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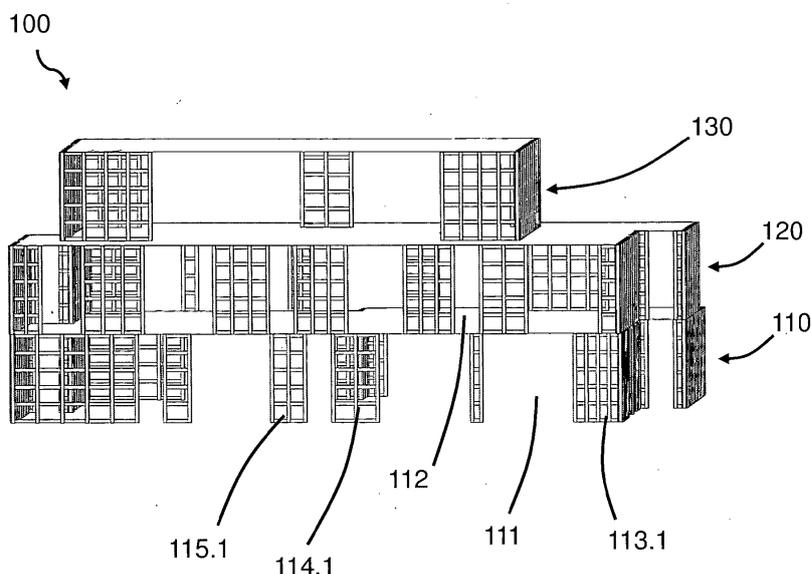
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(54) **METHOD FOR PROVIDING A WOOD BASED LOAD-BEARING PANEL FOR USE IN THE ASSEMBLING OF A CONSTRUCTION SYSTEM**

(57) The present invention relates to a method for providing a wood-based load-bearing panel (113.1, 114.1, 115.1) for use in the assembling of a construction system (100), wherein a position is allocated to the panel, a panel template is provided, at least one variation of the panel template is determined based on a variation of parameters so that the load-bearing capacity of the variation

is comprised between 1 and 4 times the required vertical force that the variation must bear at the position of the panel, then a variation is selected, and the panel is manufactured from the selected variation. The invention also relates to a wood-based load-bearing panel (115.1) obtainable with such method, and to a construction system (100) including such panel (115.1).

Figure 12



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## Description

### Background of the invention

**[0001]** The present invention relates to a method for providing a set of wood-based panels that can be used to assemble a construction system.

**[0002]** Different solutions are known for designing and manufacturing wood-based panels for construction systems, such as multi-floor buildings. In each case, the set of wood-based panels must bear the loads of the levels (or storeys) above them.

**[0003]** A first type of wood-based panel is called "TFW", for "Timber Frame Wall". It consists of a frame comprising wooden mounts and crossbeams assembled to each other. These frame elements are manufactured from timber machined to the desired dimensions, manually and/or with numerical control machines. The assembly of the frame is done then by using rod-type members (tips, screws, bolts...) which connect the mounts to the crossbeams so as to form a structural frame on which the bracing panels (generally called "OSB", for "Oriented Strand Board") are attached. Such unit is called "panel" of wall. This frame has several advantages. In particular, the panel is light, and its assembling can be easily completed on site by workers with standard components. In addition, other functional elements can be inserted to fulfil a function such as thermal insulation, soundproofing, fire resistance function, thermal inertia, or any other complementary function.

**[0004]** However, it appears difficult to completely automate the assembly of "TFW" panels, as it still requires a human operator, even on the most developed lines. The manufacturing of a construction system with "TFW" panels thus leads to an increased manufacturing cost, because of the necessary manpower. In practice, "TFW" panels are rarely used for buildings having more than three storeys.

**[0005]** A second type of wood-based panel is called "CLT", which stands for "Cross-Laminated Timber". The elements are pre-fabricated panels which are assembled on site. The main material is laminated wood (or lamellas). In details, it consists of a set of plies (or layers) superimposed on each other. Each ply comprises a set of wooden structural strips parallel to each other. These strips are also arranged, on each other, such that the strips of a given ply are orthogonal to the strips of adjacent plies. This means that the strips of a given ply may be substantially horizontal, while the strips of its adjacent ply may be substantially vertical. The panel is manufactured by preparing each ply at the time, then by superimposing the plies, so that one of the faces of the strips of a ply is in contact with one of the faces of the strips of adjacent plies, which defines a contact interface. Glue is arranged at contact interfaces, in order to retain the strips - and therefore the plies - against each other.

**[0006]** CLT panels offer a strong mechanical resistance, so they are suited as load-bearing walls for high-

rise constructions. However, the fact that strips are contiguous and form a continuum of wood and glue leads to several drawbacks. First, providing a load-bearing panel requires a significant volume of wood, which is inefficient in terms of wood, glue, and costs. Second, there is no room between the strips for inserting insulating elements. Third, hygroscopic deformations of strips of the same ply may be transferred from a strip to another, thereby accumulating deformations.

**[0007]** In addition, manufacturing a CLT panel may require an additional cutting step. Indeed, when strips are bonded together on their side to form a solid layer of the size of the pre-manufactured panel, openings must be cut. Most of the time, the parts that have been cut cannot be repurposed and must be recycled. This cutting step thus not only increase the production time, but also generated useless wood pieces.

**[0008]** A third solution is disclosed in the international application WO 2013/150188. The panel consists of a set of superimposed plies, each ply including a set of wooden structural strips parallel to each other. But contrary to "CLT" panels, here the strips of each ply are spaced apart from each other. Thanks to this distance between strips, in each ply, functional elements are arranged in the clearances between the strips, so each ply alternates structural elements (wooden strips) and functional elements. A wide range of insulation materials can be combined within the same panel, to provide for different functions. Also, like "CLT" panels, the plies are "crossed", i.e. the strips of a ply are orthogonal to the strips of an adjacent ply, so the panel alternates plies with horizontal strips and plies with vertical strips. In addition, the strips of each ply, while being parallel to each other, are not on the same line as the strips of shifted with the parallel strips of other plies. Finally, the strips are retained against each other by glue arranged on contact interfaces between the faces of the strips of two adjacent plies.

**[0009]** US application US 2019/0249431 discloses a comparable cross-laminated panel, but this time glue is replaced by series of grooves arranged on the faces of the strips. The grooves of interacting faces are complementary, so that when the faces are in contact the grooves prevents the strips from sliding along each other in the plan of the strips. In addition, a set of screws is provided to cross the thickness of the strips that are in contact, so that they can be maintained against each other in the direction orthogonal to the plan of the strips. In addition, the plies of horizontal strips are identical, i.e. they are not shifted. The same applies to plies of vertical strips, so the strips are stacked across plies, which improves strength and stiffness of the panel for the same amount of wood.

**[0010]** In each case, the panel has a structure which alternates wood-based strips and insulating elements. Architects usually require that the thickness be the same over a given wall, which means that the panels should have the same structure, and that it is usually not possible

to reduce the thickness of certain panels which will be supposed to bear less load. In a multi-level building, this means that all the panels should be oversized in terms of wood quantity in order to potentially bear several heavy levels, compared to what is necessary to comply with construction standards. This leads to inefficient panels, with too many wood pieces used, and less space for additional insulating elements.

**[0011]** Overall, there is thus a need for designing and manufacturing a load-bearing wood-based panel in which the amount of wood can be reduced, while the amount of insulating elements can be increased.

### Summary of the invention

**[0012]** It is accordingly an object of the present invention to provide a more efficient wood-based panel, and a method for manufacturing a wood-based panel, where the quantity of wood is adapted, while maintaining the benefits of cross-laminated panels which alternate structural wood-based strips and insulating elements.

**[0013]** To this end, the present invention relates to a method for providing a wood-based load-bearing panel for use in the assembling of a construction system, wherein the construction system includes a set of levels which include structural elements, wherein the method includes:

- Allocating a position to the wood-based load-bearing panel within the construction system;
- Providing a panel template, which includes a series of at least three superimposed plies, at least two plies of which including a series of wood-based strips distributed along the ply, the wood-based strips of at least one ply being substantially vertically oriented within the construction system;
- Determining at least one variation of the panel template, based on a variation of parameters such as any of the number and section of plies and the number and distribution of wood-based strips in each ply of the panel template, so that the load-bearing capacity of the variation is comprised between 1 and 4 times the required vertical force that the variation must bear at the position of the wood-based load-bearing panel within the construction system;
- Selecting one of the at least one variation; and
- Manufacturing the panel from the determined variation.

**[0014]** The present invention takes a panel-by-panel approach, which starts from a panel template (similar to the already known CLT panels) and considers the position of each panel in the construction system. It specifically anticipates the forces that will be applied on each

panel due to the whole structural environment, and it adapts the parameters of each panel to that force. The invention thus reduces the amount of wood needed, which saves wood and allows to fill the panel in with even more insulation material than in prior art techniques.

**[0015]** In this regard, the inventors have found that it was generally sufficient that the load-bearing capacity of the panel be no more than 4 times the required vertical force that the panel must bear. This load-bearing margin has proven to be sufficient to ensure the structural capacity of the panel, while offering an improved volume of wood for manufacturing the panel.

**[0016]** The present invention thus maintains the advantages of known CLT panels, especially panels with both wood-based strips and insulating elements. The panel can still be manufactured before it is assembled on site, just like other CLT panels. But thanks to the present invention, these panels are provided with less wood, better efficiency, and improved thermal resistance.

**[0017]** Preferably, the determination is based on a series of variations. In that case, the step of determining at least one variation of the panel template further includes:

- Starting from the panel template;
- Varying parameters of the panel template such as the number and section of plies, and the number, width and position of the wood-based strips in each ply;
- Determining at least two variations of the panel template from at least two variations of the parameters of the panel template;
- Determining the load-bearing capacity of the variations;
- Determining the required vertical force that the variation of the panel template must bear at the position of the wood-based load-bearing panel within the construction system; and
- Comparing that load-bearing capacity with the required vertical force that the variation of the panel template must bear.

**[0018]** Preferably, the step of determining at least one variation uses "stacks", which are made of the vertically oriented wood-based strips that are aligned and close to each other from a ply to another. In details, the method further includes:

- Gathering substantially vertically oriented wood-based strips into a series of stacks;
- Determining the local load-bearing capacity of each stack; and

- Determining the local required vertical force that each stack must bear at its position in the wood-based load-bearing panel within the construction system; and
- Comparing, for each stack, the local load-bearing capacity and the local required vertical force that the stack must bear.

**[0019]** This preferred embodiment is based on the recognition that the forces are mainly suffered by the stack of vertical strips. The number of plies and the distribution of the vertical strips will thus influence the overall dimension of wood material that bears the structure above the panel. By varying those parameters, it allows to meet the desired load-bearing capacity, but in such a manner that only the necessary amount of wood is used.

**[0020]** In this embodiment, the at least one variation of the panel template is preferably determined so that the local load-bearing capacity of the stacks is comprised between 1 and 4 times the local required vertical force that the stacks must bear for a majority of stacks. This criteria allows that the desired load-bearing capacity can be spread along the width of the panel, since all the local stacks of the panel are taken into account. Even more preferably, the at least one variation of the panel template is determined so that the local load-bearing capacity of the stacks is comprised between 1 and 4 times the local required vertical force that the stacks must bear for all stacks (and not just for a majority of stacks). This criteria allows to determine one of the most suitable panels.

**[0021]** The selection of the variation is preferably based on only one number. To do so, the step of selecting one of the at least one variation further includes:

- Generating for each variation, an inefficiency function which is indicative of the load-bearing capacity surplus of the variation; and
- Selecting the variation with the lowest value.

