# SIMPLIFIED RANKING SYSTEM FOR RECOGNITION AND EVALUATION OF EARTHQUAKE ARCHITECTURE

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**ABSTRACT :**

From the definition of the term “earthquake architecture” in the paper is developed a simplified evaluation method to determine level of the earthquake logic from the structural as well as from the architectural point of view for buildings located in seismic areas. The paper also purposes some evaluating criteria based on simple structural and architectural parameter ranking system to better identify earthquake architecture which might be considered as the intersection of design principles in architecture and earthquake engineering. The intensity of relations between the two fields is further divided into different levels. Parameters of the proposed simplified ranking system compose two major groups:

- parameters related to building structure and earthquake engineering and
- parameters related to architecture and architectural expression echo through the prism of earthquake resistance.

The waste diversity of parameters and difficulties to make an objective and unified quantitative judgment, present the complexity and essence of the earthquake architecture. With such an evaluation method it is possible to classify earthquake architecture in different levels of intensity which is presented with the given examples. The purpose of the paper is to encourage the development of new principles and forms of architectural design in seismic areas. We would like to include the architect more active in the seismic resistance design since technology, codes and cooperation with earthquake engineers are not the only or satisfactory solutions for appropriate culturally respectful design of buildings in earthquake prone areas. The paper opens discussion about the possibilities of architectural response to the earthquake threat.

**KEYWORDS:** earthquake architecture, architecture, structures in architecture, earthquake resistant design, seismic architecture.

## 1. INTRODUCTION

Earthquake architecture refers to a particular type of architecture which arises in earthquake prone areas, as a response to the requirements of earthquake engineering and is a consequence of combining earthquake engineering and architecture. The realization of a building without a suitable earthquake resistant structure is not possible today, however, it is possible to design a building in such a way that earthquake resistance is not expressed and structural influence on architecture is minimal. In such cases we can speak of *concealed* ways of earthquake resistance of a building. On the other hand, architecture can respond in the concept itself, i.e. in two ways: *effectively,* with increased horizontal stiffness of a building or (in addition to that) *symbolically*, with metaphorical changes in design. Earthquake architecture is the "missing link" between earthquake engineering and architecture. It combines the best of both fields and establishes a new approach and quality in construction in earthquake prone areas, mainly in compliance with measures of architectural excellence.

The complex requirements of earthquake engineering directly influence the architectural composition and concepts in architecture, thus detailed examination of influences is the basis for any architectural activity in seismic areas. The modern methods for increasing earthquake resistance of buildings are based on the seismic codes, as well as on the usage of passive and/or active systems for damping and dissipation of earthquake energy. According to [Mezzi et al, 2004] they enable a freer building design and more flexible solutions in architectural design in earthquake prone areas. It has been noted that, by introducing more and more detailed standards and regulations, the principles of earthquake resistant design are becoming important determining factors of architectural design in earthquake prone areas. It seems reasonable to believe that architecture should always be local, i.e. designed in accordance with micro-location features of the site, and that it should in some way respond to the earthquake threat. Adjustment to the earthquake resistant construction requirements is often regarded as pressure on artistic freedom and a limitation in following trends coming from the areas of the developed world not prone to earthquakes. But the problem in question is not the limitations, but rather lack of knowledge and inability to develop a particular and, within frameworks of earthquake resistant construction, inventive architecture.

<u>Our hypothesis is that, at the contemporary time, in searching for a new, particular expression in architecture, the response of architecture to earthquake threats can present an important source of stronger architectural identity typical of earthquake prone regions.</u> In the paper the hypothesis is supported by proposal of the simplified evaluation method of the earthquake architecture with aim to increase the architect's response to the earthquakes and to decrease the areas of possible conflicts and constraints.

## 2. CONCEPTS OF MODERN EARTHQUAKE RESISTANT DESIGN AND CONCEPTS OF ARCHITECTURAL COMPOSITION AND DESIGN

When designing a building in a seismic area, we have to comply with the regulations and recommendations given in building standards and codes. These demands have a decisive influence on the design of structural system of the object, which in turn interferes with the architectural concept. Earthquake engineering has developed a variety of ways for increasing earthquake resistance of buildings, which present different concepts of building protection in line with generally established design philosophy in earthquake prone areas. Roughly, the ways of achieving suitable earthquake resistance of a building can be divided into the following four groups: A) tectonic construction (regularity, symmetry, height limitation, etc.), B) basic protection according to regulations (modern earthquake resistant construction, required combination of strength and ductility), C) passive protection (base isolation, energy dissipation systems), D) active protection (base isolation + semi-active and active damping systems) and developing systems.

