SEISMIC REGULATIONS VERSUS MODERN ARCHITECTURAL AND URBAN CONFIGURATIONS

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ABSTRACT :

Every time an earthquake affects a contemporary city, numerous lessons arise regarding the performance of modern buildings. Due to the devastating effects produced in modern cities by earthquakes, since the beginning of the 20th century earthquake engineering researchers all around the world obtained fast advances in the development of analytical knowledge on seismic building performance. However, lessons included in post-earthquake reconnaissance reports regarding the influence of architectural features on building seismic performance, seem just to be academic exercises. These lessons barely reach either architectural and city planning practice, or the decisions that city officials and politicians take that affect the vulnerability and resilience of cities in seismic zones. In general they aren't taken in consideration by architects, urban planners, politicians and city officials, and not even by many structural engineers, who continue including in the design of urban zoning regulations (UZR) the same modern building configurations categorized in seismic codes as "irregular". In the majority of contemporary cities, UZR encourage or in some cases enforce configurations long recognized by earthquake engineering as seismically vulnerable. It is not surprising that when an earthquake affects a contemporary city, buildings worst hit are precisely those with modern architectural configurations that are common all around the world. This paper presents a brief summary of a study on the origin and development of UZR during 20th Century and on the evolution of them in opposite direction with the development of seismic design and regulations.

KEYWORDS: seismic codes, modern architecture, building configurations, urban zoning regulations

1. ORIGIN OF CONTEMPORARY CITIES

The Industrial Revolution produced the rapid growth of cities and it was responsible for important changes in the patterns of living and working. During the second half of the 19th Century, most of the capitals and important cities of the Western industrialized countries underwent urban renovation following Baron Haussman urban planning concepts adopted in Paris. Most of these plans demolished existing medieval walls and old houses, opened new wide boulevards, "radial" avenues and squares. These plans organized the city layout according to geometric concepts. New urban regulations controlled total building height, adjacencies and alignments, in order to create the "urban street wall."

In parallel, the development in new building construction materials and technology was the base for the configuration of contemporary cities. At the end of the 19th Century, however, overcrowding, physical deterioration, absence of sanitation and complex socioeconomic factors produced extensive slums in the industrial or productive cities. At the beginning of the 20th century, modern architects and the new urban planners reacted against the messiness created in postindustrial cities where factories settled. They struggled to change urban regulations and traditional architecture in order to improve environmental conditions and provide decent and sanitary housing for the new urban inhabitants.

In 1928 in Europe, a group of these progressive architects and urban planners met in Switzerland, founded the Congrès Internationaux de l'Architecture Moderne, CIAM (International Congress of Modern Architecture) for promoting social justice and discussing and establishing concepts and prescriptions regarding modern architecture and urban planning. The Athens Charter, published in 1943, set out guidelines for urban development that recommended simple, clear urban planning patterns. The premise on this document were interpreted by architects, city planners, officers and politicians as the non-contextualized model guide for "The city of the future" and the features that represented progress. The Modern Movement generalized the concept of single building conceived as an isolate unit. Up to then in the traditional city, single buildings represented mostly important public and private institutions, churches, palaces and other. Modern movement decentralized cities by setting up self-sufficient garden residential suburbs, while leaving downtowns for financial and commercial activities. In traditional downtowns, based on the *laisser faire* (let's each one doing what she/he wants to do), corporative and new modern commercial buildings disrupt the homogenous urban street wall turning downtowns into a heterogeneous "collage" of traditional and modern single buildings.

2. ORIGINS OF MODERN ARCHITECTURE

At the end of the 19th Century, the collective response of a diverse group of architects to the reconstruction of Chicago following a disastrous fire in 1871, in combination with the advances in the USA in the production of steel frame structures and long span glass, triggered the construction of the first skyscrapers. In Europe, the use of concrete as a structural component developed parallel to iron and steel technology.

