

(12) **UK Patent**

(19) **GB**

(11) **2540126**

(13) **B**

(45) Date of B Publication

**16.12.2020**

(54) Title of the Invention: **Casting method and apparatus**

(51) INT CL: **E04G 11/02** (2006.01)    **B28B 7/22** (2006.01)    **E04C 5/07** (2006.01)

(21) Application No: **1511354.1**

(22) Date of Filing: **29.06.2015**

(43) Date of A Publication: **11.01.2017**

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<b>GB191016166</b>	

(58) Field of Search:

As for published application 2540126 A viz:

INT CL **B28B, E04C, E04G**

Other: **WPI, EPODOC, TXTE**

updated as appropriate

Additional Fields

Other: **None**

**GB 2540126 B**

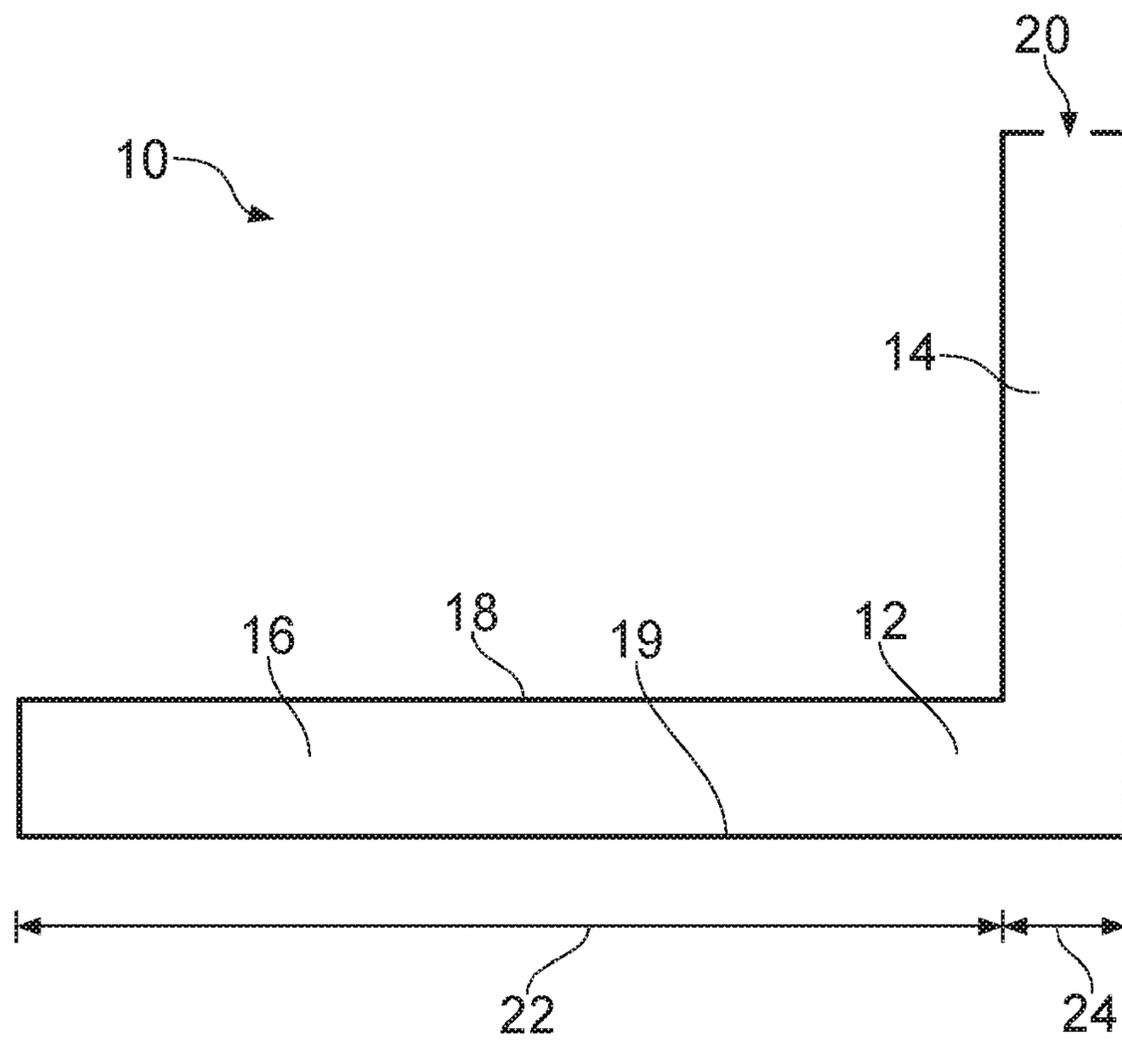


FIG. 1

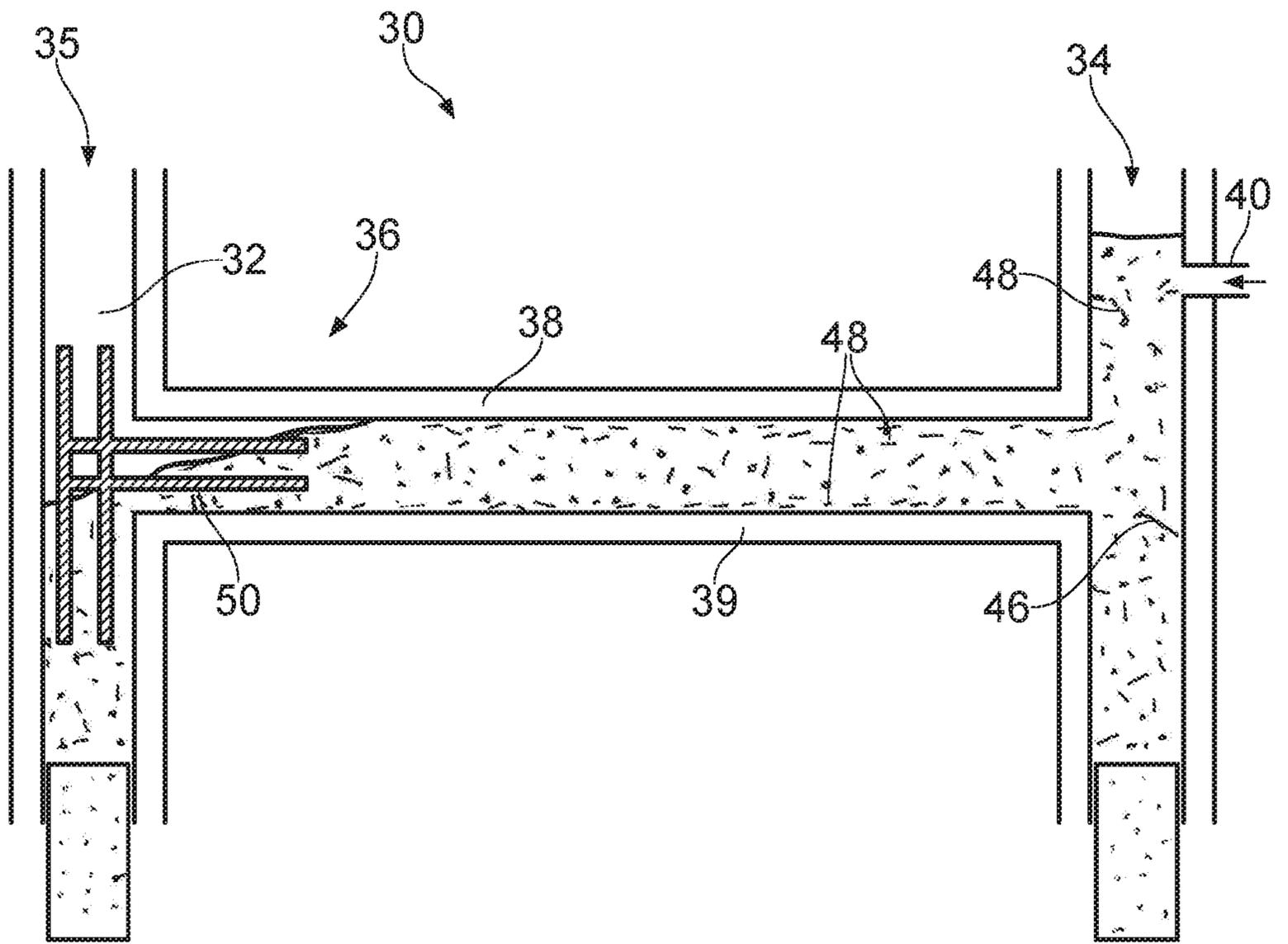


FIG. 2

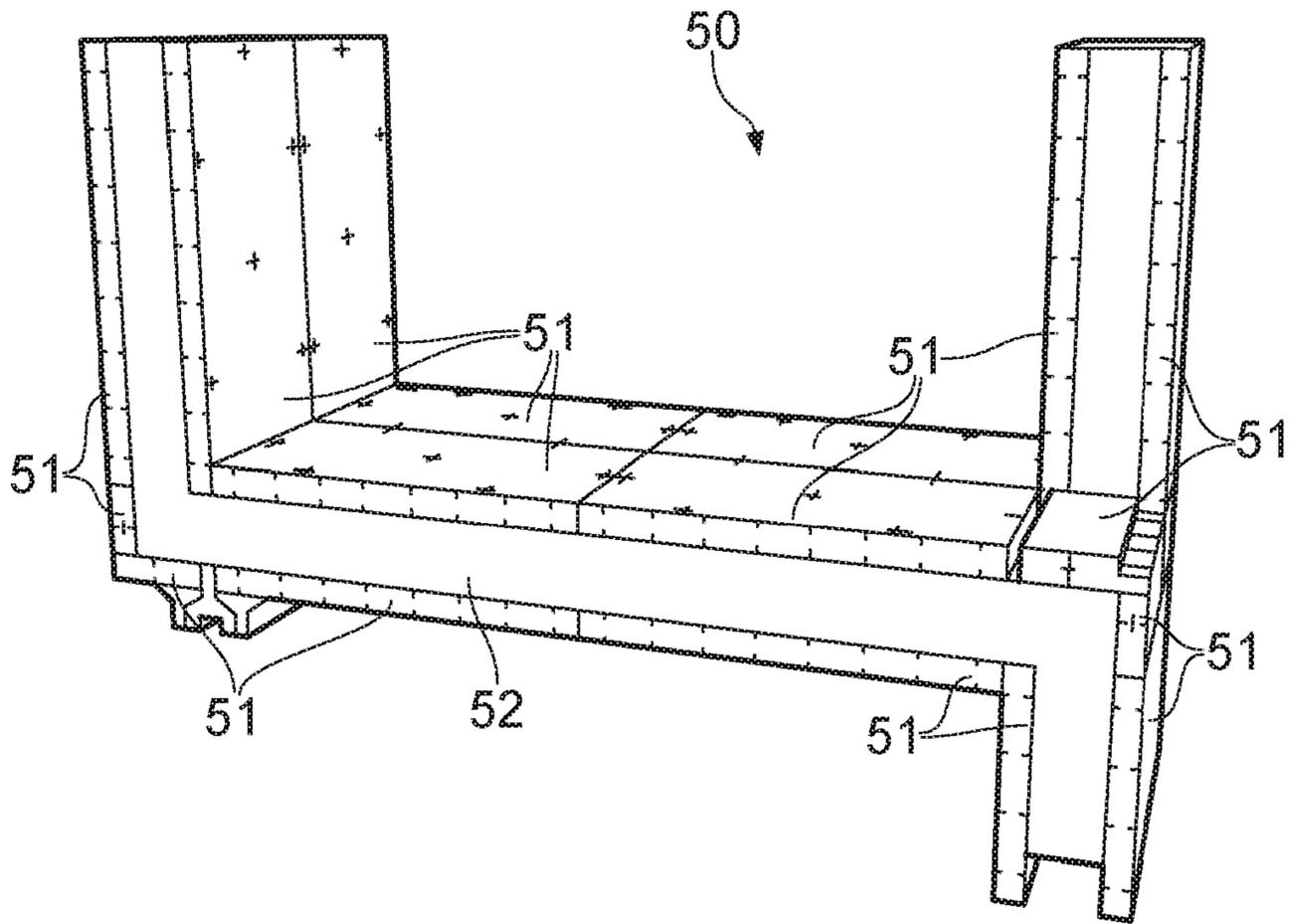


FIG. 3

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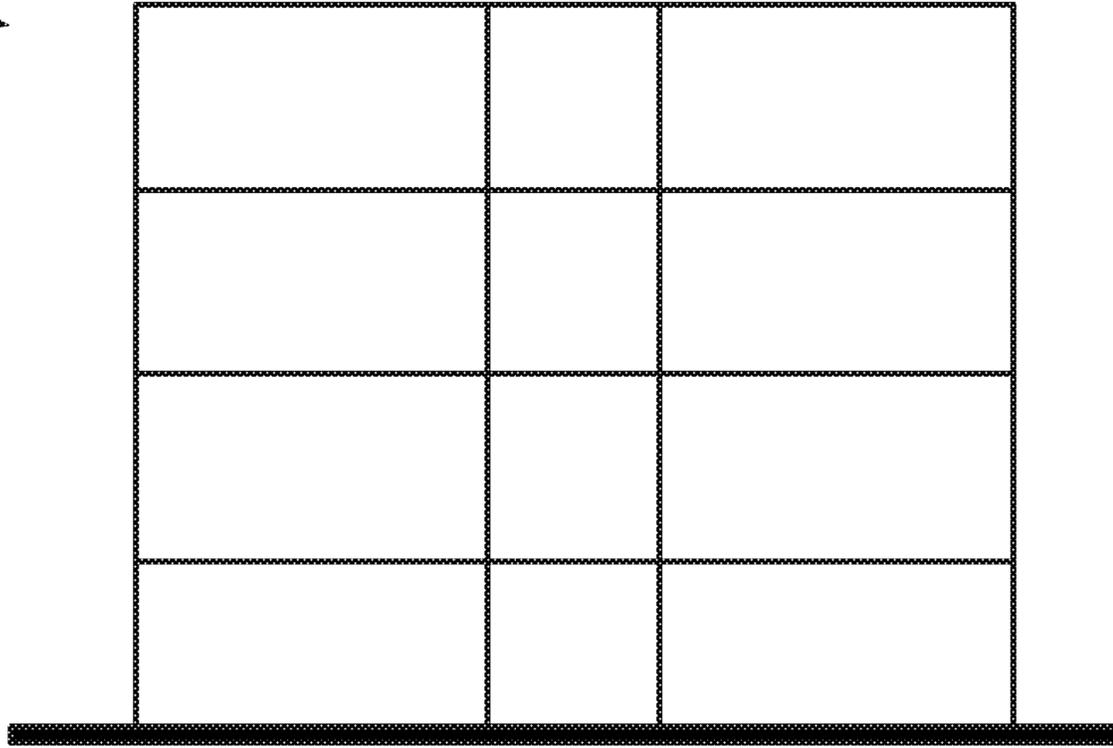