On the other hand architectural composition and concepts have not changed much from antique, when first architectural theorist Vitruvius determined architecture by structure (firmitas), usefulness (utilitas) and aesthetics (venustas). Studying the architectural theory, we find these postulates in various forms throughout all history and it seems they have remained unchanged from their formation until today. Despite the differences in interpretation, none of the more serious definitions questions the status of architecture as art. The work of an architect has the characteristics of a cultural act and artistic achievement. With the development of architectural theory, the previously mentioned postulates have been complemented by numerous other detailed starting points and subdivisions, among which we most frequently come across spatial (urban) aspects, which are actually a matter of context. Architectural concepts, which arise through evaluation and ethics, are nowadays determined also by: location and urbanisation of the environment, the morphology of a building and its surroundings, context, the significance of an building with regard to purpose and/or importance, historical determination, building typology, the concept of architectural design, the elements of architectural design, the harmony of composition (ratios, relations) and other starting points, about which an architects forms an opinion, assesses the existing situation and carries out architectural intervention in the space. In doing so, the architect takes full responsibility for the space, which can be upgraded, neutralized, or deformed etc. by his intervention.

Thus architecture is not an idealised form, but a consequence of starting points offered by the site, when it is evaluated, read and analysed in the process of creation, and which, after all, represents the prevailing category for determining architecture. Structure and in our case earthquake design of a building is the necessity which ensures safety and stability of a building. Modern construction and earthquake engineering enables much more than in the past; therefore the need for architectural freedom has increased as well, and should be more accessible with the help of technology. Architecture is perceived in different ways. It comprises the visual aspects of a building in space and the abstract perception of architecture not visible to the eye, but which can be comprehended through the use and sensual perception of the building. Regarding visual effects, the earthquake resistant load bearing structure can be emphasised or hidden and concealed. In his article A post-biblical view Lebbeus Woods clearly emphasises the importance of adequate construction in seismic areas: "Earthquakes as natural event are not inherently catastrophic. Destruction is not the 'fault' of earthquakes, but rather of the buildings, which, even in the regions regularly visited by earthquake, are not designed to work harmoniously with the violent forces periodically released." [Woods in: Garcia, 2000]. It is this ability to harmonize the actual (structural) and architectural (aesthetic) response to earthquake forces which we ought to be searching for and appreciate in assessment.

## 3. EARTHQUAKE ARCHITECTURE

### *3.1. Definition*

The phrase earthquake architecture was first introduced in the paper "Earthquake Engineering and Earthquake architecture" by Bob K. Reithermann in 1985. [Reitherman, 1985]. C. Arnold uses the phrase earthquake architecture to describe a degree of architectural expression of some aspect of earthquake action or resistance [Arnold, 1996]. The breadth of expressive possibilities ranges from metaphorical (only visually expressed) to the more straightforward exposure of used seismic technology.

Earthquake architecture can be defined as any visual or conceptual inter-connection between the concepts of earthquake engineeringand concepts of architecture. The inclusion of the requirements of earthquake resistant design in the process of creating and conceptualizing the architecture of a real building can be based on visual or conceptual level. Looking at it visually, we can speak of *hidden and concealed* ways of earthquake resistant architecture on the one hand, and *revealed* or *emphasised* on the other. From the conceptual point of view, earthquake architecture is realized only by including the principles of earthquake engineering in the architectural concept itself, and in this way we achieve the highest level of cooperation through identification, where architecture is based entirely on the principles of earthquake engineering. Strategies for realizing the vision of a more widely accepted earthquake architectural approach inevitably depend on architects. Structural engineers need to be the catalysts for the vision to be caught and progressed [Charleson et al, 2001].

Seismo-logical architecture represents a special approach to the architectural design where the main source of inspiration comes from the earthquake engineering and where the specific local tectonic activity became a generator for designing the architecture. Earthquake architecture is any response of the architect to the earthquake threat through the creative architectural transformation. It embraces the visual effects of seismic design on the architecture, usage of earthquake engineering technology, which helps to enrich aesthetic expression of the building, as well as decision to use the principles of the seismic design as the main architectural motive. One of the results of our research is that seismo-logical architecture could become an important way to design buildings in the earthquake prone areas.

### *3.2. Identification and evaluation of earthquake architecture*

Criteria for the recognition and evaluation of the earthquake architecture should be based on the definition of earthquake architecture itself. As defined in chapter 3.1, it interconnects earthquake resistance with architectural-symbolical response and integration in space. The earthquake architecture is meaningful only in earthquake prone areas with certain seismic activity ($a_g \geq 0{,}1g$). In our research study we decided to develop a simplified ranking system (grades from 1 to 10) where 1 means lowest and 10 means the highest possible expression (or assurance) of certain structural or architectural evaluation parameter.