In 1892 in France, engineer F. Hennebique developed a new structural system "the Trabeated" and demonstrated the strengths of concrete reinforced with steel rods. This new material made possible structures that created the bases for the development of the new modern architecture. Brick, mortar, stone and wood were left behind. Belgian architect-engineer Auguste Perret experimented the Trabeated system in 1903, in the first reinforced concrete (RC) building on 25 bis Rue Franklin, Paris. On this eight-story high apartment building, Perret clearly separated the RC frame structure that supported the entire load and provided large clear spans between columns from the exterior walls, which only function was to separate the interior space from the exterior. This structural system also allowed a *free floor plan* since interior partitions did not support any weight.

In 1914, Swiss-French architect Le Corbusier (LC), developed the *Domino System* for economic housing, characterized by: standardization of building components, repetition of model building, industrial organization for the production of components, elemental RC frame structural system constitute by slender columns, named *pilotis*, and flat solid slab that covered long spans between columns without girders. The gravity load-bearing structure consists of RC solid slabs (cast in place or precast), transferring the gravity loads to the columns and finally to the footings. The features of this model housing constitute an early example of what later were the bases of modern architecture, known as the famous *five points towards a modern architecture*. LC applied those ideas in the model of house *Citrohan 2* and made them real in 1925 with the construction in Paris of the *Pavillon de l'Esprit Nouveau*, later reconstructed in Bologna, Italy. In 1919, German architect Walter Gropius founded the *Bauhaus*, German School of Architecture and Applied Arts. In 1925, Gropius designed the *Bauhaus building* in Dessau, Germany, constituted by various volumes joint in an asymmetrical U-shape floor plan, with an open first story (soft story) and strip windows that became a symbol of modern architecture.

The features of Dominó system and Bauhaus building constituted the bases of modern architecture, that are contained in LC's famous *five points towards a modern architecture* published in 1926, described in Figure 1.