FIG. 4a

410

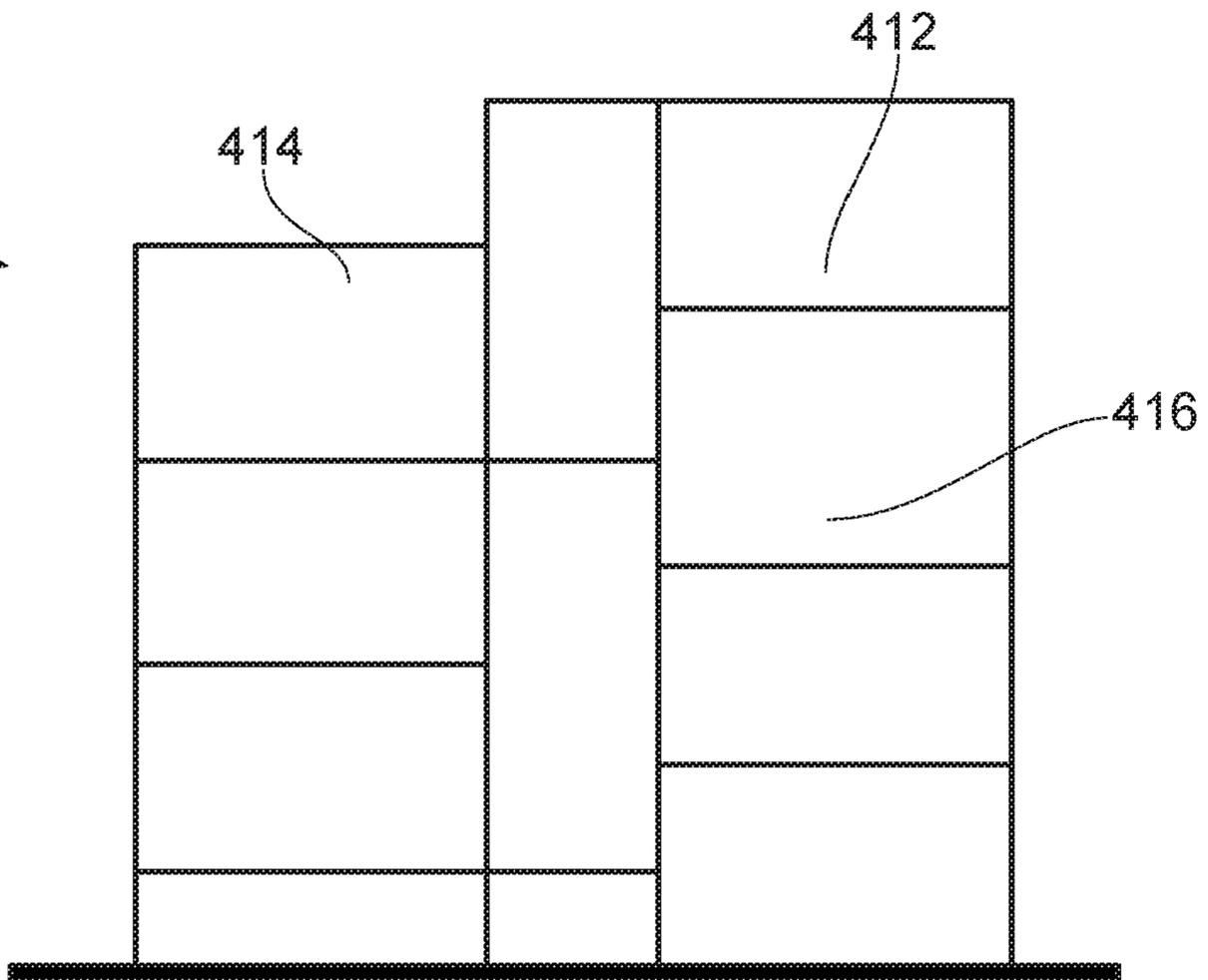


FIG. 4b

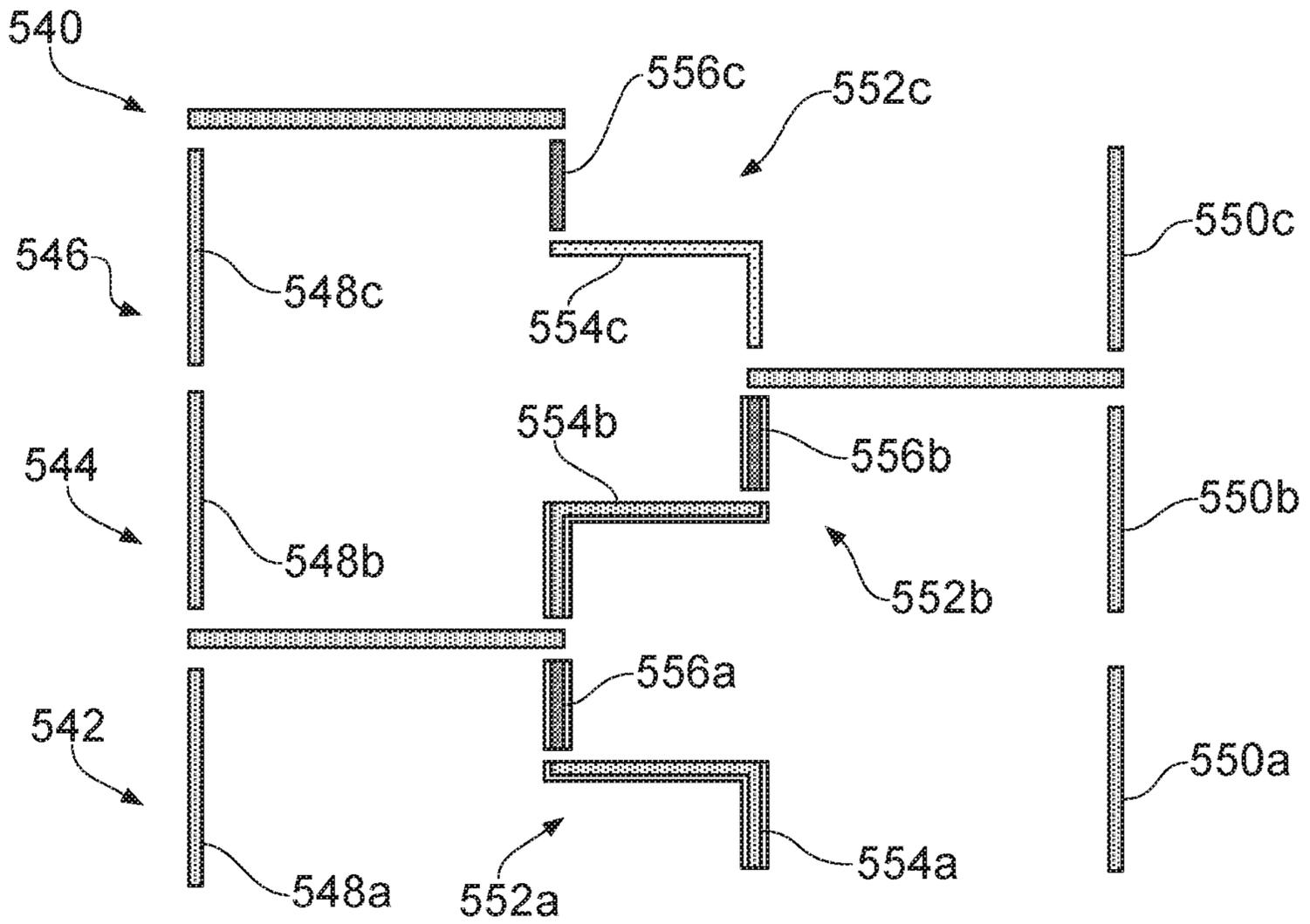


FIG. 5a

