INORGANIC-BONDED COMPOSITE WOOD PANEL SYSTEMS FOR LOW-COST HOUSING: A CENTRAL AMERICAN PERSPECTIVE

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ABSTRACT

The Central American region of the world has an acute housing shortage. Given the practical financial constraints that exist in this area, the solution to this ever-expanding housing problem lies in the development of low-cost building materials that are able to satisfy the many production, construction, economic, cultural, safety, and health requirements imposed by the natural barriers, lack of infrastructure, and lack of community services in this region. Composite wood-cement panels made from a mix of wood strands, chips or fibers, and cement appear to have the potential to satisfy these requirements. Specifically, they lend themselves to modular construction, satisfy the cultural preference for cement-based materials in the tropics, satisfy health and safety needs, provide resistance to attack by decay and fungi, and provide protection against combustion. To provide essential background information concerning the use of these materials, a preliminary study was conducted to assess some of the technical requirements for a wider use of inorganic-bonded composite wood panel systems in the Central American area. This article provides a general description of the Central American area and of its housing needs. Some experiences with the use of cement-bonded wood composites are described, along with material strength requirements, house design, and other considerations relative to the potential use of these materials to solve the endemic housing problem of this region of the world.

Chronic shortages of suitable housing exist throughout the developing nations of the world. Reasons for these shortages vary, but lack of planning, exploitation of natural resources, and rapid population growth have greatly exacerbated the problem.

The need for low-cost housing specifically suited to the needs of these people has long been recognized by essentially all world bodies concerned with humanitarian issues along with those governments concerned with global political stability. Given the practical financial constraints that exist in these countries, however, it is evident that the solution to world housing problems lies largely in the development of low-cost building materials that are able to satisfy the many production, construction, economic, cultural, safety, and health requirements imposed by the natural barriers, lack of infrastructure, and lack of community services in developing nations.

Composite wood-cement panels made from a mix of wood strands, chips or fibers, and cement appear to have the potential to satisfy these constraints. These panels 1) lend themselves to modular construction; 2) satisfy the cultural preference for cement-based materials in the tropics; 3) can satisfy health and safety requitetrtents: 4) provide resistance to attack by decay and fungi; and 5) provide protection against combustion.

The Central American region is a part of the world with strong needs for housing. This article provides a general description of the Central American area and defines its housing needs. Experiences with past, present, and fixure use of cement-bonded wood composites are described along with material design and other considerations relative to the potential use of these materials to solve endemic housing problems. Fiber-cement composites, made of cement and recycled paper, are currently made and used in these countries in the form of flat sheets resembling gypsum board. The use of other wood-cement composites such as excelsior board, particleboard, or wood-splinter is not widespread however. This paper describes some uses given to inorganic bonded panels in the Central American region. Some preliminary estimates of the possibility of wood-

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splinter cement panels to meet local codes are presented that are based on preliminary laboratory test results.

HOUSING DEMAND IN CENTRAL AMERICA

Geographically speaking, the Central American region is composed of seven countries: Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica, Belize, and Panama. Politically speaking, however, only the first five countries are considered to belong to the Central American region, which covers an area of approximately 523,271 square kilometers. These countries have a population of about 32 million inhabitants (Table 1) with an average growth rate of about 2.5 percent per year. Average household size is 5.16 persons (23).

All seven countries may be considered developing nations. Most have a past history of political unrest and economic problems and have suffered from natural disasters such as earthquakes, tropical storms, and hurricanes. Lack of housing is a major problem in all of these countries (Table 1), especially among low-income groups. An estimated 3.6 million units are needed in order to provide minimum housing for some 18,576,000 inadequately housed inhabitants. Several low-income housing alternatives have been considered by each country (Table 2), but more economical solutions have yet to be found and implemented.

BUILDING MATERIAL RESOURCES

All seven of the Central American countries are located in tropical regions. At one time, extensive tropical forests covered the land, but over-cutting and misuse have led to an ever-increasing shortage of standing timber for solid wood products. Furthermore, much of the remaining mature timber is located in nature parks and biological preserves where it is protected from cutting.