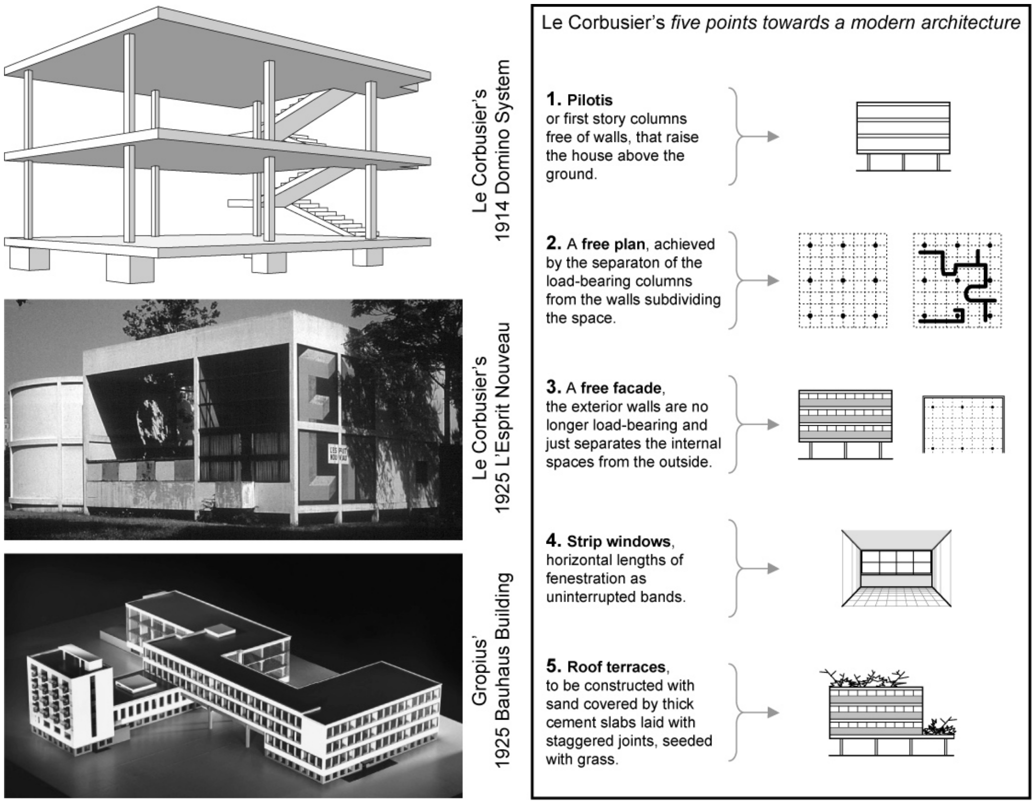


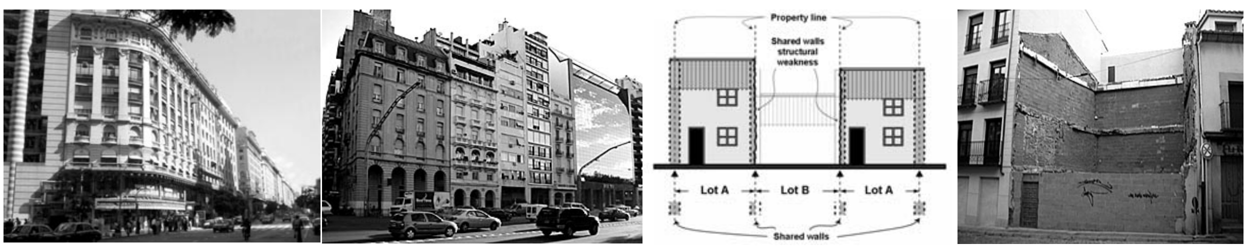
Figure 1 Origins of Modern Architecture

During the 1930s, many European architects and urban planners, followers of the Modern Movement, and Bauhaus faculty members, run fled away from European dictatorships and after, from the II World War, to the USA and to other countries in the American Continent and colonies of the European countries. As a result, the Modern Movement ideas and teaching strategies spread quickly around the world. LC was especially successful in obtaining followers and locating buildings in Iberoamerica, French colonies and, at that time, the recently independent India. Even Japan, after World War II (1939-1945), wanted to show that they were incorporating to the Western idea of "progress" symbolized by modern corporative buildings. During the second half of 20th Century, frame structures and modern building configurations surpassed Japanese construction traditions. The term *International Style* came to refer generally to modern European architecture of the 1920s and 1930s, and the later modern architecture patterns that spread very fast all around the world, originating the present configuration of contemporary cities. In the 1940´s Mies van der Rohe one of the pioneers of Architectural Modern Movement and later of the International Style, designed some of the first famous modernist buildings in Chicago, combining new modern materials and construction technology.

3. SEISMIC EFFECTS IN SOME RC BUILDING CONFIGURATION IRREGULARITIES ENCOURAGED BY URBAN ZONING REGULATIONS

Urban zoning regulations or ordinances are instruments by which municipalities are organized. The main objective of them is to regulate use of land in a way beneficial to its inhabitants, and also efficient for commercial and governmental organizations. The following paragraphs briefly describe some examples of how UZR in most of contemporary cities frequently encourage the use of those building configurations by giving reward or *premium* for other community-oriented benefits, and sometimes enforce them.

The *urban street wall* configuration is constituted by buildings that are adjacent to each other in each block and their main façade aligned parallel to the street line as one continuous building along the street edge. Some examples are illustrated in Figure 2. Its origin comes from 19th Century, when important cities of the Western industrialized countries underwent urban renovation as in Figure 2A. Downtown renovation included the simultaneous construction of adjacent buildings by blocks, sharing the property-line walls, with the same height and using similar construction materials and techniques. With the endorsement of modern movement *single building* and *laisser faire* doctrine, UZR relaxed as in Figure 2B. Each building incorporates in the existing block as a single unit. Structural models of these buildings are based on the premise that it is an isolated unit. However, several problems arise if neighboring buildings are not taken in consideration. If neighboring buildings load resisting system consists of shared walls, special care has to be taken not to weaken the lateral force strength of those buildings, and take in consideration the effects that those existing structures can produce in the new one, and the new one on the existing ones (Figures 2C and 2D). If the neighboring buildings are modern, other type of problems can be present. Special care should take on both buildings foundation interaction.