Evaluation parameters can be estimated either from conceptual (sometimes concealed characteristics that can be determined only from buildings plans and concepts) or from visual (visible exterior and interior characteristics) or from combination of both. Suggested approach embraces most of the aspects of the earthquake architecture and demands the knowledge about numerous parameters of the building that can be divided into two basic groups:

- S) Parameters related to building structure and earthquake engineering
- A) Parameters related to architecture and architectural expression echo of the building through the prism of earthquake resistance.

Proposed structural parameters (S) to be evaluated in relation to requirements of earthquake engineering and used technology are as follows:

- S1) Level of **seismic risk** ($a_g$ according to the seismic map).
- S2) Building **importance** (according to the used design codes, i.e. EC8).
- S3) Used **design code** and its capability to include contemporary knowledge – year of building completion in relation to pertinent building code.
- S4) Overall **solution quality.**
- S5) Building layout and its **regularity** in plan and elevation.
- S6) Prevailing **material** of structural system.
- S7) **Structural system** in general and its capability to resist seismic forces.
- S8) **Floor diaphragms** and their capability act monolithically and to distribute seismic load to vertical load-resisting elements.
- S9) **Vertical** seismic load-resisting **structural elements** and their capability to distribute horizontal forces into foundations.
- S10) **Foundations** and their capability to transfer seismic loads into the ground.
- S11) **Quality of details** according to demands of earthquake building codes.
- S12) **Non-structural elements** and their capability to not interfere with load resisting elements.
- S13) **Modern technological systems** and their capability to reduce seismic forces.
- S14) **Realization** possibilities and economically **justifiable price** of earthquake resistant building structures and systems.

On the other hand, the proposed architectural parameters (A) to be evaluated in relation to architectural/symbolic response to the earthquake hazard are as follows:

- A1) Urban position and particularities of the **location** of the building (“genius loci”).
- A2) Building **importance** from the architectural and/or cultural point of view.
- A3) **Contemporaneousness**, progressiveness and avant-garde of architectural design.
- A4) **Artistic expression** of the architectural concept (general impression of the building).
- A5) Level of the **symbolic (metaphoric) response** to the earthquakes.

A6) Consistence of the general **architectural concept and** its connection to the major **logic of earthquake resistant design.**
A7) **Architectural expression and** its relation to **earthquake engineering** (negation, provocation, confrontation, ignorance, cooperation, identification).
A8) Reasonable **building morphology** and its general **suitability** to earthquake prone areas (composition, forms, geometry, proportions…).
A9) Level of the architectural expression of earthquake resisting structure **in the exterior** architecture of the building (level of the landscape/urban identity).
A10) Level of the architectural expression of earthquake resisting structure **in the interior** architecture of the building (level of the interior design identity).
A11) Level of the architectural expression of earthquake resisting structural **details** in the architecture of the building structure.
A12) **Functionality**, rational use of space and living quality related to earthquake resistant structural system.
A13) Level of the architectural expression **of modern technological systems**.
A14) **Realization** possibilities and **economy** of architectural solution.

For the practical application of listed parameters a more detailed formulations and explanations are needed. They will be prepared in our further research and presented in our next publications. The waste diversity of listed parameters and difficulties to make an objective and unified quantitative judgment, present the complexity and essence of the earthquake architecture. Some of the parameters (S7 to S10 and A6 to A10) are with no doubt more important than others. We might say that they represent the main core of the evaluation – they might be also considered as exclusive, meaning that their negative ranking immediately result in overall negative evaluation result. Figure 1 shows the results of the ranking system for imaginary building with different levels of earthquake architecture. The left side of the diagram shows the structural parameters, while the right side shows the architectural parameters. Dashed lines show average values. It can be seen that structural system of the building has high level of the earthquake logic. On the other hand architectural response is ranked much worse and it seems it ignores seismic reality. Although that kind of building assures suitable earthquake safety, it does not react on the earthquake in appropriate architectural way.