**[0022]** Alternatively, the selection of the variation is made not only on one panel, but instead on a set of panels which are present on the same level (or storey). Such a global approach allows to potentially compensate the low load-bearing capacity of one panel with the higher load-bearing capacity of neighboring panels. To do so, the step of selecting one of the at least one variation further includes

- Considering at least two panels of the same level;
- Considering variations for the at least two panels;
- Generating for each set of variations of the at least two panels, an inefficiency function which is indicative of the overall load-bearing capacity surplus of the set of variations; and

- Selecting the set of variations with the lowest inefficiency function.

**[0023]** In all these embodiments, the at least one variation of the panel template can be determined within a set of pre-determined panel designs, based on a range of parameters such as the number of plies, and the number, width and position of the wood-based strips in each ply. By doing so, the variation can be determined based on a given range of pre-determined panel designs rather than on a tailored design. Then the manufacture of such a given range of panels is easier and less expensive.

**[0024]** Preferably, all the wood-based strips of at least one ply have the same width. The wood-based strips can thus be the same, so the industrialization of the manufacturing process is simpler and less expensive.

**[0025]** To get a more accurate determination of the required vertical force that the variation of the panel template must bear, the required vertical force that at least one variation of the panel template must bear is determined based on a distribution of a set of forces applied on the ceiling right above the panel. Indeed, the more forces are distributed on the ceiling above the panel, the more accurate the determination of the required vertical force on the panel.

**[0026]** To take full benefit of the invention, especially the reduction of wood, at least one ply of the panel template also includes a set of insulation elements interleaved between at least some of the wood-based strips.

**[0027]** In this case, the values of the distance between the substantially vertically oriented wood-based strips can be multiples of a given length, in particular the nominal width of available insulation elements, in particular of the nominal width of available insulation elements. In the latter case, insulation material is not wasted, as it does not have to be cut during manufacturing.

**[0028]** The plies of the panel can be "crossed", i.e. the wood-based strips of each ply are parallel to each other, and the wood-based strips of each ply are not parallel to the wood-based strips of the neighboring plies, preferably at 90°. This notably allows the plies to be easily connected by screws.

**[0029]** Preferably, at least some of the wood-based strips of different plies are aligned. This structure facilitates the provision of "stacks", since the aligned vertical strips can be part of a stack, and a force can be considered at the bottom of this stack.

**[0030]** The invention also relates to a wood-based load-bearing panel obtainable with the above-mentioned method, wherein the panel includes a series of at least three superimposed plies, at least two plies of which including a series of wood-based strips distributed along the ply, the wood-based strips of at least one ply being substantially vertically oriented within the construction system. This panel has the advantages of the present invention, especially the structure and the use of wood is adapted to the position of the panel in the building. This

in turn allows to save wood and to interleave more insulation elements.

**[0031]** Preferably, the width and height of the panel depend on transportation and storage requirements, which facilitates the industrialization of the panel.

**[0032]** Preferably, at least one opening is provided in the panel. Such opening is not considered as having a bearing function in the panel.

**[0033]** The present invention also relates to a construction system, comprising a set of levels, which include a floor, a ceiling and load-bearing walls, wherein at least one of the load-bearing walls includes a wood-based load-bearing panel according to the invention. The structure of the panel is thus adapted to its position.

**[0034]** Preferably, all the load-bearing walls of one of the levels include wood-based load-bearing panels such as the above-mentioned panels. This configuration ensures that no excessive amount of wood is used on a level. It also allows to potentially compensate the inferior load-bearing capacity of one panel with the superior load-bearing of its neighboring panels.

#### Brief description of drawings

**[0035]** Other features and advantages of the invention will become apparent from the following description of embodiments of the invention, given for illustrative purposes, by reference to the annexed drawings.

- Figures 1A and 1B are different views of a first illustrative example of a wood-based load-bearing panel according to the invention.
- Figures 2A, 2B, 2C and 2D are views of four other illustrative examples of a wood-based load-bearing panel according to the invention.
- Figures 3A, 3B, 3C and 3D are different views of another example of a wood-based load-bearing panel according to the invention, including a set of insulation elements.
- Figure 4 is a diagram of an example of a method for providing a wood-based load-bearing panel according to the invention.
- Figure 5 is a three-dimensional view of an example of construction system.
- Figures 6 and 7 are three-dimensional views of a set of wood-based load-bearing panels in the example of house of Figure 5, before the implementation of the method for providing a wood-based load-bearing panel according to the invention.
- Figure 8 is a three-dimensional view of one of the levels (or storeys) of the house of Figure 5, including floor, ceiling and a set of panel templates.

- Figure 9 is a three-dimensional view of one panel template of Figure 8.
- Figures 10A, 10B and 10C are three-dimensional views of different variations of the panel template of Figure 9.
- Figure 11 is an example of table showing the different forces calculated on each of the stacks for different variations of the panel template of Figure 9.
- Figure 12 is a three-dimensional view of a set of wood-based load-bearing panels in the house of Figure 5, after the implementation of the method for providing a wood-based load-bearing panel according to the invention.

#### Detailed description of the invention

**[0036]** Figures 1A and 1B show a first example of panel 10. In the invention, this panel can be used as a load-bearing panel in a building. This panel is wood-based, as it includes a series of wood-based strips. The panel 10 has a height  $H_{10}$ , a width  $W_{10}$  and a depth  $D_{10}$  (which are also visible on Figure 9). The panel includes a series of superimposed plies 11, 12, 13, 14 and 15. Each ply includes a set of wood-based strips, which can have the same width or not, and which can be next to each other or separated by a distance.

**[0037]** In the example of Figures 1A and 1B, the first ply 11 includes three wood-based strips 11.1, 11.2 and 11.3, which are substantially vertical and parallel to each other. They are also called "posts". Strips 11.1 and 11.2 are separated by a distance  $P1$ , while strips 11.2 and 11.3 are separated by a distance  $P2$  (or "post pitch"). The second ply 12 includes five wood-based strips 12.1, 12.2, 12.3, 12.4 and 12.5, which are substantially horizontal and parallel to each other. They are also called "traverses". Two adjacent strips, e.g. 12.2 and 12.3 on Figure 1A, are separated by a distance  $P'$  (or "traverse pitch"). The third ply 13 and the 15 ply are structured as the first ply 11, i.e. they include three substantially vertical wood-based strips 13.1, 13.2, 13.3 and 15.1, 15.2, 15.3. The wood-based strips of plies 11, 13 and 15 are all aligned with each other, so that they form a series of three vertical stacks 51, 52 and 53. For instance, stack 51 is made up of strips 11.1, 13.1 and 15.1. The distance between stacks 51 and 52 is  $P1$ , while the distance between stacks 52 and 53 is  $P2$ . The fourth ply 14 are structured as the second ply 12, i.e. it includes five substantially horizontal wood-based strips 14.1, 14.2, 14.3, 14.4 and 14.5. The distribution of the strips is thus homogeneous along the panel. In this example, all the strips have the same shape, i.e. the same width and depth. The substantially vertical strips have the same length, just like the substantially horizontal strips also have the same length. When manufacturing the panel, the strips can thus be easily interchanged, which allows to save time

and money.

**[0038]** A panel according to the invention may include another distribution of the wood-based strips. In particular, it may include other numbers of plies and wood-based strips, as well as other orientations and sizes of wood-based strips. In terms of orientation, it is preferable that the wood-based strips of each ply are parallel to each other, on the one hand, and that the wood-based strips of each ply are not parallel to the wood-based strips of the neighboring plies. In addition, it is preferable that some of the strips be horizontal (compared to the orientation of the construction system), and that some other strips be vertical, although other orientations are possible depending on the function and position of the panel in the construction system.

**[0039]** In general, a panel according to the invention includes a series of at least three superimposed plies, at least two plies of which including a series of wood-based strips distributed along the ply, the wood-based strips of at least one ply being substantially vertically oriented in the construction system. The substantially vertical wood-based strips can then form stacks, which help load the bear for the panel. As detailed below, the number of plies and the number and distribution of wood-based strips in each ply of the panel will be determined according to the invention.

**[0040]** The width  $W_{10}$  and the height  $H_{10}$  of the panel may vary from one building to another. In particular, it may depend on the height of each floor. It may also depend on the capacities of the manufacturing tools. Above all, they depend on transportation and storage requirements, so that the panels can be transported and sorted in a proper manner from a plant to a construction site.

**[0041]** The distribution of the substantially vertical wood-based strips in "stacks" will help the determination of a panel according to the invention. It is thus preferable that at least some of the wood-based strips of different plies are aligned.

**[0042]** For the purpose of the invention, the strips can be any wood-based strips, so they can stem from any wood species, be it natural or as a wood-polymer composite (e.g. by impregnation of a wood element with a lactic acid water-based solution). The mechanical properties of the wood will then be taken into account when determined the load capacity of the panel.

**[0043]** From a mechanical standpoint, one can consider that such a panel is subject to three different forces. The first force is the "vertical compression line load", which represent the permanent load vertically imposed on the panel (e.g. the self-weight, the occupancy, the furniture...). The second force is the "wind load", which normal to the plane of the panel. The third force is the "racking force", which is horizontal.

**[0044]** Figures 2A, 2B, 2C and 2D show four other illustrative examples of a panel according to the invention. The panel 20 of Figure 2A is similar to the panel 10 of Figures 1A and 1B, i.e. it includes five plies, and the "odd" plies (i.e. plies 11, 13 and 15) have three substantially

vertical wood-based strips, such as strips 11.1, 11.2 and 11.3 for ply 11. The vertical strips of each ply are aligned in order to form the three same stacks 51, 52 and 53 as in panel 10. The difference with panel 10 is that in panel 20 the "even" plies (i.e. plies 12 and 14) have seven substantially horizontal wood-based strips, such as strips 12.1, 12.2, 12.3, 12.4, 12.5, 12.6 and 12.7 for ply 12. The distribution of the wood-based strips is homogenous along the panel. For the same height as panel 10, the density of horizontal strips is higher than in panel 10.

**[0045]** The panel 30 of Figure 2B is similar to the panel 10 of Figures 1A and 1B, i.e. it includes five plies, and the "even" plies (12 and 14) include five substantially horizontal wood-based strips, such as strips 12.1, 12.2, 12.3, 12.4 and 12.4 for ply 12. The difference with panel 10 is that in panel 30 the "odd" plies (i.e. plies 11, 13 and 13) have five substantially vertical wood-based strips, such as strips 11.1, 11.2, 11.3, 11.4 and 11.5 for ply 11. The vertical strips of each ply are aligned in order to form the five same stacks 51, 52, 53, 54 and 55. Again, the distribution of the wood-based strips is homogenous along the panel. For the same width as panel 10, the density of vertical strips is higher than in panel 10, so it can bear more weight and load that panel 10.

**[0046]** The panel 40 of Figure 2C is an example of inhomogeneous distribution of the wood-based strips along the panel. It still includes five plies, and the "even" plies (12 and 14) include five substantially horizontal wood-based strips, such as strips 12.1, 12.2, 12.3, 12.4 and 12.4 for ply 12. The panel 40 includes three stacks 51, 52, and 53, but in an inhomogeneous manner. The stack 51 is made of strip 11.1 from first ply, then two strips next to each other of the third ply, then two strips next to each other of the fifth ply. The stack 52 is made up of strips 11.2 and 11.3 of the first ply, two strips of the third ply and two strips of the fifth ply, the strips of each ply being next to each other. The stack 53 is made up of strips 11.4 and 11.5 of the first ply (next to each other), the one strip of the third ply and one strip of the fifth ply. The stacks have thus more wood and can bear more weight and load. The shape of the ending stacks 51 and 53 allows for a specific connection with neighboring panels (if the ending stacks of neighboring panels have a shape that is complementary to the ones of stacks 51 and 53).

