How Base Isolation benefits the Architectural Design of Hospital buildings

A. Guisasola
Architect, undertaking a Doctorate in Architecture.
Professor, Dep. Structures.
Faculty of Architecture, Urban Planning And Design,
University of Mendoza
Arquitectura Sísmica S.A.

15 WCEE
LISBOA 2012

SUMMARY
This paper reports on an investigation into how base isolation can produce benefits for the architectural design of hospitals. If a relatively new technology such as base isolation can be coupled with interdisciplinary collaboration from the birth of a project, it seems possible to achieve an improvement not only in their seismic, but also in their architectural design.
The methodology adopted for this research consisted of identifying the architectural implications of the use of base seismic isolation in hospitals.
The three basic architectural components: *Firmitas* (structure), *Utilitas* (function) and *Venustas* (aesthetics) that comprise Vitruvian definition of architecture were analysed for each building.
The paper concludes that the use of base isolation in the hospital buildings studied has increased the overall quality of their architectural design.

Keywords: architectural design, base isolation, seismic protection

1. INTRODUCTION

Among the different dangers that threaten the human beings, earthquakes are causes completely out of people's control. They cannot avoid them. They can just take preventive measures against them to diminish their effects.

Among public buildings, hospitals play a strategic role in disasters. They provide an important function of community service, because they effectively must ensure continued operation after an earthquake

The architect conceives and designs the building configuration and therefore influences on the seismic behavior of buildings (Arnold and Reitherman 1999 Charleson 2008). Architects therefore have a crucial position to influence the seismic safety of buildings. (Lupoi, Lupoi , Di Pasquale, DeSortis, Sanò, 2001)

The Theory of Architecture must take into consideration the principles of seismic-resistant structural design (Tedeschi 1978) and be updated with regard to the advances in the seismic protection technologies in the same way it does with regard to sustainability, resource consumption, recycling and other modern issues.

New technologies of seismic protection, like seismic base isolation are a great advance in engineering in order to diminish the effects produced by earthquakes on architectural works. But not many architects have a thorough knowledge about the possibilities offered by this technology, nor an adequate integration between both disciplines to allow new projects to take advantage of this technology.

In the design of most new buildings with base isolation, the architecture is restricted to solving detailing problems, such as installations, stairs, elevators, and the elements which may obstruct the free displacement of the building.

The objective of this research is to demonstrate the benefits of developing an architectural project designed from the start with base isolation (BI), taking as an example the architectural design of hospitals.

2. DEVELOPMENT

Conventional architectural seismic design takes into account “an acceptable seismic risk” acknowledge some may diminish the damage level in the building. It does not avoid damage. This leads to two conceptually approaches to the problem. One consists in controlling the damage by designing for it though it isn`t eliminated. The other approuch pursues the drastic reduction of damage by the use of new isolation devices. This second solution is very different and it requires an adaptation of design attitudes, which enable a new conception of the damage reduction in buildings when a seismic event occurs. In this way, new technologies of seismic protection have new applications creating a new concept of architecture.

Base isolation technology has been proven worldwide in numerous earthquakes, showing a level of structural performance that has never been reached before. Today there are over 16.000 buildings protected with seismic base isolation in the world (Martelli, Clemente, Forni, Panza, Salvatori, 2010).

2.1. Seismic Architecture

People are the cause and purpose of Architecture. Human beings are unique. They need to protect themselves from natural and social threats. Originally they lived in caves but now have created skyscrapers (Salvadori 1979). Architecture must offer a protection from the different elements which may put lives at risk. It must shelter human beings safety.

Seismic engineering stands as an interdisciplinary branch of Civil Engineering and Earth Sciences, mainly aimed at mitigating the effects of the seismic threat. The complex requirements of seismic engineering directly influence achitectural composition and concepts (Parducci 2007). Thus, detailed analysis of areas influences is the indispensable basis for any architectural building activity in seismic prone.