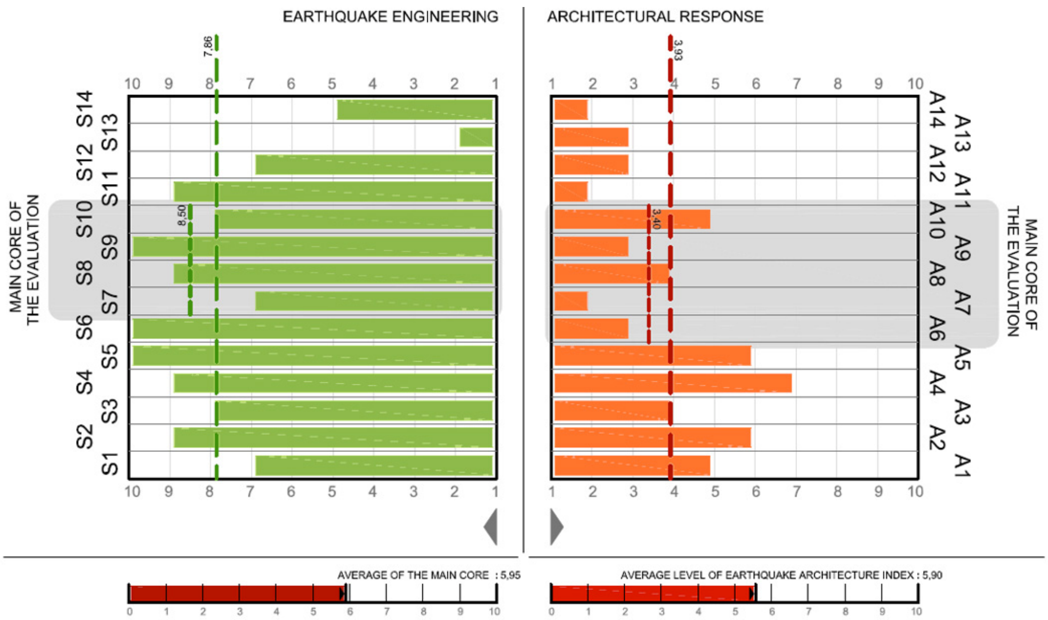


Figure 1 Example of the graphical representation of the simple ranking system for evaluation and identification of earthquake architecture. Structural (S1-S14) and architectural (A1-A14) parameters and their average values show the level of earthquake architecture

With such an evaluation method it is possible to classify earthquake architecture in different levels of intensity. Independent from criteria included in the evaluation method is evident that bigger score means higher level of the earthquake architecture. For the purpose of this paper we could rank earthquake architecture in the following levels of intensity.

### *3.3. Levels of Earthquake Architecture (intensity levels)*

In the present paper, which presents the first steps of our research, we decided to analyze four interconnection levels between earthquake engineering and architecture (0,1,2 and 3), whereas "level zero" represent negation or negative side of earthquake architecture (so called anti- or non-earthquake architecture):

Level 0: Architecture negates or ignores requirements of the earthquake reality;
Level 1: Earthquake resistance as a concept is inferior to architecture;
Level 2: Concepts of architecture and earthquake engineering are complementary;
Level 3: Earthquake resistant structure identifies architecture.

We have noted that there is not much earthquake architecture in earthquake prone areas. We can claim that a large number of buildings do not show architectural, i.e. visible or conceptual characteristics of earthquake architecture, or they use merely hidden ways of earthquake safe construction and earthquake engineering technology. In these cases the possibility of using earthquake architecture as a form of expression thus remains unrealized potential.

### *3.4. Examples of Earthquake Architecture (groups according to the intensity levels)*

The three assumed levels of including earthquake engineering in architecture can be supported with the following examples.

*3.4.1. Level 0: Architecture negates requirements of the earthquake reality*
A negative side of earthquake architecture called "anti-" or "non-earthquake" architecture. In this case the visual and abstract in architecture is achieved by contradicting earthquake reality, which negates (confrontation) or ignores (indifference) the requirements of earthquake design. At the worst, architecture can defy the rules of earthquake resistant construction with intentional mistakes in design. This negative side represents the conflict in the relationship between earthquake engineering and architecture, thus also within earthquake architecture itself. In this case legislation is the only guarantee that "anti-earthquake" architecture cannot be realised to the full extent in practice (Figure 2).


Figure 2 Structures adapted to the requirements of architecture and in confrontation with seismic design: a building without vertical regularity and with "soft storeys"

*3.4.2. Level 1: Earthquake resistance as a concept is inferior to architecture*
The expressiveness of architecture is above structure, which as an inferior partner mainly provides safety and serves the architectural concept, which actually does not originate in earthquake design. An already

conceptualized building, sometimes together with the structure, seeks confirmation in earthquake engineering and adapts minimally to the requirements of earthquake safety in further procedures. Advanced technologies can be used, structure is hidden behind facades and majority details are hidden. Two such examples are shown in Figure 3. Architecture achieves a high level of autonomy, sometimes at the expense of earthquake resistance of a structure. The influence of structure on architecture is thus minimal and mostly has an inferior role.