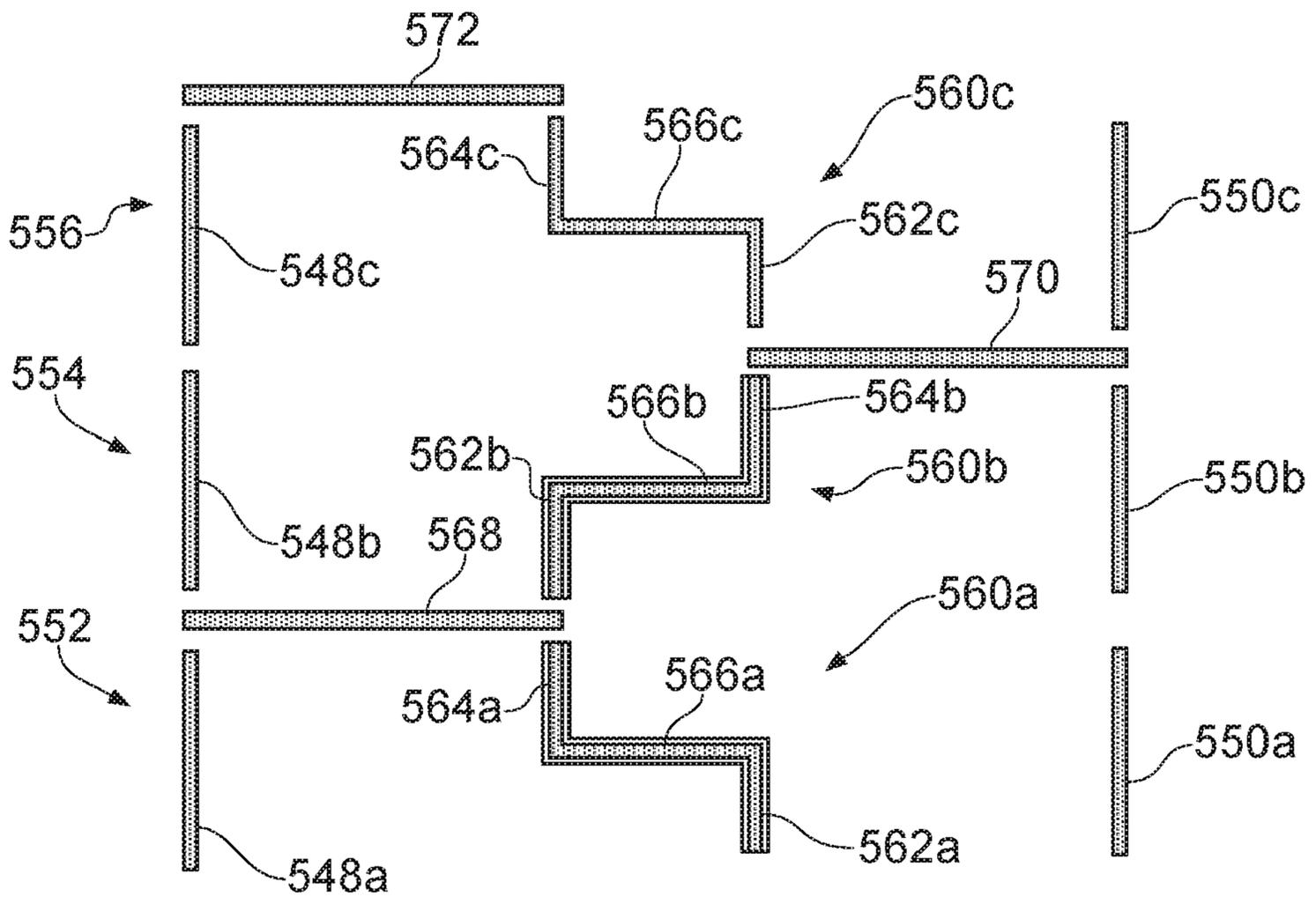


FIG. 5b

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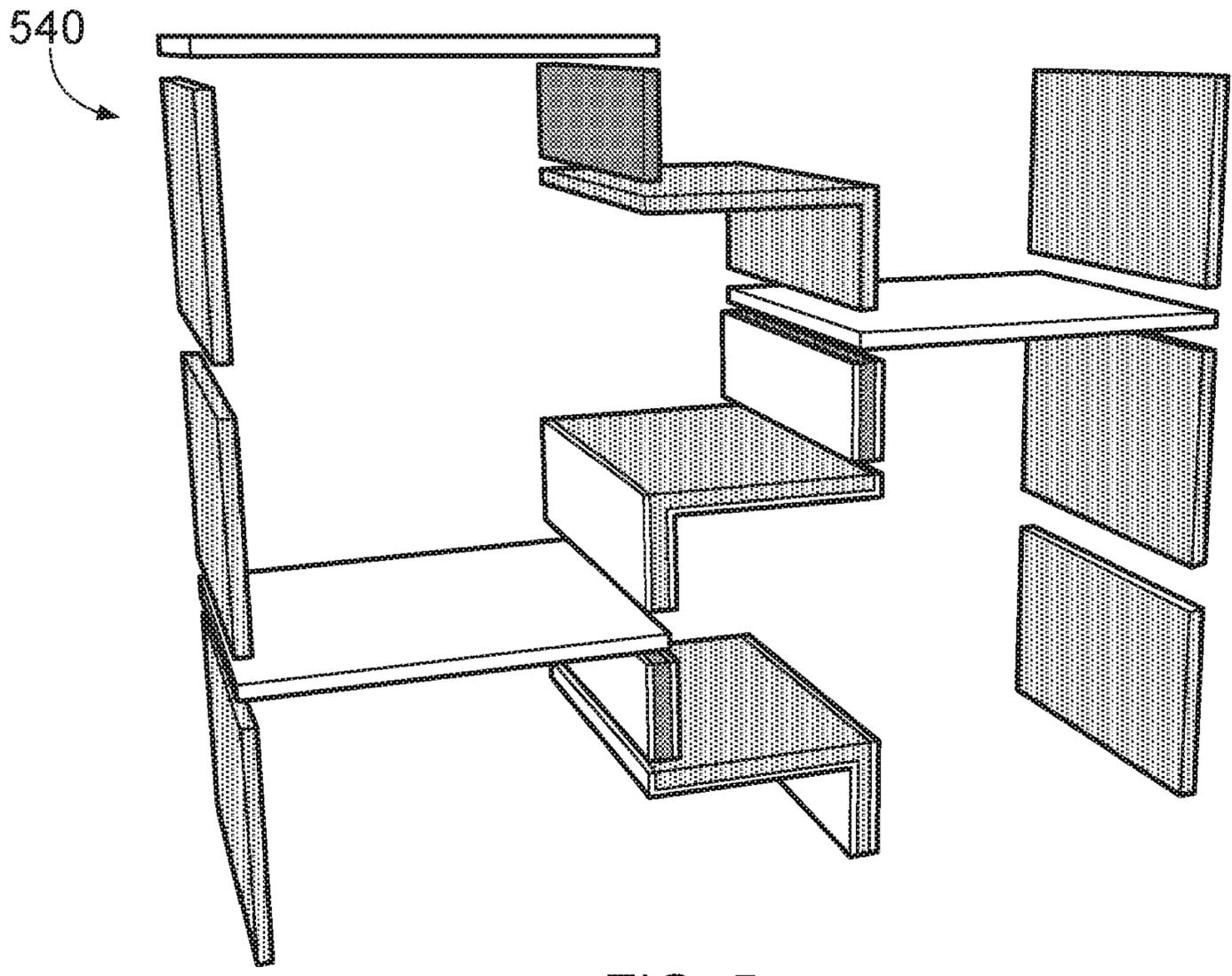


