engineers to take earthquake resilience into account in their designs is becoming increasingly critical as urbanization keeps growing and more people move into earthquake-prone areas. Architectural earthquake-resistant designs are necessary to protect building integrity and occupant safety during seismic disasters.

Many studies, like Welsh-Huggins and Liel [2], Joyner and Sasani [3], Hashemi et al. [4], and Achour et al. [5], have studied the structural considerations needed and materials' potential in resisting earthquakes, which concern structural calculations, material selection, and connection details. Moreover, a study by Arnold et al. [6] divided the architectural decisions that may influence seismic resistance into three main categories: "the building categories, structurally restrictive detailed architectural design, and hazardous nonstructural components" [6]. By the first category, he meant the building's size, shape, and proportions in three dimensions, as well as internal planning and the overall architectural shape. The second category refers to the design of building elements, like columns or walls, that may have a negative impact on structural detailing and contradict safe seismic design principles. The latter, the nonstructural elements, are the responsibility of the architect to design, as if they are not sufficiently constructed against seismic forces they could pose a risk to human life. That is part of the responsibility of architects: to maintain the harmony between logic and beauty while simultaneously balancing form and function [7]. Another study discussed the relationship between architectural and structural design as "an integrated design procedure into which structural and architectural aspects merge harmoniously" [8]. The study highlighted the development of base isolation design in Italy, highlighting advancements throughout the past 30 years, from the earliest groundbreaking cases to contemporary solutions.

A variety of cutting-edge engineering concepts, tools, and approaches are used in modern seismic design procedures to increase the resilience of infrastructure and structures to earthquakes. Due to significant research, knowledge gained from previous earthquakes, and developments in engineering and materials science, these strategies have changed over time. Performance-based design, base isolation, energy-dissipation technology, seismic bracing and shear walls, innovative materials, and others are just a few examples [9,10]. However, some controlled damage is to be anticipated, and after enough shaking this damage may render the building unable to be economically repaired [11]. New technology can significantly lower earthquake-related hazards by improving our capacity to anticipate, plan for, prepare for, reduce, and respond to seismic events. Several recent technological advancements can help lower the risk of earthquakes; one is base isolation. Base isolation demands using energy-dissipating isolation devices to keep the structure elevated off the ground [12]. Another contribution of new technology to earthquake-resistant design is numerical simulations of real-world events. This is a computer simulation or computational modeling technique used to replicate real-world phenomena using mathematical equations and computer algorithms. It involves creating a virtual representation of a physical system or process and then using numerical methods to solve the mathematical equations that govern the behavior of that system [13]. Numerical simulation can assist seismic designers in many ways. The dynamic behavior of structures under different earthquake-loading situations can be modeled using numerical simulations. Engineers can foresee how various construction materials, arrangements, and support systems may react to ground trembling [14]. This helps the designers in their design optimization and structure responses [15,16], risk analysis [17], retrofitting strategies [18], nonlinear behaviors of materials [19], and cost-effective solutions [20].

Generally, architecture schools pay more attention to functional and aesthetic values in design. However, limited research has been undertaken on how architects might use architectural design strategies and considerations to assist in developing resilient structures. Therefore, this research aims to examine the significance of taking earthquakes into account when designing buildings and give a general review of the major ideas, methods, and tools that may be utilized to improve structural resilience and public safety. For this reason, this study attempts to prepare a comprehensive checklist by surveying the current literature and identifying some techniques from some known and challenging structures worldwide. It also covers knowledge for modifying existing structures to increase their earthquake resilience and new construction projects. Our research also focuses on working with architects, structural engineers, and geotechnical engineers to improve structures' ability to withstand earthquakes rather than just leaving it up to them. The significance of interdisciplinary cooperation among architects, engineers, and geotechnical specialists in creating thorough and efficient design solutions is also covered in the discussion.

2. Literature Review

The nature of earthquakes must be understood before discussing earthquake considerations in architectural design. When the Earth's crust suddenly releases energy, seismic waves that travel through the ground cause earthquakes [21]. Large portions of the Earth's crust, called tectonic plates, move when they collide, which releases energy [22]. An earthquake's hypocenter, or focus, is where it first forms within the planet's crust. The epicenter is the location on Earth's surface immediately above the hypocenter. Seismic waves, the energy's primary mode of radiation outward from the epicenter, can move the ground and create shaking [23].

Two basic categories into which these seismic waves fall are primary (P-waves) and secondary (S-waves). The first is the quickest seismic wave that can pass through solids, liquids, and gases. The direction of wave propagation is pulled back and forth by them. At the same time, the latter can only move through solids and are slower than P-waves. They produce a motion perpendicular to the wave propagation's direction—either up and down or side to side [24].

The Richter and moment magnitude scales are the two most prevalent measures used to determine how severe an earthquake is (Mw) [25]. These scales provide a number representing the earthquake's magnitude and quantify the energy released during an earthquake. Greater energy is released with higher magnitudes, which can cause damage and stronger ground shaking [26]. It is also crucial to consider the frequency and length of the seismic waves during an earthquake. While "frequency content" refers to the range of frequencies in the seismic waves, the term "duration" relates to how long the ground shakes [27]. The structural reaction and possible harm to structures and infrastructure are affected by both elements.

2.1. *Earthquakes and the Built Environment*

Earthquakes are the built environment's worst enemy. The waves they spread destroy buildings, bridges, and other manmade structures. There are many ways that earthquakes can affect the built environment, including ground shaking, surface rupture, soil liquefaction, and landslides [28]. Ground shaking is an earthquake's main effect. The size of the earthquake, the distance from the epicenter, and the state of the local soil all impact the amount and length of the shaking. Building damage from ground tremors is possible, especially if the structure cannot withstand seismic forces [29]. Occasionally, earthquakes can lead to a rupture of the earth's surface along the fault line. This can be seen as a visible displacement of the Earth's surface called surface rupture. Surface rupture can seriously harm nearby structures and infrastructure by directly impacting them [30]. Seismic waves may result in a condition known as soil liquefaction in regions with loose, saturated soils. The ground undergoes a temporary weakening, exhibiting characteristics resembling a liquid during a phenomenon known as liquefaction. As a result, structures built on liquefiable soils may experience settlement, tilting, or even collapse. [31]. Earthquakes have the potential to induce landslides on slopes and hillsides, especially in areas characterized by unstable soil or steep terrain. The occurrence of landslides can exacerbate the impact of an earthquake by potentially burying structures and obstructing transportation routes [32].

Architects and engineers need to comprehend earthquake features and potential effects to build structures that can withstand these pressures. Considering these variables, architectural designs can be optimized for human safety and structural resilience in earthquake-prone areas.

2.2. *Design Codes and Regulations*

Buildings must be constructed to endure the seismic forces generated by earthquakes, and design guidelines and regulations are essential to this process. To design structurally secure and resilient buildings, architects and engineers must adhere to the standards and norms outlined in these rules, known as building codes. They are frequently based on in-depth analysis, historical information, and the lessons discovered from previous seismic disasters. By adopting particular design criteria and performance goals, they seek to reduce the dangers posed by earthquakes.

Numerous building codes emphasize earthquakes, and the widely accepted International Building Codes (IBCs) provide a foundation for seismic design and construction methods. Moreover, international organizations like the International Code Council (ICC) produce these codes, considering several variables like the area's seismicity, the soil's characteristics, and anticipated ground motion [33]. IBCs often include a variety of topics, such as foundation design, building materials, and structural design [34]. They ensure that earthquake design procedures are uniform and consistent around the world.

In addition, local authorities frequently create their building codes and regulations tailored to their local seismic conditions and international codes. These local codes may complement or amend the provisions of international standards to address regional geological traits, geotechnical issues, and construction techniques. To address the unique needs and guarantee legal compliance, architects must be aware of regional laws and modify their designs accordingly. Municipal rules could also include guidelines for seismic retrofitting of already-built structures, essential for improving the earthquake resilience of older structures not initially built to withstand seismic pressures. In order to lessen the consequences of earthquakes, retrofitting steps can be implemented, such as reinforcing structural components, enhancing connections, and adding dampening devices [35].