From the first settlements by the Spaniards in the 16th century until the early 20th century, houses in the Central American countries were constructed in the traditional Spanish style using adobe, stone, and brick. Wood was used in these buildings in a limited structural capacity

TABLE 1. — Population statistics and housing needs in Central America, 1996.

Country	Area[a]	Population[a]	Population density	Estimated housing need
	(km^2)	(millions)	(Hab/km^2)	(10^3 units)
Guatemala	108,889	10.99	102	860
Belize	22,966	0.21	10	11
El Salvador	21,041	5.87	282	600
Honduras	112,088	5.46	49	540
Nicaragua	131,670	4.21	32	510
Costa Rica	51,100	3.42	67	160
Panama	75,517	2.68	36	106
Total	523,271	32.84		3600

[a] World Almanac 1996.

TABLE 2. — Different construction systems used in the Central American region, by country.

	Country						
	Belize	Guatemala	Honduras	El Salvador	Nicaragua	Costa Rica	Panama
Straw				X			
Adobe				X			
Reinforced earth				X	X		
Wood				X			
Metal sheet w/wood structure				X			
Concrete panels w/bamboo as reinforcement						X	
Prefer prestressed cellular panels						X	
Mesh reinforced polyurethane concrete panels						X	
Concrete block or clay brick with RC[a]	X	X	X	X	X	X	X
Full scale RC walls						X	
Wood wool or wood strips with Portland cement			X			X	
Sandwich panels					X	X	
Bamboo		X			X	X	
Prefer RC wall panels and columns			X			X	
Cellulose fiber-cement dry wall	X	X	X			X	
Light weight RC wall panels						X	
Metal structure with hollow blocks	X						
Lightweight RC with mechanical and wet joints			X			X	
Other						X	X

[a] RC = reinforced concrete.

TABLE 3. — Cement production in Central America (25).

Country	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
	(thousand metric tonnes)									
Belize	--	--	--	--	--	--	--	--	--	--
Costa Rica	386	350	306	285	309	315	--	--	--	--
El Salvador	435	399	450	460	480	455	447	444	448	--
Guatemala	491	455	574	1392	1260	880	591	611	623	--
Honduras	485	368	348	360	375	268	321	326	402	--
Nicaragua	298	280	245	284	265	256	225	140	140	--
Panama	327	304	305	336	350	200	169	300	300	--

TABLE 4. — Natural forest areas and net deforestation rate in Central America, 1990 (26).

Country	Natural forest area	Net deforestation rate
	(km^2)	(%)
Belize	19,960	0.2
Costa Rica	14,280	2.6
El Salvador	1,230	2.1
Guatemala	42,250	1.6
Honduras	46,250	2.0
Nicaragua	60,130	1.7
Panama	31,170	1.7

for roof and floor beams and for lintels over windows and doors. Among the very poor, austere houses were constructed of rough hand-hewn wood planks. This situation changed at the end of the 19th century for Costa Rica with the introduction of modem sawmills and woodworking equipment. Furthermore, the earthquake of 1910 with the accompanying widespread destruction of houses constructed of adobe and stone greatly enhanced the use of wood as a construction material. Most of the houses failed catastrophically during the Cartago, Costa Rica, earthquake of 1910 and many lives were lost. Similar events have occurred in other countries such as Guatemala, El Salvador, and Nicaragua. As a partial result of the 1910 disaster, most houses in Costa Rica subsequent to that period were constructed of wood. With the ready availability of tine hardwood dimension lumber, wood housing became fashionable among the higher income groups and continued to be the construction material of choice for some 40 years. Construction practices began to change again in the 1930s with the introduction of reinforced concrete. Reinforced concrete construction proved to have good resistance to earthquakes and excellent resistance to wind, fire, and termites. As a result, reinforced masonry and concrete became the predominant materials of house construction in Costa Rica and wood was relegated to specialty uses such as beams, roof trusses, and internal walls.

