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ECOLOGICAL MATERIALS AND TECHNOLOGIES IN LOW COST BUILDING SYSTEMS - NEW TECHNIQUES FOR CLAY APPLIED TO THE TYPES OF BUILDINGS FOR HOUSING

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ABSTRACT

Due to the awareness of the exhaustion of energy resources, some studies on construction techniques, linked to local traditions, to readily available materials, to low load energy and to self- building are been carried out. The high recyclability of natural materials that can be used in low-cost buildings (such as clay, straw, bamboo, wood) associated with construction techniques capable of exploiting the principles of bioclimatic architecture for energy needs, allow us to create building environmentally conscious and responsible. This study was developed according to the following steps: at first, we proceeded to collect information on the state of art. In particular, we analyzed different types of construction based on clay solutions (rammed earth - pisè, hand-formed bricks - adobe, lightened earth, weight-reduced blocks -massoni, cob, extruded blocks, compressed blocks) and different types of materials and/or compositions of clay/sand/straw mixture (clay and straw, clay and wood, clay and minerals aggregates). A series of earthen construction projects has been investigated, in order to identify their technology choices and design, in relation to operational, manufacturing, and constructive aspects. These data were then compared in terms of energy performance, maintainability, flexibility, comfort. The next step involved the design of a habitation module of transitory residencies with wooden framework and outside walls in lighter earth hand-formed blocks.
At the same time the project of a special block (made of clay and fibers derived from foliage of common reed -Arundo Donax) was developed, to meet the needs of sustainability and ease of construction. An experimental test on this block was carried

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out, aimed at the identification of mechanical performance in relation to the different compositions of the mixtures.

Key words: Tecnology, Earth, Sustainability, Materials, Ecology.

Introduction

The interest for the "earth-architecture" is constantly growing for several years in Europe and in the rest of the world, as an expression of the new approach to "sustainability" for the resources and the environment. The "earth-architecture", today as in the past, is widespread in almost all latitudes. Today the diffusion of this construction technology is closely linked to its manifold interpretation, and to the socio-economic conditions of countries where it is used: in developing countries as a form of indigenous empowerment, linked to local tradition, the construction technology economically dominant countries, industrialized countries, such as alternative technique, ecological and bio-compatible, become necessary to deal with crisis related to the scarcity of primary energy and healthy living.

The raw earth nowadays

The necessity to exploit the potentialities of the natural materials, among which the raw earth, in the optics of the sustainability it was born in the 1970's, when in the energetic crisis, that cultural embryo is formed from which an ecological sensibility is developed. In Europe an important stimulus to the search and the applications of this material has come from France, where in the 1980's, the experimental district Domaine de la Terre to Villas Fontaine near Lione has been projected and realized. At the end of the XX century, the record of the development and the diffusion of these techniques have gone to Australia and the United States. In economically depressed areas of the world the availability of the material and its "natural" predisposition to the self-building, has been at the base of projects that have allowed numerous works for disadvantaged populations in many countries; an emblematic experience was appointment of Hassan Fathy in some countries of the african sub-Sahara.
In the first decade of the XXI century, the experimentations and the realizations of innovative and creative architectures are multiplied with the raw earth: Martin Rauch, Rick Joy, John Arde, study COX, Rural Studio, Design Bluff, only to quote some of them have taken back the consolidate techniques of the raw earth employing traditional and evolved constructive technologies, to give place to objects of absolute architectural modernity. The analysis of case studies made it possible to detect the most common construction methods adopted may be traced to three major families: the compacted hearth, adobe and weight reduced earth. The research developed in recent years has allowed comparing the performance of systems and components also added with earthen materials that increase performance, mechanical or thermo-acoustic (straw, sawdust, hemp, etc.)

