

# Innovative Systems for a Sustainable Architecture and Engineering

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## Summary

Results and considerations are presented from a research aimed to point out the most appropriate configurations – taking into account the available innovative protection systems - and to develop a methodology for building design based on the study of the main factors – architectural, technological and structural – which influence the response of buildings to environment actions. The research is structured in four phases: data collection, requirements definition, performance analysis, summary of results. The goal consists of an organic list of solutions allowing for minimising the environmental impact, optimising the use of materials and construction techniques, enhancing the recycling of materials, reducing the energy consumption, integrating the architecture with the innovative technological and structural systems. The research is currently being carried out and some results obtained at the intermediate stage are presented.

**Keywords:** sustainable architecture, passive approach, innovative systems, building performances.

## 1. Introduction

Starting from the 1992 UN conference of Rio de Janeiro on environment and development, the scientific community has pointed out the sustainable development as the only allowable form of cohabitation between humanity and environment; therefore, sustainability has become the great research theme of disciplines regarding the territory modification as architecture and engineering. Recently, new design methods, materials and construction techniques have been devised to improve the functionality and safety of buildings against both ordinary and exceptional environment interaction. For example, it is now well acknowledged that a good seismic design should consider the system ability to dissipate energy and the effects of the lateral deformation on the seismic response of the entire building. These considerations involve both the morphological, technological and structural aspect of buildings. Nevertheless, so far they have not significantly influenced the fundamental concepts guiding the architectural design and in current practice one cannot substantiate the existence – and correct application – of clear guidelines when adopting new conceptions of functional and structural design and the related innovative techniques.

A research is currently carried out at the University of Perugia, devoted to analyse the relation among architectural, technological and structural configuration and the behaviour of buildings in interacting with the environment. The aim is to outline the criteria that can lead the architectural conception to achieve a suitable building behaviour. The keyword is the "passive approach" [1], meaning that the performances of buildings are not derived by strengthening their elements or inserting special apparatuses but by a suitable use of structural configurations and natural characteristics of the construction materials. One basic idea is that some essential parameters, like volumetric irregularity, non-homogeneous materials, lack of symmetry, usually considered as non appropriate characteristics for the building protection against dynamic attacks (earthquake, wind, explosion), on the contrary can be profitably used to achieve damping effects and energy dissipation.

## 2. Environmental Sustainability

### 2.1 Architectural Design and Sustainability

The sustainable development is expressed in the programs, globally shareable, resumed in the famous "Agenda 21" and it would have as fundamental goal *to assure to the following generations that they will fulfil in their turn their aspirations*. Consistently with the previous statement, the sustainable architecture should "consume few energy", taking into account both the construction and management aspects of the buildings. Therefore, designers, architects and engineers, cannot leave the construction culture out of consideration.

Italy, for example, having accepted the 1997 Kyoto Treaty, has introduced since January 2003 a European resolution providing for reducing the 6.5% of the greenhouse gas emission, that is 93 thousands tons of carbon dioxide. To pursue this goal the reduction of energy consumption from fossil sources must be imperative. At present, the construction methods are not differentiated along the country while the climatic situations are very variable from south to north and require for both winter and summer climatic control (what's more the stand-alone air-conditioning plants are spreading anywhere). If renewable energy has to be used a more accurate knowing of the climate, site and building is required with consequences on the design.

For obtaining the outlined goals, the actual trend [2, 3] consists in developing architectural systems having the capacity to react to the environmental stimulations in such a way that they do not require, or require a minimum amount of, energy from non renewable sources for controlling the internal ambient conditions. The true challenge of architectural design lays in the capacity of using what the nature offers: sun, wind, site microclimate, thermal capacity of soil and construction materials, cooling of evaporating water, atmosphere transparency and opacity to different radiations, season varying shadow of trees, colours of facades and roofs.

### 2.2 Enhanced Frontiers of Sustainability

The sustainability in assuring health and well-being of the building occupants is generally based on the control of three factors: energy, pollution and resources' consumption or waste. Therefore the sustainability regards the "everyday" environmental effects of the building and mainly the energy consumption for maintaining the comfort conditions.

