Use of giant reed *Arundo Donax* L. in rural constructions

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Abstract: Buildings are accountable for over 40% of energy use in OECD countries. Most energy is used for indoor environment control and artificial lighting; the rest is used for the production of materials and the construction and demolition of buildings. The correct utilization of natural materials could lead to energy saving during the use of the buildings and during the phase of demolition because the less the material is subjected to transformations, the less energy cost it is. Moreover, the study of the properties of materials, in order to choose the most suitable one, allows energy saving during the building use. In particular, the utilization of local material in rural buildings minimizes the energy cost for its transport as well as its environmental impact, because, when the building is demolished, the material is reintroduced into the environmental system. In this work the principal physical and mechanical properties of the giant reed *Arundo donax* L. were studied and analyzed. It is a natural material available everywhere around the world and is an abundant natural resource particularly in temperate climate and subtropical areas. The giant reed has been a conventional construction material since ancient times. It was used to make baskets, building walls, fences, roofs, floors, music instruments, paper and bio-fuel. Owing to its lower thermal conductivity coefficient, it was also used in rural traditional constructions in some places. This paper proposed new technical solutions to use the giant reed in sustainable rural constructions and in the industry of eco-buildings, in particular a panel constituted by giant reed. The analysis of the theoretical thermal performances of the panel was carried out by using a heat transfer analysis software. The analysis was conducted in a steady-state situation but the situation is a simulation of the radiant and convective heat exchange within the air space of the wall.

Keywords: eco-building, bio construction materials, rural buildings, *Arundo Donax* L.

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1 Introduction

The building sector is accountable for over 40% of the energy spent and 30% of the green-house gases emitted by OECD countries (UNEP, 2009). The energy spent in constructions is not used only for indoor environment control (lighting, climate control) and the operation of systems, but also for the transport and assembling of components and the so-called “grey energy”, that is, the energy contained in building materials. In view of the above, a more and more pressing need is felt to propose a new way of building that reduces heat loss, uses natural and local materials, exploits renewable sources and ensures a high comfort with a minimum environmental impact. This is exactly one of the reasons why the development of bio-architecture has been boosted. This design discipline aims at spreading a correct attitude towards the environmental ecosystem (Sassi, 2006). The philosophy underlying this building practice is founded on environmental and health protection and on energy saving achieved by means of non-noxious, ecological and high-efficiency materials (Fichera, Di Fazio and Barreca, 1997). This approach particularly focuses on the indoor “climate factor” and the principle that natural forces must not befought, but rather exploited to create a higher living comfort. Furthermore, bio-architecture research is

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largely based on the acknowledgement that these new criteria on orientation, energy and water saving, air circulation and use of greenness were the foundations of millenary traditions, such as the Arab and Mesopotamian architectures. Therefore, the material culture and the building traditions today, which are handed down from ancient times exactly in the Mediterranean area, must be recovered by evidently combining them with the latest scientific discoveries and techniques to optimize the materials performance. It would be useful to refer to past building solutions and techniques that are still present in certain rural contexts. As a matter of fact, the modern transposition of traditional vernacular techniques is recognised as an excellent solution to the building problems of developing countries. For instance, a particular trend of bio-architectural research has been directed towards the recovery of the traditional building techniques using natural materials like adobe, pisé, thatch, bamboo and straw bale (Di Fazio and Lamberto, 2009). A natural material is a material which has the minimum energy distance between the raw material and the semi-finished product and low disposal cost at the buildings' end of life. Another characteristic of a natural material, which ensures its effective use in bio-architecture, is that it must come from places which is close to where it is employed; in other words, the environmental cost of its transport must be low. The recovery of ancient building techniques and natural materials must follow new approaches which meet the requirements of current utilizations (Sorbetti Guerra et al., 2009). Bio-architecture must not be erroneously considered as a simple re-use of past materials and building techniques or as the simple re-proposal of the archetypes of vernacular projects and the refusal of new materials and building techniques. It is necessary to think of a different use of natural materials by means of innovative techniques and processing which can lead to the highest performance efficiency. This evaluation must be strictly tied to the analysis of the material performances, an analysis which must lie on a precise scientific basis. By referring to a building technique, which is tested in various geographical contexts in the past, this paper proposes and analyses a particular walling solution for rural buildings by the use of panels made up of a natural material largely used in agriculture over the centuries: the stem of *Arundo donax* L, commonly known as Giant Reed. In particular, the paper analyses the theoretical steady-state thermal performances of the proposed technical solution considering the high summer temperatures, typical of the wet warm regions, which favours the spontaneous diffusion of this vegetable species and, as a consequence, the availability of considerable amounts of building material.