The design of the module housing for temporary residence

On the basis of the experiences conducted in Italy and in foreign countries, the planning of a housing form has been developed for the transitory residence in the 'etnea' area, opting for resistant structure in wood and masonry in formed blocks of weight reduced earth. The choice of base has been that to conjugate local energies, employing material, technologies and manpower "to zero kilometers" (on site), to low cost, with the raw earth as principal material, strengthened with reed fibers. This form has been developed thinking towards an employment of the block of raw earth in the formation of the external vertical partitions of the lodging. The principal building body has been conceived with a resistant "platform" structure, with only one level above ground, to wood lamellar frame, with beams and section pillars squared. Floor and roof, are formed in a "sandwich" panel, formed by two layers of wooden partition tables encasing a rigid thermal insulation material, composed of a wooden composite, protected by waterproof sealant. The external walls, to be constructed on-site, are a single layer of a uniform thickness in blocks of raw earth, handmade and reinforced by foliage of common reed. This block is the object of the current research. The finishing are made of natural, weight-reduced and reinforced, or in wooden panels. The interior walls are formed with a modular system in wooden multilayered panels (ennobled wooden layer, multilayer wooden panels encasing a rigid thermal insulation material, ennobled wooden layer).

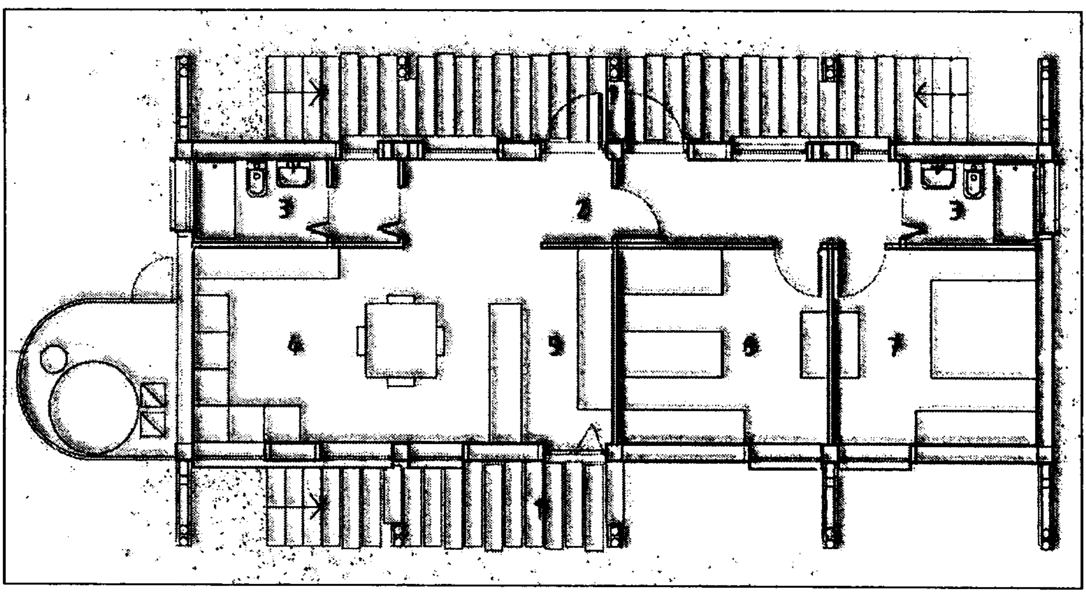

FIG 1. Plant of the module: 1veranda, 2 corridor, 3 bathroom, 4 living room, 5 kitchen, 6 bedroom, 7 master bedroom

