Board 2B: WIP: What architects should learn according to the industry in seismic countries

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Work in Progress: What architects should learn according to the industry in seismic countries

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Abstract

Certainly, seismic events take more lives than any other natural phenomenon. Also, earthquakes have financial consequences that can even destroy a country´s economy. While earthquakes are part of the natural evolution of our planet and we can neither predict them nor stop them, we can include them into our planning and design. For this reason, construction professionals play a key role in designing our built environment in seismic countries and regions. One of the ways knowledge areas about seismicity grows is from lessons learned from previous events, were both, academia and industry, have their own role. The purpose of this study is to learn what architects should learn during their college years, regarding earthquakes, architecture, and construction, according to academics and the industry. For this, this pilot study uses a survey as the instrument to collect data. The survey was administered to 8 academics and 18 professionals who were part of a professional development program. Particularly, the main areas the survey covered were seismic theory, architecture program structuring, and seismic design and construction. The results provide insight into the curriculum design of architectural programs in countries with high seismicity. Furthermore, we discuss the differences in the responses coming from the academia, industry, and the current curriculum. Lastly, implications for research and practice are provided.

Introduction

Earthquakes are one of the most lethal natural hazards and cause financial consequences that have the potential to destroy a country's economy [1], [2]. Earthquakes are natural disasters with the greatest catastrophes and collateral effects. Since the famous Lisbon earthquake in 1755 [3], there have been tens of millions of victims. In addition, 1,100 catastrophic earthquakes were reported in the 20th century. To get an idea of the impact these natural disasters have on society, in 1556 in China 830,000 deaths were recorded due to a single earthquake [1]. In addition, there is the earthquake in Haiti in 2010 that left 222,570 casualties [2], which caused Haiti's development to regress 40 years. At present, the 2023 Turkey-Syria earthquake has left more than 47,000 deaths, and has damaged or destroyed hundreds of homes [4]. Taking into account the above data, earthquakes, compared to tsunamis, cyclones, heat waves, among others are the natural disasters that result in more deaths worldwide [5].

Earthquakes not only cause deaths but also huge financial deficits. For example, Japan suffered economic damages of $210 billion due to an earthquake in 2011 [6]. This figure only corresponds to direct economic losses, i.e., costs of repair/reconstruction of infrastructure and physical contents. On the other hand, indirect losses, which are more complex to calculate, involve loss of profits, loss of productivity, loss of key company personnel, loss of business customers, and other secondary losses [7]. Knowing these concepts, indirect losses can be greater than direct losses after an earthquake [8].

Ecuador is evidently a country affected by earthquakes. The country ranked third in the top ten countries with the highest number of casualties per 100,000 inhabitants due to natural disasters in 2016 [9]. Although Ecuador is vulnerable to landslides and floods as well, earthquakes contribute the most to the mortality rate in terms of natural disasters [10]. According to the National Oceanic and Atmospheric Administration (NOAA), more than 130,000 people have died from earthquakes in Ecuador from 1556 to 2016 [11]. Additionally, 2016 was marked in Ecuador's history as 389,511 people were affected due to the Pedernales earthquake [12]. This earthquake in Pedernales caused direct losses equivalent to 2% of the country's gross domestic product [13].

Although earthquakes are part of the natural progression of our planet and cannot be forecast or stopped, we can include them in our planning and design to prevent their catastrophic consequences. For this reason, building professionals play a crucial role in the design and construction of our existing built environment in seismic zones. The Pacific Ring of Fire is the most seismic zone of the planet. Therefore, the countries that are in this zone are more prone to earthquakes. In this sense, it is recommended that architecture students learn about seismology [14]. It is paramount that the architecture curriculum includes an appropriate design and correct spatial-dynamic analysis [15]. Considerations in the configuration of buildings such as, form, size, height, and materials used have a meaningful impact on how the structure performs during an earthquake. All of these aspects are directly or indirectly related to architectural decisions and have a great impact in managing the seismic reaction [16].