A B C D

Figure 2 Urban street wall and shared wall problem

Pounding between adjacent buildings due to inter-story drift can occur: (a) When adjacent buildings have different period of vibration, each building moves in a different direction at the same time, and they can crash into each other; (b) When each adjacent building has different inter-story height the crashing of slabs of one into vertical components of the other can produce serious damages and even building collapse.

Other problem between adjacent buildings without seismic joint is the partial immobilization of lower stories of a tall building by lower adjacent buildings that can produce damage in the transition zones between the lower stiffened stories and the free flexible portion as illustrated in Figure 3.

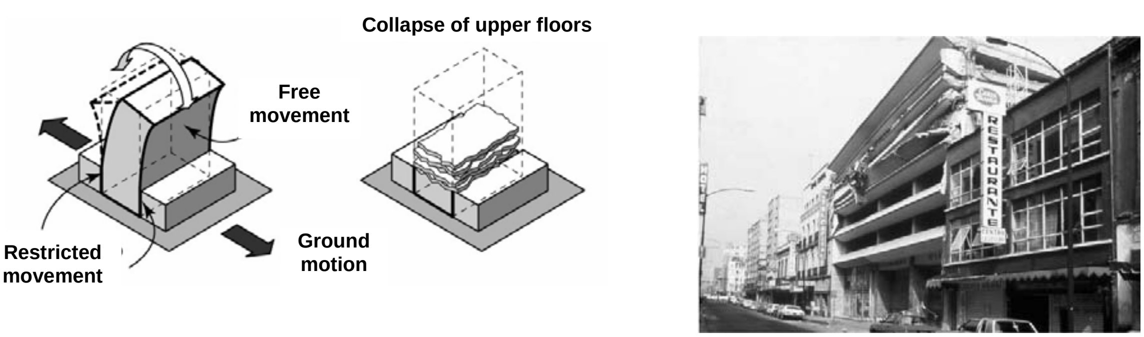


Figure 3 Partial immobilization of lower stories

As shown in Figure 4, in corner buildings torsional irregularities can be present due to irregular distribution of rigidity; if floor plan is rectangular, two open façades to the streets and two “blind façades” stiffer than the other two, can produce eccentricity and rotation on horizontal components, that in turn can produce pounding effects in adjacent buildings; If floor plan is triangular (non-parallel systems irregularity), not only eccentricity but, if the building is tall, overturning effects could occur.

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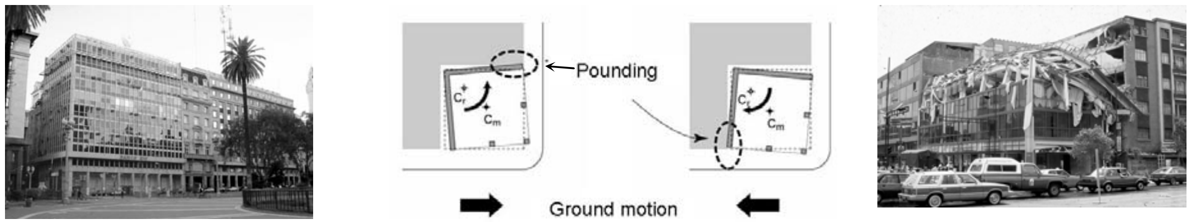

Figure 4 Corner buildings

UZR incorporated *Setback* regulations since the *N.Y. City 1916 Zoning Resolution* that established height and setback controls when the city became the financial center of USA and the massive construction of tall buildings started depriving neighboring properties of light and air. Figure 5 shows examples of different types of setback configurations: (a) stepped and (b) two or three-story solid street fronting base and setback towers. These configurations could produce the following: out-of-plane offsets; stiffness irregularity; weight (mass) irregularity; vertical geometric irregularity; in-plane discontinuity in vertical lateral force resisting elements.