But from a larger point of view, even the exceptional environmental action on constructions have to be taken into consideration because they can have ultimate effects which consequences can have an impact, direct and indirect, on the environment. This is particularly true in our countries characterised by advanced social and economic structures. In fact we can identify two types of social structures that can maintain an equilibrium with the environment applying opposite strategies. The first one is the *environment-controlled* society that lives using the environment products without influencing it. The second one is the *environment-controlling* society that uses in an intense way the environment resources and requires high technologies for maintaining the impact below the safety level.

The impact is not only represented by the insertion of the construction on a site, but by the use of resources for its building, maintenance and retrofitting and by the effects that the construction use determines on the environment. The construction has to defend itself, or rather its contents, from the "environmental attack" but using systems allowing a correct interaction with the environment itself. The relation between the construction and the environment is characterised by a strong interaction that is controlled by the human behaviour particularly by the designers. To this people it is required of mediating and optimising the requirements of economy, sources' safeguard, well-being, safety. Therefore the designers have to look at sustainability in terms of performances of the building involving both the impact reduction and the increase of safety.

## 3. Configurations and Structural Performance

Building dimensions has been recognized as one of the fundamental parameters in controlling their response to strong external attacks as earthquakes. Limitations on the global dimensions of the buildings, first of all the height, have been, and still are, provided by codes for aseismic constructions. Nowadays [4] more representative parameters, like some ratios of the building

dimensions, are referred for controlling the building configuration. Typical parameters are the shape ratios - height/width and length/width ratios - influencing the overturning, the axial overloading, the torsional effects of the building response to a dynamic input.

Therefore, the building shape, rather than the dimensions, is the parameter having a decisive influence on the dynamic behaviour (from mechanisms of inverse pendulum, soft story, torsion rotations) and on the stress concentration (from variations of vertical and horizontal shape). Shape global parameters are used for controlling the regularity, symmetry and compactness of the buildings, that is the characteristics allowing for an optimum seismic behaviour where damages and energy dissipations are spread on a large number of elements. Irregularities, asymmetry and looseness highly reduce the building performance because they cause a strong reduction of the dissipative capacity, consequently the codes penalise the so configured buildings taking into account the irregularities of the vertical and plan geometry and of the structural system.

This essentially means that in general a symmetrical and compact shape should be the target when designing an optimum performing aseismic building. But the regularity concepts have to be revised considering new aseismic systems [5] that requires new design concepts, rather than the regularity.

#### **4. Innovative Systems for a Passive Improved Protection**

The current design philosophy of seismic resistant buildings is based on their capacity of dissipating energy, that is on a "passive" approach. In conventionally designed buildings the dissipation is associated to plastic deformations of the structural elements and therefore it requires to accept the damages derived from undergoing those deformations. The so called "capacity design" provides the design of lateral force resisting systems controlling the damage levels consequent to the hypothesised plastic mechanisms. The development of innovative systems in the last decades allows for reducing the structural response and sustaining even exceptionally intense earthquakes with return period of 1000 or 2000 years. These systems operate, thanks to different passive mechanisms, without damaging the structural elements, but concentrating the energy dissipation into undamageable or replaceable elements [6].

Isolating devices - set up between the foundation and the elevation - achieve the decoupling of the movement of the elevation that laterally oscillates, like a rigid body, above the isolators. Commercial isolators consist of normal or high damping rubber bearings, lead core rubber bearings, friction devices, ductile metal devices.

Energy dissipating devices - generally set up in bracing systems connecting different level of the building - work on the displacements associated to the lateral drifts, therefore they better perform if structures are flexible. The available devices are based on the flexural plasticization of ductile metal elements, on the sliding of friction surfaces, on the shear deformation of viscous-elastic rubber elements, on the axial displacement of fluid viscous dampers.

Tuned mass systems moderate the building response thanks to the interaction with its dynamic behaviour. These systems can be improved from strictly passive to hybrid, enhancing them with energy supplied systems controlling the interchanged force and allowing an optimised control of the structural response. Anyhow, from a methodological point of view they remain passive systems.

#### **5. New Conceptual Approaches to Building Design**

It is well known that the building configuration and morphology are/should be affected by the choices regarding the protection from the environmental attacks. The true question is that if the protection systems are conceived at the conceptual design stage we can obtain a real efficiency because their set up is effective and economic [7]. The use of the previously listed systems requires special structural configurations and consequently interact with the building morphology [6]. Three leading concepts have been identified when the innovative protection systems are used: they are described here below and illustrated by the schemes of Figure 1.