2.3. Structural Systems for Earthquake Resistance

In the context of the impact of seismic events on building, the subject of the structure is at the forefront. Buildings need to have strong structural systems in place to withstand earthquakes. Using the proper structural systems, architects can improve a building's capacity to withstand seismic forces and reduce damage. Several building structures are designed to support buildings and withstand earthquakes, including Reinforced Concrete Structures, Steel Structures, Timber Structures, and Hybrid Systems. Here are some brief explanations of them:

2.3.1. Reinforced Concrete Structures

Because of their durability and strength, reinforced concrete structures are frequently used in earthquake-prone areas. Steel reinforcement's tensile strength is combined with concrete's compressive strength to create reinforced concrete [36]. Reinforced concrete is suited for withstanding the dynamic stresses produced by earthquakes because of its flexibility and energy absorption capacity. Key factors which enable load transfer and minimize brittle failure are suitable column and beam diameters, proper detailing of reinforcement, and efficient connections. Reinforced concrete structures provide a solid base for implementing appropriate seismic design measures. Buildings and infrastructure can be created to withstand earthquakes and guarantee the safety of people by integrating the material's inherent strength and ductility with suitable engineering techniques [37].

2.3.2. Steel Structures

Steel buildings are very strong and can survive considerable earthquake deformations. The outstanding strength-to-weight ratio of steel enables effective structural designs. Beams and columns make up steel frames, which offer flexibility and capacity for releasing energy [38]. Steel structural systems for seismic resistance are frequently utilized in moment-resisting and braced frames. In an attempt to provide flexibility and robustness, connection design, member sizing, and details must be carefully considered [39–43].

2.3.3. Timber Structures

If timber structures are constructed and designed appropriately, they have the capacity to withstand seismic events. Timber has natural dampening qualities and is capable of absorbing earthquake energy. Cross-laminated timber (CLT) panels and glued laminated timber (glulam) beams are two examples of cutting-edge timber systems that provide great strength and stiffness [44,45]. To maintain stability and integrity during earthquakes, timber structures must be constructed to resist lateral forces and have suitable connections and bracing mechanisms.

2.3.4. Hybrid Systems

Hybrid structural systems integrate materials such as concrete, steel, and timber to capitalize on each material's advantages and improve performance during earthquakes. These systems can be designed in various ways, increasing seismic resistance while considering particular project requirements [46]. In order to increase stiffness and energy absorption, a hybrid system can, for instance, use concrete shear walls, steel plate shear walls [47], and steel frames for long spans.

Structural engineers and architects must work closely to choose the best structural system based on the project requirements, site conditions, and seismic considerations. An appropriate structural system guarantees the building's safety, usability, and long-term resistance during seismic occurrences.

2.4. Architectural Considerations for Earthquake Resistance

Incorporating particular design factors that improve a building's earthquake resistance is a crucial task for architects. Architectural choices greatly impact a structure's overall performance and safety during an earthquake, even though structural systems are the main means of resisting seismic forces. Key architectural factors for earthquake resilience include the following:

2.4.1. Building Configuration and Layout

A building's layout and configuration can influence its response to seismic forces. Regular building forms, such as square or rectangular floor plans, perform better during earthquakes than complicated or irregular geometries. Regular geometries better distribute forces equally, lessening concentrated, localized stress [48]. To maximize structural performance and reduce earthquake susceptibility, architects should work to design straightforward, symmetrical building designs. Moreover, large open areas, such as atriums or large halls, can be difficult to design for earthquakes because they alter how forces pass through a structure. Strong floors and efficient support systems are essential to maintaining the building's structural integrity [49]. Moreover, a building can avoid severe swaying during an earthquake by properly distributing mass vertically. The risk of an overturning structure is decreased by placing heavier components lower in the structure [50].

2.4.2. Reducing Mass and Stiffness Irregularities

Changes in mass and rigidity can have adverse structural effects during earthquakes. Uneven distribution of mass and stiffness can result in uneven force distribution and torsional effects, leading to structural instability [51]. Through meticulous balancing floor plans, considering the even distribution of structural elements, and avoiding abrupt changes in stiffness or mass in the building, architects can reduce irregularities in mass and stiffness. Special consideration must be given to buildings with irregular elevation, mass, or stiffness to adequately manage seismic forces. Setbacks and soft story arrangements are two irregularities required for proper design [52].

2.4.3. Openings, Facades, and Cladding

With the previous in mind, architects must therefore consider enhancing the resistance of these components towards earthquake forces. Giving openings and facades the proper detailing, reinforcement, and anchoring is essential [53]. When combined with the proper joints and connections, flexible materials, such as curtain walls, can accommodate structural movement while preventing cladding separation during seismic events.

2.4.4. Rooftop Structures

Rooftop constructions, including mechanical equipment, rooftop gardens, and water tanks, should be suitably engineered and secured to withstand seismic stresses [54]. These buildings should have strong connections and enough anchorage to avoid collapsing or dislodging during earthquakes. Research has been expanded for more seismic design solutions because rooftop structures are a subset of a larger typology known as multi-story structures. Seismic isolation is a successful technique in these circumstances. Using flexible isolators at a building's foundation, seismic isolation is a novel passive method that increases earthquake safety by relocating the fundamental period of the structure away from potentially harmful resonance frequencies [55]. According to studies, using this technique to retrofit existing buildings can reduce the danger of earthquakes. With the aid of a specially developed optimization procedure, Charmpis, Phocas and Komodromos [55] could identify configurations of isolators distributed vertically throughout the height of a building that produce favorable structural behavior. This procedure can automatically and effectively explore the enormous set of potential retrofit solutions formed by all conceivable isolator number, location, and property combinations.

Another method is to attach the device's mass to the main structure using High-Damping Rubber Bearings (HDRB). This technique produces an unconventional Tuned Mass Damper (TMD) with a significant mass ratio by fusing stiffness and damping qualities. This method avoids excessive weight increases while maintaining structural or architectural functioning by converting existing masses into tuned masses [56].

Making decisions for new buildings or retrofitting is rationalized by seismic fragility, loss, and resilience. A relatively new seismic vibration control solution for higher buildings is inter-storey isolation (ISI). The isolation bearings are positioned at an intermediate level to isolate the upper storey block (USB), which also functions as a non-traditional tuned mass damper (TMD) to the lower storey block (LSB), reducing vibration [57]. The fundamental benefit of inter-story seismic isolation is the blockage of energy flow between the upper and lower stories, making it an effective way to divide the various components of high-rise buildings with distinct uses and, consequently, variable seismic performance needs [58].

In their seismic design, tall structures that use multi-story isolation, often called multi-story base isolation, are more resilient to earthquakes. Using this method, a tall building's various levels are equipped with a set of seismic isolation mechanisms that enable individual floors or groups of floors to act freely of one another during an earthquake. The goal is to lessen the building's ability to transmit seismic forces, protecting residents and minimizing structural failure [59]. The traditional seismic design method concentrates on creating a whole structure that can withstand the forces produced by an earthquake. However, the structure may experience severe pressures and deformations as a result. An alternate tactic is multi-story isolation, which effectively separates the upper floors from the lower ones in terms of seismic vibration by permitting controlled movement at different levels [60]. During seismic occurrences, precautions must be taken to prevent rooftop components from becoming hazardous by falling and potentially damaging the primary structure or neighboring buildings.

2.4.5. Escape Routes and Safe Areas

Designing secure locations and clear, accessible escape routes should be a top priority for architects. These locations should be placed wisely to offer residents safe zones during an earthquake [61]. In order to function both during and after seismic disasters, stairwells, elevators, and emergency exits need to be appropriately designed [62]. Safe spaces should be structurally strong and free of potential risks, such as flying debris or broken building parts.

2.5. Other Considerations

2.5.1. Advanced Structural Analysis and Simulation

Finite element analysis, computational modeling, and simulation software developments have completely changed how structures are assessed for seismic performance [63]. With the aid of these tools, engineers and architects can examine how buildings will respond to various earthquake scenarios, assess structural responses, and improve designs for greater resilience. Advanced analysis methods, including nonlinear dynamic analysis, make it possible to forecast structural behavior more precisely, including identifying crucial failure modes and potential weak spots [64,65].

Engineers can develop and test damping systems, base isolators, and other methods to lessen seismic forces' effects through simulation and analysis. These devices can improve a structure's seismic performance by reducing vibration transfer to the structure [66].

Another technique is Response Spectrum Analysis, which describes how the structure reacts to various ground motion intensities. Response spectra show the structure's highest response at various frequencies. By simulating these reactions, engineers can better predict how different structure components will respond to an earthquake [67,68].

2.5.2. Interdisciplinary Collaboration

Close cooperation between architects, structural engineers, and other relevant specialists is necessary to address these architectural issues. Architects and structural engineers should collaborate to ensure that architectural design choices adhere to the structural criteria for earthquake resilience. Architects can help develop safer, more durable structures that can better withstand the forces generated by earthquakes by including these factors in their designs.