FIG. 5c

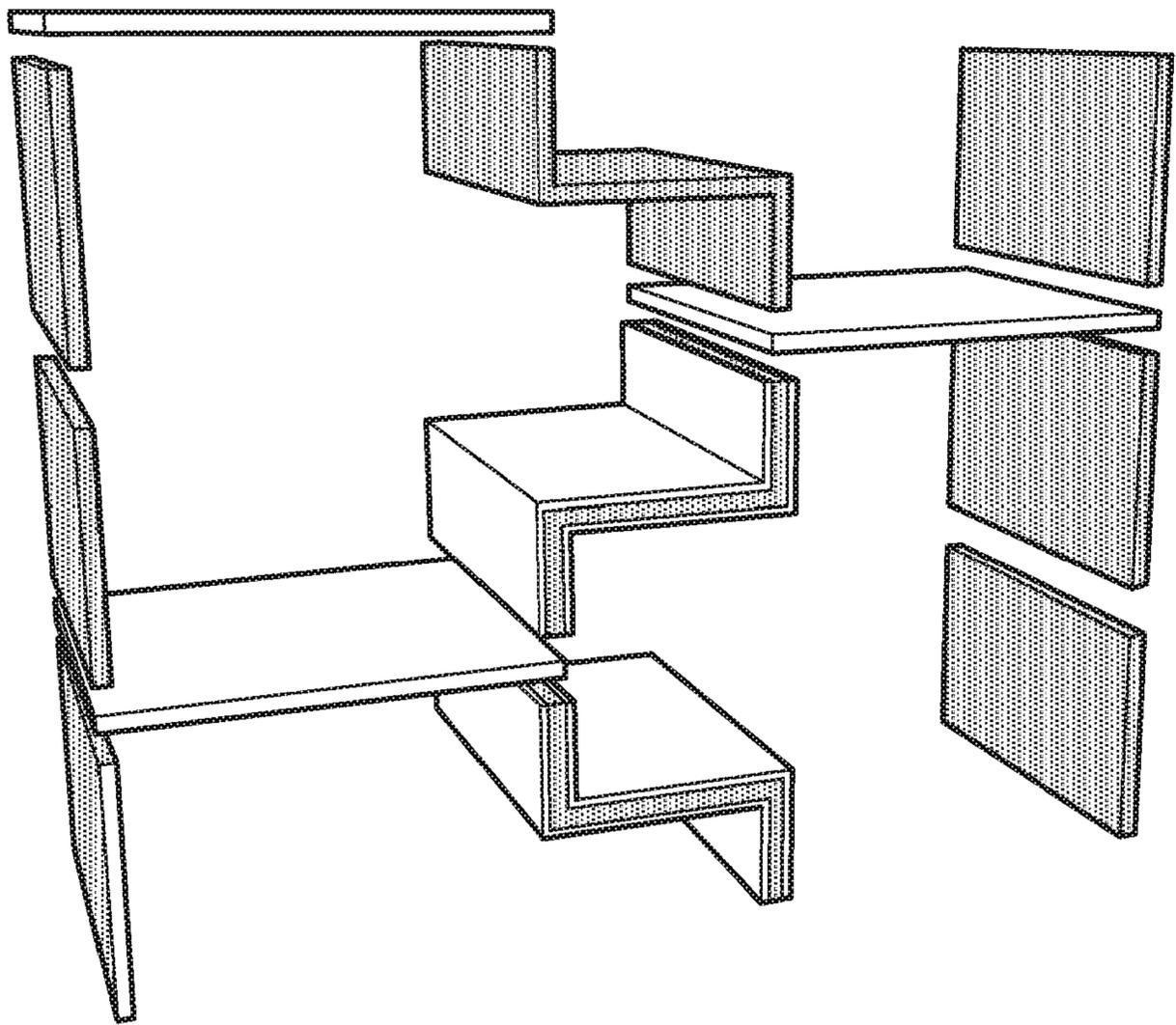


FIG. 5d

09 09 16

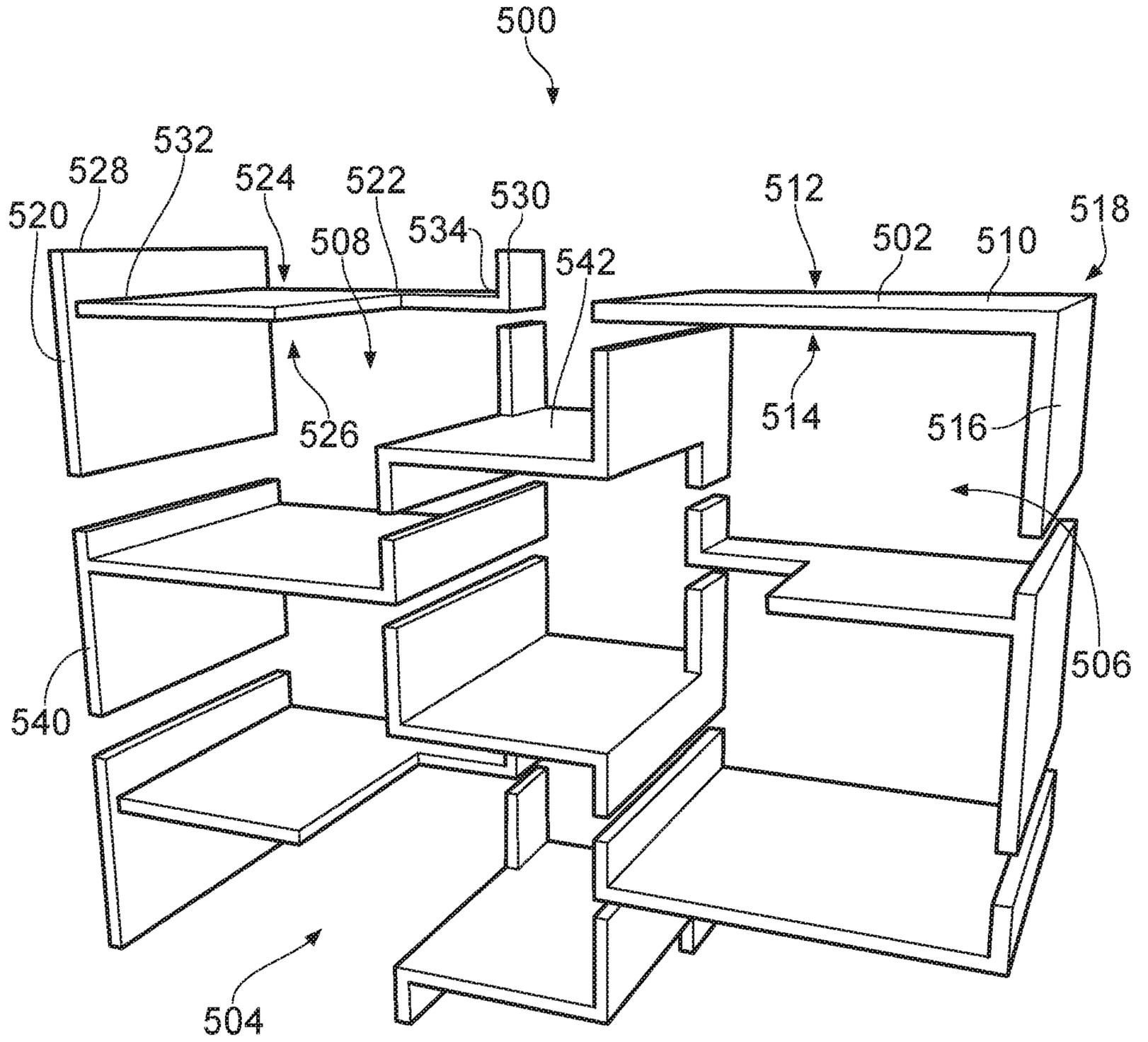


FIG. 5e

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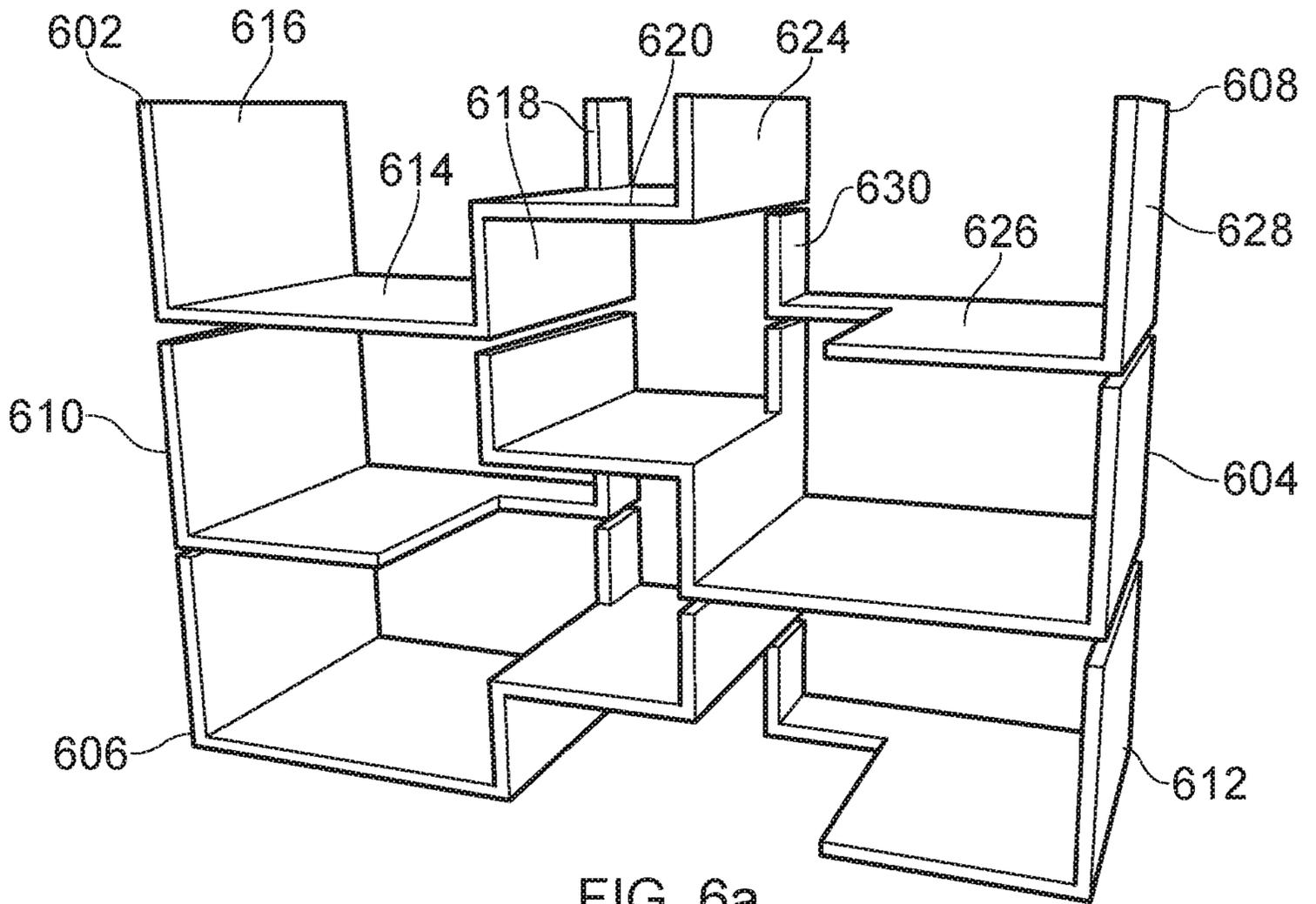