Other factors that have contributed to the decline of wood include the rising cost of solid wood and the criticism by environmentalists who want to deter exploitation of the remaining tropical forests. The decline of all-wood housing has taken place in other counties of the region also, and in Latin America as a whole. In many areas, wood is viewed as a "poor man 's" building material. De Freitas (8) writes that although most South American countries are rich in timber resources, they do not use these resources to alleviate housing problems, largely because there is no established tradition of building with wood and the technical expertise needed for building durable wood housing is lacking. In keeping with this finding, Brealey (4) reports that in Venezuela, masonry or concrete are the preferred materials of construction for residential housing; furthermore, the general public doubts the durability, security, and structural safety of timber houses. Granskog (11) reports that in Latin America as a whole, wood housing is often associated with squatter settlements or with temporary housing that can be ravaged by hurricanes and insect attack. Finally, Hallett (12) reports that in Mexico wood has developed a poor image owing to the use of very poor quality materials in slums and shanty towns. In general, therefore, there is considerable resistance to the use of all-wood housing in Latin America.

Promoters of cementitious materials, on the other hand, claim that these products eliminate the most serious problems traditionally associated with the use of wood, i.e., damage from decay and termites and the hazards of fire, while simultaneously eliminating the demand for mature old-growth timber from virgin forests. Traditional cementitious materials by themselves, however, also have serious shortcomings such as greater weight, complexity of construction, and perhaps most importantly, cost. Thus, there is great potential for the use of composite materials that use both resources to best advantage.

Most Central American countries have well-established cement industries **(Table 3).** Several of them also have sizable wood resources, composed mainly of low value species. In addition, however, they also have large quantities of agricultural residues (sugar cane bagasse, rice straw, and banana residues) that could be incorporated into cement-bonded wood composites. Even in those countries with limited remaining natural forests **(Tables 4** to **6),** large quantities of small-diameter stems suitable for use in wood-cement composites are rapidly becoming available from reforestation projects and from plantation plantings.

CEMENT-BONDED WOOD COMPOSITES AND THEIR USE IN CENTRAL AMERICA

Cement-bonded wood composites consist of wood particles or strands embedded in a matrix of Portland cement (15,16,22). There is a great potential for the use of low value wood species, residues, and recyclable materials in such composites. Furthermore, they can be produced by either labor-intensive or machine-intensive operations, whichever is most economically feasible. Owing to the binder used, i.e., Portland cement, the

TABLE 5. — Roundwood production in Central America. Solid volume of roundwood without bark (25).

Country	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
	(million m^3)									
Belize	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Costa Rica	3.2	3.4	3.5	3.6	3.9	4.0	4.1	4.1	4.2	4.3[a]
El Salvador	4.0	4.0	4.1	4.1	4.2	4.3	4.4	4.5	4.6	4.7
Guatemala	9.5	9.8	10.0	10.2	10.4	10.7	11.0	11.3	11.3[a]	11.3[a]
Honduras	4.8	5.1[a]	5.4	5.5	5.8	6.0	6.0	6.1	6.2	6.2
Nicaragua	3.4[a]	2.9	3.0	3.0	3.1	3.2	3.2	3.3	3.4	3.6
Panama	1.0[a]	0.9	1.0[a]	0.9[a]	0.9[a]	0.9[a]	1.0[a]	1.0[a]	1.0	1.0

[a] FAO estimate.

TABLE 6. — Sawnwood production in Central America (25).

Country	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
	(thousand m^3)									
Belize	161	191	22	14	14[a]	14[a]	14[a]	14[a]	14[a]	14
Costa Rica	306[a]	412	412	412[a]	503	515	439	412	412	412[a]
El Salvador	39	46	43	44	47	54	70	70	70	70
Guatemala	104	103	131	83	83[a]	21[a]	34[a]	14[a]	20[a]	20[a]
Honduras	468	427	436	405	464	447	412	328	303	321
Nicaragua	222[a]	222	222[a]	222[a]	180[a]	140[a]	110[a]	80	80[a]	80[a]
Panama	531	46	45	30[a]	25[a]	18	50[a]	48[a]	16	37

[a] FAO estimate.

material can be considered non-toxic yet resistant to decay and termite attack. Fire resistance is also much higher than that of any other wood-based material. An added advantage over massive concrete panels is their ability to withstand larger deformations before failure. In seismically active areas, less brittle materials help to dissipate energy, reducing the buildup of large forces that may cause catastrophic failures.

