

INTEGRATING ARCHITECTURAL AND SEISMIC DESIGN OF BUILDINGS IN TEACHING PRACTICE

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ABSTRACT:

Earthquake-resistant requirements are usually considered at the latest stages of the design process, resulting in a frontal confrontation with the building's architecture rather than an added value to its design. While this situation may be justified in practice, there is no valid argument to repeat such reductive approach during the educational process developed in many schools of Architecture. I propose, on the contrary, a new integrated process of seismic-architectural design, wherein the requirements derived from the need of achieving an earthquake-proof building, are introduced in the early stage of the process. In order to achieve this, the mutual influence between factors affecting the seismic behavior and those depending on the architecture of a building is explored and developed as a main design strategy. Thereby, seismic design becomes a design driver for the entire process of producing a project of architecture. Finally, this integrated architecture-seismic design method is assessed by a case study developed at the Faculty of Architecture in Izmir, Turkey, by which the application of such integrated design strategies in the architecture of seismic-prone places is highly promoted.

KEYWORDS: architecture, seismic design, teaching methods, earthquake architecture

1. INTRODUCTION

Within the context of teaching architectural design, it has been widely recognized the importance of introducing structural concepts and principles in the early stages of the process of designing a building. Apart from the fact that architecture decisions will later determine to a large extent the structural behaviour of a building, the main driver for this academic interest has been the assumption that linking the structural matters –as source of technical-based knowledge, to certain aesthetical objectives may increase the architectural values of a given design work. Nevertheless, many problems arise during the setting of any design methodology involving the incorporation of technical-based knowledge because of the conflicting objectives between structural and architectural design, and the lack of a suitable students' background in mechanics and other former sources of technical knowledge. On the other hand, seismic design - before the eyes of architects- seems to be a consistent set of rules that constraints and limits their freedom to design the architecture of a building; Due to its inherent complexity, earthquake-resistant requirements are then usually considered at the latest stages of the design, resulting in a frontal confrontation with the building's architecture rather than an added value to its design.

There exist, however, an increasing interest to eliminate such confrontation by introducing the so-called seismic requirements within the process of designing a building (Charleson 2008; Charleson and Taylor 2004; Charleson 1997; Mitra et al. 2013; Slak and Kilar 2007). The main objective is making architects aware of the consequences that design decisions have in the structural behaviour of the buildings subjected to ground motion produced by earthquakes. This interest has been materialized by several initiatives inside and outside the Faculties of Architecture, such as post-graduate or late education of architects on principles of seismic design; introduction of seismic design-related courses during the architects' formation (within the faculties of Architecture); and, introduction of seismic design principles in earlier stages of the design process of architecture (not only within the Faculty, but also within the Studio).

In this article I will refer to the achievement of an effective integration architecture-seismic design through the setting of guidelines for a teaching practice in schools of Architecture. The new approach hereafter proposed, addresses to set an integrated process of seismic-architectural design, wherein the requirements derived from the need of achieving an earthquake-proof building, are introduced in the early stage of the process. Since architecture students learn architecture by applying strategies of design, the key to achieve a successfully integration is to develop a method to design earthquake-proof architecture based on strategies of design. One of these strategies addresses the three-dimensional control of the configuration. Such control is set by the assessment of the stiffness distribution in each direction of analysis. Thereby, seismic design becomes a design driver for the entire process of producing a project of architecture. Finally, this integrated architecture-seismic design method is assessed by a case study developed in the Faculty of Architecture in Izmir, Turkey, by means of which the application of integrated design strategies to the architectural production of buildings in seismic-prone places is highly promoted.

2. GUIDELINES FOR AN EFFECTIVE INTEGRATION BETWEEN ARCHITECTURAL AND SEISMIC DESIGN

2.1 Background

The 'studio' is the place where students of Architecture learn to design; an integrated process of design cannot be achieved, consequently, out of this framework. Studios are conducted by a team of instructors, usually with heterogeneous level of experience and fields of expertise, whose role is to diversify the perspectives in the discussion of designs proposed by students. Such group dynamic is based on a strong line of argumentation that promotes strategies for design, so that the studio frequently runs through an initial construction of arguments, the discussion of proper strategies of design, and finally, the design of a project itself. The development of strategies is thus the key to introduce seismic design principles within the studio for two main reasons: first, because a seismic-based design strategy is easier to apply by the students in their designs than a set of rules, and second, because the study of seismic strategies for design demands less management of technical knowledge and therefore can be afforded in the scarce time students have available for it within an always overloaded curricula.