FIG. 6a

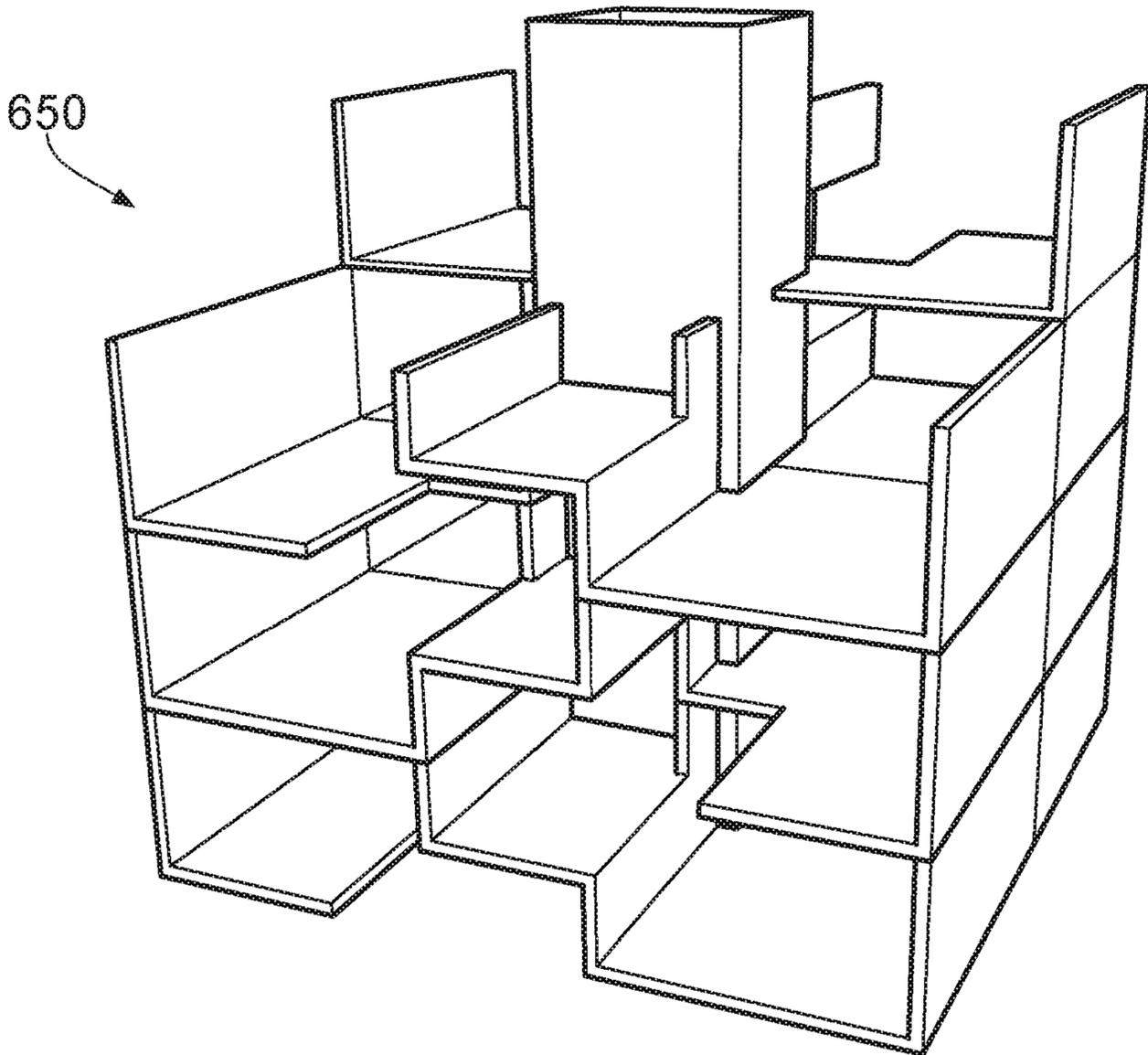


FIG. 6b

## CASTING METHOD AND APPARATUS

The present disclosure relates to methods and apparatus for casting concrete material and, in particular although not exclusively, to constructing a building.

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Plain concrete is a brittle material that has relatively high compressive strength but is typically unable to sustain a significant tensile stress as is required in structural building applications. In reinforced concrete (RC), steel bars may be provided within the concrete in order to accommodate tensile stress and enhance the overall structural behaviour by increasing the ductility of the material.

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RC is a widespread building material; among its many advantages, the following are particularly relevant in the context of building construction:

1. RC is suitable for mid- and high-rise structures;
- 15 2. RC delivers high thermal and acoustic performance due to its density and keeps vibrations at minimal levels;
3. RC possesses inherently good fire resistance capability;
4. RC structures can be cast in-situ monolithically, and are therefore robust, with high structural redundancy;
- 20 5. RC structures can be pre-cast off-site (prefabricated);
6. if cast to a high quality standard, RC can be durable and virtually maintenance free;
7. concrete is available in all industrialised countries.

25 RC buildings can be either pre-cast or cast in situ. RC floor slabs are traditionally cast in-situ by pouring concrete onto an open deck on which steel bars have been previously positioned and fixed. In many cases, normally vibrated concrete (NVC) is used. NVC requires vibrating (with a poker in the jargon) and the top surface is typically finished by striking-off any extra material to achieve a flat and even surface. The latter process can be performed manually with the aid of mechanical tools. The quality of finish achieved by such operations is dependent on on-site workmanship and as a result the production of floor slabs in this manner is a labour-intensive activity and hence expensive.

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In conventional in situ fabrication, wall or other vertical members are cast on the floor once the floor cast has set. A so-called "cold joint" is formed as a consequence of having two adjoining, separately-cast concrete members, as in the case of a floor slab with supporting or overlooking walls/columns. Cold joints are typically located at the

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intrados and extrados of the floor slab for the reason outlined above. These joints require special attention to precise positioning of reinforcing bars. In order to be able to provide their structural contribution, reinforcing bars have to be properly positioned within the concrete member on the basis of stress analysis and empirical experience. The bars may also need to be protected from corrosion by an adequate concrete cover. It follows that the provision of steel bars before pouring of concrete is a crucial task in respect of ensuring durability and structural performance of the structure. Placing and fixing reinforcement bars is typically a labour-intensive activity and is always on the critical path of the construction schedule. The difficulty of placing reinforcements in these areas sometimes cause durability problems in sections in which an optimal positioning is not achieved at the time of casting.

The amount of setting time required after placing a section of concrete before the formwork, or mould, can be dismantled is of critical importance for the sake of productivity and optimisation of the construction schedule. In particular, the dismantling time of horizontal members such as floor slabs is almost invariably on the critical scheduling path either because of equipment turnover or because of the structural support that the floor section needs to provide to the next level being built. Horizontal members take predominantly flexural stresses, and their own dead weight sets up a significant portion of such stresses. There are two factors in particular that affect the strength attained by cast concrete: temperature and moisture level during curing. The normal practice of casting floor slabs on an open deck leaves the top surface of the cast exposed to the atmosphere and so temperature and moisture control can be particularly difficult. Typically, no control of the curing conditions is undertaken on site. Designers are therefore reluctant to allow early dismantling of formwork and the curing time period is typically set in the range of two to four weeks, although the actual time required for curing might be substantially less depending upon the curing conditions. Such an unnecessary time lag increases the total time and cost of constructing a building. Efficient scheduling and sequencing of the casts may therefore be limited in the conventional approach.

Several building methods have been proposed to increase the productivity of erecting RC structures. Currently most established methods achieve improved productivity by being based on floor-cycle schedule: vertical (columns and walls) and horizontal (beams, floor slabs) members are pre-cast and craned in position separately. Such a method raises the structure evenly, level after level (an exception being made for the access core shafts and the like, which are sometimes slip-formed beforehand). Pre-cast construction

allows a degree of industrialisation in the construction process in which more sophisticated production techniques can be used, as opposed to the largely craft-based nature of formwork for in-situ casting. However, pre-cast techniques require transportation of casts from an off-site place of manufacture to the site of the building. Such transportation may in itself be difficult, costly and time-consuming for large prefabricated concrete sections.

The present invention may address at least some of the above-mentioned problems that are encountered in the prior art. The listing or discussion of an apparently prior-published document in this specification should not necessarily be taken as an acknowledgement that the document is part of the state of the art or is general knowledge.