Experience with wood-cement panels in Central America has been limited. In Costa Rica, cement-bonded wood cornposites in the form of wood-wool panels were first introduced in small housing projects between 1976 and 1977. The first large application was in 1980 when 100 houses were built in which wood-wool cement panels were used for interior partitions, shower walls, and floors. Use of the material for exterior walls occurred between 1978 and 1979 when some 25 homes were constructed in which both the interior and exterior walls were fabricated from wood-wool cement panels. Cement-bonded wood composites were also used for interior paneling in several other buildings. Aside from normal wear and tear, these homes are still in good condition today.

BUILDING MATERIAL AND DESIGN CONSIDERATIONS

A primary concern in introducing new materials into traditional markets in the region is compliance with local codes. Conventional logic dictates that low-cost materials should be free from strict regulations, and that low-income groups should be free to build with as few code restrictions as possible. The effects of recent natural disasters, however, have shown that houses not built to appropriate code specifications have suffered severe damage that has often resulted in lost lives.

Most countries have developed their own codes and specifications (2,5,6,7. 9,10,14,17,19,20) while others follow guidelines from foreign design codes (13,18).

Most local codes (2,5,7,20) include design loads and wind and seismic design factors. Enforcement of codes is left to the various engineering and architectural associations, the local governments. and the project engineer or architect. The level of enforcement depends on the aggressiveness of the associations (most of which have their own inspectors), local county or municipal inspectors, and the on-site engineers and architects. In most Central American countries. for example, a licensed professional, usually an architect or engineer, is required to inspect each house in order to ensure that construction plans are followed and that specified materials are used.

These codes do not specifically restrict or hinder the use of any specific material. Rather, they provide a comparable-performance basis of acceptance for non-traditional materials. Thus, there are no specific limitations on the use of cement-bonded wood composites. Rather, acceptance of the material is based on proof of performance, i.e.. basically, showing by test that the cement-bonded wood composite will perform as well in service as traditional materials.

Specifications may be written both by the engineering and architectural associations and by the appropriate government offices responsible for urban development programs. New materials or systems usually must be approved by

TABLE 7. — Extreme normal-to-surface seismic and wind loads according to construction system and different Design Codes of Central America.

Construction system	Wall unit weight		Guatemala[a]	El Salvador	Nicaragua	Costa Rica
	kg/m²	psf	Highest seismic load (kg/m²)			
Concrete block	257.00	52.55	106.85	35.98	232.33	84.81
Prefabricated	168.00	34.35	69.85	23.52	151.87	55.44
Cellular	142.00	29.04	59.04	19.88	128.37	46.86
Bamboo-concrete	102.00	20.86	42.41	14.28	92.21	33.66
Dry wall	20.00	4.09	8.32	2.80	18.08	6.60
Full scale	145.00	29.65	60.29	20.30	131.08	47.85
Wood-cement (7.5 cm)	52.00	10.63	21.62	7.28	47.01	17.16
			Highest wind load (kg/m²)			
			382.62		122.50	87.77
			Lowest seismic load (kg/m²)			
Concrete block	257.00	52.55	21.64	17.99	175.27	56.54
Prefabricated	168.00	34.35	14.15	11.76	114.58	36.96
Cellular	142.00	29.04	11.96	9.94	96.84	31.24
Bamboo-concrete	102.00	20.86	8.59	7.14	69.56	22.44
Dry wall	20.00	4.09	1.68	1.40	13.64	4.40
Full scale	145.00	29.65	12.21	10.15	98.89	31.90
Wood-cement (7.5 cm)	52.00	10.63	4.38	3.64	35.46	11.44
			Lowest wind load (kg/m²)			
			30.56		30.00	35.28

[a] Corresponds to the California building code.

them also. A special committee of the engineering and architectural association, or an equivalent government office, determines the requirements or procedures to be followed for approval. Requirements usually conform to those specified in local codes, including seismic strength, wind resistance, and fire propagation.

OTHER CONSIDERATIONS RELATED TO THE USE OF WOOD AND WOOD BY-PRODUCTS

Of the various materials used for house construction in the Central American region, cement-based materials have emerged as the dominant construction material. This has led to a tradition of construction so that many contractors and laborers are trained in the use of reinforced concrete and masonry as a structural material in Central America, whereas few are trained in the use of wood.