**[0047]** The panel 50 of Figure 2D is another example of inhomogeneous distribution of the wood-based strips along the panel, this time in order to provide an opening 16 in the panel. There are four stacks. The stack 51 is on the left of the opening 16, while the three other stacks 52, 53 and 54 are on the right of the opening 16. The stacks 51, 53 and 54 are made up of one strip by "odd" ply, while the stack 52 is made up of two strips next to each other by "odd" ply. Horizontally, each of the "even" plies 12 and 14 includes one horizontal strip (such as strip 12.5) below the opening 16, and four horizontal strips (such as strips 12.1, 12.2, 12.3 and 12.4) over the opening 16. These four horizontal strips form a lintel 17

for this panel.

**[0048]** In the examples of Figures 2C and 2D, two strips next to each other can be replaced by one single and larger strip. But as mentioned above, for manufacturing, it is preferable that all strips have same width so they can all be interchanged.

**[0049]** The space between the wood-based strips can be filled with insulation material. In details, at least one of the plies include insulation elements interleaved between at least some of the wood-based strips. In the example of Figures 3A to 3D, the panel 60 is fully filled with insulation elements. The successive figures allow to see the different insulation elements within the panel 60. On Figures 3A and 3D, external insulation elements 21 and 24 are disposed on both sides of the panel. On Figure 3B, we can see horizontal thermal elements 22.1, 22.2, 22.3 and 22.4 interleaved between horizontal strips 12.1, 12.2, 12.3, 12.4 and 12.5. On Figure 3C, we can see vertical sound-proofing fiber elements 23.1, 23.2, 23.3 and 23.4 interleaved between vertical strips 11.1, 11.2, 11.3, 11.4 and 11.5.

**[0050]** In terms of manufacturing, it is preferable that all insulation elements of a same type (thermal or sound-proofing elements) have the same width. It is thus preferable that the distances P1 and P2 between the strips are multiples of a given length, preferably the nominal width of the insulation elements. By doing so, the insulation elements can be simply interchanged during manufacturing.

**[0051]** The invention can be used to design and manufacture a construction system such as the house 100 of Figure 5. This construction system includes a set of levels (or storeys) 110, 120 and 130. As can be seen on Figures 5 and 6, each level of the construction system 100 is made up of several structural elements. The first level 111 includes a floor 111, a ceiling 112, and load-bearing walls 113, 114 and 115. In the invention, at least one of the load-bearing walls (here, at least walls 113, 114 and 115) includes a wood-based load-bearing panel determined according to the invention. Preferably, all the load-bearing walls (i.e. walls 113, 114 and 115 and all the other walls) of one of the levels (here, the first level 11) include wood-based load-bearing panels according to the invention.

**[0052]** Reference is made to Figure 4, which shows a diagram of an example of a method for providing a wood-based load-bearing panel according to the invention.

**[0053]** In step 201, the load-bearing walls of the construction system 100 (including walls 113, 114 and 115) are split into a set of wood-based load-bearing panels. In the example of Figure 6, given that the walls 113, 114 and 115 have a small width, one panel is enough for each wall. Larger walls may be split into a set of panels so that the width and height of the panels meet transportation and storage requirements (as well as optionally other criteria such as the capacities of manufacturing tools). The result of such a split on the whole construction system 100 into a series of panels is visible on Figure 7, which

is a geometrical modelling of the building. The resulting panels 113.1, 114.1 and 115.1 for walls 113, 114 and 115 are visible on Figure 8, where one can see the interaction between the panels 113.1, 114.1 and 115.1, on one hand, and the floor 111 and the ceiling 112, on the other hand.

**[0054]** In step 202, a position is allocated to the wood-based load-bearing panels in the construction system 100. For instance, the position of panel 115.1 can be noted  $P_{115.1}$ . This position is important for the invention, since the structure of the panel 115.1 will be determined below in accordance with its position  $P_{115.1}$  in the building.

**[0055]** In step 203, a panel template such as panel 10 is provided. By "template", the invention refers to an example of panel which can be used as a starting point to determine the appropriate panel according to the invention.

**[0056]** A more detailed view of panel template 10 is given on Figure 10. Just like the one on Figures 1A and 1B, the panel template 10 used as a starting point is made up of a series of five superimposed plies, where the "odd" plies include three vertical wood-based strips so that the strips of different plies are aligned with each other, and the "even" plies include five horizontal wood-based strips. The panel template thus includes three stacks 51, 52 and 53.

**[0057]** Then a loop of steps 204 to 209 is implemented. The purpose of this loop is to get at least one variation which has a load-bearing capacity F2 being comprised between 1 and 4 times the required vertical force F1 that this variation must bear.

**[0058]** In step 205, a variation of the panel template is generated (or determined) by varying the number of plies and the number and distribution of the wood-based strips in each ply of the panel template 10. This variation can be performed by varying at least one parameter of the panel template, as indicated in step 204.

**[0059]** Examples of variations 70, 80 and 90 are shown on Figures 10A, 10B and 10C. The width  $W_{10}$  and height  $H_{10}$  of the variations 70, 80 and 90 are equal to the ones of the panel template 10. Variation 70 differs from panel template 10 by the addition of one stack, so that it now includes four stacks instead of three. This means that there is a higher density of stacks, but that at the same time there is more wood material. Then variation 80 includes five stacks, i.e. an even higher density of stacks. Variations 70 and 80 both have a homogenous distribution of stacks along the panel. Variation 90 also includes five stacks, but here the stacks are distributed in an inhomogeneous manner, the second and third stacks and then the fourth and fifth stack being closer to each other. Such variation allows to strengthen the panel in certain zones of the panel, in particular where two close stacks are present. Other variations may also be contemplated. For instance, if the thickness of the wall does not need to be constant, the number of plies may also vary (the more the plies, the more load it can bear).

**[0060]** In one embodiment, the variations 70, 80 and 90 can be determined within a set of pre-determined panel designs such as designs 20, 30, 40 and 50, based on a range of parameters. These parameters can be the number of plies, and the number, the width and the position of the wood-based strips in each ply. This set of pre-determined panel designs allows to manufacture panels in a more cost-efficient way, notably because less expensive tools can be used. However, in other embodiments, the structure of the panels can be tailored to each situation, i.e. with no set of pre-determined panel designs.

**[0061]** In step 206, for a variation such as variation 70, the required vertical force  $F1_{70}$  that the variation must bear at the position  $P_{115.1}$  of the panel 115.1 within the construction system 100 is calculated.

**[0062]** In another embodiment, the vertical wood-based strips being preferably gathered into a series of stacks (like stacks 51, 52...), the forces F1 and F2 are calculated for each stack. In details, for each stack 51, 52, 53..., the local required vertical force  $F1_{51}$ ,  $F1_{52}$ ,  $F1_{53}$ ... that this stack must bear at its position in the panel within the construction system is calculated. Also, for each stack, the local load-bearing capacity  $F2_{51}$ ,  $F2_{52}$ ,  $F2_{53}$ ... of this stack 51, 52, 53... is also calculated.

**[0063]** The vertical force  $F1_{70}$  that the variation 70 must bear can be determined based on a distribution of a set of forces applied on the ceiling 112 right above the panel 115.1. To calculate F1 for panel 115.1, template 10 and variations 70, 80 and 90, the elements of the building, especially the ceiling above the panel, is modelled as a grid, i.e. as a set of points distributed along the ceiling, on each of which a vertical force is applied. Each point of the grid is subject to a force. The value differs from one point to another, depending on the structural environment of the building.

**[0064]** The vertical force F1 depends on the position of the panel in the building. For instance, from a level to another, top to bottom, the vertical forces on each wall increase. The same applies to horizontal loads, since the lower levels bind the higher levels to the foundations of the building, and since wind forces increase with altitude. The location within a given level also influence the vertical force, notably because of the absence or presence of one part of the structure right above, or because of local particularities.

**[0065]** The vertical force F1 can be calculated for each variation of the panel, and alternatively for each stack of each variation of the panel. The principle for calculating F1 is based on Parametric Design and Finite Element Analysis (FEA), which are part of the common general knowledge of the person skilled in the art.

**[0066]** In the example of posts gathered as "stacks", each stack can be modelled as an equivalent vertical beam, the mechanical properties of which depend on the load-bearing section of the panel. Each beam includes one top end bound to the ceiling 112, and one bottom end bound to the floor 111. Both ends are rotationally

locked with a mechanical spring whose constant stiffness depends on the shear stiffness in the vertical plane of the panel, which is given by the constitutive elements of the beams, notably the type and number of connections between the strips, the wood species, the section of the strips, as well as the overall dimension of the load-bearing section of the panel.

**[0067]** If the calculation is based on a stack-by-stack approach (like on Figure 10), the calculation of F1 can be performed for each stack ( $F1_{51}$ ,  $F1_{52}$ ,  $F1_{53}$ ...). But if the calculation is based on panel-by-panel approach, the calculation of F1 can be made for each stack, then an average of all forces F1 will be calculated for the whole panel.

**[0068]** In step 207, for variation 70, the load-bearing capacity  $F2_{70}$  of the variation is also calculated. Alternatively, the load-bearing capacity of the variation of each stack  $F2_{51}$ ,  $F2_{52}$ ,  $F2_{53}$ ... can be calculated. The load-bearing capacity depends on the structure of the variation. It can be calculated as a function of some of the parameters of the variation, with an analytic modelling of the panel, which can be based on standard specifications and/or on mechanical experiments.

**[0069]** As an example, F1 and F2 can be calculated by applying the design rules of Eurocode EN1995-1-1, Annex C, "Built-up columns". The built-up columns can be modelled for each stack of the panel (or variation). The content of Eurocode EN1995-1-1 is incorporated by reference. Annex C can be combined with Section 6.3.2 of this document, "Columns subjected to either compression or combined compression and bending", which allows to further account for both in-plane and out-of-plane bending forces for the design of the panel. In particular, the skilled person can use Equations 6.23 and 6.24. In Equation 6.23, the first parameter is:

$$\frac{\sigma_{c,0,d}}{k_{c,y} \times f_{c,0,d}} \leq 1$$

This first parameter corresponds to F1/F2, where F1 and F2 are:

$$F1 = \frac{\sigma_{c,0,d}}{A}$$

$$F2 = \frac{k_{c,y} \times f_{c,0,d}}{A}$$

Where A is the cross section area of the built-up columns,  $\sigma_{c,0,d}$  is the vertical compression stress (or force applied on surface A),  $f_{c,0,d}$  is the material compression strength, and  $k_{c,y}$  is a buckling load factor.

**[0070]** The skilled person knows how to calculate F1 and F2 based on Eurocode EN1995-1-1 and on his

knowledge on Finite Element Analysis (FEA). He also knows how to use other methods in order to obtain identical or similar values of F1 and F2.

**[0071]** In particular, the skilled person knows how to calculate F1 for one panel. To calculate the (local) vertical force  $F1_{S1}$ ,  $F1_{S2}$ ... on each stack, the skilled person will know how to model each stack as a vertical column and how to use linear loads.

**[0072]** In steps 206 and 207, the calculation is made on each stack 51, 52 and 53 of the variation, so three forces F1 and F2 are calculated. In another embodiment, a global calculation is made for the panel, so only one force F1 and F2 is calculated.

**[0073]** In step 208, a parameter F3 depending on F1 and F2 is generated. This parameter F3 can be the difference between F2 and F1, so it gives a "load-bearing surplus". Alternatively, F3 can be replaced by F4 which is the ratio between F2 and F1, so it gives a "load-bearing margin". F3 and/or F4 can help determining whether the force F2 is comprised between 1 and 4 times the force F1. It also helps selecting the most appropriate variation, i.e. the variation with the better F3 value.