The invention is defined by the claims. According to a first aspect of the present disclosure there is provided a method of constructing a building, comprising:

casting a substantially horizontal floor section of the building and a substantially vertical wall section of the building in a single casting operation using a single mould to define the floor section and the wall section.

A substantially horizontal surface may be within 5 degrees of horizontal, for example. A substantially vertical surface may be within 5 degrees of vertical, for example. In general, a column may be considered to be a type of wall. In general, a floor section may be interchangeable with a ceiling section. The building may be a residential building or commercial building. The building may be human-scale, or for human occupation.

The method may comprise casting self-compacting concrete. The casting may be performed at a site of the building. The casting may be performed in situ at the building. For example, the casting may be performed so that a structure is formed in its final position as part of the building.

The method may further comprise using a mould volume to define the floor section and the wall section. The mould may comprise a substantially vertical open section and a substantially horizontal closed section. The closed section may have a top shutter portion defining an upper extent of the closed volume. The open section may have an opening. At least a part of the closed section may define said floor section of the building. The opening may be at the top or the bottom of the open section.

The closed section may be in fluid communication with the open section for lateral displacement of the concrete material from the open section to the closed section. The single casting operation may comprise introducing concrete into the mould volume such that the concrete displaces laterally within the closed section to define an upper surface of the floor section against the top shutter. Introducing concrete into the mould volume may comprise introducing the concrete into the open section of the mould to define the wall section of the building. Introducing concrete into the mould volume may comprise flow of the casting material from the open section of the mould into and along the closed section defining the floor section.

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The method may comprise arranging a plurality of moulds or mould volumes to define wall sections and floor sections of the building such that at least part of the building has a split-level and/or open-section construction. The building may be multilevel. The split level approach generates an increased volume within the building created.

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The plurality of moulds may comprise a first mould and a second mould. The plurality of mould volumes may comprise a third mould. The method may comprise using the first mould to define a first monolithic structure. The method may comprise subsequently using the second mould to define a second monolithic structure above the first monolithic structure. The second mould may be constructed from the same or different mould sections as the first mould. The method may comprise using the third mould to define a third monolithic structure above the second monolithic structure. Each monolithic structure may have a first vertical section and a second vertical section provided at opposing ends of a horizontal section. Each first vertical section may extend only from a lower face of the respective horizontal section. Each second vertical section may extend only from an upper face of the respective horizontal section. The first vertical section of the first structure may be vertically aligned with the second vertical section of the second structure. The second vertical section of the first structure may be vertically aligned with the first vertical section of the second structure. The first vertical section of the first structure may be vertically aligned with the first vertical section of the third structure. The second vertical section of the first structure may be vertically aligned with the second vertical section of the third structure.

The wall section may be a first wall section. The method may comprise casting a second substantially vertical wall section of the building in the single casting operation using the single mould to define the floor section and the first and second wall sections. The method may comprise providing the first wall section on an opposing side of the floor

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section to the second wall section. The first wall section may extend only from a top surface of the floor section. The second wall section extending only from a bottom surface of the floor section. The first wall section may extend from both the top and bottom surfaces of the floor section. The second wall section may extend from both the top and bottom surfaces of the floor section. The first wall section may extend a first distance along the floor section. The second wall section may extend a second distance along the floor section. The first distance may be greater than the second distance.

The floor section may be a first floor section. The method may comprise casting a second substantially horizontal floor section of the building in the single casting operation using the single mould to define the first and second floor sections and the wall sections. The first floor section may be connected to the second floor section by a wall section. The first floor section may be at a different height to the second floor section.

The casting operation may be performed in-situ at a site of the building. Alternatively, the casting operation may be a pre-cast operation. Pre-casting the structure by providing concrete comprising reinforcing fibres into a mould having a substantially horizontal closed section has been found to be particularly advantageous. The method may comprise assembling the mould from a plurality of mould portions. The mould may be created in-situ at the site of the building. Alternatively, the mould may be created off-site. The moulds may be bespoke. The method may comprise bringing the moulds to the site for assembly and disassembly.

According to a further aspect of the disclosure there is provided a building. The building comprises a part of a floor section and part of a wall section of the building that are cast in a single mould in a single casting operation.

According to a further aspect of the disclosure there is provided a method of casting a concrete material using a mould volume comprising an open section and a closed section, the closed section having a substantially horizontal top shutter portion defining an upper extent of the closed volume and the open section having an opening. The method comprises introducing the concrete material into the mould volume such that the concrete material displaces vertically within the open section and laterally within the closed section to define an upper surface against the top shutter.

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The concrete material may comprise concrete and fibres. The fibres may be mutually aligned by lateral displacement of the concrete material within the closed section. The

concrete may be self-compacting concrete (SCC). The concrete may comprise water, aggregate, and cement. The fibres may comprise reinforcing fibres or metal fibres. The metal may be steel, such as stainless steel, or another alloy.

- 5 The closed section may be in fluid communication with the open section for lateral displacement of the concrete material from the open section to the closed section. The mould volume of the closed section may be at least as large as the mould volume of the open section. A linear lateral dimension of the closed section may be greater than a corresponding linear lateral dimension of the open section.

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The method may include ventilating the closed section through at least a part of the substantially horizontal top shutter portion. Ventilating the closed section may be carried out through a permeable lining to the top shutter portion. The top shutter of the closed section may comprise a removable plug. The method may comprise controlling  
15 ventilation of the closed section using the removable plug. The method may include deploying a coating to reduce surface tension on the inside surface of the top shutter portion.

The mould may comprise an insulating layer. The insulating layer may comprise one or  
20 more of: a vacuum layer, an inner layer having a relatively high thermal reflectivity compared to an outer layer, or a layer of thermally insulating wool, for example.

The method may comprise preheating the concrete material before casting. The method may comprise using a heating system within the mould to heat the concrete material.  
25 The heating system may be the same installed for heating/cooling of the building through so-called "core-activation" or similar. The method may comprise using ohmic heating to heat the concrete material by applying an electric current through the concrete. Ohmic heating may be provided due to the conductivity of fibres within the concrete material. The material may be introduced into the mould volume in a single casting operation.

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According to further aspects of the disclosure there are provided apparatus configured to automatically perform any of the methods described above.

According to a further aspect of the disclosure there is provided a mould having a mould  
35 volume comprising an open section and a closed section, the closed section having a top shutter portion defining an upper extent of the closed volume and the open section having an opening.

In general, the feature described with reference to one aspect of the disclosure may be provided in combination with a feature described with reference to another aspect of the disclosure.

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The invention will now be described by way of example, and with reference to the enclosed drawings in which:

figure 1 shows a cross sectional view of a mould;

figure 2 shows a cross sectional view of another mould;

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figure 3 shows a cross sectional view of a further mould;

figure 4a shows a conventional building layout;

figure 4b shows a split-level building layout;

figure 5a shows an exploded cross-sectional view of a split-level building with open-cast horizontal sections;

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figure 5b shows an exploded cross-sectional view of a split-level building with enclosed horizontal sections;

figure 5c shows an exploded perspective view of the split-level building with open-cast horizontal sections illustrated in figure 5a;

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figure 5d shows an exploded perspective view of the split-level building with enclosed horizontal sections illustrated in figure 5b;

figure 5e shows an another arrangement of monolithic building sections;

figure 6a shows a further arrangement of monolithic building sections; and

figure 6b shows an arrangement of monolithic building sections around a central shaft.

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As described above, in conventional casting concrete is spread and poured onto an open deck and then excess material is manually struck-off the top surface. When relying on existing practice, overlooking vertical structural members such as walls or columns cannot be cast simultaneously with a floor slab on which they stand. This is because if the overlooking vertical structural member were placed on an unset slab then fluid concrete from the unset slab would flow out from open deck of the slab under hydrostatic pressure due to the concrete filling the overlooking member. Unlike such traditional casting approach, the present method enables horizontal and vertical members to be cast simultaneously. As such, the time taken to construct a particular structure can be reduced because fewer breaks for concrete to set are required.

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Figure 1 shows a cross sectional view of a framework, which may also be described as a mould 10, for use in methods of casting concrete and constructing a building.

5 The mould 10 defines a mould volume 12 and has a first substantially vertical open section 14 and a substantially horizontal closed section 16. A substantially horizontal surface may be considered to be within 5 degrees of horizontal and a substantially vertical surface may be considered to be within 5 degrees of vertical.

10 The open section 14 is 'open' in that it has an opening, or inlet 20, to enable concrete material to enter the mould volume 12. At least a part of the closed section may define said floor section of the building. The opening is at the top of the open section 14 in this example. The vertical orientation of the open section 14 means that concrete material that is introduced, by pouring or pumping for example, into the mould volume 12 through the inlet 20 displaces vertically within the open section 14.

15

The closed section 16 is 'closed' in that it is enclosed on all sides by either the mould 10 itself or the open section 14. The closed section 16 is in fluid communication with the open section 14 in order to receive concrete material from the open section 14. The horizontal orientation of the closed section 16 means that concrete material that is received in the closed section 16 displaces laterally within the closed section. The closed section 16 has a top shutter 18 defining an upper extent of the closed section 16 and a bottom deck 19 defining a lower extent of the closed section 16. The top shutter 18 and the lower deck 19 together provide a double-sided slab formwork.

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25 The closed section 16 in this example is at least as large as the open section 14. A linear lateral dimension 22 of the closed section 16 is greater than a corresponding linear lateral dimension 24 of the open section 14.

The mould 10 of figure 1 is suitable for use in a method of casting concrete material. 30 The method of casting concrete material comprises introducing the concrete material into the mould volume 12 such that the concrete material displaces vertically within the open section 14 and laterally within the closed section 16 to define an upper surface against the top shutter 18. By use of this method horizontal and vertical concrete sections can be cast simultaneously and so the number of process steps and associated setting time can be reduced. 35 The use of the closed section 16 overcomes the problem associated with open deck casting that a mass of a vertical section causes displacement of concrete

within a horizontal section on which it is placed in the case where the horizontal and vertical section are cast simultaneously.