The acceptance of cementitious materials is based largely on their fire, decay, and insect resistance, among others, and on their perceived performance during natural disasters. When properly constructed, they have survived both earthquakes and tropical storms. Concrete also allows a wide variety of house designs and construction systems since it can be molded into any form. Because cement construction has emerged as the preferred housing material, it is now regarded as a status symbol.

Adobe houses are still common in countries such as El Salvador, although those made some decades ago have performed quite poorly. Failure has been attributed to the deterioration of the wood flames used in their construction, which, owing to decay and insect attack, often lack the strength needed to resist seismic forces.

Aside from the natural resistance to changes in traditional building practice, a major problem hindering the introduction of cement-bonded wood composites in construction is that little information is available in the region concerning the performance of other types of construction systems. Although wood-cement products of this kind have been developed and widely used in Europe, the benefits of such construction have practically gone unnoticed in the Central American region. Lack of use has not resulted from lack of interest but rather from lack of information concerning their performance and advantages. Also, possibly because of the relatively limited economic sales potential of the region, the major producers have not made a determined effort to introduce the material into the region.

DESIGN OF LOW-COST HOUSING

In the Central American region, house construction has taken place both with and without formal technical planning and assistance. Nevertheless, in both cases, the resulting houses have provided inadequate living space. This does not result from lack of information since minimum space requirements have long-since been established by several agencies such as AID (1) and the countries themselves. Rather, it results from practical constraints including scarcity of land, which dictate the use of small lot sizes and the cost of the housing itself, i.e., the larger the house the greater its cost with the result that most homeowners are unable to afford the space they need. The key issue to be resolved, therefore, is how to provide affordable housing with adequate living areas subject to the constraint that the houses must be constructed on small lots without giving the impression of overcrowding.

Several designs for low-cost housing have been developed in the past and used in low-cost housing projects. Initially,

these "starter" houses tire usually little more than "shells." The owner then finishes the house to suit his specific needs within the limits of family financial resources. In general, the trend has been to reduce the size of houses in order to meet the lot size and financial limitations just mentioned. Furthermore, the houses have not been designed to easily accommodate future expansion. As a result, homeowners have made once-in-a-lifetime financial commitments to houses inadequate in size with no hope of expansion.

In general, designs should be sufficiently flexible to allow' changes in response to local cultural preferences. In rural areas, for example, culture favors those designs that separate the kitchen/dining areas from the social areas, i.e., the living room. In addition, the design must permit ready adaptation to local climatic conditions. In hot climates, for example, space should be provided for social gatherings in cool roofed outdoor areas.

The type and size of furniture most commonly used in the home should also be considered when defining minimum house dimensions. A recent study of the type and size of furniture used in low-cost housing projects in Costa Rica (3) indicated that there was essentially no understanding of the relationship of firniture size to available floor space. Most furiture proved to be too large to permit the free movement of the inhabitants in a house. Ideally, maximum dimensions consistent with function and comfort should be established for all commonly used furniture.

STRENGTH REQUIREMENTS

Based on the weight charcteristics of the materials and both wind and seismic coefficients established in the design codes of these countries, the expected extreme seismic and wind loads to which walls of different construction systems could be exposed were estimated and summarized in **Table 7.** There are no known published scientific studies relative to other non-traditional construction systems used in the area; thus, the expected extreme load values presented in **Table 7** cannot be readily used to compare expected load to actual strength of other non-traditional construction systems. There are, however, some results of ongoing research at the USDA Forest Products Laboratory with wood-splinter cement panels made with recycled wood that yielded modulus of rupture (MOR) values that ranged from 200 to 800 psi (14 to 56 k/cm^2) (24). Based on these available test results, a preliminary analysis of panels exposed to the minimum and maximum loads described in **Table 7** was conducted. Wall panels made with this material are assumed to act as simply supported slabs exposed to the loads described in **Table 7.** The results are presented in **Table 8.** The range of values from bending stress from tests was 14 to 56 k/cm^2. If the values of the last two columns of **Table 8** are compared with the range of test values, the results show that in terms of bending strength, the material should readily meet or exceed local code requirements for wind load. Further studies are required for this material (splinter-cement) to determine physical properties and other mechanical characteristics such as joint strength, racking resistance, and impact. The effect of particle size, species, and juvenile wood should also be considered since the raw materials from each country may differ with respect to these aspects.