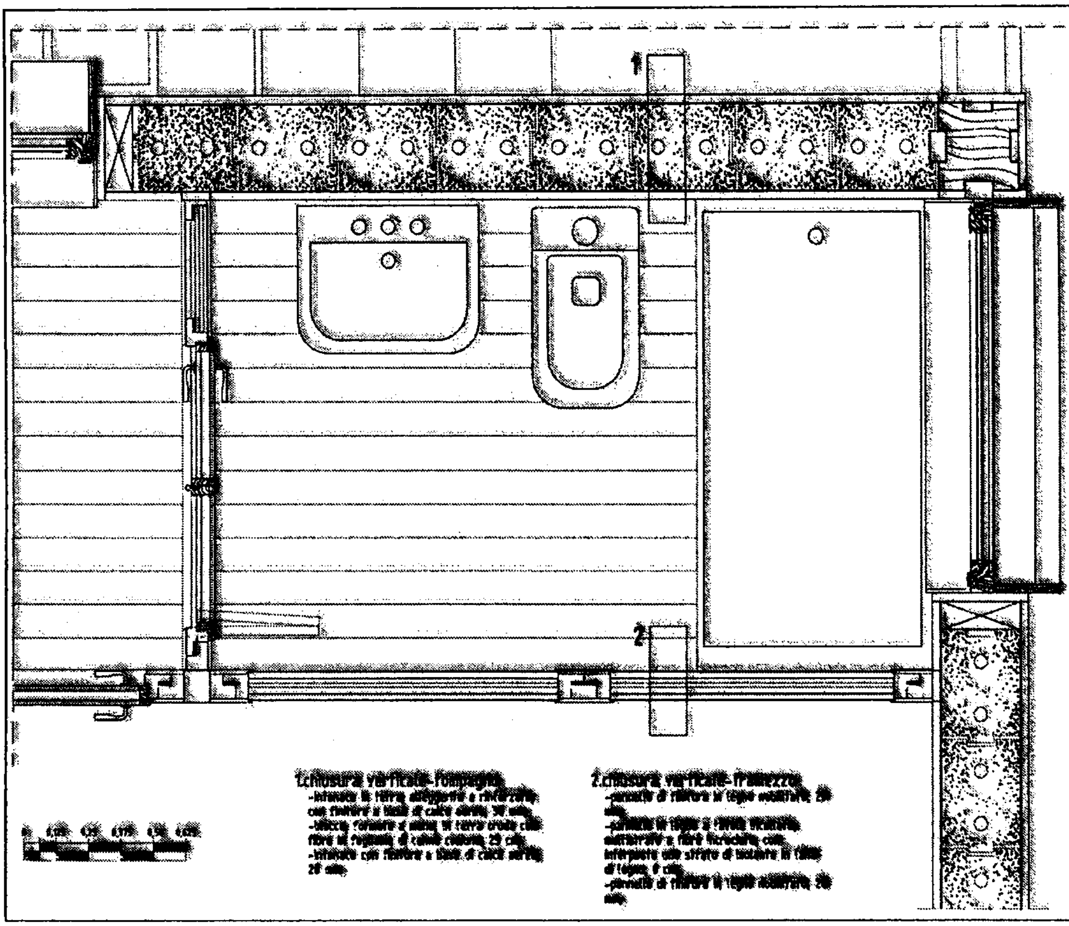

FIG 2. Horizontal section of detail.

Experimental research for the characterization of the block

The choice of construction techniques to be used for the proposed project relies on the reinforced block with plant fiber, handmade using a metal mold. This construction technique has been preferred to the other because it is easily reproducible in different geographical, technical and structural conditions used in transient and permanent, easily accomplished with the help of a few essential information and technical practices. It was considered in the light of data in the literature and ergonomic requirements related to weight and ease of handling, the size of the object, more fit for purpose, are 30x25x12,5cm. The choice of the basic components of the mix, to package the blocks, was conducted with preference of local materials. In regard to the situation of having to make these artifacts in the territory of Catania, the choice fell on clay as primary component, on a volcanic sand known as "azolo" (used in the Etna area, obtained by crushing the lava rock) as aggregate, and on foliage of giant reed (Arundo donax, Linnaeus, 1753 or reed home, present in the whole region, cultivated and spontaneous) as added fiber. These fibers added to the mix, to improve the performance, were chosen with the criterion of local availability, the use of a waste material and with the intention to bring an innovation to the constructive techniques in raw earth, in how much its employment has not been made a will in literature yet.

Production of samples / blocks

The criteria for the composition and formation of the mixture were obtained from data collected from the literature, the skills acquired in the experiments conducted and the assistance of laboratory experts. For the purposes of a preliminary assessment of the acceptability of the artifacts, 5 sets of blocks were produced in the laboratory, as described in TABLE 1, each of one has his own composition of mixture.

TABLE 1. Composition of the mixtures for the production of the blocks (*) 43% of the mass of the dry.