- Architect–Engineer Collaboration

Effective earthquake-resistant architecture design requires interdisciplinary cooperation between structural engineers and architects. Structural engineers offer specific knowledge in structural analysis, load distribution, and material qualities, while architects contribute their skills in spatial design, aesthetics, and functional requirements. Architects and engineers can create integrated design solutions that balance architectural objectives with structural integrity and seismic resistance by collaborating early on in a project. Close coordination between the structural and architectural teams ensures the building's design maximizes earthquake resilience and aesthetic appeal.

- Design–Build Collaboration

Translating design intent into reality requires effective cooperation between structural engineers, contractors, and construction teams. During the design phase, architects should consult with construction experts to address constructability issues, pinpoint prospective difficulties, and investigate cutting-edge construction methods. Regular coordination and communication throughout the building process ensure that seismic design requirements are met, and the design objective is realized.

- Stakeholder Engagement

A successful earthquake-resistant architectural design depends on including stakeholders like building owners, occupants, and governmental authorities. In an attempt to comprehend stakeholders' individual requirements and expectations, architects should promote open communication. Building owners should be included in talks about design decisions, retrofitting possibilities, and long-term maintenance plans to help ensure that the structure fits their needs while following seismic design guidelines [69]. Incorporating considerations for the safety and resilience of the broader community collaboration with public authorities and regulatory agencies ensures compliance with local norms and regulations.

Interdisciplinary cooperation encourages a comprehensive strategy for designing earthquake-resistant buildings. The expertise of architects, structural engineers, geotechnical specialists, construction experts, and stakeholders is combined to thoroughly grasp the project's requirements and limitations. A safer and more resilient built environment results from this collaborative effort, yielding integrated design solutions prioritizing architectural excellence and the capacity to withstand seismic impacts.

2.5.3. Technological Innovations

Technological breakthroughs have considerably improved the design of earthquake-resistant buildings. New tools, techniques, and materials made possible by innovative technologies increase structural resilience, allow for more precise assessments, and boost monitoring capabilities. The following technological advancements in earthquake-resistant architecture design deserve special mention:

- Base Isolation and Damping Devices

Additional precautions, including base isolation and damping devices, are taken to increase buildings' seismic resilience. Base isolation entails putting the structure atop seismic energy-absorbing bearings or isolators. Separating the structure from ground motion lessens the forces imparted to the superstructure. Viscosity dampers and tuned mass dampers are two types of damping devices used to disperse seismic energy and lessen structural vibrations. These devices can be added to different structural systems to lessen the impact of earthquakes.

Earlier attempts by Kelly [70] to use natural rubber as a measure of protection date back to 1976. He realized that the best way to employ these energy devices to defend structures from earthquakes would be to pair them with an isolation system (he used handmade isolators), providing them with the significant displacements needed to produce the necessary hysteresis. Another attempt to lessen the seismic vulnerability of civil structures and infrastructures is geotechnical seismic isolation (GSI). GSI is regarded as a novel technique. The application of rubber–soil mixtures to the acceleration and interstory drift of low to medium-rise buildings [71]. In the study by Tsang et al. [72], an equivalent liner model was used to simulate both the GSI's and the soil's dynamic reaction. A study by Darlington and Becker [73] looked at how nonzero rotation boundary conditions affect design fundamentals like horizontal and rotational stiffness and found that flexible boundary conditions reduce horizontal stiffness, which depends on the total rotation at the ends and axial load, with larger loads requiring more rotation. The soil's dynamic response was assessed using the secant shear modulus and the damping ratio. A flexible multi-story building isolated with a variable friction pendulum system (VFPS) under near-fault ground vibrations has a dynamic reaction that can be used as another technique to withstand earthquake hazards. The VFPS efficiently regulates seismic response, but underestimating bi-directional frictional forces can lead to overestimating superstructure accelerations and isolator displacements.

- Resilient Infrastructure Systems

Infrastructure system developments concentrate on creating tools that improve the built environment's overall resilience. This includes incorporating distributed energy storage systems, microgrids, and smart grid technologies [74,75]. These technologies guarantee the availability of essential services, such as power supply, communication networks, and emergency response systems, both during and after earthquakes [76]. Buildings can more effectively survive seismic disasters and aid post-earthquake recovery efforts by including resilient infrastructure systems in their architectural design.

Architects should keep up with new technological developments and how they might be used to create earthquake-resistant structures. Then, they may improve buildings' effectiveness, security, and resilience by using technological advancements, helping to create sustainable and earthquake-resistant environments.

3. Methodology

The methodology of the study primarily relies on a comprehensive systematic literature review, wherein existing scholarly works are rigorously examined, followed by the application of inductive reasoning to derive meaningful insights. To find the most recent studies on the topic, we surveyed a substantial quantity of literature by searching on Google Scholar and the grey literature without using limitations, as the study intends to consider possible ways for architects to participate in a well-designed earthquake-resistant built environment. We used the following keywords: earthquake, architectural design, seismic hazard assessment, design codes, structural systems, interdisciplinary collaboration, technical advancements, case studies, and resilience.

Another aim of this study, which acts parallel to the literature review, is to compile the methods and approaches utilized in several buildings in the seismic/nonsesmic regions worldwide to understand the design techniques, tools, and other considerations to create a checklist for architects to use when designing buildings in seismic regions and some nonseismic active areas. Since these buildings were constructed using specialized earthquake-resistance techniques and methods in these areas. This study examined eight examples as case studies to evaluate and comprehend the methods linked to architectural design.

3.1. Case Studies

These eight structures were chosen because of their seismic locations and substantial construction, which may allow for architectural design solutions that go beyond structural and geological issues. These examples were chosen based on an intensive search of the most familiar buildings in which seismic design is taken seriously and potential lessons can be learned. Moreover, the solutions for seismic resistance are different in each building.

3.1.1. Taipei 101, Taiwan

The landmark skyscraper Taipei 101 in Taipei, Taiwan is known for its ability to withstand earthquakes. The 101-story tower was finished in 2004 and is located in a seismically active area. A tuned mass damper (TMD) system is one of the novel innovations incorporated into its structural construction.

The TMD, a sizable pendulum suspended towards the top of the structure, counteracts the lateral motions of the building brought on by earthquakes, reducing swaying and improving occupant comfort and safety [77]. The TMD is not the only solution applied for the building to resist earthquakes, but it works with other structural solutions such as perimeter columns and outriggers. The design of Taipei 101 shows how cutting-edge structural systems and seismic concerns may be successfully incorporated into architectural design (Figure 1).

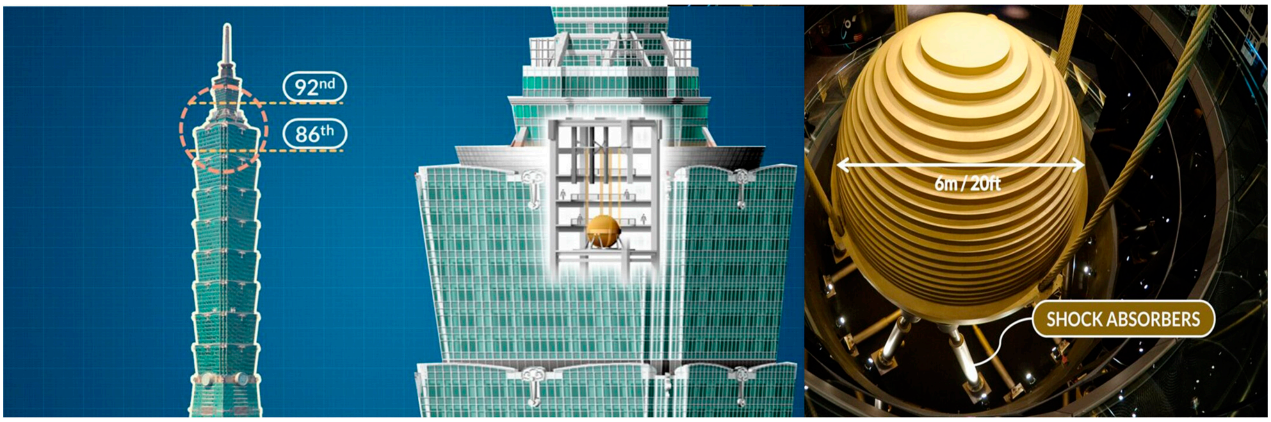

Figure 1. Taipei 101, Taiwan with an explanation of the TMD [1].