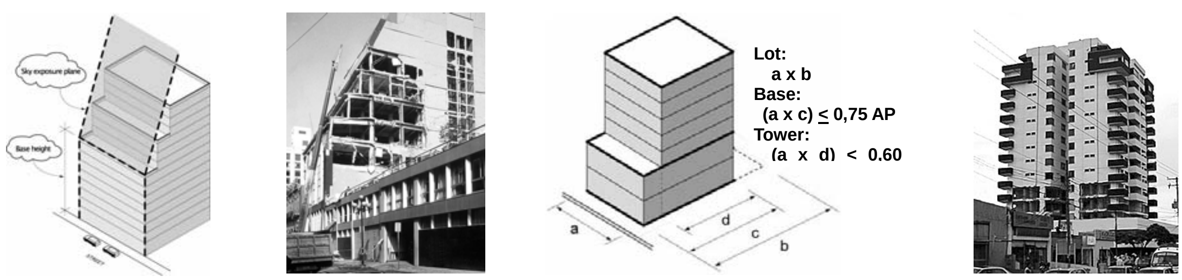

Figure 5 Setbacks

5. MODERN ARCHITECTURAL CONFIGURATION IN SEISMIC BUILDING REGULATIONS

From the beginning of the 20th Century, researchers that studied the effects of earthquakes in structures recognized that there exists an evident relationship between the modern architectural configurations and the seismic performance of buildings. In the majority of building codes that are in force at present one of the most important factors that have to be considered for deciding the analysis procedure to be used for the RC building structure design, is the evaluation of the building level of irregularity in plan and in elevation. At present most seismic codes include special requirements and penalties for the analysis of buildings with irregular configurations.

After the Kanto Earthquake in Japan in 1923 that produced great destruction in Tokyo and Yokohama, the new modern technologies in RC and steel were evaluated. Dr. Naito, Professor of Architecture at Waseda University in Tokyo, was one of Japanese architects and engineers who had studied before that earthquake the effects of ground motion on new RC and steel frame structures. R. Reitherman (2006) quotes that “H. M. Engle, one of the most influential American earthquake engineers of the time, noted for example that «the three buildings in Tokyo specifically designed by Dr. Naito to be earthquake resistant actually fulfilled their function in 1923, while many other large structures designed more along customary American lines were subject to very serious damage in many cases in the shock of 1923» [Engle 1929, p. 89].” Engle also stated that Naito «after 1923 made available to engineers in this country [USA] the details and design of some of those buildings that he designed before 1923 and which survived the shock so successfully» [Engle 1956, p. 39-5].” On relation with architectural configurations, G. Berg (1982) mentions “Dr. Naito proposed four fundamental principles of earthquake resistant design: First, a building should be designed to act as much like a rigid solid body as conditions would permit. To this end, structural members should be rigidly connected and generously braced.

Dr. Naito saw this as a way to keep building periods short and thereby prevent resonance with ground motion. Second, a closed plan layout should be used; that is, the plan shape of the building should be a complete closed rectangle rather than a U, L, T, or H shape. Third, rigid walls should be used abundantly and disposed symmetrically in plan, and they should be continuous over the height of the building. Fourth, lateral forces should be allocated to the bents of the building in accordance with their rigidities. He developed a modified portal method of frame analysis that would permit rapid and reasonably accurate analysis of a bent to determine its rigidity. However, the postulates of CIAM were spreading all around the world as the new paradigm that represented the model guide for “The city of the future” and the features that represented progress.

Arnold and Reitherman (1982) comment that until 1973 the Uniform Building Code (UBC) didn’t include any seismic regulation or recommendation for irregular configurations. In the 1970’s, due to the destructive effects produced by recent earthquakes in modern buildings (Anchorage, 1964; Caracas, 1967; San Fernando, 1971; Managua, 1972; Guatemala City, 1976; Imperial Valley, 1979), a group of architects in California participated in significant studies with earthquake engineers, to promote the inclusion in seismic codes of some special recommendations for the design and construction of building with modern architectural configuration. Also several articles and books were published with recommendations for architectural design in seismic zones.