Seismic Architecture is the combination of principles related to architectural design and earthquake engineering. It combines the necessary elements from both fields and establishes new conceptual interlinks in the field of architecture. Earthquake resistant construction requirements are often seen as a negative pressure on artistic freedom and a restriction on the adoption of architectural ideas coming from non-seismic areas in the world. However, the main problem is not these restrictions but the lack of knowledge to develop seismic-resistant structural designs through an adequate, creative, bold, safe and sustainable architecture.

2.1.1. Architectural Qualities

From the field of Architecture Theory, the starting point for analyzing Architecture Qualities are those qualities defined as Utilitas, Firmitas and Venustas by Marcus Vitruvius Pollio, roman architect, writer, engineer and treatise writer from second century B.C. Over time, these qualities have evolved from the complexity acquired by architecture.

Venustas refers to beauty as an aesthetic element, the meaning and communication of a message. Utilitas means the function the work will be used for, the organization and distribution of the architectural spaces and Firmitas represents the concepts of durability, firmness, stability, permanence, resistance and configuration, among others. Safety when mentioned by Vitruvius, refers to the material and technical aspects of architecture.
With engineering, architecture shares the “Firmitas” quality and thus there is a contact area where architecture and construction join. Therefore, it is necessary to identify the common components so as to have a wider and more complex view of the Architectural and Structural Design, which is critical in seismic areas (Figure 1)

2.1.2. Seismic Architecture Qualities

Firmitas is one quality representing the possibility to design in an appropriate way an Architecture that is suitable for seismic high risk areas, adding Base Isolation (BI) as a strategy of damage reduction. BI becomes of vital importance and must be present from the conception itself of the Architectural Design.
Hence, Architecture, when it is inserted in a seismic context, receives an external action such as the earthquake, and must respond by means of internal actions. Then, the architectural work must have the architectural performance and the structural performance that are appropriate to support the said work (Figure 2).

The analysis developed by means of interrelating the three qualities of the Seismic Architecture which uses base isolation as a damage reduction strategy, shows how architectural design is optimized and enhanced (Figure 3).

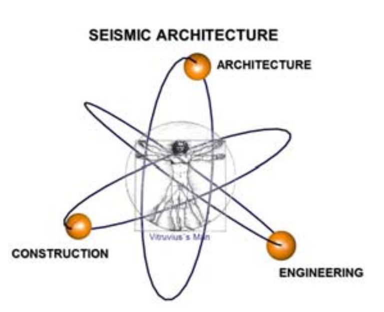


Figure 1: Integration of seismic architecture disciplines

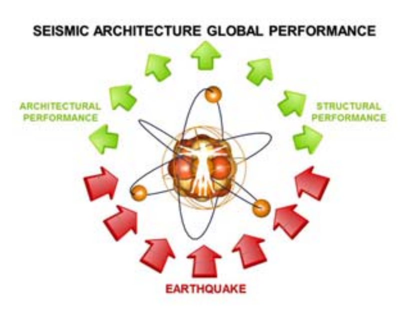


Figure 2: Interdependence of Architectural Design with its context

Figure 3: Architectural Design in a seismic zone

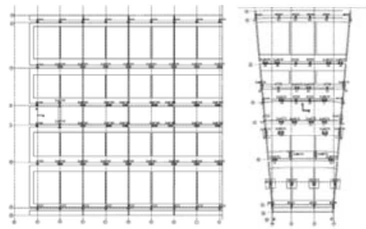
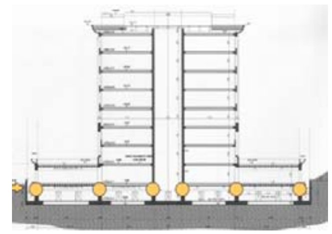
2.2. Analysis of Hospitals with Base Isolation

The selection of the hospital building typology is based on its use, because the survival of hospitals is vital for emergency situations. They must be operative after an earthquake so as to help victims.

The methodology which is applied to the analysis of hospital buildings consisted of identifying the more outstanding architectural implications of the works so as to discover the architectural potentialities arising as a consequence of the use of base isolation (BI) in the architectural design (A). The selected hospitals are from different seismic regions in the world, including Italy, New Zealand, Japan, Chile, and Portugal.