The role of architects is essential in building safe and earthquake-resistant structures in seismic countries. There is a big debate regarding what are topics needed in the architectural curriculum in seismic countries regarding seismic theory, practical design, and construction considerations [17]. Our study begins to fill this gap by examining what architects should learn according to the industry in seismic countries. Through a literature review and interviews with industry experts, the importance of adequate seismicity education and training for architects in earthquake countries is investigated. This study aims to explore the answer to what does the industry and academia suggest architects should learn in regard to seismic countries.

Background

In general terms, the theoretical framework of this study focuses on the importance of further education for architects in seismology and earthquake-resistant design in high-risk countries. It has been shown that proper education in seismology and earthquake-resistant design is essential for building professionals in these locations. The lack of knowledge in seismology and seismic-resistant design is one of the main causes of inadequate construction in seismic zones. In addition, emphasis about the importance of practical education in earthquake-resistant construction for building professionals is important, as it provides them with the necessary skills to develop safe buildings in seismic zones. Although every construction professional is responsible for their own specialized area of knowledge, a good understanding on how to better complement each field to one another is a key factor to the design and construction in seismic areas. Particularly for architects, structural knowledge should be incorporated in the early stages of the project conception. That is, not from a materials behavior and deep mathematical understanding, but rather from a performance and best practices viewpoint [18].

Among the most essential aspects of an excellent structure design is the direct combination between the architectural spatial aspect with the structural requirements. The latter refers to maximum spacing between spans and the construction system, the response of the structure to seismic load simulations [19], types of materials, and their structural performance [20]. The literature has also highlighted the importance of collaboration between industry and academia for the training of architects in seismic countries. Such cooperation helps to generate theoretical, experimental, and practical knowledge for architects to be prepared to develop safe and strong buildings in seismic zones.

An approach taken by some construction schools is to use nature characteristics and responses as pedagogic tools for different fields. For example, trees have good resistance to lateral forces due to the stiffness of their trunk. In a building, the columns would represent the trunk and the lateral force would be the earthquake [21]. Basic concepts of structural dynamics of houses, buildings, bridges, foundations, among other work can also be related to structures formed by nature's own action, i.e., understanding the functioning of these structures allows for a more functional vision of "earthquake-resistant" designs [21].

Furthermore, any student who is going to enter the construction field should know about earthquakes, from their origin due to the movement of tectonic plates, their intensity and magnitude characteristics, the intrinsic relationship with the geotechnical field and, finally, the vibration modes of a structure. For this, it is essential to understand the basic concepts of seismology, in which the Pick Ground Acceleration (PGA) of a seismic record is involved [22].

Additionally, it is important to have clear definitions of hypocenter, epicenter, fault surface, among other factors; all this to determine a probabilistic design earthquake that will occur in a time window [23]. This allows establishing architectural designs that resist seismic events.

As mentioned on several occasions, earthquakes are natural occurrences that can cause harm to people, the environment, and every type of property. They can lead to loss of life, injury, damage, disruptions to social and economic activities, and environmental damage. Because earthquakes can greatly disrupt communities, local builders have incorporated seismic risk into their construction practices, using various strategies to protect people from these natural disasters. This has resulted in unique building techniques, construction details, and temporary technical devices aimed at reducing the vulnerability of structures [24].

Reducing the risk of earthquakes is a multifaceted endeavor that requires the participation of students and professionals in civil engineering and architecture as well as a wealth of information, numerous viewpoints, and a multitude of actions and choices. Effective handling of the necessary modifications to minimize earthquake risk is a demanding undertaking that involves the active or passive involvement of all individuals residing in a specific area.

It is important to define that seismic risk refers to the likelihood that the social or economic impact of an earthquake will meet or surpass specific values at a particular site, multiple sites, or in a given area within a defined timeframe. Seismic hazard, on the other hand, describes any physical event linked to an earthquake, such as ground shaking or failure, that could result in negative consequences for human activities [25].

There are many earthquake occurrence models available for seismic hazard assessment that civil engineers and seismologists use. For instance, the Poisson model is commonly used, but has limitations in representing earthquake driving mechanisms and seismicity patterns. Other stochastic models like Markov and semi-Markov better describe infrequent large earthquakes, while unique patterns like foreshock-mainshock-aftershock sequences are better represented by other models. Some of these models are difficult to implement and require more data for model parameter estimation [26].