A studio that explores the possibilities of an effective integration of earthquake-resistant principles and architectural design will focus in the design of an architectural project targeting a minimum of basic objectives, such as:

1. Respect to the location in a specific site; integrating the building in the urban grid and, ideally, contributing to the setting of adequate evacuation routes and emergency management plans at urban levels.
2. Remarkable consistency between architectural concept and the logic of the earthquake-resistant configuration; the degree of achieved consistency then can be read as an indicator of the design suitability of buildings in earthquake-prone areas. Ideally, this consistency allows students to deliver a specific design related to the site and thus promotes identity as architectural feature of seismic designed buildings;
3. Effective double-function program that includes the elaboration of the emergency-state layout of the building as both engineering and architecture design problem. Ideally, the physical expression of the consideration of this double-function emphasizes cultural and social aspects –reinforcing architectural identity- and expresses a contemporaneous image of the building.

In order to meet these objectives it is required a design methodology organized in steps going from out-to-inside the buildings: from the context of the building, then building function, then function of the structure, and finally, structural detailing. These stages will be described in the following sections as seismic *genius loci* awareness (site analysis), dual function (building program), spatial building-up (earthquake-resistant configurations), and detailing.

2.2 Seismic Genius Loci Awareness

One of the main goals target by designs elaborated by architects, highly promoted in many schools of Architecture, is the achievement of a strong link between the project and the place where is located by unveiling what the nature of a place is or its *genius loci* (Schulz 1980); site analysis addresses then the process of unveiling what can be taken a prime source for the design according to a balanced criteria among cultural, climatic, urban, functional, social, economic, psychological, and aesthetical aspects. On the other hand, seismic design makes strong emphasis in the consideration of those particularities of the site affecting not only the behaviour of the overall response of a building, but also on the relationship between building and soil interactions. However, in both disciplines usually designers tend to forget the problem of the earthquake as a vivid traumatizing experience; architects usually overestimate the meaning of ‘earthquake-proof’ design of buildings by assuming that safety of the structure is the only concern and thus wrongly minimizing the effects of non-structural elements in the overall response, while engineers –most familiarized with the concept of serviceability- oversimplify the problem by reducing the building response to fit predefined ranges of response (displacement or acceleration for instance) and thus overlying the fact that such experience is not related to spectra thresholds but to people’s perception. In simple terms, the site analysis should bring into the problem of design –apart from the respective sources of information of each discipline- the people’s particular experience of feeling an earthquake in that place. This is not a trivial task; a site analysis whose results are intended to be applied on an integrated seismic-architectural design, involves a scanning process in which site elements and cultural aspects of a local community are revealed.

2.3 Dual Function

A second level of analysis targets the functionality of a building in terms of daily use, but also addresses the issue of the state of emergency that comes along with and after a large earthquake strikes. The main reason to encourage the consideration of the state of emergency in the design of any building located in a seismic place, comes from two sources: (a) the objective of creating a cultural link between the type of seismic-resistant architecture and the comprehensive use of a certain building in a specific place, requires the reinforcement of the sense of pertaining that only users through the proper appropriation of all spaces can achieve (including the use of space in emergency evidently); and, (b) because in doing so, the responsibility of designing earthquake-proof spaces relies on the architects and thus the seismic issue get incorporated in the process as a problem of design and not only as a problem of a ‘late-fixing’ the structural components for making them seismic-resistant. Emergency, as a design concept, brings along the consideration of the speed with which a place can be evacuated or it can be reached (depending on the specific case) and thus emphasizes the study of the accessibility issues related with the specific function of the building, and hence the importance of the site analysis in the terms previously addressed. Moreover, emergency understood as a spatial problem (not only as structural one), will question therefore the different approaches to design spaces according to cultural signatures; while open spaces may embrace in a better way the local costume of using semi-private spaces, they can also contribute to a faster evacuation and thus avoid the side effects of earthquakes, such as fear or collective panic, because –besides the effective seismic-resistant structure-building possesses a functional distribution that considers these effects on the population.