**[0074]** In the embodiment where the calculation is made for each stack, the method includes the generation, for each stack, of the difference  $D_{51}$ ,  $D_{52}$ ,  $D_{53}$ ... between the local load-bearing capacity of the stack  $F2_{51}$ ,  $F2_{52}$ ,  $F2_{53}$ ... and the local required vertical force that the stack must bear  $F1_{51}$ ,  $F1_{52}$ ,  $F1_{53}$ ... The difference D is indicative of the load-bearing surplus of the stack. In that case, it is determined whether or not the criteria F2 being comprised between 1 and 4 times the force F1 is met. To do so, it is determined if the capacity  $F2_{51}$ ,  $F2_{52}$ ,  $F2_{53}$ ... is comprised between 1 and 4 times the local required vertical force that the stacks must bear  $F1_{51}$ ,  $F1_{52}$ ,  $F1_{53}$ ... for a majority of stacks 51, 52... In another embodiment, it is determined if the capacity  $F2_{51}$ ,  $F2_{52}$ ,  $F2_{53}$ ... is comprised between 1 and 4 times the local required vertical force that the stacks must bear  $F1_{51}$ ,  $F1_{52}$ ,  $F1_{53}$ ... for all stacks.

**[0075]** In step 209, it is determined if it is necessary to implement another variation of the panel template to achieve the criteria of the force F2 being comprised between 1 and 4 times the force F1 for at least one variation of the panel template. If the answer is "Yes", the loop 204-209 is performed another time, for instance to generate variation 80 or 90. If the answer is NO, the loop 204-209 is over.

**[0076]** In different embodiments, different criteria can be applied. For instance, if at least one variation meets this criteria, the answer to step 209 can be "No". But in other instances such as the one of Figure 4, the answer will be "No" only if a given number of variations meeting this criteria have been generated.

**[0077]** Once the loop 204-209 is over, here because a given number of suitable variations have been determined, in step 210, one of the variations is selected.

**[0078]** The selection can be based on different criteria. In one embodiment, a value indicative of the load-bearing

surplus of each variation (or of each stack of each variation) is generated. Then the variation with the lowest value is selected.

**[0079]** Alternatively, the neighboring environment of the panel can be taken into account. To do so, several panels of level 110, such as panels 113.1, 114.1 and 115.1 are considered. For each of these panels, a panel template and then at least one variation of this panel template according to the invention are determined. A set of variations can be made up of one variation by panel. An "inefficiency function" F can be generated, which is indicative of the overall load-bearing capacity surplus of the set of variations. For instance, F sums up all the load-bearing capacity surplus of all considered variations (or of all stacks of all considered variations), but F can also be formulated in different ways as long as it is indicative of the overall load-bearing capacity surplus of the set of variations.

**[0080]** Figure 11 is an example of table showing the different forces calculated on each of the stacks for different variations of the panel template of Figure 9. The first five lines ("69" to "73") concern the five stacks of variation 80 (with five stacks). The four last lines ("74" to "77") concern four stacks of variation 70 (with four stacks). The first column 301 gives values of vertical force F1 for each stack. The second column 302 gives values of load-bearing capacity F2 for each stack. The third column 303 gives the values F3 of the differences between F2 and F1, so it is indicative of the "load-bearing surplus" of each stack. Finally, the fourth column 304 gives the values of the function F4, which here is the ratio between F2 and F1, and which is indicative of the "load margin" of each stack. For instance, if the value of F4 is 5, this means that the stack is 5 five times more resistant than necessary. The higher the margin, the less efficient the design, and the more oversized the structure.

**[0081]** In this example, we can see that the stacks are homogeneously distributed along variations 70 and 80, since the values of F2 are the same for each stack of the same variation. It is because F2 only depends on the structure of the variation of the panel template. The vertical forces F1 may differ from one stack to another because of the weight and load imposed by the ceiling right above the stack, given the position of the stack in the building. Indeed, F1 takes into account the position of the stack (and the panel) within the construction system.

**[0082]** Given that here F1 and F2 are calculated for each stack, the variation may be considered as appropriate depending on if the majority of stacks has a value F4 comprised between 1 and 4, or whether all of them have F4 comprised between 1 and 4. In that case, one can see that no stack of variation 70 is comprised between 1 and 4, so it is not considered as a proper variation of the panel template. But variation 80 has three out of four stacks having F4 between 1 and 4, so it can be considered as a proper variation of the panel template. The same calculation can be made for other variations, so as to get the most appropriate variation of the panel tem-

plate.

**[0083]** In step 211, the selected variation is attributed to panel 115.1. This means that the panel 115.1 can be manufactured from the determined variation 70. It will then be positioned onsite in the construction system 100 at position  $P_{115.1}$ .

**[0084]** In step 212, there is a possibility to implement the method for other panels of the construction system 100, or possibly to all load-bearing panels. If the answer is "No", steps 203-211 are performed for other panels. If the answer is "Yes", all the panels have been determined and the process is over at step 213.

**[0085]** The resulting construction system 100 is shown on Figure 12. In comparison to Figure 6, the quantity of wood has been adapted for each panel so that a relevant amount of wood was used in order to ensure the security of the construction system in terms of standard requirements, on one hand, and to avoid using an unnecessary amount of wood which leads both to waste wood and to increase overall costs.

**[0086]** In other words, the load-bearing panels of the construction system 100 are more efficient. At the same time, because of their CLT structure, they still present the advantage that they can be prefabricated in a tailored, serial and easy manner.

## Claims

1. Method for providing a wood-based load-bearing panel (113.1, 114.1, 115.1) for use in the assembling of a construction system (100), wherein the construction system (100) includes a set of levels (110, 120, 130) which include structural elements (111, 112, 113, 114, 115), wherein the method includes:

- Allocating a position ( $P_{115.1}$ ) to the wood-based load-bearing panel (115.1) within the construction system (100);

- Providing a panel template (10), which includes a series of at least three superimposed plies (11, 12, 13, 14, 15), at least two plies (11, 12) of which including a series of wood-based strips (11.1, 11.2, 11.3, 12.1, 12.2, 12.3, 12.4, 12.5) distributed along the ply (11, 12), the wood-based strips (11.1, 11.2, 11.3) of at least one ply (11) being substantially vertically oriented within the construction system (100);

- Determining at least one variation (70, 80, 90) of the panel template (10), based on a variation of parameters such as any of the number and section of plies and the number and distribution of wood-based strips in each ply of the panel template (10), so that the load-bearing capacity ( $F_{270}$ ,  $F_{251}$ ,  $F_{252}$ ,  $F_{253...}$ ) of the variation (70) is comprised between 1 and 4 times the required vertical force ( $F_{170}$ ,  $F_{151}$ ,  $F_{152}$ ,  $F_{153...}$ ) that the variation (70) must bear at the position ( $P_{115.1}$ )

of the wood-based load-bearing panel (115.1) within the construction system (100);

- Selecting one of the at least one variation (70, 80, 90); and

- Manufacturing the panel (115.1) from the selected variation (70).

2. The method according to claim 1, wherein the step of determining at least one variation of the panel template (70, 80, 90) further includes:

- Starting from the panel template (10);

- Varying parameters of the panel template (10) such as the number and section of plies (11, 12...), and the number, width and position of the wood-based strips (11.1, 11.2...) in each ply (11, 12...);

- Determining at least two variations (70, 80, 90) of the panel template (10) from at least two variations of the parameters of the panel template (10);

- Determining the load-bearing capacity of the variations ( $F_{270}$ );

- Determining the required vertical force ( $F_{170}$ ) that the variation of the panel template (70) must bear at the position ( $P_{115.1}$ ) of the wood-based load-bearing panel (115.1) within the construction system (100); and

- Comparing that load-bearing capacity ( $F_{270}$ ) with the required vertical force that the variation of the panel template must bear ( $F_{170}$ ).

3. The method according to claim 1 or 2, wherein the step of determining at least one variation of the panel template (70, 80, 90) further includes:

- Gathering substantially vertically oriented wood-based strips (11.1, 11.2...) into a series of stacks (51, 52, 53...);

- Determining the local load-bearing capacity ( $F_{251}$ ,  $F_{252}$ ,  $F_{253...}$ ) of each stack (51, 52, 53...); and

- Determining the local required vertical force ( $F_{151}$ ,  $F_{152}$ ,  $F_{153...}$ ) that each stack (51, 52, 53...) must bear at its position ( $P_{51}$ ,  $P_{52}$ ,  $P_{53...}$ ) in the wood-based load-bearing panel (115.1) within the construction system (100); and

- Comparing, for each stack, the local load-bearing capacity ( $F_{251}$ ,  $F_{252}$ ,  $F_{253...}$ ) and the local required vertical force that the stack must bear ( $F_{151}$ ,  $F_{152}$ ,  $F_{153...}$ ).

4. The method according to claim 3, wherein the at least one variation of the panel template (70, 80, 90) is determined so that the local load-bearing capacity of the stacks ( $F_{251}$ ,  $F_{252}$ ,  $F_{253...}$ ) is comprised between 1 and 4 times the local required vertical force that the stacks must bear ( $F_{151}$ ,  $F_{152}$ ,  $F_{153...}$ ) for a

majority of stacks (51, 52, 53...).

5. The method according to claim 4, wherein the at least one variation of the panel template (70, 80, 90) is determined so that the local load-bearing capacity of the stacks ( $F_{251}$ ,  $F_{252}$ ,  $F_{253}$ ...) is comprised between 1 and 4 times the local required vertical force that the stacks must bear ( $F_{151}$ ,  $F_{152}$ ,  $F_{153}$ ...) for all stacks (51, 52, 53...).
6. The method according to any of claims 1 to 5, wherein the step of selecting one of the at least one variation (70, 80, 90) further includes:
  - Generating for each variation (70, 80, 90), an inefficiency function (F) which is indicative of the load-bearing capacity surplus of the variation; and
  - Selecting the variation with the lowest value of inefficiency function (F).
7. The method according to any of the preceding claims, wherein the at least one variation of the panel template (70, 80, 90) is determined within a set of pre-determined panel designs (20, 30, 40, 50), based on a range of parameters such as the number and section of plies (11, 12...), and the number, width and position of the wood-based strips (11.1, 11.2...) in each ply (11, 12...).
8. The method according to any of the preceding claims, wherein the required vertical force ( $F_{170}$ ) that at least one variation of the panel template (70, 80, 90) must bear is determined based on a distribution of a set of forces applied on the ceiling (112) right above the panel (115.1).
9. The method according to any of the preceding claims, wherein at least one ply (11, 12...) of the panel template (60) also includes a set of insulation elements (22.1, 22.2..., 23.1, 23.2...) interleaved between at least some of the wood-based strips (11.1, 11.2..., 12.1, 12.2...).
10. The method according to claim 9, wherein the values of the distances ( $P_1$ ,  $P_2$ ) between the substantially vertically oriented wood-based strips (11.1, 11.2...) are multiples of a given length, in particular the nominal width of available insulation elements.
11. The method according to any of the preceding claims, wherein the wood-based strips (11.1, 11.2...) of each ply (11) are parallel to each other, and the wood-based strips (11.1, 11.2...) of each ply (11) are not parallel to the wood-based strips (12.1, 12.2...) of the neighboring plies (12).
12. A wood-based load-bearing panel (115.1) obtaina-

ble with the method according to any of claims 1 to 11, wherein the panel (115.1) includes a series of at least three superimposed plies (11, 12, 13, 14, 15), at least two plies (11, 12) of which including a series of wood-based strips (11.1, 11.2, 11.3, 12.1, 12.2, 12.3, 12.4, 12.5) distributed along the ply (11, 12), the wood-based strips (11.1, 11.2, 11.3) of at least one ply (11) being substantially vertically oriented within the construction system (100).

13. The wood-based load-bearing panel (115.1) according to claim 12, wherein the width ( $W_{10}$ ) and height ( $H_{10}$ ) of the panel (115.1) depend on transportation and storage requirements.
14. A construction system (100), comprising a set of levels (110, 120, 130), which include a floor (111), a ceiling (112) and load-bearing walls (113, 114, 115), wherein at least one of the load-bearing walls (115) includes a wood-based load-bearing panel (115.1) according to any of claims 12 to 13.
15. The construction system (1) according to the claim 14, wherein all the load-bearing walls (113, 114, 115) of one of the levels (11) include wood-based load-bearing panels (115.1) according to any of claims 12 to 13.