2 Materials and methods

Arundo donax L. is an herbaceous plant which belongs to the family of Poaceae. It is a perennial plant with a hollow and robust stem (*culmo*), native to lower Himalayas. It can be currently found in all temperate and subtropical regions of both hemispheres, above all in wetlands and riparian habitats along rivers and ponds, but also on the edges of crop fields and on sand dunes. It was introduced in the United States in the 17th century and in the area of Los Angeles in 1820 to control the erosion of drains. Since 1900, it has become an invasive species which has concerned large portions of territory, above all in California, and now dominates the local vegetation. At present, U.S. agencies and governmental organizations are conducting numerous studies and researches to define systems for its control and eradication, owing to the fact that besides becoming an antagonist of the other vegetable species, it can favour the outbreak of fires in the dry season and obstruct the free flow of rivers causing serious problems to structures and bridges. In southern Italy, *Arundo donax* L. is widely naturalised in ditches and river bank. In ideal environmental conditions, its height can even exceed 10 m. Nodes, located along its stem at a distance of about 20 cm from each other, give it greater strength. The stem has an average external diameter of 2-3 cm or even 4 cm and a thickness of 0.2 cm to 0.6 cm (Spatz et al., 1997). In Italy the wind-pollinated species flowers in September-October producing 40-60 cm long fusiform feathery plumes. It reproduces vegetatively by underground rhizomes, which are woody and fibrous and penetrate even one metre deep into the soil. Pieces of stem and rhizome less than 5 cm long and containing at least one node can easily sprout. In optimal water conditions its growth rate is very rapid and can reach 5 cm a day in spring; that is why it is considered one of the most important sources of vegetable material for biomass and cellulose production. The stem has good properties of heat insulation; the *K* value (heat transfer coefficient) varies depending on the stem diameter and thickness. Experimental studies showed that the best value of thermal resistance is obtained by coupling two layers of stems at 90° for a global thickness of about 4 cm. In this case a *K* value of 0.063 W m^{-1} K^{-1} is attained, which is similar to that of other insulating natural materials, such as cork and thatch.

The following values, referred to the mechanical properties of the stem, allow further description of the physical and mechanical characteristics of *Arundo donax* L.

Density: about 2,295.00 N m^{-3}

Mean tensile strength: 32.17×10^4 N m^{-2}

Mean bending strength: 130.00×10^4 N m^{-2}

Mean compressive strength: 66.50×10^4 N m^{-2}

Mean bearing strength: 26.68×10^4 N m^{-2}

2.1 Uses of *Arundo donax* L.

Its peculiar characteristics, such as its large diffusion on the territory, the lightness of its stem combined with its fair mechanical strength as well as its high flexibility, which is due to the tubular shape of the stem (Figure 1) (Speck and Spatz, 2004), have allowed different uses of *Arundo donax* L. in many human activities: for the construction of tools; as building material; as raw material for artefacts; for the manufacture of musical instruments and even as a drug. In Europe and Morocco, this plant is used for phytotreatment (Abissy and Mandi, 1999). In the south of Italy the stems of this plant have been largely used to build fences, props for plants, windbreak and shading barriers and temporary shelters for men and animals. Its low mechanical strength, which is lower than that of Bamboo, a plant of the same botanic family, and its easy combustion have restricted its use as a structural component in the building sector, where it has been confined to the construction of false ceilings or supports for roof cladding; to the panelling of walls to improve their thermal performances; or to the complete erection of internal and external earthquake-resistant walls. In particular, following a series of devastating earthquakes, which had razed to the ground many towns of Calabria, in 1783, the Bourbon government embarked on a wide programme of reconstruction with the experimentation of a new building system that can still be noticed in certain local buildings. This building system envisaged a supporting timber framed structure and a sheathing that, in the "poorest" solution, adopted above all in the rural areas, was made up of two simple mats of *Arundo donax* L. secured to the uprights of the walls and then covered with a layer of lime-and-cement plaster (Figure 2).