2.4 Spatial Building Up

Once the need of a specific type of space, both in terms of use and contextual relationships, arises as a target for the design, the spatial elements that give the project a physical form are required. Here is where most of the researchers suggest and promotes the introduction of the seismic issues as design guidelines; these design rules somehow drive the configuration of the building towards the meeting of an adequate distribution of strength and stiffness, while it simultaneously avoids setbacks and other irregularities that have been proved to augment the negative aspects of structural response of buildings subjected to earthquakes. Since good engineering is based on successful practice, and such good practice in the case of seismic engineering has been very well documented by extensive literature, I will not refer here to the recommendations otherwise given by many guidelines, handbooks and codes for seismic design. Good examples of guidelines for architectural design of seismic-resistant structures

can be found in (Arnold 1984; Charleson 2008). Nevertheless, in order to constitute an adequate set of earthquake-proof elements, used by the architect as design elements, simple forms must be promoted by the selection of shear walls, rigid diaphragms, frames and braces featured as planes and bars. The simplicity exhibited by such elements will echo in the overall constitution of the project, promoting in turn simple forms that fit better the suggestions of symmetry, continuity, and regularity given by the principles of seismic design of buildings. In the section 3 of this article, a method to achieve such regularity in the configurations of the architectural designs will be further explained.

2.5 Detailing

In the same line of arguments, a building that needs to remain functional after the earthquake – depending of the performance objectives selected- requires not only a proper design of its structural elements, but also of those non-structural ones, such as ceilings, light walls, facade components, etc. However, detailing is the most complex, and probably, the most time-consuming process in both disciplines. Whereas during the previous stages, the conceptualization of the spaces and, perhaps, the searching for an overall image and meaning in the Architecture went side by side with the principles of structural design as guidelines for more successful seismic configurations, the point where seismic design overlaps architecture, in term of the continuity of the process, occurs at the definition of the building material. The importance of material as link between engineering and architecture is transversal to the entire process of designing a building; it comes from the site analysis through the exploration of local building systems (adobe, for instance – Fig. 1) and by the inventory of surfaces and materials around the site (cost effective and well-known building practices); it is discussed during the selection of wooden, steel or reinforced concrete structures as the main structural system, not only because their inherent mechanical properties but mainly because of their absolute influence in the typology of the selected lateral force-resistant system; and, finally, its duality compromise a double reading as subject of the engineered detailing process that gives the structure the necessary fuses to safely release the seismic energy by ductility, and as overall feature that gives life to the architecture and thus contributes to the aesthetical achievements of a building.



Figure 1: The use of adobe or earth-based brick masonry is quite extended in many seismic-prone countries; an integrated design has to consider this fact and evaluate it for promoting identity (Photo by the author)

3. SIMPLIFIED STIFFNESS-BASED METHOD FOR EXPLORING SPATIAL CONFIGURATIONS IN THE DESIGN OF EARTHQUAKE-PROOF BUILDINGS

Since the objective is to achieve even and regular spatial arrays of earthquake-resistant elements, the method focuses on the reckoning of the amount of stiffness -in each orthogonal direction- for a given configuration, in such a way that students (and architects) may modify overall dimensions of the elements during the process to eventually produce an initial earthquake-proof design. However, since the application of the method aims to unveil a logic pattern that could guide the design of a specific architectural project, the reduction of the problem is required by selecting only a portion of the entire project as a case of study. Such portion must be representative of both architectural and structural aspects of the design. For introducing the problem of the increase in the required overall dimensions of the earthquake-resistant elements, three levels of EQ accelerations are defined based on theoretical ground accelerations related to a simulated location as it follows:

Table 1: type of earthquakes and associated level of ground acceleration

Type of earthquake	g : acceleration of Gravity
Average	0.4g
Large	0.8g
Severe	1.2g

It is important to notice that this simplified method has been elaborated with the explicit intention to show how earthquake forces determine the size of the earthquake-resistant elements, and thus, by modifying geometrical properties of both configuration and elements, initial earthquake-proof design can be addressed. However, the method does not consider the design of ductile mechanisms as for being introduced in the EQ-resistant system and therefore, structures designed by the principles described here will not safely dissipate the earthquake energy; moreover, without ductility none of the further configurations could safely resist any type of earthquake at all. Finally, for simplification, the explanation addresses the calculation of the stiffness (K) of shear walls, but the method can be extended to brace and moment frames as well