Figure 1A

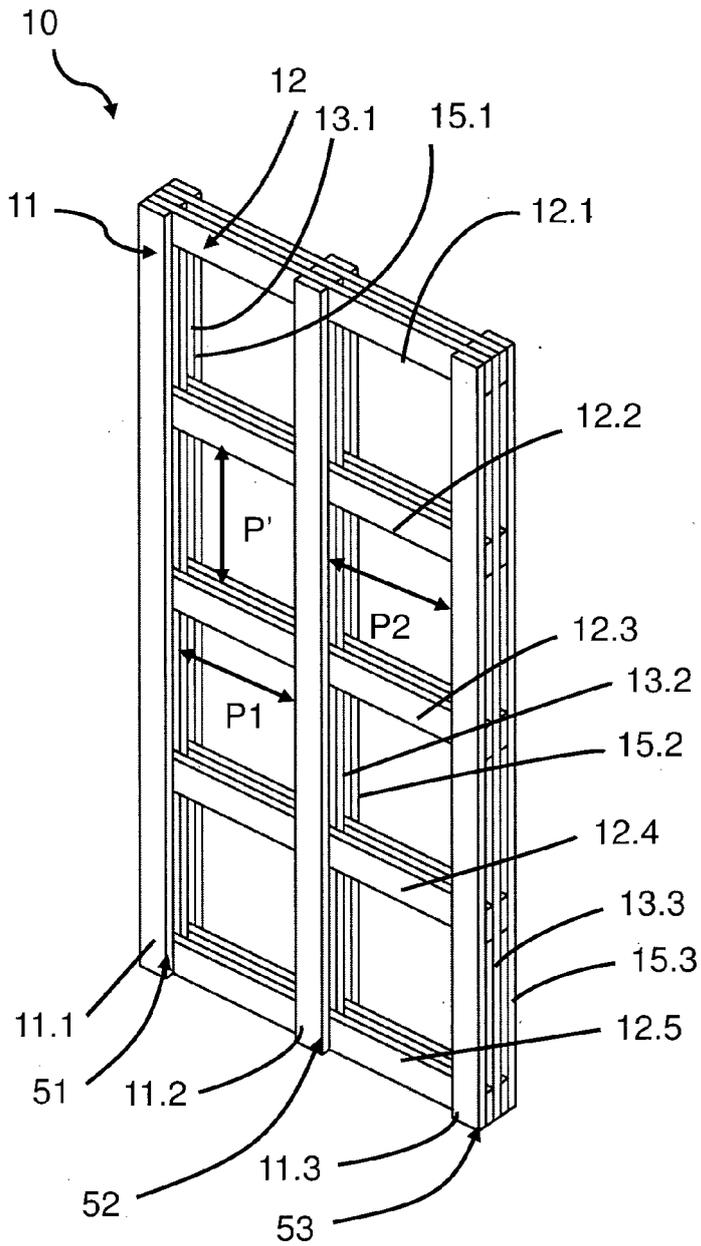


Figure 1B

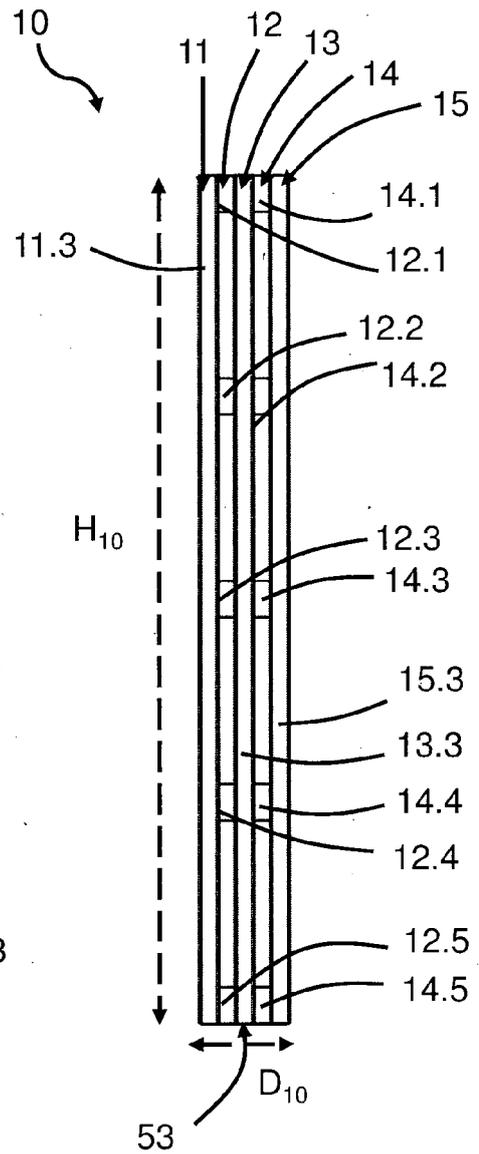


Figure 2A

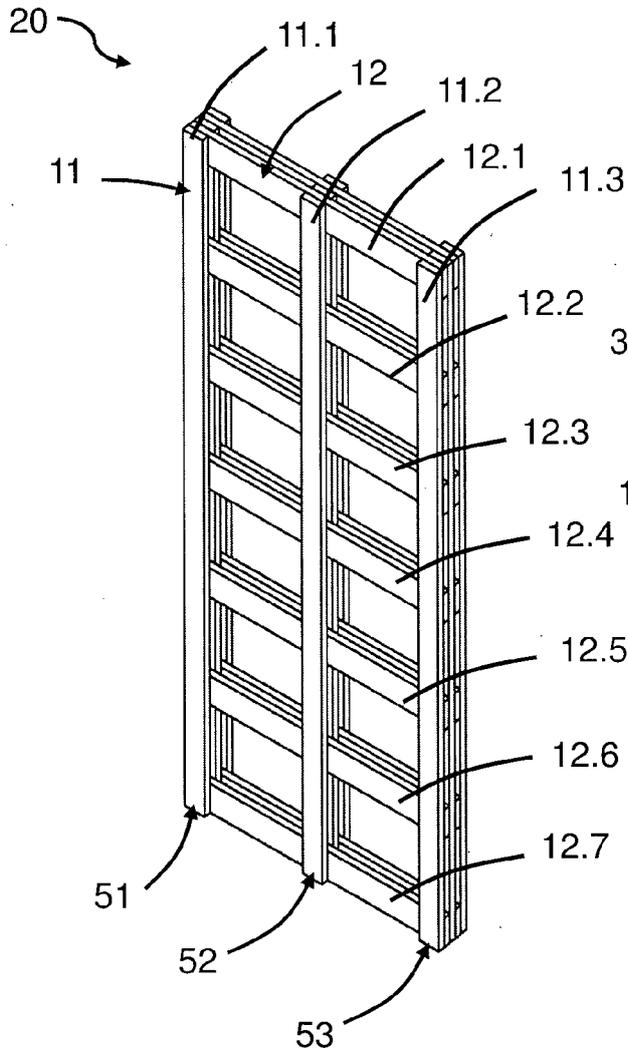


Figure 2B

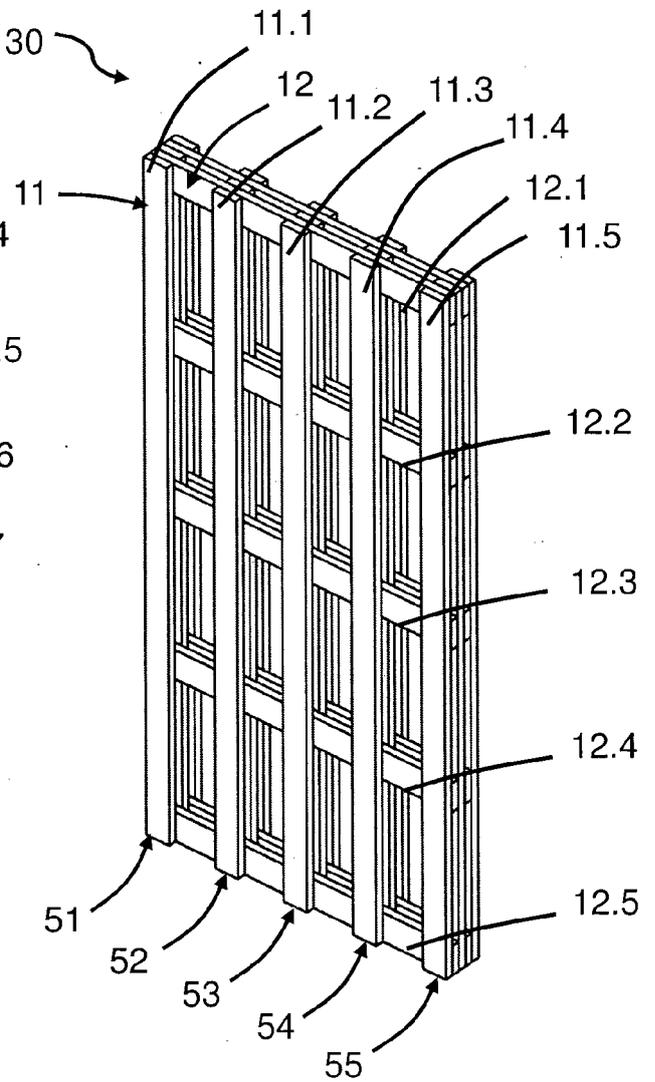


Figure 2C

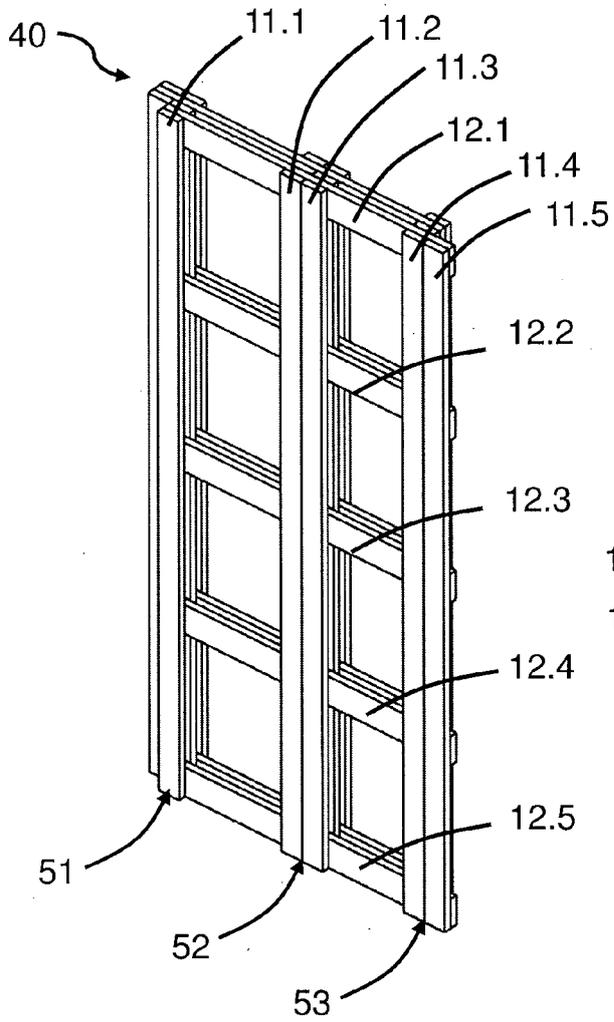


Figure 2D

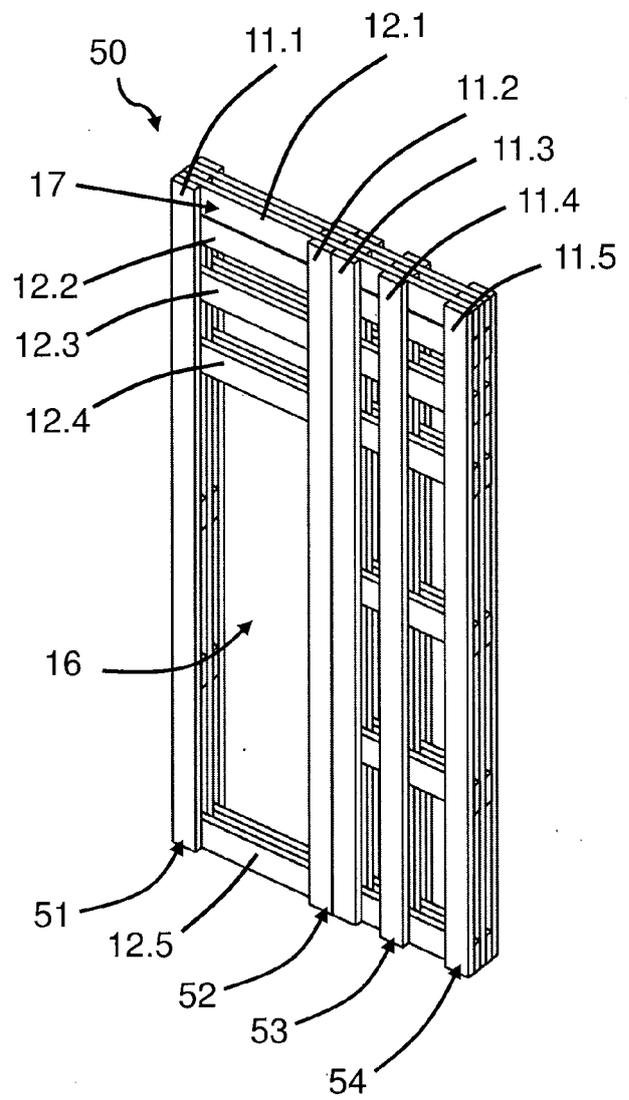


Figure 3A

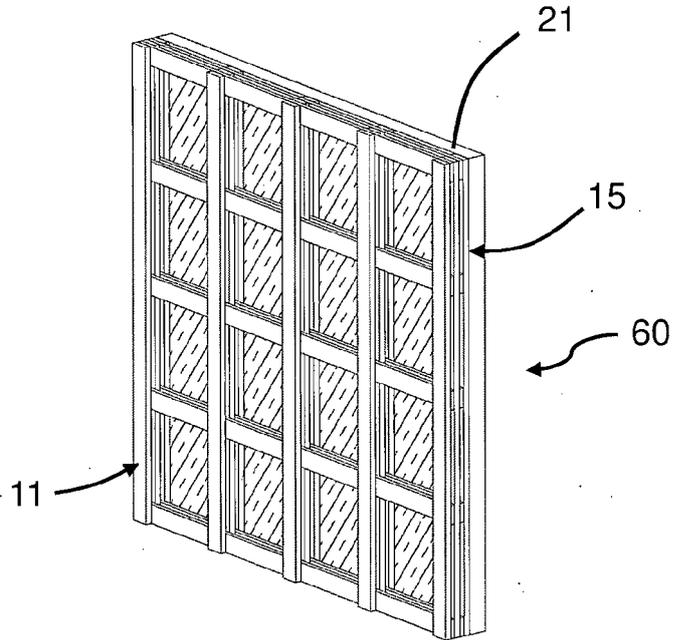


Figure 3B

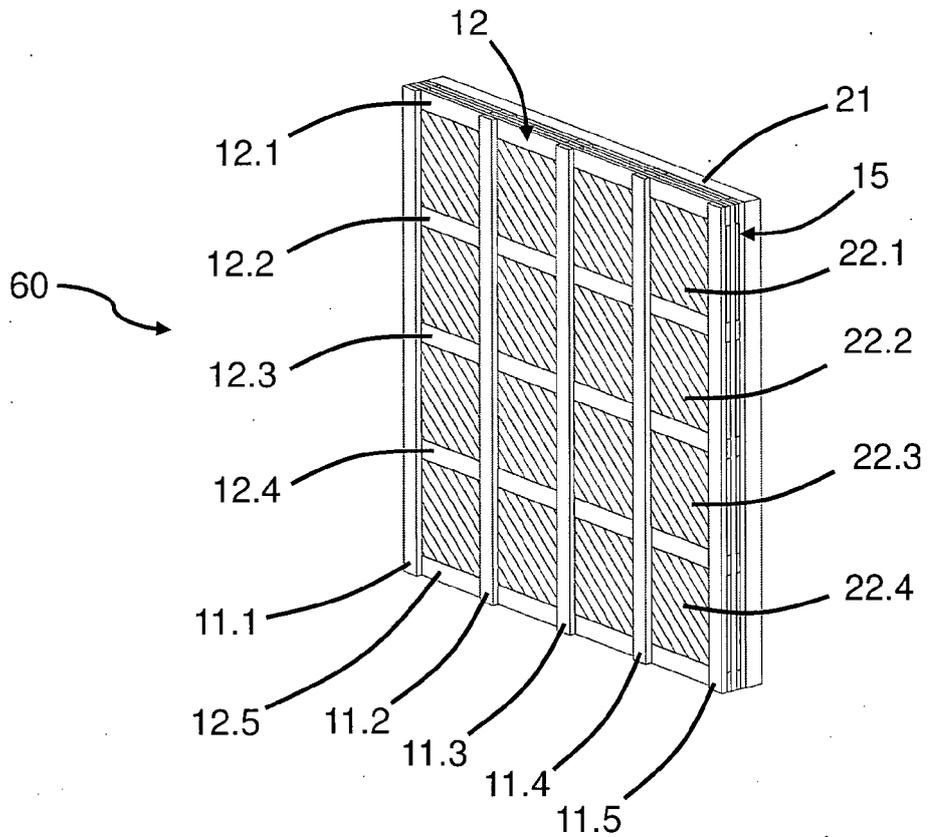


Figure 3C

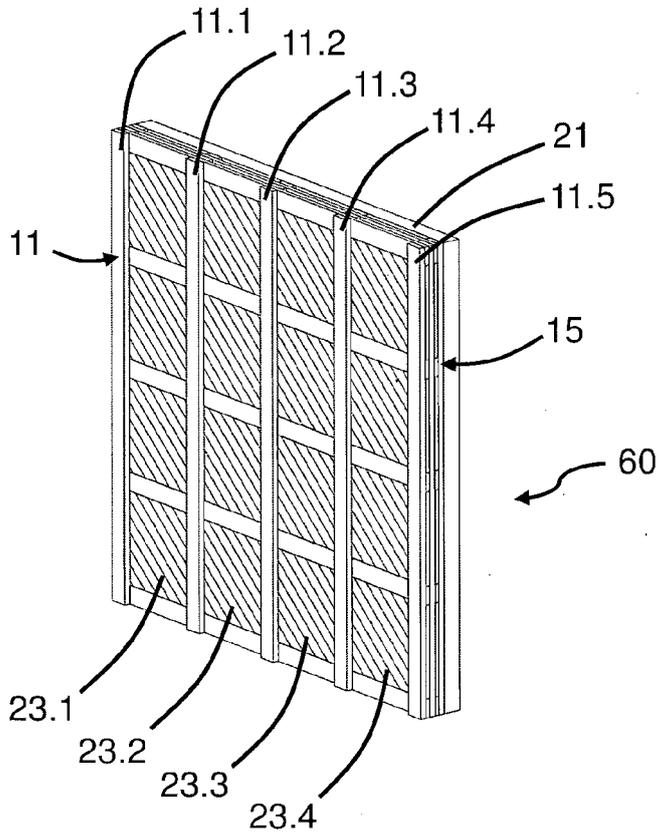


Figure 3D

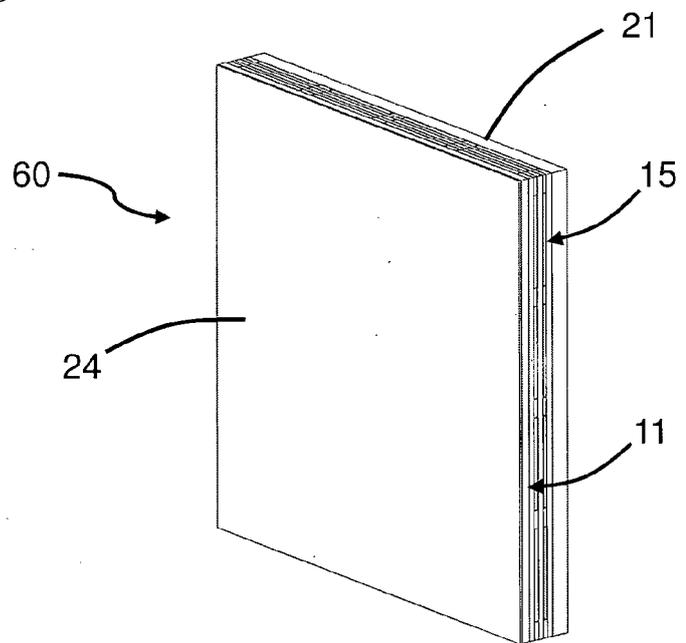


Figure 4

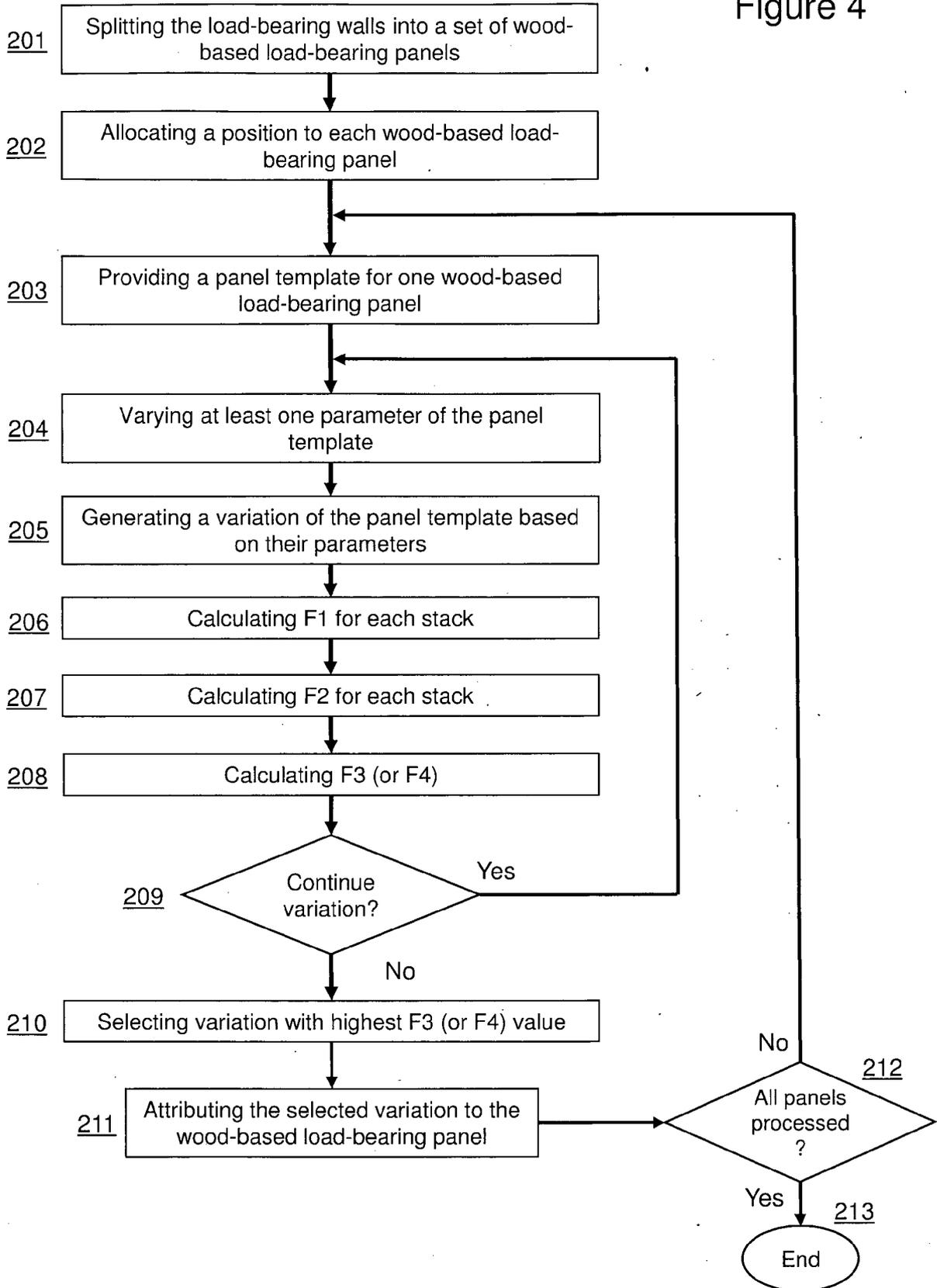