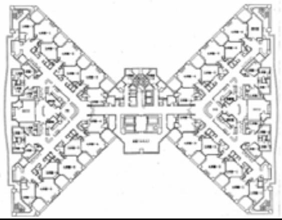
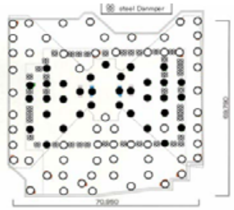
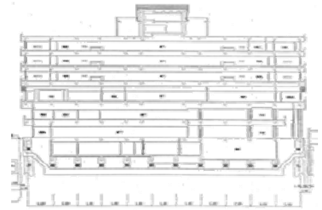
2.2.1. Analysis of Seismic Architecture qualities and architectural implications when using Seismic Isolation

Frosinone`s Hospital, Italia 1998 The first hospital with BI in Europe. Studio Speri Società di Ingenieria S.r.l. Protecne S.p.A. Sein Soc.di Ingenieria.

			
Hospital Plan	**Plan of isolators**	**Cross section, location of isolators**	**Massing**

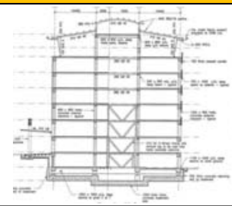
UTILITAS	FIRMITAS	VENUSTAS
Considering the needs of the users and of the health professionals, the Architectural Design provides the building with maximum technical and comfort efficiency. A high level of functionality in the of centralized horizontal and vertical circulation is provided. The decision taken as regards the lighting control proves to be effective and allos appropriate natural ventilation. A level additional to the original design was added. This maximized the space where 400 beds may be placed.	The main requirement of the building was that it should remain operative after an earthquake. In order to be as effective as possible given the use of the space of the building, a base isolation system was placed underground. This decision helped the building have a higher underground level where all the significant mechanical systems of the hospital were placed. The hospital has respond as expected during the earthquakes that have happened since it was completed. The conventional structure had two structural joints. The building was transformed by a structure with seismic isolation. This enabled to centralize the vertical circulation in the central body and the horizontal circulations in the lateral bodies, maximizing the architectural requirement program.	The Architectural and volumetric design made it possible to achieve a shape which suggests the patient an image of formal protection of the building. A clear differentiation of buildings functions expressed in the facades and easy management of the space by the users was also achieved. This building aesthetic design that uses large glazing openings in each room shows a formal plastic language consistent with the necessary comfort.

Inagi Municipal Hospital, Tokyo, Japan 1998, Kyodo Architects & Associates + Kajima Corporation

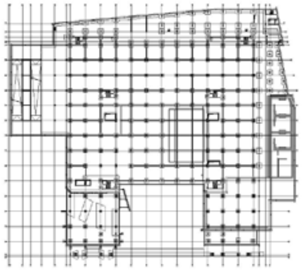
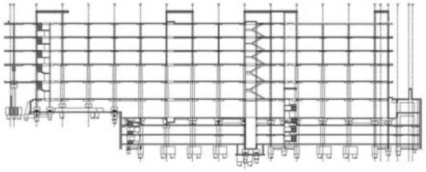
			
Plan of Tower	**Plan of isolators**	**Cross section, location of isolators**	**Masses**

UTILITAS	FIRMITAS	VENUSTAS
The interior space use was operationally optimized due to the increase of free beds. The building shape is the result of the concentration of vertical circulation in the center.	A complex morphology is hardly advised for seismic regions. After a major earthquake, the hospital continued to be operational.	Architecture durability and continuity were achieved in order to protect the heritage for future generations.