Bearing that in mind, it is not possible to avoid these natural disasters, it has been found that the earthquake resistance of structures is influenced by various factors such as architectural design, structural arrangement, slenderness ratio, placement and size of floor openings, symmetry, rigidity and strength disparities among floors, short columns, and pounding effect [27]. Implementing practical design rules can aid in creating earthquake-resistant structures and promote their adoption in the construction industry [28].

Most buildings are designed using static forces outlined in building codes, which distribute force based on elastic vibration modes. However, this load pattern may not result in the most efficient use of materials for seismic design. By modifying the structural properties to shift material from strong to weak areas until a uniform deformation state is achieved, the seismic performance of a structure can be optimized and perform better than those designed by conventional methods [29].

Additionally, in developing countries like Ecuador, the construction industry is marked by poor quality of projects, financial instability, and a growing preference for modern or imported materials and techniques. Unfortunately, the government has not taken action to address these issues due to insufficient management skills, resources, commitment, and a tendency to overlook the informal sector of the construction industry. In many developing countries, the informal sector plays a significant role in the construction industry [30].

In conclusion, the literature has distinguished the importance of education in seismology and earthquake-resistant design for architects in seismic countries. Lack of knowledge in these areas can have serious consequences for the construction of safe buildings in seismic zones, so it is essential that architects receive adequate training in these areas. Collaboration between industry and academia is also essential to ensure that architects are prepared to develop safe buildings in seismic zones.

Methodology

This pilot study aims to understand what architects should learn about earthquakes, seismic-resistant architectural design, and construction according to the industry and academia in seismic countries. To gather data, a survey was used as the primary research instrument. The survey was administered to eight academics and eighteen professionals who were part of a professional development program. The main areas of the survey included seismic theory, architecture program structuring, and soil-structure behavior and theory. The survey consisted of multiple-choice questions, with the primary focus on gathering information about the curriculum design of architectural programs in countries with high seismicity. The participants were asked to rate the importance of various topics related to earthquakes and their impact on architecture and construction.

To gather further insight into the views of architects on earthquake-related topics, a matrix was created based on the survey on the introduction to seismological engineering. This matrix was divided into six main topics. These include the causes and effects of earthquakes on infrastructure, earthquake measurement parameters and instrumentation, earthquakes in Ecuador, estimation of seismic hazard in Ecuador, seismic-resistant design philosophy of construction standards, and seismic-resistant structuring and ways to reduce seismic demand. The survey-based matrix was shared with the participants, who were then asked to provide their opinions on the importance of these topics in relation to their profession and university studies.

In conclusion, this pilot study used a survey as the primary research instrument to gather data from eight academics and eighteen professionals in the field of architecture and construction. The results of this study provide insight into the curriculum design of architectural programs in countries with high seismicity and highlight the importance of earthquake-related topics for architects. The findings of this study will contribute to the development of more effective educational programs for architects in seismic countries and help ensure the safety and resilience of our built environment in the face of seismic events.

Results

Regarding seismological engineering and earthquake-resistant design of structures, an architecture student or professional involved in the construction field would need to have knowledge on the matrix topics. Specifically, these are the causes and effects of earthquakes on infrastructure, earthquake measurement parameters and instrumentation (intensity vs. magnitude), main earthquake sources, seismic hazard estimation, earthquake-resistant design philosophy of building codes, and earthquake-resistant structuring and ways to reduce seismic demand. Below is the summary of the survey results:

Introduction to Seismology and Seismological Engineering	**Importance of the topics, where 10 is quite important and 1 is not important:**									
Earthquakes: causes and effects on infrastructure	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Deaths due to earthquakes						2		4	5	7
Economic losses (direct and indirect)						1	1	4	5	7
Structural failures due to earthquakes				2	1			4	7	5
Concept of earthquake and its causes								7	7	4
Divergence, slippage and convergence of tectonic plates							6	7		5
Epicenter vs Hypocenter							1	4	7	6
Components of an earthquake (N-S, E-O and vertical)							2	5	4	7
Earthquake measurement parameters and instrumentation (Intensity vs Magnitude)										
Definition of seismic magnitude (energy released)								6	4	8
Magnitude scales						2	1	5	4	6
Seismic intensity concept							1	4	7	6
Instrumental scales of intensity (accelerograms)						2		4	5	7
Earthquakes in Ecuador (Sources and effects)										
Earthquake registration in Ecuador						2		7	5	4
Identification of areas with the highest seismic intensity in the country							3	3	7	5
Importance of scientific publications (deduce where is going to occur the next earthquake)						3	4	5	3	3
Seismic signal amplification due to soils							2	3	7	6
Seismic hazard esimation in Ecuador										
Earthquake "prediction" (date and time, location, size)								1	5	12
Seismic hazard studies (probability - time window)							2	1	3	12
Seismically resistant design philosophy of building standards										
Design earthquake adopted by the building standards								2	5	11
Annual probability of exceedance and return period of the design earthquake									6	12
Avoid the collapse of structures and damage control									8	10
Seismic monitoring devices								4	5	9
Earthquake-resistant structuring and ways to reduce seismic demand										
Correct distribution of structural elements to resist earthquakes							1	3	7	7
Proper structural behavior							1	2	9	6
Recommendations to reduce seismic demand (soil effect, unnecessary mass, effects of torsion, etc)								3	9	6
Materials and technical procedures								1	9	8

Figure 1: Summary of survey answers

The following tables show the topics regarding to introduction to seismology and seismological engineering that both groups, seismic construction experts and experienced architect professionals stated as highly important to know in architecture curriculums.

Earthquakes: causes and effects on infrastructure
Deaths due to earthquakes
Economic losses (direct and indirect)
Structural failures due to earthquakes
Concept of earthquake and its causes
Divergence, slippage and convergence of tectonic plates
Epicenter vs Hypocenter
Components of an earthquake (N-S, E-O and vertical)
Earthquake measurement parameters and instrumentation (Intensity vs Magnitude)
Definition of seismic magnitude (energy released)
Magnitude scales
Seismic intensity concept
Instrumental scales of intensity (accelerograms)

Table 1: Sections 1 and 2 of Introduction to Seismology and Seismological Engineering.

Causes and effects of earthquakes on infrastructure includes topics such as the Pacific Ring of Fire, deaths due to earthquakes, economic losses (direct and indirect), frequency of earthquakes, structural faults due to earthquakes, earthquake concept and its causes, components of planet Earth, tectonic plates and their movement, main sources of earthquakes, divergence, sliding and convergence of tectonic plates, geological faults; epicenter vs. hypocenter, types of earthquakes according to their focal depth and geographic location, seismic catalogs, and tsunamis. Alternatively, earthquake measurement parameters and instrumentation (intensity vs. magnitude) is divided into definition of seismic magnitude (energy released), magnitude scales, concept of seismic intensity, macro-seismic scales of intensity, instrumental scales of intensity (accelerograms). Differentiating these topics is crucial since in civil engineering and architecture structures are designed based on seismic intensity.

Earthquakes in Ecuador (Sources and effects)
Earthquake registration in Ecuador
Identification of areas with the highest seismic intensity in the country
Importance of scientific publications (deduce where is going to occur the next earthquake)
Seismic signal amplification due to soils
Seismic hazard esimation in Ecuador
Earthquake "prediction" (date and time, location, size)
Seismic hazard studies (probability - time window)

Table 2: Sections 3 and 4 of Introduction to Seismology and Seismological Engineering.

On the other hand, sources and effects of earthquakes refer to the following topics: recording of earthquakes, identification of areas with higher seismic intensity, catalysts of processes (publications of building standards), importance of scientific publications (deducing where the next earthquake will occur), rapid evaluation of structures (trained personnel to perform checks), components of an earthquake (N-S, E-W and vertical), and amplification of the seismic signal due to soils. Moreover, seismic hazard estimation has three categories: earthquake "prediction" (date and time, location, size), seismic hazard studies (probability - time window), and procedure of a probabilistic seismic hazard analysis.