However, until 1974 building codes didn’t include special provisions for buildings with irregular configurations. In 1975 SEAOC included in the *in Recommended Lateral Force Requirements and Commentary* of the *Blue Book 1974* twenty examples of irregularities that had to use dynamic analysis methods instead of the traditional equivalent static force method and recommended them to be included in the next version of UBC. They weren´t. In 1978 SEAOC published the *ATC-3-06: Tentative Provisions for the Development of Seismic Regulations for Buildings* that included a section on *Building Configuration* with a series of drawings that was supposed to be included in the 1979 UBC.

At last, after the Mexico earthquake of 1985, the 1988 UBC edition included two tables defining some parameters for the identification of “irregular” configurations, in plan and elevation. Since then many recent seismic codes like the versions of the International Building Code (IBC), and many other around the world include special provisions for the analysis of buildings with the following configurations:

Plan: torsional irregularity; extreme torsional irregularity; re-entrant corners; diaphragm discontinuity; out-of-plane offsets; non-parallel systems. **Vertical**: stiffness irregularity – soft story; stiffness irregularity – extreme soft story; weight (mass) irregularity; vertical geometric irregularity; in-plane discontinuity in vertical lateral-force resisting elements; discontinuity in capacity – weak story.

The Colombian requirements for earthquake resistant design (Normas colombianas de diseño y construcción sismo resistente NSR-98) include even graphics for identifying those irregularities. Recently two new types of irregularities were included: extreme torsional irregularity and extreme soft story.

Figure 6 illustrates: the origin of Modern Architecture and of UZR in contemporary cities; some examples of modern building irregular configurations and the effects of ground motion on them; and, as consequence, the development during the 20th Century of earthquake engineering and of seismic provisions for the design and construction of RC earthquake-resistant buildings.