3.1.2. The Shard, London

In a low-seismicity area, the 95-story skyscraper The Shard in London, United Kingdom is an example of an earthquake-resistant design (Figure 2). The Shard's architectural design includes seismic resilience measures even though it is not in a seismically active area. The Shard was designed and built per the applicable seismic design norms and standards for the London area, and damping was installed at the upper levels to reduce lateral acceleration and regulate the structure's sway [78]. This technique also rendered a tuned mass damper unnecessary, freeing up an additional residential storey [79]. Elevators, fire suppression systems, and emergency lighting may all be built to function both during and after an earthquake, facilitating evacuation and emergency response [80]. Its structure consists of a steel frame with a strong lateral stability system and a reinforced concrete core. These systems give the building strength and stiffness, enabling it to survive potential seismic shocks [81]. The Shard's design serves as a reminder of how crucial it is to consider earthquake resilience, especially in areas with lesser seismic activity. The use of GEOBIM solutions, inclusive of Laser Scanner, GPR tools, and BIM and RAM 1500 software in the construction of the Shard Tower has helped the structural designers—Arup, the contractor—Mace and the electrical consultancy firm—Arup to streamline workflows, save time and effort, and improve collaboration and communication [82].

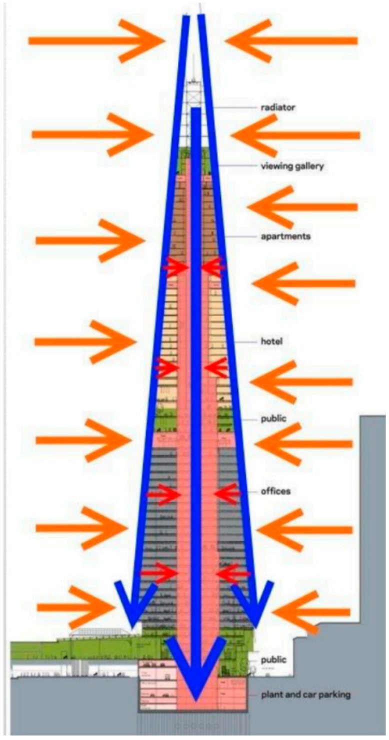

Figure 2. The Shard, London's structural concepts [2].

3.1.3. Torre Reforma, Mexico City

The Torre Reforma in Mexico City, Mexico illustrates how an existing structure can be fortified to endure earthquakes. The structure was originally built in the 1990s and is a 57-story skyscraper [83]. Older buildings had to be retrofitted due to strict building rules implemented after the terrible earthquake that struck Mexico City in 1985 [84]. Torre Reforma received a thorough seismic retrofit that included reinforcing structural components, adding dampening technology, and enhancing connections [85]. The building's seismic performance was improved during the retrofitting procedure, which also guaranteed its continuing functionality and safety.

3.1.4. O-14 Tower, Dubai

An inventive example of architectural design that considers seismic factors in a place with low to moderate seismicity is the O-14 Tower in Dubai, United Arab Emirates. A latticed concrete shell encircles the tower, giving it a distinctive exoskeleton design. This layout improves the building's resistance to lateral stresses and offers structural stability. By serving as a load-bearing system, the exoskeleton lessens the need for internal columns and increases the flexibility of interior space planning [86]. The O-14 Tower is an example of how creative architectural design can increase seismic resistance in areas with various seismic conditions.

3.1.5. The San Francisco Museum of Modern Art (SFMOMA), USA

An example of seismic design issues in a seismically active area is the San Francisco Museum of Modern Art addition, which was finished in 2016. A cutting-edge base isolation system, consisting of lead-rubber bearings and sliding isolators, was included in the architectural concept. This method lessens the transmission of seismic pressures to the superstructure by allowing the building to move separately from the ground during an earthquake [87]. The base isolation system improves the museum's resilience and safeguards its priceless artworks, showing how seismic design may be successfully incorporated into architectural planning.

3.1.6. The Akashi Kaikyo Bridge, Japan

The world's longest suspension bridge, the Akashi Kaikyo Bridge, links Kobe with Awaji Island in Japan. Given that the area is earthquake-prone, it was finished in 1995 and was built to withstand powerful seismic shocks. Numerous seismic design elements are incorporated into the bridge, such as reinforced piers with deep foundations, adaptable seismic isolation bearings, and a powerful damping system [88]. The bridge can absorb and discharge seismic energy by taking these precautions, ensuring stability and reducing earthquake-related damage.

3.1.7. The Guangzhou Opera House, China

Zaha Hadid Architects created a masterwork of architecture with the Guangzhou Opera House in Guangzhou, China. The structure was finished in 2010 and is located in a somewhat seismically active area. The architectural design's distinctive structure, comprising an inner concrete frame and an outside steel frame, considers seismic factors [89]. While the concrete frame serves as a core for structural integrity, the steel frame adds extra lateral stability. This combination of materials and structural systems ensures the building's resistance to seismic forces.

3.1.8. The Christchurch Town Hall, New Zealand

Following the terrible earthquakes in 2010 and 2011, the Christchurch Town Hall in Christchurch, New Zealand received major seismic retrofitting. As part of the retrofitting procedure, the building's existing concrete structure was reinforced, base isolators were added, and its overall resilience was increased [90]. The seismic retrofit helped the city recover and become more resilient by restoring the Town Hall's architectural and historical significance and ensuring its ability to withstand seismic disasters in the future.

These case studies illustrate the many methods used to incorporate earthquake-resistant design into architectural projects. The safety and well-being of people can be ensured, and the preservation of priceless structures, by including cutting-edge structural systems, base isolation, dampening mechanisms, and retrofitting techniques into the design of buildings.

4. Result and Discussion

Resisting Earthquakes through Architectural Design Techniques and Strategies

Using architectural design techniques and tactics to withstand earthquakes requires a thorough approach considering structural integrity, material choice, building configuration, and non-structural components. Here are some essential methods and tactics to improve earthquake resistance:

Remember that every project is different, and the precise design methods and approaches will rely on various elements, including regional rules, site conditions, and building types.

Table 1 below summarizes the techniques used for the chosen buildings as each building is thought per its specific location and circumstances.

Drawing from an extensive review of relevant literature, Table 2 elucidates essential strategies and prerequisites for architects within the realm of architectural design. Architects, as central figures in the building design and construction process, must actively employ these architectural design-related strategies to contribute to earthquake resilience, rather than relying solely on other professionals. These architectural strategies facilitate the solutions by other professionals dealing with calculations and solutions to resist earthquake forces in the structure entities.

Table 1. A summary of the applied techniques for earthquake resistance for the case studies.

#	Building Name	Techniques Used	Country of Origin
1	Taipei 101	- Tuned Mass Damper (TMD) - Perimeter columns and outriggers	Taiwan/a seismic region
2	The Shard, London	- Daming system and no TMD - Steel frame with a strong lateral stability system and a reinforced concrete core. - Building configuration (form)	UK/non-seismically active area
3	Torre Reforma, Mexico City	- Reinforcing structural components - Dampening technology - Enhancing connections variances, or abrupt structural system changes	USA/a seismic region
4	O-14 Tower, Dubai	- A latticed concrete shell encircles the tower	UAE/semi-active seismic area (The Zagros and Makran regions, which are the most seismically active nearby areas, are closest to the country and could potentially have an impact)
5	The San Francisco Museum of Modern Art (SFMOMA)	- Base isolation system	USA/a seismic region
6	The Akashi Kaikyo Bridge	- Reinforced piers with deep foundations - Adaptable seismic isolation bearings Damping system	Japan/a seismic region
7	The Guangzhou Opera House	- Inner concrete frame and an outside steel frame.	China/a seismic region
8	The Christchurch Town Hall (Retrofitting)	- Reinforcing existing concrete structure - Adding base isolation - Dampening mechanisms	New Zealand/a seismic region

Table 2. A checklist on architectural design considerations for earthquake resistance.