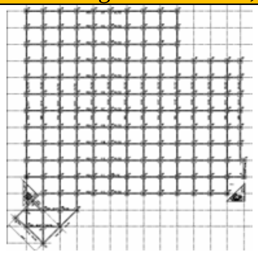
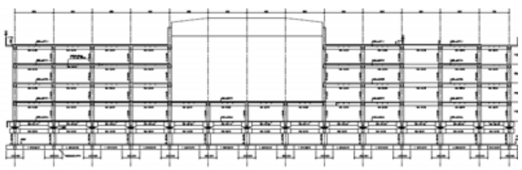
Christchurch Women`s Hospital, Christchurch, New Zealand 2005, Darryl Carey and Chow Hill Architects

			
Aerial view	**Plan of isolators**	**Cross section, location of isolators**	**Masses**

UTILITAS	FIRMITAS	VENUSTAS
One of the challenges was the integration of the hospital program and the hospital architecture in order to create a building suitable for its context and special environment. Another significant assumption was that the building should be visually attractive. The interior design space should be enriching, healthy and with a strong pro-life feeling: it should be a celebration of women and of the community health, the antithesis of the cold hospital environment. The shape respects its context in order to match with the surrounding environment. The minimal structure in internal spaces allowed for adaptable it for future performance of the hospital.	The base isolation system was placed underground so as to protect the nine floors of the building from earthquake vibrations. Thanks to the use of the seismic protection system, the structure of two steel frames of the four levels mainly concentrates in the perimeter. There was a very good performance during the Darfield (Canterbury) Earthquake in 2010 with no interruption of service. This base isolated building is the first to go through a moderate magnitude earthquake and it suggests the good performance of the Architecture in a seismic area. Protection of life, investment, both of the building and the components, was achieved.	The building facades match the environmental conditions of the area providing a unique hospital concept. Thanks to the adoption of the seismic protection system from the start of the project, an intelligent mixture of design with context and function has been achieved.

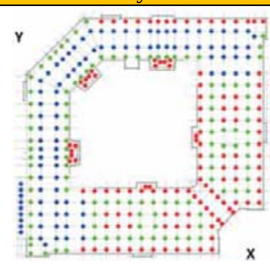
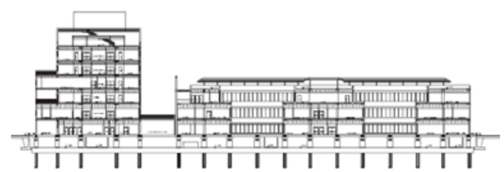
Da Luz Hospital, Portogallo, Lisbon 2006 Albert de Pineda, Architects, Risco ,STA Consultores, ICIST-IST			
			
Aerial view	**Plan of isolators**	**Cross section, location of isolators**	**Massing**

UTILITAS	**FIRMITAS**	**VENUSTAS**
The use of this technology allowed compliance with the premises and the architectural program. A complex configuration was achieved not only in plan but also in height. This makes the non-interrupted architectural functionality easier since the buildings whould have been divided in more regular buildings if the design had been traditional. This hospital Architectural Design, which used new seismic protection technologies from the project start, achieves seismic resistant structure that does not interfere with the activities in the different spaces. It also achieves essential sustainability conditions with excellent comfort and appropriate natural lighting and ventilation.	This hospital Architectural Design was developed with the arrangement of different wings and volumes above a 110m x110m square base, with no structural joints, placed on base isolators. A suitable performance, which will allow the building to be operative with no interruption of its services after a serious earthquake, is expected.	The complex morphology makes it possible to achieve volumetric expressions with no visual vertical interruptions. Thanks to the fact that the architectural design developed with the use of base isolation devices from the beginning, more advanced cladding elements appropriate for the building sustainable optimization could be used.