5 Self-Compacting Concrete (SCC), a concrete that in its fresh state can flow and fill complex-shaped volumes under its own weight without requiring vibration to achieve consolidation, can be used in the casting process in order that the concrete can be displaced both laterally and vertically. Further aspects of the method of casting concrete material are described below with reference to figures 2 and 3 in particular.

10 The mould 10 of figure 1 is suitable for a method of constructing a building and can enable the efficient and economical construction of multi-storey/multi-unit, split-level buildings. The method of constructing the building comprises casting a substantially horizontal floor section of the building and a substantially vertical wall section of the building in a single casting operation using the mould 10 to define the floor section and  
15 the wall section. The casting operation of the method of constructing the building may comprise the method of casting concrete material. The single casting operation may introduce, or inject, concrete into the mould volume 12 such that the concrete displaces laterally within the closed section 16 to define an upper surface of the floor section against the top shutter 18. It has been found that the fluid concrete forms a smooth  
20 upper surface of the floor against the top shutter 18 without the requirement for manual inspection or modification. This result is counterintuitive because it is considered in the art that an open deck is required in order for both the provision and assessment of a smooth floor surface. The formation of a smooth surface against the top shutter requires substantially less skill and manual input than the formation of a smooth surface by  
25 striking material off an open deck in situ. In this way, the methods disclosed herein therefore reduce the difficulty and time required to prepare a smooth floor surface and therefore also reduce the associated cost of producing the floor in situ. By casting the floor in situ, the difficulty and cost associated with transporting and assembling prefabricated casts can be eliminated. Further aspects of methods of constructing a  
30 building that are described below with reference to figures 2 to 6.

Figure 2 shows a cross sectional view of a mould 30 similar to that of figure 1. In this example, the mould 30 has a first vertical open section 34 and a second vertical open section 35. The first vertical open section 34 is provided on an opposing side of the  
35 horizontal closed section 32 to the second vertical open section 35. The first and second vertical open sections 34, 35 both extend from each of the top (above the top shutter 38) and bottom (below the deck 39) of the horizontal closed section 36.

Void formers or conduits may be provided at predetermined locations within the mould volume. Void formers and conduits may easily be embedded in some top shutter embodiments, whereas the provision of such conduits is difficult in open-deck casting.

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A coating or liner may be provided on an inside surface of the top shutter portion 38 in order to reduce surface tension with the concrete material or facilitate drainage of trapped air and water from the mould volume 32. In this way, the smoothness of the surface produced by the top shutter portion 38 may be improved further. The liner may

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be permeable to air or water. It has been found that:

1) using a permeable liner, the horizontal surface formed against the top shutter portion 38 of the horizontal closed section 36 may be as good as one cast vertically; and

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2) without a permeable liner, the horizontal surface is not as smooth and may contain defects that are about 4 to 8 mm in depth, however, the structural performance of the horizontal casting is not impaired.

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The mould 30 is shown during use in which self-compacting concrete (SCC) material 46 is being injected into the mould volume 32 via the inlet 40 in order to cast a monolithic structure (by casting using a single pour without joints) a floor/ceiling slab and part of supporting/overlooking walls or columns.

25

SCC (also known as self-consolidating concrete) does not require vibrating during placement and compaction. SCC is able to flow under its own weight, and so may complete fill the mould 30 and achieve full compaction, even in the presence of congested regions containing reinforcements or in complex-shaped volumes. Once hardened, SCC can provide a dense, homogeneous structure with similar engineering properties and durability to traditional vibrated concrete.

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A "Specification and Guidelines for Self-Compacting Concrete" dated February 2002 is available from EFNARC, Association House, 99 West Street, Farnham, Surrey GU9 7EN, UK (<http://www.efnarc.org/pdf/SandGforSCC.PDF>). The SCC used herein may conform to this specification.

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SCC typically has the following fresh-state performance:

1. normal flowability, with a slump flow in the typically in the range 600-850 and more preferably in the range 660-750mm;

2. high viscosity, with a slump flow time to form a 0.5m diameter,  $T_{500}$  typically between 0.5 and 2.5 seconds and preferably greater than 1.5 seconds;
3. passing ability related with the eventual presence or absence of reinforcement. In the latter case, no passing ability is required.

The concrete can be reinforced to carry tensile forces with either bars or fibres or a combination thereof. Bars 50 may comprise metal (such as steel, stainless steel, or another alloy) or polymer. The bars 50 may be placed at a meeting point of the vertical open section 35 and the horizontal closed section 36. Fibres 48 in the concrete material may comprise metal fibres, such as steel, stainless steel, or another alloy. The concrete material comprises concrete (including water, aggregate, and cement) and fibres 48 where desired. The casting of fibre reinforced SCC in the mould 30 results in a monolithic slab-wall (or slab-columns) joint, whereas the conventional approach requires a cold joint at slab-wall joints.

Fibre reinforcement in such a process may partially or fully replace conventional bar or rod reinforcement. After mixing with conventional (non SCC) concrete, fibres tend to adopt a random orientation with variability of distribution of fibres that are present due to inefficient mixing or placing. Such orientation and distribution variations result in spatial variation in structural loading capability and can be considered to be outside of designs control. For these reasons, the use of fibre-only reinforced concrete is conventionally considered to be unsuitable for structural applications such as suspended sections, which must take considerable loads; designers are reluctant to endorse suspended slabs using conventional methods without reinforcing bars, or similar, regardless of the magnitude of the load due to the potential consequences of a structural failure due to a lack of reliability and confidence regarding the orientation of fibres, and the consistency of the distribution of fibres, throughout the cast volume. However, by providing fibres within the SCC material, reinforcing structures can be formed by pouring the concrete material, which has the effect of providing a relatively homogeneous distribution of fibres. An acceptable structural strength may be achieved using a fibre dosage of less than  $80\text{kg/m}^3$  in some examples. By removing the requirements for placing structural reinforcement such as steel bars and cables, the present method therefore further reduces the operator skill required in order to provide the structure.

However, traditional reinforcements such as steel bars may be provided in addition to the fibres 48 within the concrete material. For example, in some applications

it may be desirable to reinforce structures at joints between portions of the structure, such as where a wall or floor meet.

At least some of the fibres 48 may be mutually aligned during the casting process due to lateral displacement of the concrete material within the closed section. The cast process can exploit the direction of flow to achieve a favourable orientation of fibres; a predominant orientation in the direction of expected tensile stresses can be achieved, thus significantly increasing the structural effectiveness of the fibres compared to material in which fibres are randomly orientated. Where necessary, guides (or fins) may be provided protruding from the top shutter in order to direct fluid flow and therefore encourage a desired fibre orientation. As shown in figure 2, the fibres 48 within the closed section 32 are predominantly horizontally orientated whereas the fibres within the open section 34, which have not undergone flow in the lateral direction, are predominantly randomly orientated.

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The load-bearing capacity of fibre reinforced concrete depends principally on the fibre type, including the shape material properties, fibre distribution, fibre dosage, fibre orientation and the composite action (bonding) of the particular type of fibre to the concrete in the concrete material. An orientation factor  $\alpha$  of the fibres, defined in the direction perpendicular to a given cross-section, is given as the total sectional area of fibres  $A_f$  divided by the volume fraction of fibre  $V_f$  and multiplied by the number of fibres  $n$  crossing that section. That is,  $\alpha = n \cdot A_f / V_f$ . It has been found that when the orientation factor  $\alpha$  of a section is increased from 0.5 (random orientation) to 0.8 (predominant orientation) the peak strength (the maximum flexural stress the specimen can sustain) of the section is increased substantially, and may be doubled in some examples.

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By using the flow of the fluid concrete to control the alignment and distribution of the fibres a more consistent distribution and orientation that suits the stress patterns in the structural member results, and so the required density (and associated cost) of the fibres within the concrete material may be reduced.

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After setting up the mould and connecting a concrete inlet pipe, the casting process does not require any further manual operation. For example, the fibre distribution is not significantly influenced by on site workmanship. The flow of concrete and the way the formwork is filled can be prescribed by the designer in collaboration with a concrete sub-contractor and concrete provider in advance and can be set up on site by positioning an inlet pipe at the inlet 40 and modifying the filling rate. Trial casts or simulations may be

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undertaken for a specific mix design or prescribed concrete rheology. In other words, the fresh state performance identified before in terms of slump flow and T500. The quality of the cast depends on the suitability of the concrete rheology, mixing process and envisaged flow but does not rely on site workmanship. As such, the present method is less labour-intensive than open deck casting and enables an improved cast to be achieved whilst reducing operator skill requirements.

An apparatus may be provided in order to perform automatically at least some of the steps of the casting or building methods described herein. The apparatus may limit or remove the requirement for manual workmanship in forming the concrete structure. The apparatus may comprise a concrete material pump and a controller. The concrete material pump may be configured to pump concrete material from a reservoir into the mould volume of the mould. The controller may be configured to operate the pump in accordance with a flow rate setting in order to provide a required flow rate. The controller may be configured to operate the pump such that pumping ceases when the mould volume is full of concrete. The controller may comprise a timer set in accordance with a pump rate and the volume of the mould. Alternatively, the mould may comprise a concrete level sensor configured to provide a signal to the controller when the mould volume is full or at another predetermined threshold. In this case, the controller may be configured to control operation of the pump in accordance with the signal from the concrete level sensor.

As the formwork entirely encloses the cast concrete, thermal insulation may be integrated into the formwork in order to accelerate the concrete strength development process using the so-called "thermos method", for example. The insulating layer may comprise one or more of: a vacuum layer, an inner layer having a relatively high thermal reflectivity compared to an outer layer, or a layer of thermally insulating wool, for example. The enclosed shutter around the slab makes it easier to apply heat-accelerated curing techniques while otherwise this is not feasible because of a lack of insulation or protection against loss of moisture. By accelerating concrete development the construction time and therefore cost may be reduced. One, or a combination of the following steps may be taken in order to accelerate concrete development:

1. Heat of hydration (heat developed by the reaction of cement with water) is retained by the insulating formwork to sustain temperature;
2. Concrete is pre-heated before pouring;

3. Concrete is heated by a pipework system through which hot water is circulated; such system is possibly the same installed for heating/cooling of the building through so-called "core-activation" or similar; or
4. Concrete is heated by direct electric heating due to the conductivity of metal fibres within the concrete material.