	SERIES 1	SERIES 2	SERIES 3	SERIES 4	SERIES 5
Clay	38 Kg	34 Kg	34 Kg	34 Kg	34 Kg
Azolo	17 Kg	22 Kg	22 Kg	22 Kg	22 Kg
Fibers	0,380 Kg	0,760 Kg	1,520 Kg	3,04 Kg	6,08 Kg
Water(*)	24 Kg	24 Kg	24 Kg	24 Kg	24 Kg

It was soon found the ideal percentage of soil and aggregates, which corresponds to the No. 2 series; it was repeated in the series 3, 4, 5, changing the dosage of fiber.
The preparation of materials needed for packaging the mixture was conducted according to an established methodology, widely applied and documented from the literature. It was organized according to a series of work steps that can be summarized as follows: mining below the organic layer and transport of the material earth, finding, and screening and washing of aggregates and fibers; storage and screening of the earth, that cleared of stones and gravel has been subjected to sieving with sieves of 12 mm; wetting the ground, using a sprayer at a rate of about 40% of the total water on the mixture; mixture, made with manual mode. The mixture was left to mature for about 6 hours before use.
The realization of the blocks was carried out manually, using a metal mold. The procedure was completed within the following steps: forming, with the help of formworks and tools by introducing the mixture into the mold, levelling the surface free and eliminating excess material. Subsequently the form was lifted and rotated to remove the block (that was intact in its geometry in all 5 cases of different doses of the components); storage and drying, when some pallets have been used, equipped with spacers (wooden spacers to avoid the direct contact between the elements and allow a regular flow of air). The blocks were left to "mature" for 2 months in optimal

conditions, placed in a dry, ventilated and protected from direct sunlight and rainwater.

FIG 3. Basic components (foliage of common reed, "azolo", clay) and blocks.

Laboratory tests

With the prototypes were made specimens for each mixture about size of 15x25x12, 5 (½ block), required for all tests: visual analysis, absorption test, test of Geelong (evidence of erosion), shrinkage test, evidence of impact resistance, penetration test, uniaxial compression test. Tests conducted are derived from proceedings governed by New Zealand standards (NZS 4298: 1998, Material & Workmanship for Earth Buildings) of March 1998 [13], Standard Code of Practice for Rammed Hearth Structures, Zimbabwe in 2001 (SAZS 724:2001) [12] and Standards Australia 2002 [8], from Ecole Nationale des methodologies developed by Ente Traveaux Publics of the Etat de Lyon (France) [7] and Thematic Manual of Raw Earth [1].

Results of the investigation and comparison with literature data

The visual analysis showed an overall good quality of products, the cracks are not so severe as to compromise the use of technical elements on site. The analysis to the touch (Achenza-Sanna, Thematic Manual of Raw Earth) showed extreme compactness of the material. The rubbing of the samples surface, with the palm of the hand, did not result in release of fine particles of the mix, if not negligible. The absorption test (Achenza-Sanna, Thematic Manual of Raw Earth), conducted on two specimens for each series of the technical products, gave results comparable with those given in the literature. Evidence of erosion (New Zealand Standard Commitee BD/83 Earth Building - NZS 4298), conducted with the test of Geelong, which aims to determine the resistance to erosion of the surface of the block, showed a good response performance of samples. All the technical tested elements, 3 for each series, may be accepted, because the obtained data respect the parameters of tolerance shown in the reference table (TABLE 2).

TABLE 2. Erosion values from NZS code 4298.

Properties	Criteria	Index Of Erosion
Depth of the hole D (mm)	$0 < D < 5$ $5 \leq D < 10$ $10 \leq D < 15$ $D \geq 15$	2 3 4 5 (non accettato)
Depth of penetration U (mm) If the sample is thicker than 120 mm	< 120 ≥ 120	Accepted Not accepted

From the analysis of the depth of the holes produced by controlled drip, we obtained an index of erosion between 2 and 3, while the values of penetration depth of water were between 13 and 15 mm, much lower than those provided by the limits of the standard codes (TABLE 2 and 3).

TABLE 3. Measured values of erosion.

	Series 1			Series 2			Series 3			Series 4			Series 5		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Depth of the hole D (mm)	3	4	3,5	4	4,5	5	4,5	4	4,5	5	4,5	5	5	5	5
Index of erosion	2	2	2	2	2	3	2	2	2	3	2	3	3	3	3
	All accepted because lower than 5														
	Series 1			Series 2			Series 3			Series 4			Series 5		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Depth of penetration U (mm)	14	13	14,5	13	14	13	14	14	15	14	14	14,5	15	14	13,5
	All accepted because lower than 120 mm														

The analysis of the withdrawal [1], is the only test that, as regard the two sets of tested blocks (those of series 1 and series 2), gave, on average, inadequate values (TABLE 4).