#	Architectural Considerations	Explanation
1	Seismic Analysis [91–93]	To analyze the seismic hazard at the site, the region's seismicity, the state of the soil, and anticipated earth motions are to be considered.
2	Structural System [94–97]	Choosing a suitable lateral force-resisting structural system. Moment frames, shear walls, braced frames, and dual systems are common systems. Create a structural system with sufficient strength, stiffness, and ductility.
3	Building Configuration and Layout [98,99]	Designing symmetrical building designs with regular shapes to distribute earthquake forces evenly. Avoid abnormalities like setbacks, floor height variances, or abrupt structural system changes that might concentrate stress.
4	Mass Distribution [100–103]	Mass should be distributed evenly throughout the building to reduce possible torsional impacts during an earthquake. Concentrated masses tend to twist and produce uneven forces, making an object more vulnerable.
5	Openings, Facades, and Cladding [104–108]	Thinking about making these components resistant to earthquake forces, sizes, materials, and positions in the building.
6	Rooftop Structures	Mechanical equipment, rooftop gardens, and water tanks should all be properly organized and secured to withstand seismic loads.
7	Seismic Isolation [109–111]	Install ground motion-decoupling base isolation systems to separate the building from the ground. In this situation, isolation devices like bearings or isolators are used between the foundation and superstructure. This lessens the amount of damage caused by seismic forces that are transferred to the building.

Table 2. *Cont.*

#	Architectural Considerations	Explanation
8	Energy Dissipation Devices [42,112–116]	Install energy dissipation equipment inside the structure to absorb and disperse seismic energy. By reducing the stresses transferred to the building, dampers, braces, or tuned mass dampers can be utilized to increase seismic resistance.
9	Escape Routes and Safe Areas [117–120]	These places should be strategically positioned to provide the locals with earthquake-safe zones. Stairways, elevators, and emergency exits must be properly designed in order for them to operate both during earthquake disasters and thereafter.
10	Compliance with Building Codes [121–124]	Observe regional building codes and guidelines for earthquake-resistant construction. These codes outline the minimal specifications for design, materials, building techniques, and safety considerations.
11	Professional Expertise [125–127]	Work with skilled structural engineers, geotechnical engineers, and architects experienced in earthquake design. Their expertise is crucial for developing and putting into practice successful earthquake-resistant techniques.

5. Conclusions

This study highlights the critical importance of building designers carefully evaluating the risk of earthquakes, considering their potential to cause significant harm to both infrastructure and people. This investigation has outlined how to improve buildings' seismic resistance and guarantee the safety of occupants through analyzing architects' fundamental concepts and practices. As pillars in reducing the risks connected with earthquakes, the focus points of seismic hazard assessment, commitment to exacting design standards, application of strong structural systems, and incorporation of cutting-edge technological breakthroughs are underlined. The applied mixed-method approach, which included thorough literature reviews, inductive reasoning, and case studies, proved a potent tool for illuminating the complex features of seismic resilience in architectural design. This study incorporates a comprehensive grasp of the various problems posed by seismic events and the potential solutions architects might use by embracing various research approaches. The research's most important finding is the evident value of interdisciplinary cooperation. In order to create resilient constructed environments, structural engineers, geotechnical experts, and architects must collaborate. The fusion of many specialities opens the door for creating designs that can withstand the massive forces unleashed by seismic catastrophes. Architectural designs that are earthquake-resistant benefit greatly from technological advancements. Using advanced structural analysis and simulation tools, performance-based design methodologies, structural health monitoring systems, 3D printing, prefabrication techniques, and resilient infrastructure systems provides architects with new opportunities to maximize seismic resilience and improve the general performance of buildings. Throughout this research, various architectural design strategies and methods came to light as crucial in reducing earthquake risk in seismic and non-seismic zones. The adaptability and applicability of the findings are further supported by the realization that these methodologies could be used in various geographic situations, building sizes, and forms. We require a design strategy that concentrates on the particular difficulties caused by seismic threats.

These realizations lead to establishing a thorough checklist as the study's contribution. The distribution of masses, the design of openings, the strengthening of rooftop structures, and a host of other factors are all included in this checklist, which includes practical advice for architects. The checklist can accelerate the development of structures that demonstrate improved resistance to seismic pressures by standardizing these tactics and promoting collaborative efforts among varied professions.

Funding: This research received no external funding.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Stepinac, M.; Lourenço, P.B.; Atalić, J.; Kišiček, T.; Uroš, M.; Baniček, M.; Novak, M.Š. Damage classification of residential buildings in historical downtown after the ML5. 5 earthquake in Zagreb, Croatia in 2020. *Int. J. Disaster Risk Reduct.* **2021**, *56*, 102140. [CrossRef]
2. Welsh-Huggins, S.J.; Liel, A.B. Evaluating multiobjective outcomes for hazard resilience and sustainability from enhanced building seismic design decisions. *J. Struct. Eng.* **2018**, *144*, 04018108. [CrossRef]
3. Joyner, M.D.; Sasani, M. Building performance for earthquake resilience. *Eng. Struct.* **2020**, *210*, 110371. [CrossRef]
4. Hashemi, A.; Bagheri, H.; Yousef-Beik, S.M.M.; Darani, F.M.; Valadbeigi, A.; Zarnani, P.; Quenneville, P. Enhanced seismic performance of timber structures using resilient connections: Full-scale testing and design procedure. *J. Struct. Eng.* **2020**, *146*, 04020180. [CrossRef]
5. Achour, N.; Miyajima, M.; Kitaura, M.; Price, A. Earthquake-induced structural and nonstructural damage in hospitals. *Earthq. Spectra* **2011**, *27*, 617–634. [CrossRef]
6. Arnold, C.; FAIA; RIBA. Architectural considerations. In *The Seismic Design Handbook*; Naeim, F., Ed.; Springer: Boston, MA, USA, 2001; pp. 275–326.
7. Latif Rauf, H.; S Shareef, S. Understanding the relationship between construction courses and design in architectural education. *Int. J. Recent Technol. Eng.* **2019**, *8*, 3201–3207.
8. De Luca, A.; Guidi, L.G. Base isolation issues in Italy: Integrated architectural and structural designs. *Soil Dyn. Earthq. Eng.* **2020**, *130*, 105912. [CrossRef]
9. Freddi, F.; Galasso, C.; Cremen, G.; Dall'Asta, A.; Di Sarno, L.; Giaralis, A.; Gutiérrez-Urzúa, F.; Málaga-Chuquitaype, C.; Mitoulis, S.A.; Petrone, C. Innovations in earthquake risk reduction for resilience: Recent advances and challenges. *Int. J. Disaster Risk Reduct.* **2021**, *60*, 102267. [CrossRef]
10. Ranghieri, F.; Ishiwatari, M. *Learning from Megadisasters: Lessons from the Great East Japan Earthquake*; World Bank Publications: Washington, DC, USA, 2014.
11. Constantinou, M.C.; Whittaker, A.; Kalpakidis, Y.; Fenz, D.; Warn, G.P. *Performance of Seismic Isolation Hardware under Service and Seismic Loading*; Technical Report No. MCEER-07; University of Buffalo: Buffalo, NY, USA, 2007; Volume 12.
12. Rakicevic, Z.; Bogdanovic, A.; Farsangi, E.N.; Sivandi-Pour, A. A hybrid seismic isolation system toward more resilient structures: Shaking table experiment and fragility analysis. *J. Build. Eng.* **2021**, *38*, 102194. [CrossRef]
13. Winsberg, E. Computer Simulations in Science; 2013. Available online: https://plato.stanford.edu/entries/simulations-science/?utm_source=feedly (accessed on 16 August 2023).
14. Richard, B.; Cherubini, S.; Voldoire, F.; Charbonnel, P.-E.; Chaudat, T.; Abouri, S.; Bonfils, N. SMART 2013: Experimental and numerical assessment of the dynamic behavior by shaking table tests of an asymmetrical reinforced concrete structure subjected to high intensity ground motions. *Eng. Struct.* **2016**, *109*, 99–116. [CrossRef]
15. Haukaas, T. Unified reliability and design optimization for earthquake engineering. *Probabilistic Eng. Mech.* **2008**, *23*, 471–481. [CrossRef]
16. Luo, J.; Wierschem, N.E.; Hubbard, S.A.; Fahnestock, L.A.; Quinn, D.D.; McFarland, D.M.; Spencer, B.F., Jr.; Vakakis, A.F.; Bergman, L.A. Large-scale experimental evaluation and numerical simulation of a system of nonlinear energy sinks for seismic mitigation. *Eng. Struct.* **2014**, *77*, 34–48. [CrossRef]
17. Smerzini, C.; Pitilakis, K. Seismic risk assessment at urban scale from 3D physics-based numerical modeling: The case of Thessaloniki. *Bull. Earthq. Eng.* **2018**, *16*, 2609–2631. [CrossRef]
18. Xiang, N.; Li, J. Experimental and numerical study on seismic sliding mechanism of laminated-rubber bearings. *Eng. Struct.* **2017**, *141*, 159–174. [CrossRef]
19. Psycharis, I.N.; Lemos, J.; Papastamatiou, D.; Zambas, C.; Papantonopoulos, C. Numerical study of the seismic behaviour of a part of the Parthenon Pronaos. *Earthq. Eng. Struct. Dyn.* **2003**, *32*, 2063–2084. [CrossRef]
20. Lu, J.; Elgamal, A.; Yan, L.; Law, K.H.; Conte, J.P. Large-scale numerical modeling in geotechnical earthquake engineering. *Int. J. Geomech.* **2011**, *11*, 490–503. [CrossRef]
21. Zarshenas, P. Investigation & Development of the «Zarshenas Earthquake Prediction Theory»(ZEPT) or The Effects of Solar & Cosmic Energies on the Occurrence of Earthquakes. *Recent Adv. Petrochem. Sci.* **2023**, *7*, 1–19.
22. Bychkov, S. Energy Generation Process of Catastrophic Earthquakes in Turkey 2023 and the Driving Forces of Underground Shocks. Available online: https://ssrn.com/abstract=4381590 (accessed on 16 August 2023).
23. Kumar, N.; Hazarika, D.; Sain, K. Earthquakes: Basics of seismology and computational techniques. In *Basics of Computational Geophysics*; Elsevier: Amsterdam, The Netherlands, 2021; pp. 47–80.
24. Tylor-Jones, T.; Azevedo, L. *A Practical Guide to Seismic Reservoir Characterization*; Springer Nature: Berlin/Heidelberg, Germany, 2023.
25. Ou, Q.; Kulikova, G.; Yu, J.; Elliott, A.; Parsons, B.; Walker, R. Magnitude of the 1920 Haiyuan earthquake reestimated using seismological and geomorphological methods. *J. Geophys. Res. Solid Earth* **2020**, *125*, e2019JB019244. [CrossRef]
26. Denolle, M.A. Energetic onset of earthquakes. *Geophys. Res. Lett.* **2019**, *46*, 2458–2466. [CrossRef]
27. Jibson, R.W.; Tanyaş, H. The influence of frequency and duration of seismic ground motion on the size of triggered landslides—A regional view. *Eng. Geol.* **2020**, *273*, 105671. [CrossRef]