3.1. Strategy

Firstly, it is possible to determine the stiffness (K) of any ordinary structural element provided that its physical properties and geometry are defined, in this case a shear wall, by using the relationship:

$$K = \frac{Gbl}{kh} + \frac{3Ebl^3}{12h^3} \quad (1)$$

Inversely, dimensions of the wall can be determined, using equation (1), if K is known. In order to find K, the static relationship between displacement u , the applied force F, and K can be used as stated by:

$$F = u * K \quad (2)$$

Since due to safety issues, in seismic design the maximum displacement of a structure shall be limited to avoid excessive damage and collapse, u can be set according to a particular seismic code. In most of the seismic codes, this maximum displacement is limited by the peak story drift ratio; Usually, the peak story drift ratio for stiff systems (such as shear walls and braced frames) is 0.01 – 0.02 [or height/100 – height/200], and 0.03 – 0.04 [or height/300 – height/400] for flexible systems, such as moment frames. Consequently, using these criteria, u in equation (2) is defined, and thus the remaining problem is to find the applied force F that, in this case, regards to seismic forces. Using

Newton's laws this earthquake force is defined as a relationship between the mass of the building and the ground acceleration:

$$F = m * a \quad (3)$$

where a is the peak EQ ground acceleration and m is the seismic mass of the structure defined by the following relationship:

$$m = \frac{w}{g} \quad (4)$$

where w is the total weight of the structure and g is the acceleration of gravity. Thus, the strategy consists of six steps:

Step1: find the seismic mass of the structure m using equation (4); wherein w is the weighted sum of dead and live loads of the building. The total weight is then divided by g , thus m is defined in kN/g.

Step2: find the set of seismic forces F_{EQ} , by equation (3) that takes the three different values of ground acceleration a given in Table 1, such that $F_{EQ} = m * a$, where $a = 0.4g, 0.8g,$ and $1.2g$.

Step3: determine the maximum target displacement according to seismic code to assure safety in the structural response under earthquake loading; a conservative approach limits the peak story drift ratio equal to 0.02.

Step4: determine the required stiffness K_{req} according to equation (2), for each EQ force; $K_{req-n} = F_{EQ-n} / u$ for each case, so that the required stiffness is dependent on the selected level of earthquake defined by n .

Step5: determine the necessary dimensions of the shear walls to cope with K_{req} using equation (1); that can be solved by matching $K_{wall} = K_{req}$. In order to simplify the procedure, an iterative process of assigning random values to b and l can be applied until $K_{wall} = K_{req}$

Step6: check for torsional effects in both directions to promote the use of symmetrical plans, in terms of similar distribution of stiffness (Figure 2).

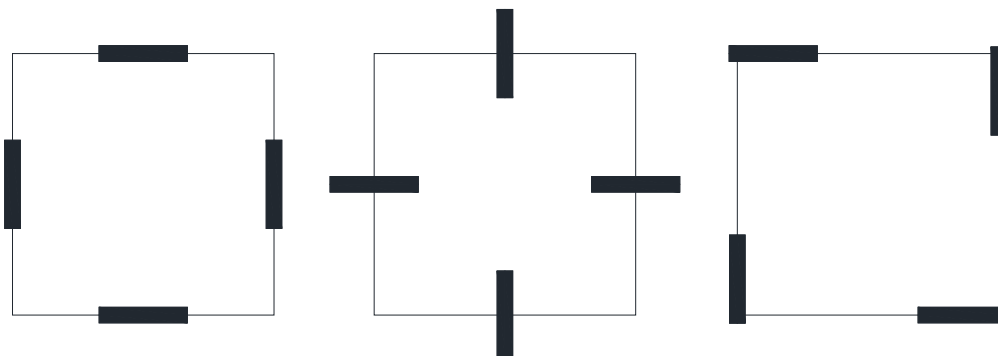


Figure 2: different schematic configurations with equal degree of strength in each direction, but different torsional behaviour.

4. ASSESSMENT

The new integrated architecture-seismic design method proposed here is assessed by a case study developed at the Faculty of Architecture, Ya ar University, in Izmir, Turkey. The studio is running by students of Architecture in their third year of studies, throughout an entire academic semester, with the assistance and guidance of a five-based team of instructors, among which there is one structural engineer. Students only possess a basic technical knowledge on statics and building systems, so that the required theoretical background –with strong emphasis in physical principles and strategies for seismic design- is resolved by running a technical course in parallel to the studio. Along the main goal of effectively achieving an integrated seismic-architectural process of design, the application of such integrated design strategies in the architecture of seismic-prone places, such as Turkey, is highly promoted with a double purpose: to reinforce the link between local identity and architectural expressions, and also, to raise awareness about the social responsibility of architects in the negative consequences associated with the occurrence of earthquakes, such as economic losses and extended reparation processes.