Seismically resistant design philosophy of building standards
Design earthquake adopted by the building standards
Annual probability of exceedance and return period of the design earthquake
Avoid the collapse of structures and damage control
Seismic monitoring devices
Earthquake-resistant structuring and ways to reduce seismic demand
Correct distribution of structural elements to resist earthquakes
Proper structural behavior
Recommendations to reduce seismic demand (soil effect, unnecessary mass, effects of torsion, etc)
Materials and technical procedures

Table 3: Sections 5 and 6 of Introduction to Seismology and Seismological Engineering.

Furthermore, earthquake-resistant design philosophy of the building codes covers the following: design earthquake adopted by the building codes, seismic hazard curves, annual exceedance probability and return period of the design earthquake, seismic hazard maps, avoidance of collapse of structures and damage control, seismic behavior of different structural systems and materials, importance and types of foundations. Finally, seismic-resistant structuring and ways to reduce seismic demand are divided into: mandatory minimum requirements of construction standards (prohibition of collapse and damage control), correct distribution of structural elements to resist earthquakes, measures to combat earthquakes larger than the design earthquake, adequate structural behavior, bad structuring practices, recommendations to reduce seismic demand (soil effect, unnecessary mass, torsion effects, among others), informality, dishonesty and lack of memory in the construction sector, and materials and technical procedures.

Of the six main themes in the matrices that refer to the survey, the following summary was made to get an idea of what each sub-theme covers. This is a brief review of seismological engineering and earthquake-resistant design that is recommended to be incorporated into the architecture curriculum. The Pacific Ring of Fire is the most seismic zone on the planet, where most earthquakes and volcanic eruptions are concentrated. Each year, around 20,000 earthquakes are recorded worldwide, some of which can be very intense and cause severe damage to infrastructure and people. Earthquakes are responsible for thousands of deaths and economic losses each year. Direct losses include damage to buildings and infrastructure, whereas indirect losses include the costs associated with the disruption of production and utilities.

In addition, it is suggested that an architect knows that seismology is the branch of geology that studies earthquakes and their impact on the Earth. An earthquake is an abrupt shaking of the Earth's surface caused by the sudden release of energy accumulated in the Earth's interior. The causes of earthquakes are the result of plate tectonics, which is the study that describes the movement of such plates and their interaction in the Earth's crust. The thickness of the Earth's crust varies according to geographic location and is thicker in continental regions and thinner in oceanic regions. Furthermore, in architecture classes it is recommended that the difference between the epicenter and hypocenter of an earthquake be explained. Likewise, it is very important to provide information about seismic catalogs and the definition of seismic magnitude. On the other hand, it is essential for an architect to have a clear understanding of the concept of seismic intensity and the different scales that exist to measure this parameter as well as the use of accelerograms which is essential.

Moreover, it is necessary for both engineers and architects to keep in mind where seismic hazard estimates are derived from, including return periods and annual exceedance probabilities of earthquakes. It is suggested that students in the faculty of architecture know that the design earthquake adopted by the building standards is based on seismic hazard curves. These seismic hazard maps are also used to evaluate the seismic exposure of an area and to develop an appropriate construction plan.

In contrast, seismic-resistant structuring is a critical aspect of building construction, since earthquakes can cause serious damage and endanger people's safety. For this reason, it is important for architects to be informed about the mandatory minimum requirements of building codes and ways to reduce seismic demand. It is essential for constructors to know that one of the most important measures to combat earthquakes is the correct distribution of structural elements. Also, it is necessary to consider the size of the design earthquake and to take additional measures to combat larger earthquakes. Lastly, it is also important to mention poor structuring practices that can increase seismic risk. Hence, it is essential for architects to be aware of recommendations to reduce seismic demand, such as minimizing ground effect, eliminating unnecessary mass, and minimizing torsional effects.

In conclusion, it is recommended that architects involved in the construction of houses and buildings in seismic countries have knowledge of causes and effects of earthquakes on infrastructure, earthquake instrumentation and measurement parameters, sources of earthquakes in seismic countries, seismic hazard analysis, earthquake-resistant design and construction philosophy adopted in building codes, and, finally, earthquake-resistant structuring and ways to reduce seismic demand. All this with the aim of complementing architecture with engineering and making projects safer for users.