The first is *discontinuity*. The insertion of devices within the construction requires the disconnection among portions of the building that have to perform relative displacements under seismic attacks. Figure 1 (a, b, c, d) shows some typical schemes of base isolated, twined, suspended buildings [8]. All the schemes are characterized by internal or external gaps among portions of the building.

The second concept is *movement*. Both decoupling the motion of different portions and dissipating energy through the relative displacements implies the movement of the structures that, on the contrary of the traditional and intuitive assumption, do not stay but move.

Another identified characteristic is *flexibility*. In fact, for allowing the displacements required for the optimum performance of the internally located dissipating systems, a marked flexibility has to be attributed. The structural flexibility involves technological aspects regarding the deformation compatibility of structural and non structural elements and the connections. The devices have to be suitably located for not introducing - or compensating, if present - the effects determined by morphological irregularities.

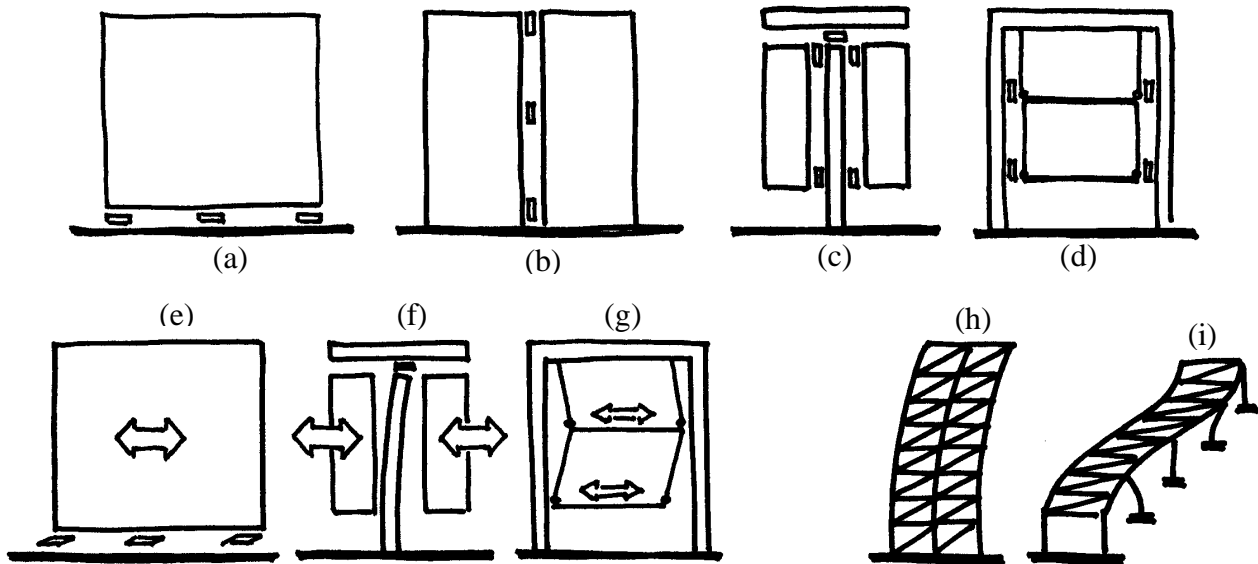


Fig. 1 Discontinuity (a,b,c,d), movement (e,f,g) and flexibility (h, i)

## 6. A Sample of Sustainable Architecture and Engineering

The design of the new Student Hostel to be built in the campus of the Faculty of Engineering of the University of Perugia (Italy) is briefly presented in this chapter. This design get together the demands and the best considered concepts to achieve a really sustainable architecture. The building, included in the campus, has been conceived, from both the spatial and functional point of view, as a completion of the existing buildings. In the Figures from 2 to 4 are reported a plan, a section (the isolators' position can be seen) and some virtual views of the buildings.