Militar Hospital, Santiago de Chile, 2007 Hoehmman Stagno & Partners, Militar Politenic Engeneers, PUC – DICTUC			
			
General plan	**Plan of isolators**	**Cross section, location of isolators**	**Massing**

UTILITAS	FIRMITAS	VENUSTAS
Complex morphology in plan and height allowed more freedom in the architectural design. The 9m x 9m reinforced concrete frame grid allowed a functional distribution coherent with the hospital program needs due to the low interference of the structure with the activity. All the rooms have natural lighting and ventilation due to a huge inner courtyard located in the center of the building.	The base isolation system consisting of 194 isolators, was installed on the basement roof above a parking level so the construction of an extra slab was not necessary. Large dimensions of 126 m x 115 m, including four floors and a basement, without structural joints were achieved. The building had an optimal structural behavior in the Conception´s Earthquake in 2010. High levels of structural and architectural efficiency were reached. Protection of the investment, both of the building and the components, was achieved.	The contemporary architectural concept is possible thanks to the use of Base Isolation due to the program requirements of the project Heritage, identity and history will be protected through the years. Architecture acquires a protective image and significance. Pleasant and comfortable interior spaces.

Del Mare Hospital, in process, Arch. Marzullo y MSM Studio

			
General plan	**Plan of isolators**	**Cross section, location of isolators**	**Massing**

UTILITAS	FIRMITAS	VENUSTAS
Freedom to achieve complex shapes in plan and elevation through the insolation system which achieved an architectural design according to the needs of the program and the premises of this hospital. The grid of reinforced concrete frames 9m x 9 m, allowed a functional optimization, because it has natural lighting and ventilation in all rooms of hospitalization, due to little interference from structure on building function.	Large dimensions of the building (150m x 150m) with a big central yard. The building has an irregular ground plan and different heights: the high L-shaped tower of 8 levels and the low tower of 3 levels. It does not have structural separation joints.	Greater formal freedom shown in the Architectural Design is possible thanks to the use of Base Isolation , achieving more massing freedom.

3. PARTIAL CONCLUSIONS

After performing the analysis of the selected hospital typology, the following conclusions on the qualities of seismic architecture and the importance of the economic factor are discussed.

3.1. UTILITAS: Benefits tog the functions by the use of BI in AD
- The optimization of the area of use is achieved, since it enables a better architectural exploitation.
- The degree of interference of the structure from the point of view of the use and distribution of the architectural space is lower.
- The functions of hospital buildings after a severe seismic movement are no disrupted.
- The psychological trauma generated by the perception of an important seismic movement and the devastating experiences that are caused by the deadly effects of the earthquakes is reduced

3.2. FIRMITAS: Benefits to the structure by the use of BI in AD
- It enables complex configurations which respond to the project needs.
- The deformations or distorsions in the structures in case of severe seismic movements are reduced.
- Damage in a building during a severe seismic movement is drastically reduced, both structural and non structural elements.
- The damage of the building contents is reduced (high-technology equipment, machinery, etc.)
- Life Protection and Architecture Protection are optimized
- It is possible to preserve the cultural heritage, the meaning and identity from earthquake distruction.

3.3. VENUSTAS: Benefits to beauty by the use of BI in AD
It enables configurational freedom that was not previously recommended for traditional seismic-resistant designs.
Potentiality of creative freedom in the aesthetic design of the works increases more and more.

4. FINAL CONCLUSIONS

With Base Isolation buildings, besides being more efficient, safe, functional and economical, may achieve new design prospects in seismic regions. The architectural-structural theoretical conceptual knowledge of the architectural implications of Seismic Architecture is essential to develop efficient and adequate architectural models.

Seismic Architecture provides a means of passive protection against a potential earthquake. For such purpose, it has to incorporate new technologies like Base Isolation, within its conceptual-theoretical knowledge and then use it for a comprehensive protection system which will drastically reduce human losses and damage caused by an earthquake.

Solving an architectural work which not only contributes to decrease the seismic vulnerability and the environmental problem, but also provides benefits gives the possibility of living together with our planet, of living a promising future.

AKNOWLEDGEMENTS

To my fellow engineers who shared their knowledge, especially Juan Carlos de la Llera (Chile), Jose Inaudi (Cordoba, Argentina), Agustin Reboredo (Mendoza, Argentina) and Andrew Charleson (New Zealand).
To my friends Luis Matons Cañomeras, Juan José Marino and Julio Diaz Valentín who took part in the adventure of structural design knowledge.
To my friend Fausto Giovannardi (Italy) who via e-mail has supported me and contributed to this research.

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