28. Bray, J.D.; Frost, J.D.; Rathje, E.M.; Garcia, F.E. Recent advances in geotechnical post-earthquake reconnaissance. *Front. Built Environ.* **2019**, *5*, 5. [CrossRef]
29. Ali, U.; Ali, S.A. Comparative response of Kashmir Basin and its surroundings to the earthquake shaking based on various site effects. *Soil Dyn. Earthq. Eng.* **2020**, *132*, 106046. [CrossRef]
30. Kääb, A.; Altena, B.; Mascaro, J. Coseismic displacements of the 14 November 2016 M w 7.8 Kaikoura, New Zealand, earthquake using the Planet optical cubesat constellation. *Nat. Hazards Earth Syst. Sci.* **2017**, *17*, 627–639. [CrossRef]
31. Mele, L.; Flora, A. On the prediction of liquefaction resistance of unsaturated sands. *Soil Dyn. Earthq. Eng.* **2019**, *125*, 105689. [CrossRef]
32. Cabas, A.; Lorenzo-Velazquez, C.; Ingabire Abayo, N.; Ji, C.; Ramirez, J.; Garcia, F.E.; Pérodin, J.; Hwang, Y.W.; Dashti, S.; Ganapati, N.E. Intersectional Impacts of the 2021 M w 7.2 Nippes, Haiti, Earthquake from Geotechnical and Social Perspectives. *Bull. Seismol. Soc. Am.* **2023**, *113*, 73–98. [CrossRef]
33. Cerato, A.; Vargas, T.; Allred, S. A critical review: State of knowledge in seismic behaviour of helical piles. *DFI J. J. Deep. Found. Inst.* **2017**, *11*, 39–87. [CrossRef]
34. Hosseini, S.A.; Yazdani, R.; de la Fuente, A. Multi-objective interior design optimization method based on sustainability concepts for post-disaster temporary housing units. *Build. Environ.* **2020**, *173*, 106742. [CrossRef]
35. Gkournelos, P.; Triantafillou, T.; Bournas, D. Seismic upgrading of existing masonry structures: A state-of-the-art review. *Soil Dyn. Earthq. Eng.* **2022**, *161*, 107428. [CrossRef]
36. Herring, T.C.; Nyomboi, T.; Thuo, J.N. Ductility and cracking behavior of reinforced coconut shell concrete beams incorporated with coconut shell ash. *Results Eng.* **2022**, *14*, 100401. [CrossRef]
37. Gkournelos, P.D.; Bournas, D.A.; Triantafillou, T.C. Combined seismic and energy upgrading of existing reinforced concrete buildings using TRM jacketing and thermal insulation. *Earthq. Struct.* **2019**, *16*, 625–639.
38. Fadden, M.F. Cyclic Bending Behavior of Hollow Structural Sections and their Application in Seismic Moment Frame Systems. Ph.D. Thesis, University of Michigan, Ann Arbor, MI, USA, 2013.
39. Brunesi, E.; Nascimbene, R.; Rassati, G. Seismic response of high-rise mega-braced frame-core buildings through FE analysis. In Proceedings of the Geotechnical and Structural Engineering Congress, Phoenix, AZ, USA, 14 February 2016; pp. 276–287.
40. Farzampour, A.; Eatherton, M.R. Parametric computational study on butterfly-shaped hysteretic dampers. *Front. Struct. Civ. Eng.* **2019**, *13*, 1214–1226. [CrossRef]
41. Farzampour, A.; Mansouri, I.; Dehghani, H. Incremental dynamic analysis for estimating seismic performance of multi-story buildings with butterfly-shaped structural dampers. *Buildings* **2019**, *9*, 78. [CrossRef]
42. Farzampour, A. Innovative structural fuse systems for various prototype applications. *Materials* **2022**, *15*, 805. [CrossRef] [PubMed]
43. Farzampour, A. Structural behavior prediction of the Butterfly-shaped and straight shear fuses. *Structures* **2021**, *33*, 3964–3972. [CrossRef]
44. Wong, E.Y. Verification of an analytical hysteresis model for dowel-type timber connections using shake table tests. Ph.D. Thesis, University of British Columbia, Vancouver, BC, Canada, 1999.
45. Pei, S.; Dolan, J.D.; Liu, H.; van de Lindt, J.; Ricles, J.M. Active damping for cross-laminated timber structures to improve seismic performance. In Proceedings of the World Conference of Timber Engineering WCTE, Auckland, New Zealand, 16–19 July 2012.
46. Hollaway, L. A review of the present and future utilisation of FRP composites in the civil infrastructure with reference to their important in-service properties. *Constr. Build. Mater.* **2010**, *24*, 2419–2445. [CrossRef]
47. Paslar, N.; Farzampour, A.; Chalangaran, N. Parametric study on the partially interconnected steel plate shear walls with stiffeners. *Structures* **2023**, *53*, 749–763. [CrossRef]
48. Guevara, L.T. *Architectural Considerations in the Design of Earthquake-Resistant Buildings: Influence of Floor Plan Shape on the Response of Medium-Rise Housing to Earthquakes*; University of California: Berkeley, CA, USA, 1989.
49. Liu, W.; Qin, C.; Liu, Y.; He, W.; Yang, Q. Shaking table tests on earthquake response characterization of a complex museum isolated structure in high intensity area. *Shock Vib.* **2016**, *2016*, 1–23. [CrossRef]
50. Singh, G. Effect of Structural Configuration on Floor Acceleration Demand in RC Buildings. Ph.D. Thesis, National Institute of Technology Kurukshetra, Haryana, India, 2022.
51. Khanal, B.; Chaulagain, H. Seismic elastic performance of L-shaped building frames through plan irregularities. *Structures* **2020**, *27*, 22–36. [CrossRef]
52. Dhabre, A.R.; Dhamge, N. Study of literature on seismic response of RC irregular structure. *Int. Res. J. Eng. Technol. IRJET* **2019**, *6*, 3721–3724.
53. Filiatrault, A.; Perrone, D.; Merino, R.J.; Calvi, G.M. Performance-based seismic design of nonstructural building elements. *J. Earthq. Eng.* **2021**, *25*, 237–269. [CrossRef]
54. Al-Kodmany, K. Sustainability and the 21st century vertical city: A review of design approaches of tall buildings. *Buildings* **2018**, *8*, 102. [CrossRef]
55. Charmpis, D.C.; Phocas, M.C.; Komodromos, P. Optimized retrofit of multi-storey buildings using seismic isolation at various elevations: Assessment for several earthquake excitations. *Bull. Earthq. Eng.* **2015**, *13*, 2745–2768. [CrossRef]
56. De Angelis, M.; Perno, S.; Reggio, A. Dynamic response and optimal design of structures with large mass ratio TMD. *Earthq. Eng. Struct. Dyn.* **2012**, *41*, 41–60. [CrossRef]