Figure 1 *Arundo donax* L.

Figure 2 Rural buildings in the south of Italy with external walls panelled with *Arundo donax* L.

The good properties of heat insulation of this solution ensure adequate thermal performances of the walls (Esteves et al., 2003). As regards the protection from the high temperatures typical of the Calabria and Mediterranean regions, temperature there in certain summer days exceeds 35℃. The solution adopted in the construction of the external walls of earthquake-resistant buildings with mats of *Arundo donax* L. has shown a good reliability in time, so much that many examples are still perfectly intact. The layer of plaster is an effective barrier against weathering agents, parasites and moulds.

2.2 Proposed technical building solution

Starting from such a solution, this paper proposes the construction of a vertical partition panel composed of a wooden bearing frame and each face consists of two crossed layers of *Arundo donax* L. In particular, this panel includes a wooden skeleton, which is composed of vertical uprights, placed at a distance of about 50 cm from each other. The two faces, which are made up of *Arundo donax* L. stems placed side by side on two orthogonal layers, form an internal air space of about 20 cm (Figure 3).

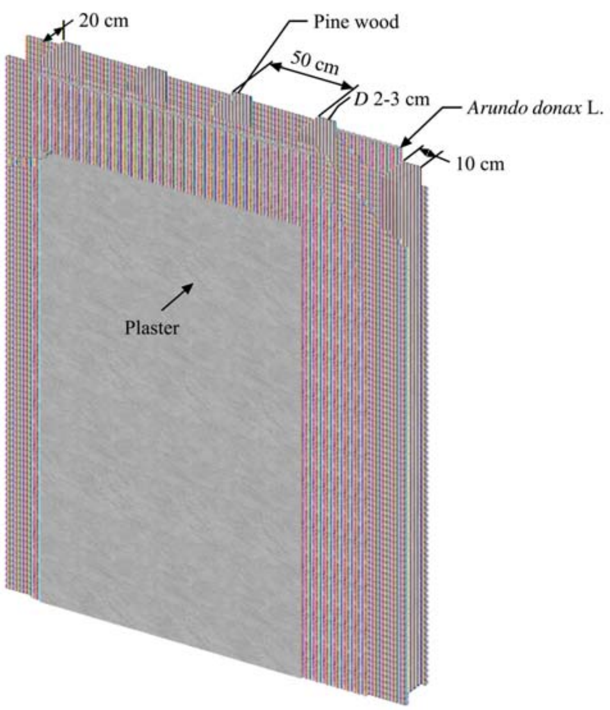

Figure 3 Panel with stems of *Arundo donax* L.

The most external layers are finished with a breathable lime plaster. The air space between the two walls of *Arundo donax* L. communicates with the outside through holes located at its top and bottom. The ventilation of the air space deserves a particular attention since, by exploiting the internal ascending air flows, which is generated as the air temperature increases, it allows the convective disposal of the excess heat that passes through the wall. In order to improve the thermal performances of the wall during summer and to reduce the emissivity of the internal faces of the air space, it is convenient to insert an aluminium sheet of a few tenths of millimetre before securing the stems of *Arundo donax* L. to the wooden uprights.