Figure 3 Structure adapted to the requirements of architecture. The structure of a museum in Bilbao simply follows the architectural idea which is completely formalistic and artistic. In the end, the entire structure is covered with façade (left). The same example on business building in Ljubljana (right)

*3.4.3. Level 2: Concepts of architecture and earthquake engineering are complementary*

Structure design is expressed and visible in the facades of buildings and the interior. Structure design is one of the motives of architecture and is also a logical consequence of building design. In this instance a high level of cooperation of both fields and mutual understanding are needed. The influence on architecture can be substantial; however, it can also be almost invisible or minimal, if it means the integration of structure into architectural design. A few examples where the cooperation between architecture and earthquake engineering was one of the guides in architecture design are presented in Figure 4.


Figure 4 Example of cooperation between architecture and earthquake engineering: Manantiales building, Chile (left), Wool House in Wellington (middle) and tectonic (trapezoidal) shape of Hancock Building in Chicago with visible bracings over the facade (right)

*3.4.4. Level 3: Earthquake resistant structure identifies the architecture*

This level is based on using structure as the exclusive aesthetic norm, i.e. structure is the only articulated form which determines architecture. This principle could be named (earthquake resistant) structure as architecture and enables a high intensity of development in both earthquake engineering and architecture [Lyall, 2002]. It is hardly possible to speak of influence on architecture, since this level is all about structure which is architecture (Figure 5). The author can be an engineer who uses structural design to also give a building its final form, or an architect with detailed knowledge of earthquake engineering, materials and structures.

Concepts of earthquake protections in contemporary architecture also derive from ideas of bionics applicable to engineering and architecture. One of the most powerful tools nature has at its disposal to solve resistance problems in live organisms is force microfragmentation [Pioz in: Garcia, 2000]. The shift from metaphor of the machine to the metaphor of the organism is evident [Abley in Heartfield, 2001]. The aim of such an approach is to engage in a high level of cooperation with engineers or use integral knowledge to design architecture which would be a synthesis of smart materials, form and structure. Some examples are given in Figure 6.


Figure 5 Example of identification of architecture with seismic design, where the architecturally expressed structure of diagonals and use of the tectonic logic is used as the main architectural concept: Tod's building in Tokyo (left) and Dance centre Aix-en-Provence (right)


Figure 6 Example of "force microfragmentation": Municipal multimedia library in Sendai (left), project of the Olympic stadium "Bird's Nest" in China (middle), two projects of a residential buildings, one in Santa Fe and the other in Canada (right)

There are no clear divisions between the above mentioned levels of relations in earthquake architecture, which means that transitions from one level to another are sometimes possible in the process of architectural work in earthquake areas. With everything considered, it is important to distinguish between the actual effect architectural design has on horizontal resistance of a building and the symbolic or metaphorical reaction as a response of architecture – art to uncontrollable forces of an earthquake, which in some cases, due to irregularity and the desire to "provoke", even causes weaknesses or conscious structural mistakes. In this case we speak of a negative version of relationship within earthquake architecture.

## 4. CONCLUSIONS

From the first preliminary results of review, analysis and evaluation of earthquake architecture we can make the following observations and conclusions:

- Earthquake architecture represents a special approach to the architectural design where the main source of inspiration comes from the earthquake engineering and where the specific local tectonic activity became a generator for designing the architecture. Earthquake architecture is any response of the architect to the earthquake threat through the creative architectural transformation. Earthquake architecture is the "missing link" between earthquake engineering and architecture. It combines the best of both fields and establishes a new approach and quality in construction in earthquake prone areas, mainly in compliance with measures of architectural excellence.

- When evaluating earthquake architecture it is essential that architecture should be able to response to the facts of the site (earthquake hazard), so seismo-logical architecture could become the more common response for design of high-rise buildings in the seismic areas.
- In our research study we tried to develop the simplified ranking system for the recognition and evaluation of the earthquake (or seismo-logical) architecture. With proposed evaluation method it is possible to classify earthquake architecture in a few different levels of intensity.
- "Anti-" or "non-earthquake" architecture contradicts the earthquake reality by negation (confrontation) or ignorance (indifference) of the requirements of earthquake design. In this case the building code is the only tool that can prevent "anti-earthquake" architecture to be realised to the full extent in practice.
- There is not much earthquake architecture in seismic areas. Thus the possibility of using earthquake architecture as a form of expression remains unrealized potential and can present an important source of a stronger architectural identity typical of earthquake prone regions.

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