57. Saha, A.; Mishra, S.K. Implications of inter-storey-isolation (ISI) on seismic fragility, loss and resilience of buildings subjected to near fault ground motions. *Bull. Earthq. Eng.* **2022**, *20*, 899–939. [CrossRef]
58. Forcellini, D.; Kalfas, K.N. Inter-story seismic isolation for high-rise buildings. *Eng. Struct.* **2023**, *275*, 115175. [CrossRef]
59. Islam, A.; Jameel, M.; Jumaat, M. Study on optimal isolation system and dynamic structural responses in multi-story buildings. *Int. J. Phys. Sci.* **2011**, *6*, 2219–2228.
60. Comartin, C.D.; Niewiarowski, R.W.; Freeman, S.A.; Turner, F.M. Seismic evaluation and retrofit of concrete buildings: A practical overview of the ATC 40 Document. *Earthq. Spectra* **2000**, *16*, 241–261. [CrossRef]
61. Binggeli, C. *Building Systems for Interior Designers*; John Wiley & Sons: Hoboken, NJ, USA, 2003.
62. Berg, G.V.; Degenkolb, H.J. Engineering Lessons from the Managua Earthquake. In Proceedings of the Managua, Nicaragua Earthquake of December 23, 1972: Earthquake Engineering Research Institute Conference Proceedings, San Francisco, CA, USA, 29–30 November 1973; The Earthquake Engineering Research Institute: Oakland, CA, USA, 1973; p. 746.
63. Stavridis, A.; Shing, P. Finite-element modeling of nonlinear behavior of masonry-infilled RC frames. *J. Struct. Eng.* **2010**, *136*, 285–296. [CrossRef]
64. Betti, M.; Vignoli, A. Modelling and analysis of a Romanesque church under earthquake loading: Assessment of seismic resistance. *Eng. Struct.* **2008**, *30*, 352–367. [CrossRef]
65. Duncan, J.M.; Wright, S.G.; Brandon, T.L. *Soil Strength and Slope Stability*; John Wiley & Sons: Hoboken, NJ, USA, 2014.
66. Belbachir, A.; Benanane, A.; Ouazir, A.; Harrat, Z.R.; Hadzima-Nyarko, M.; Radu, D.; Işık, E.; Louhibi, Z.S.; Amziane, S. Enhancing the Seismic Response of Residential RC Buildings with an Innovative Base Isolation Technique. *Sustainability* **2023**, *15*, 11624. [CrossRef]
67. Acikgoz, S.; DeJong, M.J. The rocking response of large flexible structures to earthquakes. *Bull. Earthq. Eng.* **2014**, *12*, 875–908. [CrossRef]
68. Papazafeiropoulos, G.; Plevris, V. Kahramanmaras-Gaziantep, Turkiye Mw 7.8 Earthquake on February 6, 2023: Preliminary Report on Strong Ground Motion and Building Response Estimations. *arXiv* **2023**, arXiv:2302.13088.
69. Brown, C.; Seville, E.; Horsfall, S.; Bugler, G.; Brunsdon, D.; Hare, J. Seismic repair and retrofit prioritization framework. *Earthq. Spectra* **2022**, *38*, 2886–2900. [CrossRef]
70. Kelly, J.M. *Earthquake-Resistant Design with Rubber*; Springer: Berlin/Heidelberg, Germany, 1993; Volume 7.
71. Forcellini, D.; Alzabeebee, S. Seismic fragility assessment of geotechnical seismic isolation (GSI) for bridge configuration. *Bull. Earthq. Eng.* **2023**, *21*, 3969–3990. [CrossRef]
72. Tsang, H.H.; Lo, S.; Xu, X.; Neaz Sheikh, M. Seismic isolation for low-to-medium-rise buildings using granulated rubber–soil mixtures: Numerical study. *Earthq. Eng. Struct. Dyn.* **2012**, *41*, 2009–2024. [CrossRef]
73. Darlington, R.E.; Becker, T.C. Stiffness of rubber bearings considering nonstandard top and bottom boundary conditions. *J. Struct. Eng.* **2021**, *147*, 04021101. [CrossRef]
74. Haggi, H.; Song, M.; Sun, W. A review of smart grid restoration to enhance cyber-physical system resilience. In Proceedings of the 2019 IEEE Innovative Smart Grid Technologies-Asia (ISGT Asia), Chengdu, China, 21–24 May 2019; pp. 4008–4013.
75. Kumar, N.M.; Chand, A.A.; Malvoni, M.; Prasad, K.A.; Mamun, K.A.; Islam, F.; Chopra, S.S. Distributed energy resources and the application of AI, IoT, and blockchain in smart grids. *Energies* **2020**, *13*, 5739. [CrossRef]
76. Mishra, D.K.; Ghadi, M.J.; Azizivahed, A.; Li, L.; Zhang, J. A review on resilience studies in active distribution systems. *Renew. Sustain. Energy Rev.* **2021**, *135*, 110201. [CrossRef]
77. Kavyashree, B.; Patil, S.; Rao, V.S. Evolution of outrigger structural system: A state-of-the-art review. *Arab. J. Sci. Eng.* **2021**, *46*, 10313–10331. [CrossRef]
78. Blockley, D. *Structural Engineering: A Very Short Introduction*; OUP Oxford: Oxford, UK, 2014.
79. Oldfield, P. *The Sustainable Tall Building: A Design Primer*; Routledge: London, UK, 2019.
80. Ali, M.M.; Al-Kodmany, K. Tall buildings and urban habitat of the 21st century: A global perspective. *Buildings* **2012**, *2*, 384–423. [CrossRef]
81. Bonham, M.B. *Bioclimatic Double-Skin Façades*; Routledge: London, UK, 2019.
82. GW Prime. London's Iconic Shard Tower Built Using GEOBIM Solutions. Available online: https://www.geospatialworld.net/prime/case-study/aec/londons-iconic-shard-tower-built-using-geobim-solutions/ (accessed on 24 July 2023).
83. Hussain, S.H.; Hussain, M.S. The strategies of architectural design resisting earthquake in tall buildings. *Al Nahrain J. Eng. Sci.* **2017**, *20*, 436–445.
84. Alexander, D.E. The L'Aquila earthquake of 6 April 2009 and Italian Government policy on disaster response. *J. Nat. Resour. Policy Res.* **2010**, *2*, 325–342. [CrossRef]
85. Wood, A.; Henry, S. *Best Tall Buildings: CTBUH Awards: A Global Overview of 2016 Skyscrapers*; The Images Publishing Group: Mulgrave, VC, Australia, 2016.
86. Maqhareh, M. The evolutionary process of diagrid structure towards architectural, structural and sustainability concepts: Reviewing case studies. *J. Archit. Eng. Tech.* **2014**, *3*, 2. [CrossRef]
87. Ganz, J.A.; Acker, E.; Ackley, L.; Applegate, H.; Barki, G.; Breuer, K.; Buron, M.E.; Chapman, M.; Dreyfus, R.; Kastner, V. *Jewel City: Art from San Francisco's Panama-Pacific International Exposition*; University of California Press: Berkeley, CA, USA, 2015.