2.3 Thermal performance assessment of the panel

The analysis of the theoretical thermal performances of the panel has been carried out by using HEAT2 heat transfer analysis software. The analysis has been conducted in a steady-state situation but the situation is a simulation of the radiant and convective heat exchange within the air space of the wall. The considered temperatures are 35℃ for the external environment and 20℃ for the interior respectively. These values represent a typical environmental condition of many wet warm areas. The thermo-physical properties of *Arundo donax* L. panels have been studied and tested in laboratory and have led to a thermal conductance value ranging from 0.0630 to 0.0560 W m^{-1} K^{-1} (Soliman, 2009). This paper considers a thermal conductance value of 0.0630 W m^{-1} K^{-1}, which has been set through an experiment and applied to a panel made up of two layers of orthogonally arranged stems, as envisaged by the proposed technical solution. Further thermo-physical parameters, which have been taken into account for the global thermal analysis, are the values of adduction resistance on the surface of the wall. They have been set at 0.04 m^2 K W^{-1} for the external face and 0.13 m^2 K W^{-1} for the internal one. The overall values of the thermal conductance of the various materials composing the panel are shown in Table 1.

The same procedure of thermal evaluation has been carried out for a traditional brick masonry wall. The values of the thermal properties shown in the following table have been considered (Table 2).

Table 1 Values of the thermal properties of the materials in the analysed *Arundo donax* L. wall

Material	Thermal conductance /W · m^{-1} · K^{-1}		Volumetric heat capacity *C*/MJ · m^{-3} · K^{-1}
	λ_x	λ_y	
Arundo donax L.	0.0630	0.0630	0.2700
Pine wood	0.3431	0.3431	1.2656
Lime plaster	0.9205	0.9205	1.5188
Cement plaster	0.4310	0.4310	1.3600

Table 2 Values of the thermal properties of the materials in the analysed brick masonry wall

Material	Thermal conductance /W · m^{-1} · K^{-1}		Volumetric heat capacity *C*/MJ · m^{-3} · K^{-1}
	λ_x	λ_y	
Brick masonry	0.7113	0.7113	1.6736
Mortar	0.5300	0.5300	1.2100
Plaster limestone	0.9205	0.9205	1.5188
Plaster building	0.4310	0.4310	1.3600

3 Results

The results obtained through the numerical analysis of the heat flow through the wall under the above-mentioned conditions show that the heat flow entering the environment is slightly over 4.5639 W m^{-2} (Figure 4), a value that allows keeping comfortable environmental conditions in spite of the high external temperatures.

Moreover, such results have been compared with those obtained by means of a similar steady-state thermal analysis applied to a brick masonry wall. Repeating the thermal analysis with similar thermal boundary values for a 30 cm-thick brick masonry wall (Figure 5), a heat flow value of about 23 W m^{-2} is obtained. This value is considerably higher than that of the proposed solution.

The comparison shows that, in summer, the wooden and *Arundo donax* L. wall has a better thermal response than the traditional brick masonry wall. The better thermal performances are due, on the one hand, to the good thermal insulation capacity of *Arundo donax* L. stems and, on the other, to the effectiveness of the air space, which allows the convective and radiant heat disposal by exploiting the "chimney effect". Furthermore, the effectiveness of the air space is connected with the speed of the air flow passing through it and its temperature. Besides improving the emissivity of the two faces of the air space, the internal interposition of aluminium sheets is an effective barrier against the diffusion of vapour which, when condensing, may start