Figure 5

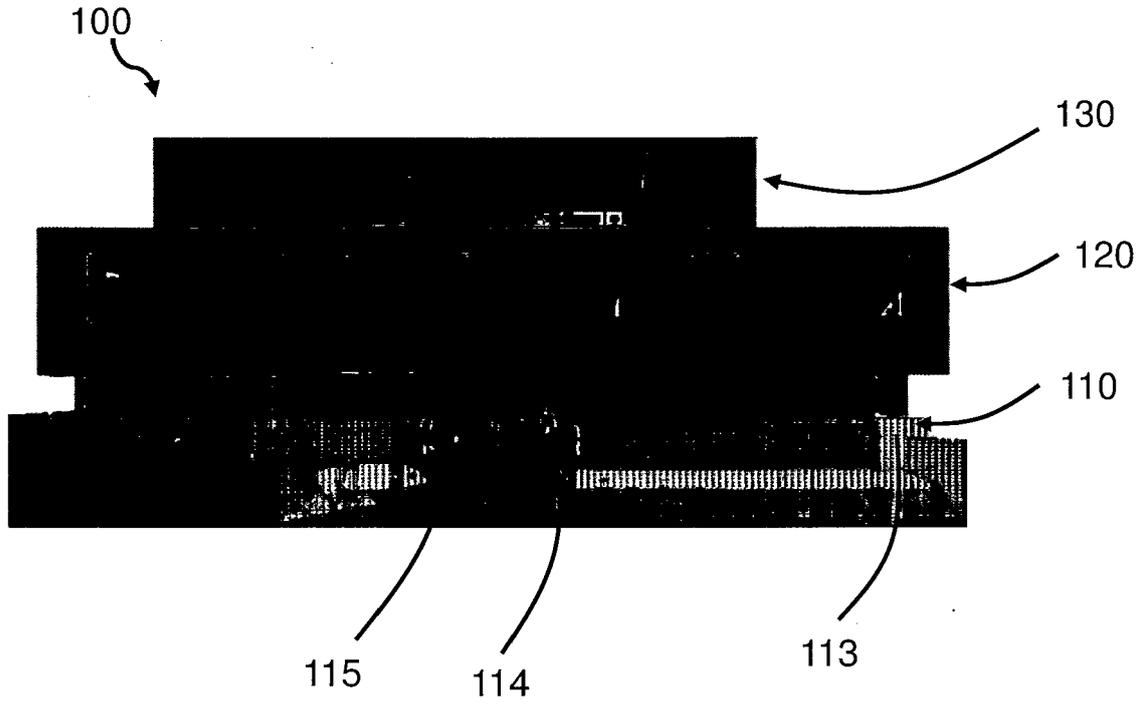


Figure 6

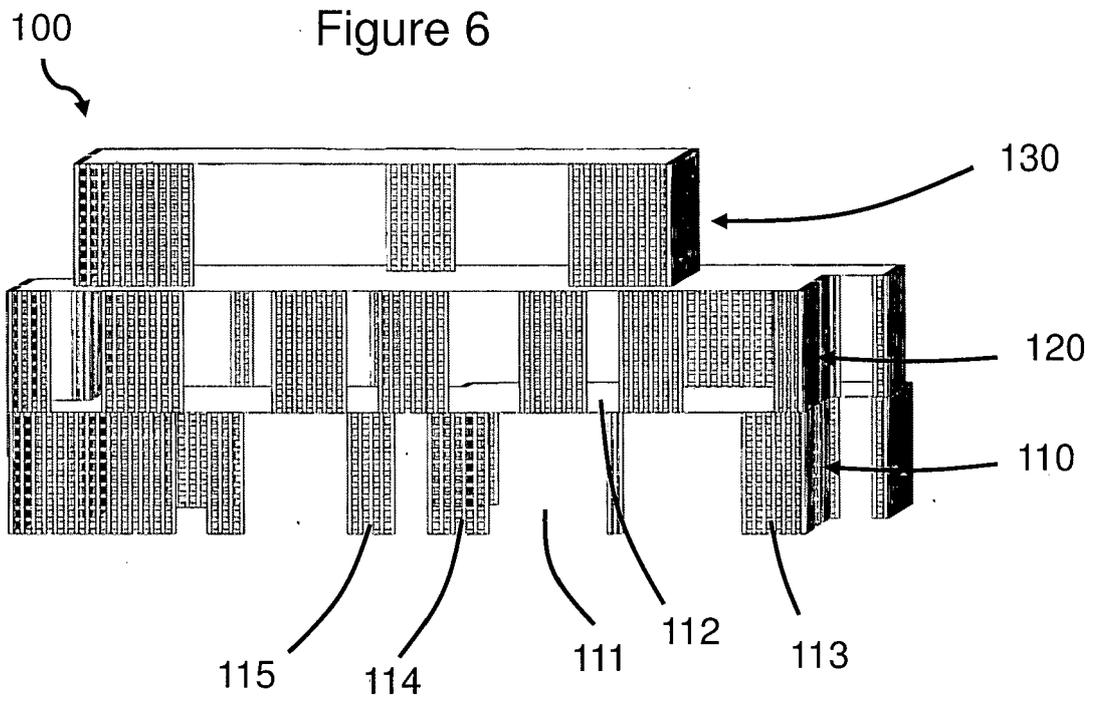


Figure 7

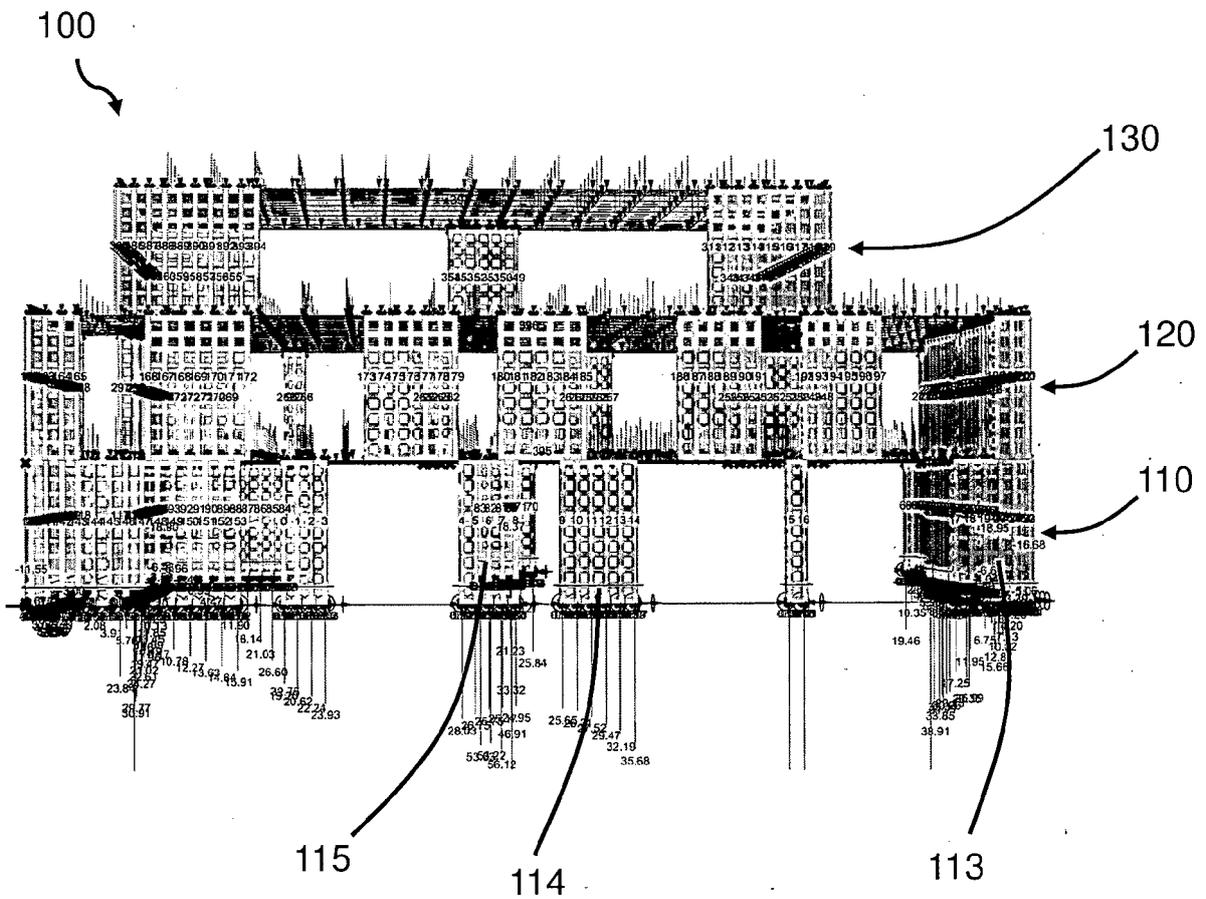


Figure 8

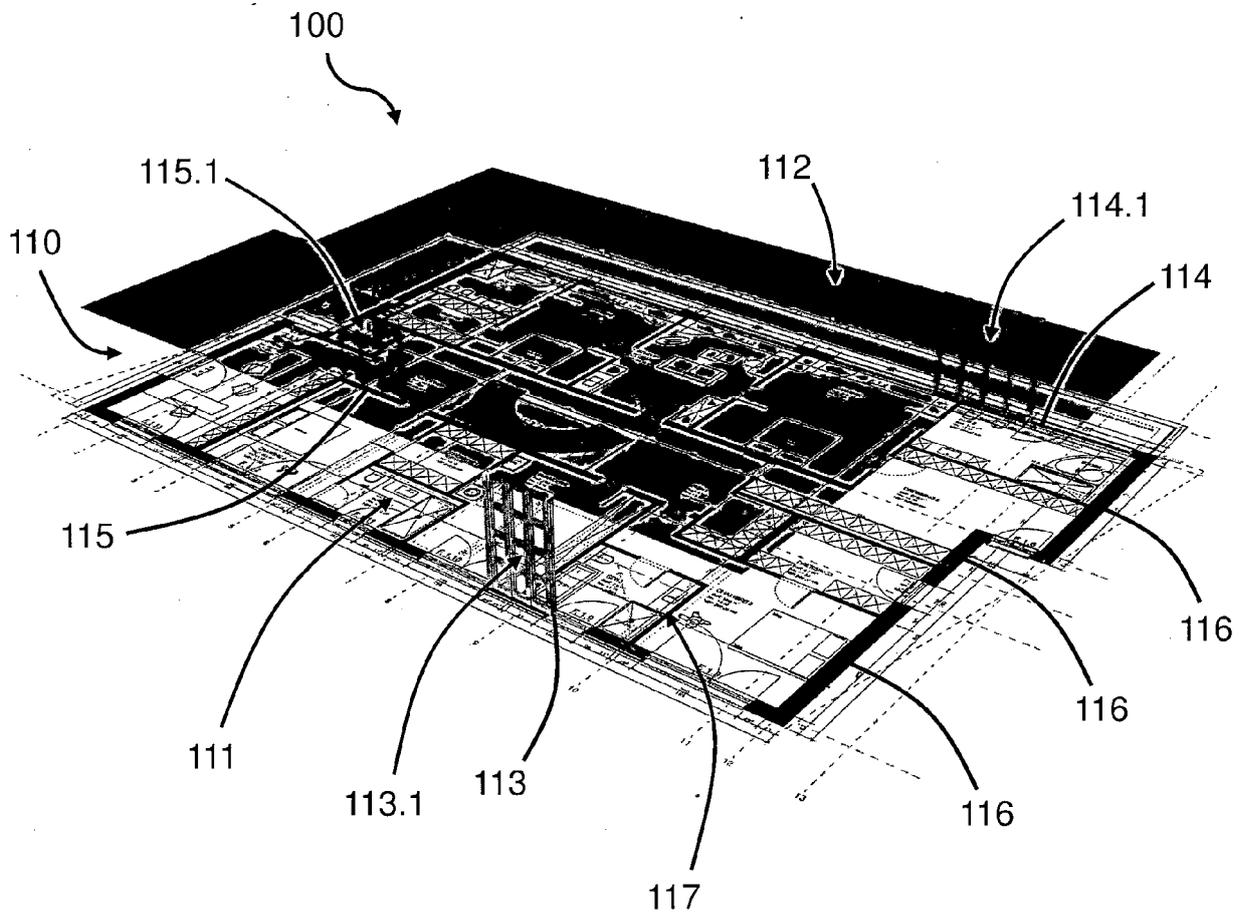


Figure 9

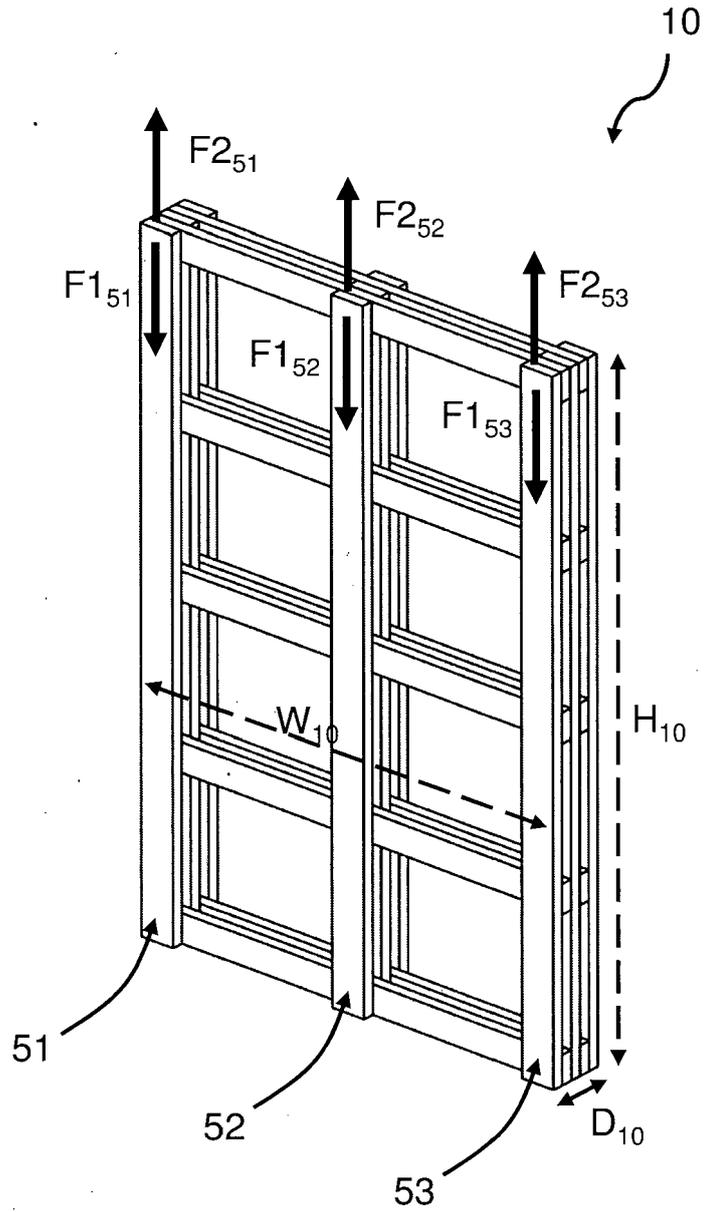


Figure 10A

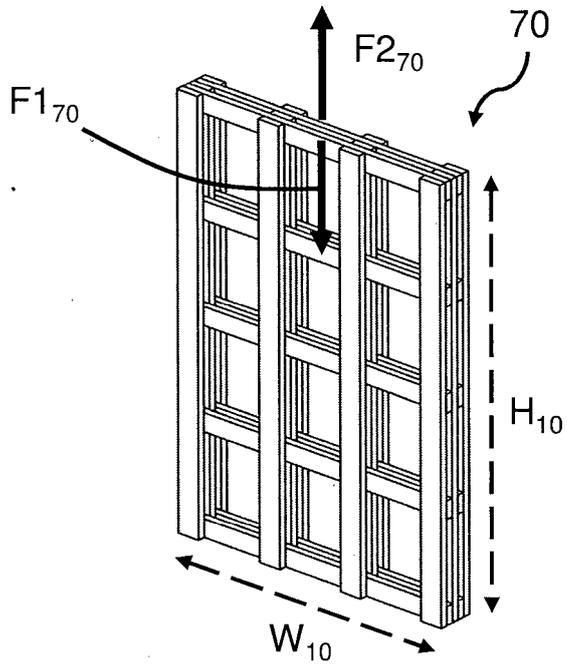


Figure 10C

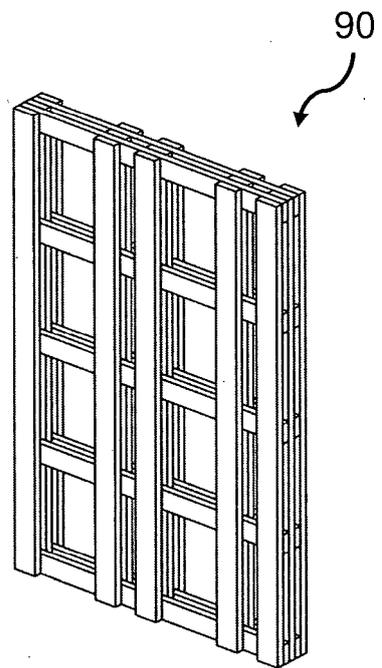


Figure 10B

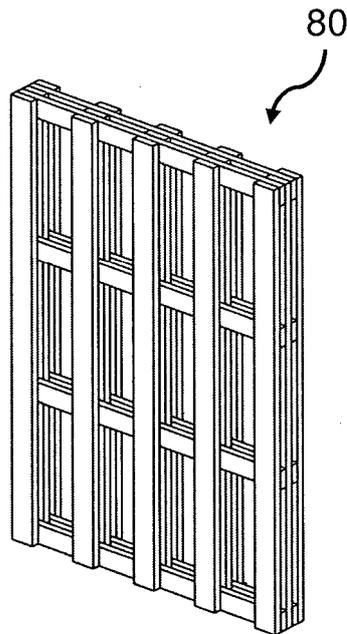


Figure 11

F1		F2		F3		F4	
Vertical forces		Load-bearing capacity		Surplus		Fitness	
69	16.5	69	84.19	69	67.69	69	5.1