FINAL COMMENTS

The Central American region has a strong and urgent need for low-cost housing. Shelter is one of man's basic needs and its satisfaction is essential to the existence of humane life conditions.

Today, wood-cement panels provide a material with many of the traits necessary to satisfy future needs for residential structures. They can be fabricated to make efficient use of materials indigenous to most areas of the world. They provide resistance to decay, insects, and fire without the use of toxic chemicals. They can be fabricated from recycled wood fiber, wood from thinnings, and other cellulosic materials.

Cement-bonded wood composites have long been used in other areas of the world, both to satisfy emergency situations (provide housing for people affected by natural disasters) and for common house construction. Owing to the nature of the binder used (Portland cement), the material can withstand the forces of nature much better than other materials. Since there is no off-gassing or leaking of harmful chemicals, these materials can be considered as environmentally friendly. Also, since these materials have proven to be termite resistant, panels need not be treated to prevent infestation by this destructive insect. This is an extremely important consideration in tropical regions where heavy infestation may be common. Hence, use of wood-

TABLE 8. — Extreme bending stresses on panel elements of wood-splinter-cement exposed to wind load. Load normal to surface.[a]

Country	w. min	w.max	t	W	L	M.min	M.max	Min-Be-St[b]	Max-Be-St[b]
	(k/m2)		(cm)	(m)		(k-m)		(k/cm^2)	
Costa Rica	36	88	7.62	1	2.4	25.92	63.36	2.68	6.55
	36	88	10.2	1	2.4	25.92	63.36	1.49	3.65
	36	88	12.7	1	2.4	25.92	63.36	0.96	2.36
Nicaragua	30	123	7.62	1	2.4	21.6	88.56	2.23	9.15
	30	123	10.2	1	2.4	21.6	88.56	1.25	5.11
	30	123	12.7	1	2.4	21.6	88.56	0.80	3.29
Guatemala	31	383	7.62	1	2.4	22.32	275.76	2.31	28.50
	31	383	10.2	1	2.4	22.32	275.76	1.29	15.90
	31	383	12.7	1	2.4	22.32	275.76	0.83	10.26

[a] w.min = minimum distributed load; w.max = maximum distributed load; t = panel thickness; W = panel width; L = panel length between supports; M.min = moment produced by w.min; M.max = moment produced by w.max; Min-Be-St = minimum bending stress produced by w.min; Max-Be-St = maximum bending stress produced by w. max.

[b] Tests performed at the USDA Forest Products Laboratory show: Minimum Bending Stress = 14 k/cm^2; Maximum Bending Stress = 56 k/cm^2 (24).

cement panels both eliminates the need for costly treatment and also significantly extends the expected service life of the structure.

Because it is produced in panel form, the material can readily be substituted for other materials or can be used in combination with other materials commonly used in the Central American countries. Inorganic wood-cement panels can readily be used in place of solid thick reinforced concrete elements, for example, in several of the construction systems now commonly used.

Wood-cement panels are lighter in weight than most of the other cementitious materials, which is an important consideration in seismically active areas. If future testing provides evidence of adequate ductility and satisfactory behavior with respect to lateral (in-plane) loads, panels of splinter-cement could be used in combination with other structural elements as load-bearing walls. Use of these lighter panels would help to reduce the size and strength requirements of other associated structural elements. Hence, wood-cement panels would provide important advantages over conventional cementitious materials in the seismically active Central American region.

The strength requirement analysis previously described, together with the preliminary test results obtained with wood-splinter panels, indicate that the panels have adequate strength to meet local wind load code requirements. Specific characteristics of the panels can be engineered once detailed mechanical tests such as joint strength and lateral and impact load capacity are conducted with the material. The manufacturing process requires special attention since cost and availability will depend on where it is made.

It is not foreseen that any country would oppose the use of this material although opposition is to be expected from manufacturers of competing materials. An important factor in the acceptance of the material is that the exterior surfaces of the house can be covered with cement mortar "stucco. " Thus, the houses can be finished to closely resemble all-concrete-based constructions that are already acccpted. Housing solutions can be based on accepted low-income house designs now in usc in every country — the only difference in construction will be the type of material used (inorganic bonded wood panels in this case).

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