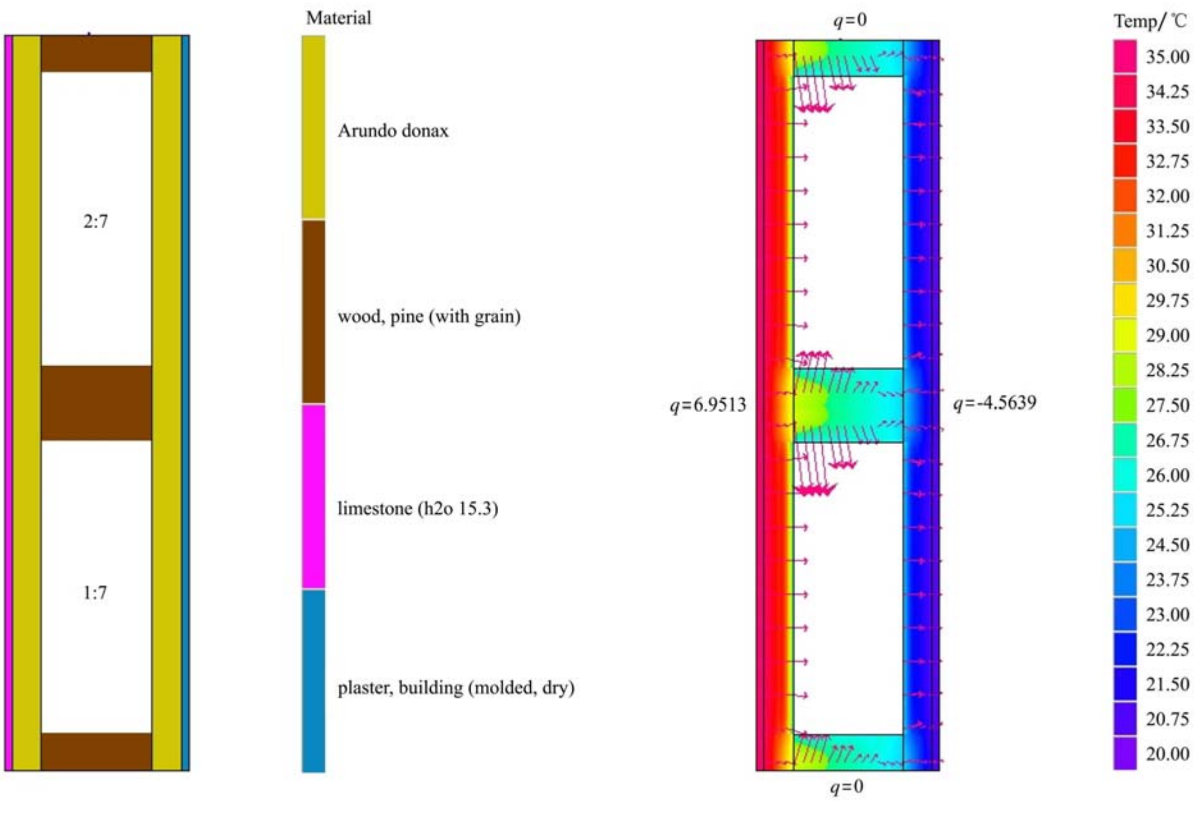

Figure 4 Section of the analysed wall and calculated temperature field and heat flow arrays