4.1 Case Study

The objective of the report is to obtain the dimension of moment frames of a modular building of a school. The school has curvilinear form. It is built with reinforced concrete and shear walls and moment frames are used. The school involves elementary school, eating space, gymnasium, studios and kindergarten. The selected section for the calculation of the stiffness of EQ-resistant elements is the kindergarten building, whose original design is displayed in Figure 3. The kindergarten includes watching area, eating area, kitchen, studio, toilets and sleeping area in ground floor and classroom, game room and corridor in first floor. The lower module is designed as a post-disaster accommodation area and meeting room so it should resist different levels of earthquake.

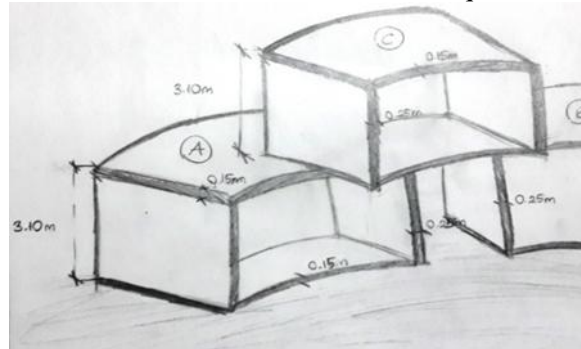


Figure 3: Original sketch of the selected section of the school-kindergarten building for the analysis.

The purpose of calculation is finding the required dimensions of structural elements for resisting three levels of seismic forces (average, large and severe). Such forces affect the building from both X and Y directions, so that both center of resistance (CoR) and center of mass (CoM) need to be assessed. As the building is laterally symmetric, only one half of the building is calculated (Figure 4). The question mark is to know if the assigned dimensions create stiffness larger than the required one: if so, the dimensions values are acceptable. The building composes two symmetrical modules in ground floor. The upper module is supported by the two modules. Only moment frames are used for the building. The process of calculation is summarized as follows:

Step 1: Live and dead load was calculated considering 400m² housing a school function, all structural elements including 16 columns in the upper floor, and airbrick non-structural walls, resulting in a seismic mass m equal to 3818.9 kN/g

Step 2: F_{EQ} for each earthquake level was calculated according to the seismic mass, thus F_{EQ-1} (average EQ) = 382 kN; F_{EQ-2} (large EQ) = 1146 kN; F_{EQ-3} (severe EQ) = 1910 kN;

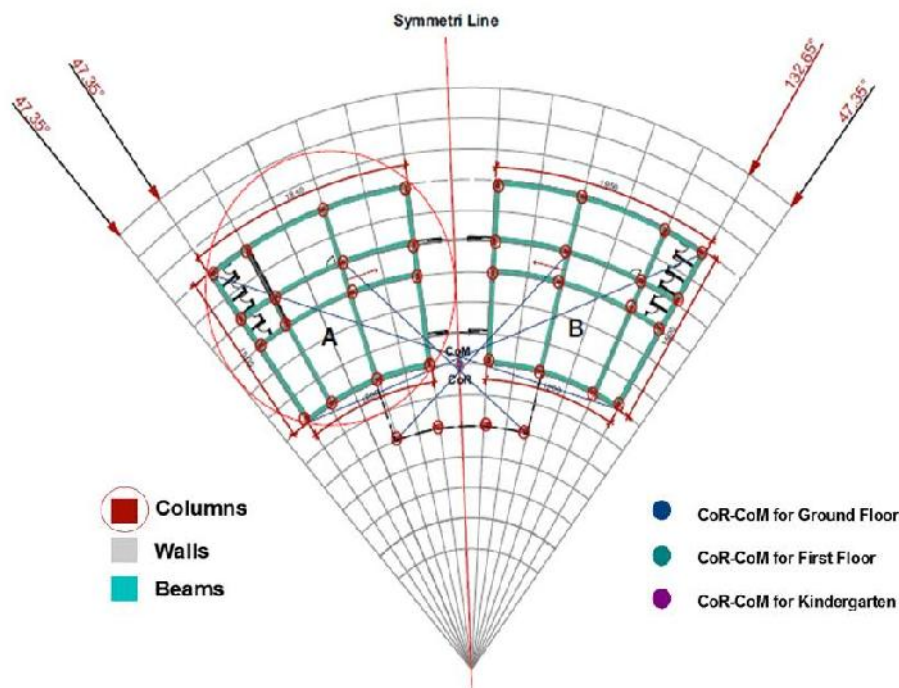


Figure 4: Ground floor plan of the kindergarten section of the school, displaying the elements considered in the analysis.