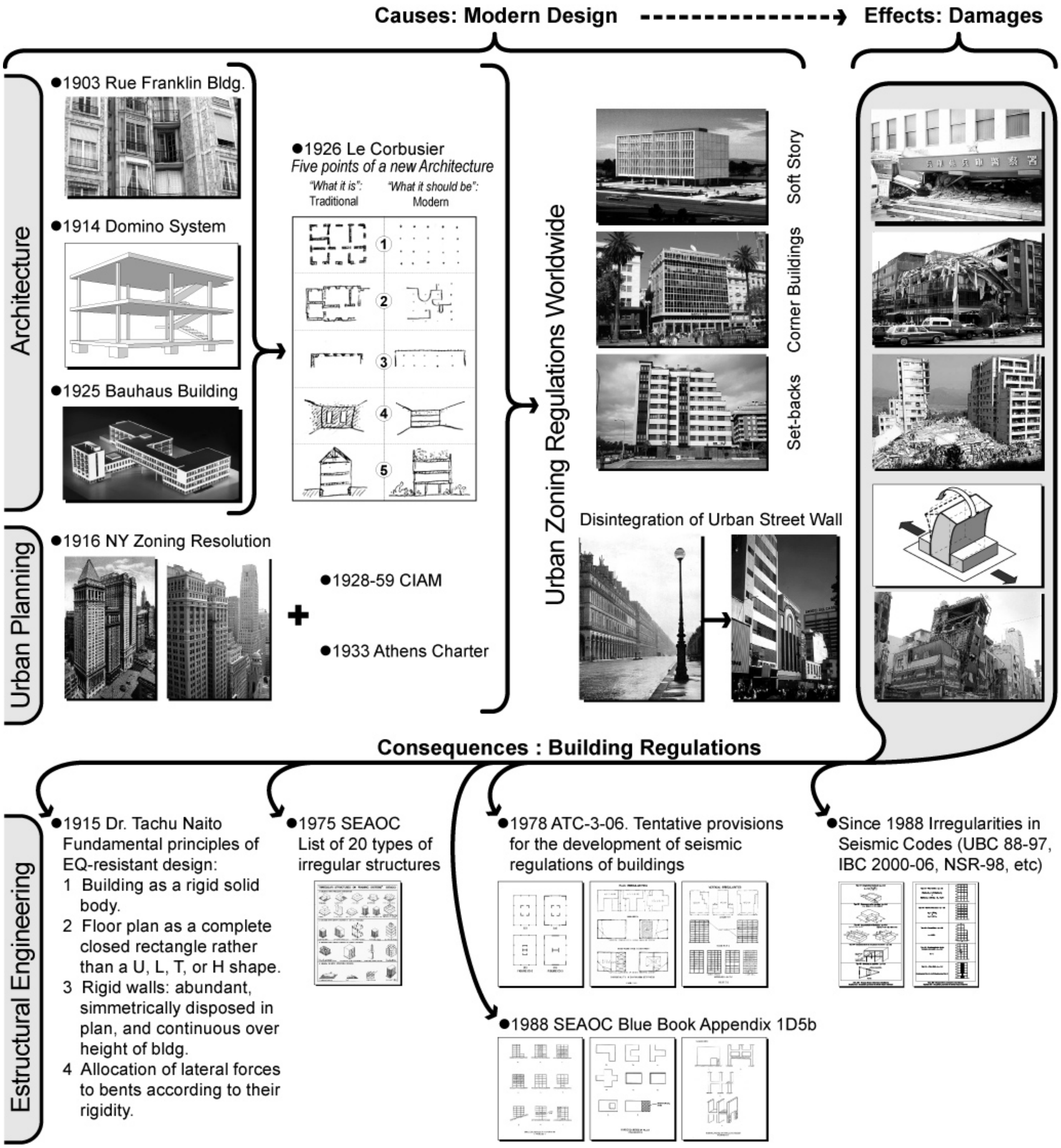

Figure 6 Causes, effects and consequences of Modern Architecture in seismic zones

CONCLUSIONS

1. Reconnaissance reports, usually published shortly after each earthquake strikes, describe common failures in buildings with those configurations identified in building codes as non-recommendable in seismic zones.
2. From the beginning of the 20th Century structural engineering researchers recognized that there exists an evident relationship between certain architectural configurations and the seismic performance of buildings. Meanwhile in non-seismic countries of Europe architects, urban designers and city planners originated a new architectural and city planning paradigm that guided the evolution of contemporary cities all around the world on the opposite direction. UZR that follow modern architecture patterns, enforced in the majority of contemporary cities located in seismic zones, promote and in some cases force the use of building configurations considered in seismic codes as non-recommendable.
3. Most architects, city planners and urban designers as well as city decision makers, unknowledgeable of the previous asseveration, have considered, since seismic codes come out, that the mitigation of urban seismic vulnerability is an exclusive responsibility of structural engineers. Some structural engineers do too…
4. It has not been, it is not and it will never be sufficient to apply seismic building codes!!! It is necessary to not only develop and bring about a multidimensional and interdisciplinary approach, but also transdisciplinary. This approach must include not only the participation of earthquake engineers, architects, city planners, and other professionals but also the active participation of city officials and decision makers.
5. At present seismic resilience of contemporary cities, depends mainly on the application of seismic codes to single buildings, as independent units and not as components of the city system. Contemporary cities in seismic zones are not an addition of single buildings; each of them is a system constituted by interrelated components, and buildings are probably the most important components. Damages in one building due to earthquake effects may, not just affect the people who are inside, but people passing by, the neighboring buildings and the surrounding environment, producing chaos in the city.
6. It is necessary to inform and instruct these professionals on the consequences of their urban planning and architectural decisions, since they share with structural engineers the great responsibility in mitigating seismic risk and in reaching seismic resilience in contemporary cities.
7. It is essential to convince city officials, urban planners and decision takers of the urgent necessity of revising and changing actual UZR. UZR in cities located in seismic zones must avoid promoting and enforcing the use of building configurations that seismic codes consider as non-recommendable. They must include also special descriptions and prescriptions for the design and construction of new buildings and the remodeling of existing ones.
8. It is necessary in seismic zones to teach conceptual knowledge on the influence of architectural configuration on building seismic performance instead of exclusive analytical procedures, in undergraduate and graduate courses in architecture, city planning and structural engineering.

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