88. Aguilar, Z.; Iemura, H.; Igarashi, A.; Yasuda, M. Observation and synthesis of long-period earthquake ground motions at the Akashi Kaikyo bridge construction site. In Proceedings of the 12th World Conference of Earthquake Engineering, Auckland, New Zealand, 30 January–4 February 2000.
89. Yaneva, A. *Made by the Office for Metropolitan Architecture: An Ethnography of Design*; 010 Publishers: Rotterdam, The Netherlands, 2009.
90. Dizhur, D.; Ismail, N.; Knox, C.; Lumantarna, R.; Ingham, J.M. Performance of unreinforced and retrofitted masonry buildings during the 2010 Darfield earthquake. *Bull. N. Z. Soc. Earthq. Eng.* **2010**, *43*, 321–339. [CrossRef]
91. Hiwase, P.; Waths, M.S.; Dange, M.N.; Malve, M.S.; Bhansali, M.T. Comparison of Seismic Analysis and Static Analysis of Residential Building Using Staad.Pro. *IOSR J. Eng. IOSRJEN* **2019**, 27–30.
92. Gönen, S.; Soyöz, S. Seismic analysis of a masonry arch bridge using multiple methodologies. *Eng. Struct.* **2021**, *226*, 111354. [CrossRef]
93. Ansari, A.; Rao, K.; Jain, A. Seismic analysis of shallow tunnels in soil medium. In Proceedings of the Stability of Slopes and Underground Excavations: Proceedings of Indian Geotechnical Conference; Springer: Singapore, 2020; Volume 3, pp. 343–352.
94. Fajfar, P. *Seismic Design Methodologies for the Next Generation of Codes*; Routledge: London, UK, 2019.
95. Lie-ping, Y.; Xin-lei, J.; Yuan, T.; Xin-zheng, L.; Zhi-wei, M.; Zhe, Q.; Xu-chuan, L.; Xiao, L. "System Capacity Design Method" for the Seismic Design of Building Structures: A Review. *Eng. Mech.* **2022**, *39*, 1–12.
96. Shoeibi, S.; Gholhaki, M.; Kafi, M.A. Simplified force-based seismic design procedure for linked column frame system. *Soil Dyn. Earthq. Eng.* **2019**, *121*, 87–101. [CrossRef]
97. O'Reilly, G.J.; Calvi, G.M. Conceptual seismic design in performance-based earthquake engineering. *Earthq. Eng. Struct. Dyn.* **2019**, *48*, 389–411. [CrossRef]
98. Ivanovna, G.N.; Asrorovna, A.Z.; Ravilovich, M.A. The Choice of Configuration of Buildings When Designing in Seismic Areas. *Cent. Asian J. Arts Des.* **2021**, *2*, 32–39.
99. Srinath, G.; Swain, S.; Gopikrishna, K. Seismic Capacity Estimation for Composite Multi-storeyed RC buildings. *Mater. Today Proc.* 2023; *in press*. [CrossRef]
100. Mohsenian, V.; Nikkhoo, A. A study on the effects of vertical mass irregularity on seismic performance of tunnel-form structural system. *Adv. Concr. Constr.* **2019**, *7*, 131–141.
101. Tso, W.; Moghadam, A. Seismic response of asymmetrical buildings using pushover analysis. In *Seismic Design Methodologies for the Next Generation of Codes*; Routledge: London, UK, 2019; pp. 311–321.
102. Vamvatsikos, D.; Aschheim, M.A. Performance-based seismic design via yield frequency spectra. *Earthq. Eng. Struct. Dyn.* **2016**, *45*, 1759–1778. [CrossRef]
103. Loss, C.; Tannert, T.; Tesfamariam, S. State-of-the-art review of displacement-based seismic design of timber buildings. *Constr. Build. Mater.* **2018**, *191*, 481–497. [CrossRef]
104. Luca, E. The use of cladding system as a mean to improve seismic behavior in high rise buildings. *UBT Int. Conf.* **2021**, 306.
105. Bedon, C.; Zhang, X.; Santos, F.; Honfi, D.; Kozłowski, M.; Arrigoni, M.; Figuli, L.; Lange, D. Performance of structural glass facades under extreme loads–Design methods, existing research, current issues and trends. *Constr. Build. Mater.* **2018**, *163*, 921–937. [CrossRef]
106. Helou, S.H. "The Seismic Susceptibility of RC Structures with Stone Clad Façades" A Post-Yield Perspective. *Int. J. Eng. Res. Technol. IJERT* **2021**, *10*, 503–508.
107. Wang, X.; Pantoli, E.; Hutchinson, T.; Restrepo, J.; Wood, R.; Hoehler, M.; Grzesik, P.; Sesma, F. Seismic performance of cold-formed steel wall systems in a full-scale building. *J. Struct. Eng.* **2015**, *141*, 04015014. [CrossRef]
108. Psycharis, I.N.; Kalyviotis, I.M.; Mouzakis, H.P. Shake table tests on the dynamic response of cladding panels with fixed connections. *J. Earthq. Eng.* **2022**, *26*, 615–639. [CrossRef]
109. Makris, N. Seismic isolation: Early history. *Earthq. Eng. Struct. Dyn.* **2019**, *48*, 269–283. [CrossRef]
110. Zhou, F.; Tan, P. Recent progress and application on seismic isolation energy dissipation and control for structures in China. *Earthq. Eng. Eng. Vib.* **2018**, *17*, 19–27. [CrossRef]
111. Mason Walters, S. Seismic isolation–the gold standard of seismic protection. *Structure* **2015**, *12*, 11–14.
112. Xiang, N.; Alam, M.S. Comparative seismic fragility assessment of an existing isolated continuous bridge retrofitted with different energy dissipation devices. *J. Bridge Eng.* **2019**, *24*, 04019070. [CrossRef]
113. Ponzo, F.C.; Antonio, D.; Nicla, L.; Nigro, D. Experimental estimation of energy dissipated by multistorey post-tensioned timber framed buildings with anti-seismic dissipative devices. *Sustain. Struct* **2021**, *1*, 000007.
114. Chen, X.; Li, C. Seismic assessment of earthquake-resilient tall pier bridges using rocking foundation retrofitted with various energy dissipation devices. *Struct. Control Health Monit.* **2020**, *27*, e2625. [CrossRef]
115. Wang, B.; Zhu, S.; Zhao, J.; Jiang, H. Earthquake resilient RC walls using shape memory alloy bars and replaceable energy dissipating devices. *Smart Mater. Struct.* **2019**, *28*, 065021. [CrossRef]
116. Bozzo, L.; Gonzales, H.; Pantoja, M.; Muñoz, E.; Ramirez, J. Modeling, analysis and seismic design of structures using energy dissipators SLB. *Tecnia* **2019**, *29*, 81–90. [CrossRef]
117. Bi, C.; Pan, G.; Yang, L.; Lin, C.-C.; Hou, M.; Huang, Y. Evacuation route recommendation using auto-encoder and Markov decision process. *Appl. Soft Comput.* **2019**, *84*, 105741. [CrossRef]

118. Ao, Y.; Huang, K.; Wang, Y.; Wang, Q.; Martek, I. Influence of built environment and risk perception on seismic evacuation behavior: Evidence from rural areas affected by Wenchuan earthquake. *Int. J. Disaster Risk Reduct.* **2020**, *46*, 101504. [CrossRef]
119. Hu, F.; Yang, S.; Hu, X.; Wang, W. Integrated optimization for shelter service area demarcation and evacuation route planning by a ripple-spreading algorithm. *Int. J. Disaster Risk Reduct.* **2017**, *24*, 539–548. [CrossRef]
120. Zhou, J.; Li, S.; Nie, G.; Fan, X.; Xia, C. Developing a revised social force model for pedestrians' earthquake emergency evacuation. *Geomat. Nat. Hazards Risk* **2020**, *11*, 335–356. [CrossRef]
121. Tannert, T.; Follesa, M.; Fragiacomo, M.; Gonzalez, P.; Isoda, H.; Moroder, D.; Xiong, H.; van de Lindt, J. Seismic design of cross-laminated timber buildings. *Wood Fiber Sci.* **2018**, *50*, 3–26. [CrossRef]
122. Poland, C.D.; Horn, D.B. Opportunities and pitfalls of performance based seismic engineering. In *Seismic Design Methodologies for the Next Generation of Codes*; Routledge: London, UK, 2019; pp. 69–78.
123. Rizwan, M.; Ahmad, N.; Khan, A.N. Seismic Performance of Compliant and Noncompliant Special Moment-Resisting Reinforced Concrete Frames. *ACI Struct. J.* **2018**, *115*, 1063–1073.
124. Bertero, V.V. Performance-based seismic engineering: A critical review of proposed guidelines. In *Seismic Design Methodologies for the Next Generation of Codes*; Routledge: London, UK, 2019; pp. 1–31.
125. Chang-Richards, Y.; Wilkinson, S.; Seville, E.; Brunsdon, D. Effects of a major disaster on skills shortages in the construction industry: Lessons learned from New Zealand. *Eng. Constr. Archit. Manag.* **2017**, *24*, 2–20. [CrossRef]
126. Nwadike, A.N.; Wilkinson, S. Why amending building codes? An investigation of the benefits of regular building code amendment in New Zealand. *Int. J. Build. Pathol. Adapt.* **2022**, *40*, 76–100. [CrossRef]
127. Charleson, A. Earthquake engineering education in schools of architecture: Developments during the last ten years including rule-of-thumb software. *J. Archit. Eng.* **2018**, *24*, 04018020. [CrossRef]