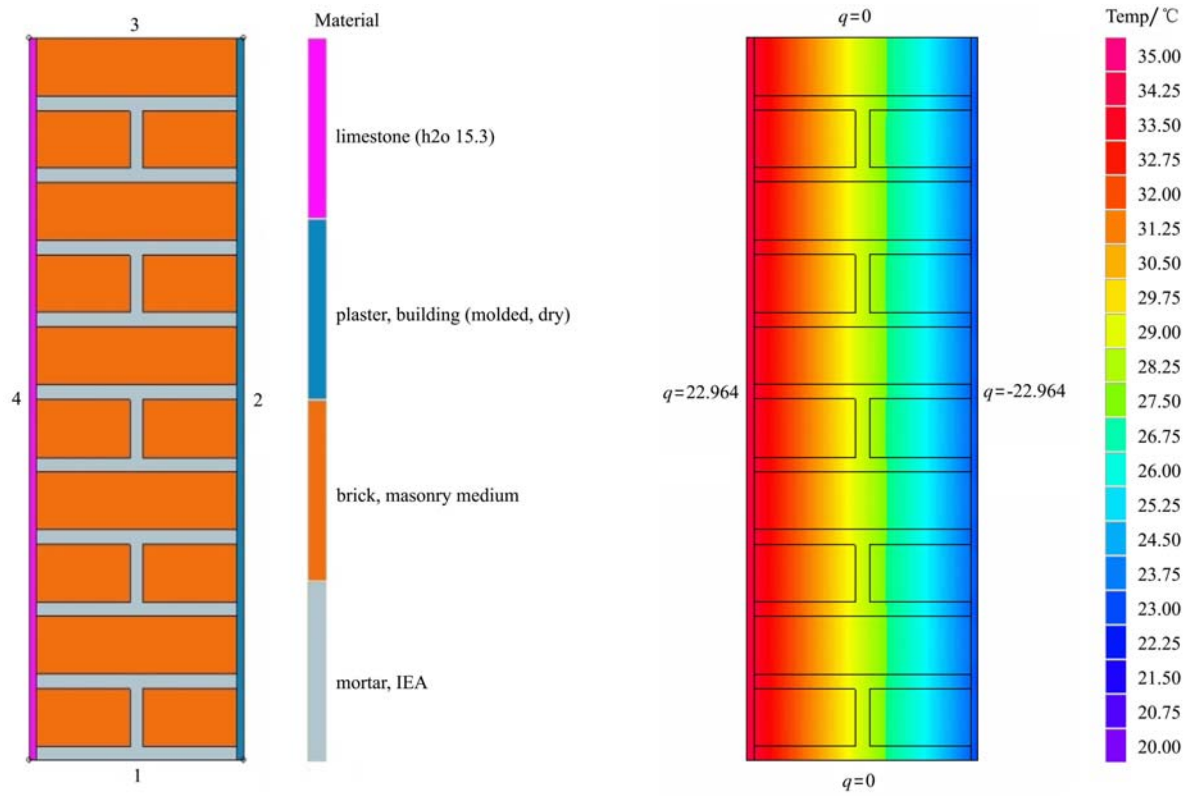

Figure 5 Section of the brick masonry wall and calculated temperature field and values of heat flow

phenomena of decay of the wall structure, especially in winter. A possible variant of the proposed solution, which should however be subjected to transient thermal analysis, could be the filling of the air space with high thermal insulation vegetable material, such as thatch, cork shavings, dry leaves. The thermal mass of the filling material could ensure a better thermal performance of the wall, even in relation to the daily thermal variability, that is, it could exploit a phase lag of the thermal wave.

4 Conclusions

The renewed interest, and the re-use of ancient building materials and techniques can be a useful starting point for the search for eco-friendly technical solutions. However, these solutions must be analysed and developed in a scientific manner, with suitable correction and improvement so that they are not only environmentally friendly, but also effective in terms of technical and functional performances. Starting from a technical solution, already adopted and applied to the earthquake-resistant buildings of the past and based on the use of *Arundo donax* L., this paper develops and proposes a solution which guarantees high thermal performances in warm zones. This solution can be usefully applied to the rural buildings of wet warm zones, where summer temperatures are dramatically high. The large availability of the material is obtained from a spontaneous herbaceous plant, which is so diffused in all the world's temperate and subtropical zones as to be even considered an invasive species; while the easy construction does not require particular manual skills and the speed of execution encourage the use of the vertical partition walls, made up of this material, in rural constructions. They are suitable for zootechnical buildings, temporary buildings, buildings devoted to the preservation of agricultural products and the restoration of existing rural buildings. Thanks to the lightness of the material, walls can be erected even by farmers or breeders themselves with modest tools. Moreover, the industrialization of the process could be particularly interesting: the manufacture of prefabricated panels for dry assembly would ensure a more rapid execution and diffusion of this technical solution to other building sectors. The presence of the internal air space between the two faces of the wall allows effective ventilation for the disposal of a part of the heat flow passing through them. The proposed solution can be considered as an example of the use of an economical local natural material which, if suitably employed, can become a useful resource, especially in extensive rural productive contexts which are not fully developed yet and demand environmentally and economically sustainable solutions.

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