Discussion

An architectural student or professional involved in the construction of earthquake resistant structures needs to know the causes and effects of earthquakes on infrastructure, earthquake measurement parameters and instrumentation, major earthquake sources, seismic risk estimation, seismic design philosophy of building codes, and how to structure and reduce seismic demand. To do this, it is important to have knowledge about the Pacific Ring of Fire, tectonic plates, earthquake magnitude and intensity measurement, possible causes and effects of earthquakes, seismic risk estimation and prediction, and resistant structuring and how to reduce seismic demand. Earthquakes can be devastating, and it is important to design resistant structures to avoid collapse and loss of life. The results obtained agree with:

It is required to pay more interest to the conceptual design phase and better inform architects about seismic difficulties and basic notions of seismic design, as well as work for better and closer alliance between structural engineers and architects [16].

Additionally, seismic architecture can be proposed to architects and architectural faculty or students, its principal audience, and it could also be helpful to structural engineers who may find its many sketches and examples helpful in discussing seismic issues with their architectural colleagues [31].

Moreover, in the faculties of architecture of universities located in earthquake-prone countries, it is recommended that, referring to the current infrastructure, even if they were or not intentionally built to minimize damages produced by an earthquake, a variety of natural selection of the effective designs that have frequently proven to withstand earthquakes have most likely happened [32]. If something has become old-fashioned is because it has been efficient in resisting past seismic events, moreover, it can resist seismic incidents in the time to come. As a result, a cohesion in the use of specific seismic resistant features can be observed in highly seismic regions around the globe [33].

Furthermore, earthquake architecture can summarize figurative references to seismic concerns, or at a more practical level, convey a design reaction to seismic loads [34]. Differing on the seismic knowledge within a design group, the potential exists for many layers of structural equipment and technique to be communicated architecturally. The main inspiration for such representation may be to enhance the aesthetic and other characteristics of architecture, but other purposes are also viable. For an earthquake architecture to be successful, a high degree of combination of structure and architecture, and cooperation between architect and engineer is imperative [35].

Finally, architectural students are expected to possess a thorough understanding of seismic design principles and their application to earthquake-resistant architecture. However, it has been observed that some students face challenges in integrating engineering concepts with their architectural intentions, possibly due to the traditional separation of engineering from design in architectural education. To address this issue, we proposed a continuous exchange of design ideas between the two disciplines, resulting in projects that employed earthquake-related metaphors both literally and abstractly. Encouraging critical discussion of design ideas and models can further enhance students' seismic understanding and their knowledge of construction processes [36].

Conclusions and Future Work

In conclusion, this pilot study investigated what architects should learn during their college years regarding earthquakes, architecture design, and construction, according to academics and industry professionals. The survey used in the study covered three main areas: seismic theory, architectural program structuring, and recommendations for earthquake-resistant design of structures. The results obtained highlight the importance of including knowledge of seismology and earthquake-resistant construction in the curricular design of architecture programs in countries with high seismicity.

Moreover, both academics and industry professionals have reached a consensus, underscoring the crucial importance of aligning educational programs with market demands. The incorporation of the three topics mentioned above into architecture curricula can significantly enhance the quality of structures in earthquake-prone regions. Additionally, several specific subjects were identified as essential components of architects' training, including compliance with construction standards to ensure ethical work and the safety of human lives, practical application of seismic theory, and the design and construction of earthquake-resistant structures.

For future work, it is recommended that similar studies be conducted in other countries with high seismicity to compare the specific needs and challenges in each region. In addition, further research should be conducted to determine how to effectively implement these topics in architectural curricula and how to evaluate the effectiveness of seismology and earthquake-resistant construction education in practice. Over time, it is hoped that this work will contribute to the reduction of the detrimental effects of earthquakes on society and the global economy.

Furthermore, future work should involve an expanded study that includes the perspectives and needs of health professionals and government emergency officials. Specifically, these experts can indicate where education should address socio-cultural issues, such as poor quality, poor standards, and corruption, which contribute to hazards, damages, harms, and devastation resulting from earthquakes. In synthesis, their perspectives can inform the development of educational programs that are better suited to meet the requirements and preferences of those who address the consequences of earthquakes.

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