Shortly resuming the design steps, the building orientation was one of the first afforded questions. In this case, taking into account the adopted typology – consisting of bed with bathroom – it has been decided to distribute the studios in two long and narrow buildings, located with a slight offset and having the main façade overlooking the south. The architectural result consists of having a very opened and well-lighted front toward SSW – with balconies - whilst the northern front is very closed and contains passages and service areas.

The second question was the control of the sun exposure and natural lightening. Optimum performances can be obtained by means of both mechanical and architectural systems, for example by using wooden sunbreakers. The third aspect consists of the thermal-acoustic isolation and is absolutely relevant. It has been conceived to enhance the performance of the exterior envelope by increasing the thermal inertia of the non-structural elements. This effect can be obtained by using a greater thickness of the opaque surfaces and, for the transparent surfaces, by using high performing glass systems and sun radiation control systems. Another question accounted for has been the control of the natural ventilation. Taking advantage of the basement floor of the garages it has been conceived to carry the fresh air through vertical chimneys included in the thickness of the perimeter walls with the goal to equip the rooms with a double ventilation. Also the roof has been designed with a double-chamber ventilation system.

Just a brief reference can be made, for the sake of brevity, to other aspects - involving the



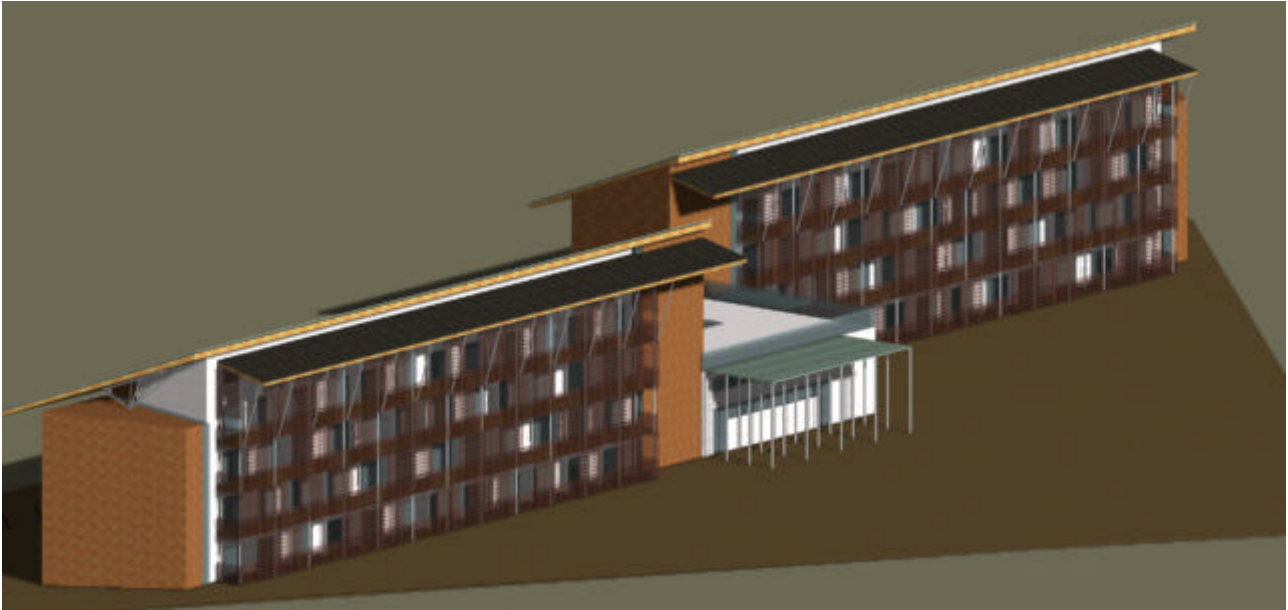


Fig. 5 Three-dimensional simulation of the two buildings

## 7. Concluding Remarks

The main architectural, technological and structural factors influencing the response of buildings to environment actions and control its environmental impact are discussed presenting the sustainability in architecture and engineering in terms of performances of the building involving both the increase of safety and the impact reduction.

New conceptual approaches to the building design deriving from the use of innovative systems allowing an improved passive protection against extreme attacks like earthquakes are proposed.

A case study is reported where the designers, by means of the operated choices of sustainable architecture and engineering, have tried to combine the structural and architectural aspects, expressing in figurative terms what usually is hidden to the inattentive observer.

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