70	14.7	70	84.19	70	69.49	70	5.7
71	13.14	71	84.19	71	71.05	71	6.4
72	11.96	72	84.19	72	72.22	72	7
73	11.15	73	84.19	73	73.03	73	7.5
74	11.15	74	112.22	74	101.07	74	10.1
75	67.8	75	112.22	75	44.42	75	1.7
76	94.25	76	112.22	76	17.97	76	1.2
77	42.72	77	112.22	77	69.5	77	2.6

301



302



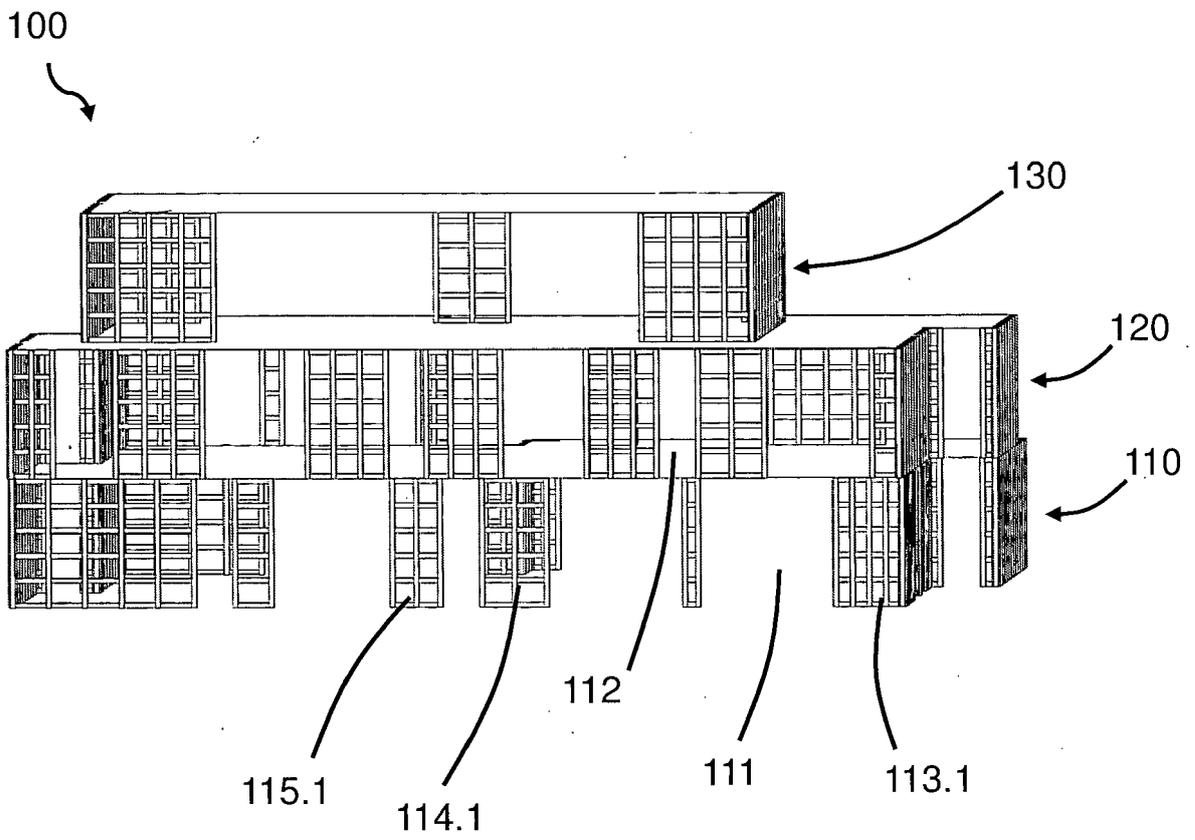
303



304



Figure 12





EUROPEAN SEARCH REPORT

Application Number  
EP 21 31 5050

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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 2019/211403 A1 (UNIV DE LORRAINE [FR]) 7 November 2019 (2019-11-07) * page 1, line 36 - page 7, line 19; figures 1-8 *	1-15	INV. E04B1/10 E04C2/12 E04C2/40
X	DE 198 34 616 A1 (WEINRICH MANFRED [DE]) 3 February 2000 (2000-02-03) * column 4, line 27 - column 6, line 22; figures 1-5 *	1-15	
			TECHNICAL FIELDS SEARCHED (IPC)
			E04B E04C
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 7 September 2021	Examiner Melhem, Charbel
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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

**REFERENCES CITED IN THE DESCRIPTION**

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