Step 3: Since the building comprises two different heights, both are considered in the analysis determining two target displacements as follows: $U_1 = 3.10/200$; $u_1 = 0.0155\text{m}$, and $u_2 = 6.20/200$; $u_2 = 0.031\text{m}$

Step 4: Since the building has a curvilinear form, the required stiffness was calculated by using trigonometric functions on the orthogonal results. The final results of the Step 5, only for the vertical axis (in reference to figure 4), are displayed in Table 2.

Table 2: Required width (b) and height (h) dimensions of the moment-frame columns for the EQ-resistant systems of the studied school module (ground floor).

Target u : 0.0015m	F_{EQ}	K_{Req-x}	K_{Req-y}	Width-b [m]	Height-h [m]
Average EQ-0.4g	1527.56	68986.57	59131.31	0.3	0.4
Large EQ-0.8g	3055.12	137973.15	1189262.70	0.3	0.5
Severe EQ-1.2g	4582.68	206959.73	177394.06	0.5	0.5

According to these calculations, dimensions of columns must be minimum 0.5m x0.5m for resisting all three levels of earthquake forces. Therefore, the final design considers the use of moment frames with columns with these dimensions, as it can be seen in Figure 4.



Figure 4: View of the kindergarten displaying only the final structural elements.

5. CONCLUSIONS AND FINAL REMARKS

While in practice engineers focus themselves on how to solve the seismic performance puzzle given by the architectural design, in teaching practice, architects can be taught to introduce the seismic requirements at the very moment to decide about the configuration of a building. Certainly a project of architecture that starts considering the seismic issues as design requirements just at this stage, still is doing a great deal for achieving an integrated architectural-seismic design, but is leaving out cultural aspects related with the exploration of a feeling of identity and pertaining to a place. A new method for integrating architectural-seismic design during the formation of architects has been presented for bridging this gap. The method proposed here has been initially tested by its application in an architectural studio, addressing the design of a school. Additionally it requires the assistance of parallel courses, previous knowledge, team-based work (discussion, ideally integrating engineers), and a cross-discipline team of instructors. The final architectural project has to observe the meeting of the basic objectives: respecting the urban position and location in the specific site; showing consistency between architectural concept and the logic of the earthquake resistant design; considering the importance of the building (as double-function program). Nevertheless, advanced and desirable objectives were observed as the students were able to apply different strategies in the design of the architecture of a building in accordance with the principles of seismic design. Moreover, students were able to assertively judge whether an architectural design can be considered earthquake-proof. Finally, besides the fact that more teaching experience using this method need to be collected in order to effectively assess its validity, future research can be promoted in terms of the application of energy-dissipation devices or base-isolation systems in the design of buildings as an integrated process of architectural-engineering design.

ACKNOWLEDGEMENTS

The author would like to thank Ezgi Celep and all the students from the Faculty of Architecture at Ya ar University, who took part in the setting of the method described in this paper.

REFERENCES

- Arnold, C. (1984). "Building configuration: The architecture of seismic design." *Earthquake Engineering*, 17(2).
- Charleston, A. (2008). *Seismic design for architects: outwitting the quake*, Routledge.
- Charleston, A., and Taylor, M. (2004). "Earthquake architecture explorations." *13th World Conference on Earthquake Engineering* Vancouver.

- Charleson, A. W. (1997). "Seismic design within architectural education." *Bulletin-New Zealand National Society for Earthquake Engineering*, 30, 46-50.
- Mitra, K., Ailawadi, S., and Rai, D. C. (2013). "Initiatives in Educating Future Architects in Earthquake Resistant Design Practices." *Seismological Research Letters*, 84(5), 820-828.
- Schulz, C. N. (1980). *Genius loci: Towards a Phenomenology of Architecture*.
- Slak, T., and Kilar, V. (2007). "Earthquake architecture as an expression of a stronger architectural identity in seismic areas." *Earthquake resistant engineering structures VI*. Ashurst, Southampton.