TABLE 4. Shrinkage values allowed from [1].

Properties	Criteria	Index of erosion
Shrinkage, measured as the percentage difference between the size and the technical elements of the formwork products	$0\% \leq$ Shrinkage $\leq 3\%$ $3\% \leq$ Shrinkage $\leq 5\%$ $5\% \leq$	normal accettable inappropriate

Samples of these two families, in fact, have shrinkage values above 5%, considered to be inadequate to ensure, with good percentage of security, the maintenance of the required mechanical properties after drying. The samples of series 3, 4 and 5 gave acceptable shrinkage values, between 3 and 5% (TABLE 5). The penetration tests (comparison with other international experiments), required to detect, qualitatively, the resistance of the outer surface of the samples, and showed overall a good performance of the blocks.

TABLE 5. Comparison of measured shrinkage values with those listed admitted in Table 4.

	Dimensions			Average withdrawal percentage	Comparision
	"a" (cm)	"b" (cm)	"c" (cm)		
Formwork	29,1	25,7	12,1		
Serie 1	26,8	23,7	11,2	7,9 %	> 5% inappropriate
Serie 2	27,3	23,9	11,4	6,2 %	> 5% inappropriate
Serie 3	27,7	24,6	11,5	4,8 %	< 5%; >3 % accettable
Serie 4	27,8	24,9	11,7	4,5 %	< 5%; >3 % accettable
Serie 5	27,9	25,0	11,8	4,1 %	< 5%; >3 % accettable

Also the impact strength test [method of Ecole Nationale des Travaux Publics, adopted also by Mattone-Pasero, 13] showed a good performance of the blocks. All values obtained from the analyzed samples showed that they meet the requirements of the test, with detachment of portions of material lower than the limits imposed by the New Zealand standard code. The compression test [7], uniaxial monotonous, carried out on the blocks, with a cell load of 60 kN and a minimum speed of load increase of 0.40 mm / min, showed a good overall performance of the products, if it is compared with data of other international experiments (TABLE 6).

TABLE 6. Values of compressive strength of common raw earth products [6].

		Tecnical features	
		Specific weight *Kg/mc*	**Compressive strength *MPa***
construction techniques	**Rammed Earth**	1800-2100	2-5 dry earth / 0-5 moist earth 3 for mixture of 1900 kg/mc 4 for mixture of 2200 kg/mc 8 for rammed earth with cement
	Lightened Earth	300-1200 terra paglia 700-1000 terra argilla 500-1200 terra legno	1,74 for lightened earth to 800 kg/mc
	Adobe	1400-1900	2 for Adobe without additive 2-5 for Adobe stabilized with bitumen
	Compressed blocks	1800-2000 1700-2200	4,12 (ALTEK GEO 50) 2,0 (CTRATerre) 3,0-4,0 (DIN)

For all tested blocks, five for each series, we obtained compressive strength values between 2.76 and 2.90 MPa, in the range of literature values obtained for products that are similar to the one tested, ie adobe (TABLE 7).

TABLE 7. Compressive strength values in laboratory.

Series	Load strength (N)	Area (mmq)	Tensile strength (MPa)	Tensile strength (Kg/cmq)
1	79956	27585	2,90	29,6
2	79364	28093	2,83	28,8
3	80661	28854	2,80	28,6
4	83095	29272	2,84	29,0
5	81526	29570	2,76	28,2
media	**80920**		**2,83**	**28,8**

Conclusions

From the analysis of data obtained from laboratory tests (carried out in our LaTPrE: Laboratory of building Production Technology, University of Catania), it is possible to deduce a first suitability of the tested technical elements. The values of our blocks (raw earth, common reed, azolo, water) are comparable to those of common Adobe. The innovative use of common reed fiber, aimed at strengthening the block, showed to be suitable for the purpose and it did not reduced the other benefits. In some cases, as in the test of Geelong, the presence of the crushed leaves of the common reed, has clearly improved the technical characteristics of the component. As regard the composition of the mixture, the series 3 and 4 (with a medium percentage of fibers) gave the best results.

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