Moisture is also retained in the cast due to the fully enclosed shutter, which may improve concrete strength.

The ventilation of the closed section 36 is desirable in order to enable efficient flow of the concrete material 46 and in order to assist in setting the concrete material 46. In the mould 30 of figure 2, the closed section 36 is ventilated via the openings at the tops of the first and second open sections 34, 35. However, a number of other options are available for ventilating the closed section 36, for example:

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- the closed section 36 may be ventilated through at least a part of the substantially horizontal top shutter portion 38.
- the closed section may be ventilated using a removable plug in the top shutter.
- closed section may be ventilated may be carried out through a permeable lining to the top shutter portion.

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Figure 3 shows another mould 50 similar to that of figure 2. The ends of the mould 50 that are in the plane of view are not visible in figure 3. The mould 50 is of a modular construction and comprises a plurality of interlocking, or interconnecting, mould portions 51 in order to define a mould volume 52 within the mould 50. The modular construction of the mould 50 improves the ease of construction of the mould 50 which may be particularly advantageous for in situ use. The modularity of the mould 50 also enables many different layouts to be provided using a reduced number of types of formwork components.

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When conventional, floor casting-cycle methods are applied to split-level open-section layouts, productivity is jeopardised because a neat floor cycle (the laying of the various floor levels) cannot be scheduled and the number of levels is effectively doubled compared to a conventional layout. A split level volume cannot easily be made using open casting of horizontal sections. This outcome is a consequence of the separation between horizontal and vertical members requiring construction joints (cold joints) that match in height at each level and the difficulty of containing the concrete in the horizontal

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sections while providing reinforcing bars to join the separate sections. In contrast, the casting processes described above in relation to figures 1 to 3, which result in monolithic building sections (without cold joints) comprising both horizontally and vertically extending portions, enable the efficient construction of various building structures and in particular to multi-unit, split-level buildings. Enclosed casting of the horizontal sections in conjunction with the vertical sections enables a wide variety of building types, including those with a stepped floor arrangement, to be constructed in a single operation. Such construction methods may take a comparable time and cost to constructing a single, flat-level storey. An efficient method for constructing a multi-storey, split-level building which can be deployed in both pre-cast and in-situ casting is therefore provided. The method can therefore improve building productivity and erection speed for split-level, open-section construction. The key to overcome the hindrance brought by the split-level is in the strategic positioning of the construction joints; this in turn is enabled by the joint casting of horizontal and vertical members. The joints may be positioned according to structural, aesthetic, or functional consideration or for the sake of better scheduling or sequencing of production on site. The single casting of horizontal and vertical structures also improves the stability of this structural connection and so may also help the building to withstand vibrations such as earthquake tremors. In contrast, cold joints between horizontal and vertical elements provided by existing methods are potentially weak points and may fail in shear during seismic shaking. Further, conventional techniques may require these joints to be positioned where bending stress is at a maximum. By providing horizontal elements integrally with vertical elements, cold joints, or day joints, may be positioned away from maximum bending stress points and place the joints where it is easier to ensure good execution.

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Figure 4 show schematic cross sections of a conventional multi-story building 400, in figure 4a, and a split-level building 410 in figure 4b.

In conventional multi-story buildings, which may also referred to as “even-level”, each floor extends horizontally on the same level throughout the plan area of that building. As a result, a building structure is formed by a number of floor slabs supported by vertical members, which are defined as load bearing columns and/or walls. This basic and fundamental layout is deep-rooted in the industry and limits the ways in which any variable internal volume can be exploited.

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The need for enclosed variable volumes within city airspaces to help accommodate the housing demands of expanding urban populations, which are expected to rise from 3.5bn

to 6bn by 2030 according to UN forecasts, is currently of significant importance due to the limited available supply of urban land.

Enhancing and increasing vertically integrated dwelling volumes improves the sensation  
 5 of space, enables rational subdivision of open plan living spaces and ultimately improves  
 the user's experience. A "split-level" layout is defined in this context as a sectional layout  
 in which, over at least some part of the plan, floor levels are staggered by approximately  
 half-a-story height and a "volume over" part of the space is extended to approximately  
 double height with the space becoming modified. Further exploitation of the split-level  
 10 feature can provide partially modified ceiling heights as well as modified floor levels  
 internal mezzanines so that different levels can be enjoyed within the same living  
 volume. For example, first and second overlapping split-level portions 412, 414 and  
 second and third overlapping split-level portions 414, 416 may provide a single unit, or  
 open volume section. Each split-level portion 412, 414, 416 may be provided to perform  
 15 a different function, such as a living space, an eating space and a working space.

Using the pouring techniques described previously it is possible to make monolithic  
 building sections using a standard pouring sequence without the time and cost penalty  
 associated with separate pouring steps. Complex building designs can be made by  
 20 tessellating such monolithic building sections to provide the structural frame for nested  
 spaces within a building. The tessellated form provides an advantage in terms of spaces  
 with greater volumes within a vertical building arrangement. Some of the nested units  
 can be left empty to provide voids in the building without modifying the structural  
 behaviour. It will be appreciated that the tessellated building sections may take a variety  
 25 of shapes, including for example T, I, L or H shapes.

Split-level open-volume buildings may have a bay with a floor that is staggered with  
 respect to a floor and ceiling of an internal volume of the building. Three-bay building  
 arrangements are discussed below with reference to figures 5a to 5d.

30 Figure 5a shows an exploded cross-sectional view of a split-level building arrangement  
 540 in which horizontal sections of bays are cast with an open deck. The building  
 arrangement 540 has three split-levels 542, 544, 546. Each level 542, 544, 546 has a  
 first vertical section 548a-c, a separate second vertical section 550a-c and a bay 552a-c  
 35 disposed between the first and second vertical members 548a-c, 550a-c. Each vertical  
 section may be considered to provide a wall and each horizontal section may be  
 considered to provide a floor.

In this example, the bays 552a-c are each formed using two separable mould portions. The separable mould portions include a lower mould portion 554a-c and an upper mould portion 556a-c. Each lower mould portion 554a-c has a vertical section and a horizontal section. The vertical sections of the lower mould portions 554a-c extend from the bottom face of the horizontal section, at an edge of the horizontal section. The horizontal sections in this example each have a bottom deck and an open top such that a floor face of the respective bay 552a-c is formed by the open top. The two-part bay sections 552a-c each require two "lifts", as referred to in the trade. That is, the two vertical sections each require sequential casting of two vertical sections. The horizontal section of the lower mould portion 554a-c, once set, provides a base on which to form a vertical section using the upper mould portion 556a-c. The vertical section formed by the upper mould portion 556a-c can only be provided once the lower mould portion 554a-c has set because otherwise the concrete-filled mass of the upper mould portion 556a-c would displace concrete from the open topped horizontal section of the lower mould portion 554a-c.

The relative arrangement of the various levels in figure 5a is similar to that in figure 5b and discussed below in relation to figure 5b.

Figure 5b shows an exploded cross-sectional view of a split-level building arrangement in which horizontal sections of the bays 566 are cast with a top shutter. In other respects, the arrangement of the various levels 552, 554, 556 is similar to that described above with reference to figure 5a.

In the example in figure 5b, each bay comprises a crank-shaped portion 560a-c that is separate from and disposed between the first vertical member 548a-c and the second vertical member 550a-c for a particular level 552-556. The crank-shaped portions 560a each provide a unitary, or monolithic, section having a first vertical section 562 and a second vertical section 564 connected by an integrally formed, closed horizontal section 566 similar to that described with reference to figures 1 to 3. The first and second vertical sections of a crank-shaped portion are therefore provided at opposing ends of the closed horizontal section 566. In this example, the first vertical section 562 extends only from a lower face of the closed horizontal section 566 and the second vertical section 564 extends only from an upper face of the closed horizontal section 566.

The central bays 552a-c formed using the open casting method described with reference to figure 5a each require at least one additional lift on each level, and therefore a productivity penalty arises, in comparison with the casting method of the bays 560a-c described with reference to figure 5b in which the horizontal section of the bays 560a-c are closed (with a double shutter).

The third level is disposed directly on top of the second level and the second level is disposed directly on top of the first level. The first vertical sections 548a-c of each level are aligned vertically and the second vertical sections 550a-c of each level are also aligned vertically.

A first horizontal section 568 is supported by the first vertical section 548a of the first level 552 and the second vertical section 564a of the first bay 560a. The first horizontal section 568 provides a ceiling of the first level 552 and a floor of the second level 554 between the first vertical section 548a of the first level 552 and the second vertical section 564a of the first bay 560a.

A second horizontal section 570 is supported by the second vertical section 550b of the second level 554 and the second vertical section 564b of the second bay 560b. The second horizontal section 570 provides a ceiling of the second level 554 and a floor of the third level 556 between the second vertical section 550b of the second level 554 and the second vertical section 564b of the second bay 560b.

A third horizontal section 572 is supported by the first vertical section 548c of the third level 556 and the second horizontal section 564c of the third bay 560c. The third horizontal section 572 provides a ceiling of the third level 556 between the bay 560c and the first vertical section 548c of the third level 556.

The first bay 560a and the third bay 560c are arranged in the same orientation. The first vertical section 562a of the first bay 560a is vertically aligned with the first vertical section 562c of the third bay 560c. The second vertical section 564a of the first bay 560a is vertically aligned with the second vertical section 564c of the third bay 560c. The first bay 560a has a reverse orientation to the second bay 560b. The first vertical section 562a of the first bay 560a is vertically aligned with the second vertical section 564b of the second bay 560b. The second vertical section 564a of the first bay 560a is vertically aligned with the first vertical section 562b of the second bay 560b. In this way, an opening between the first and second levels 554, 556 is provided between the second

vertical sections 550a-b and bays 560a-b of the first and second levels 552, 554. Similarly, an opening between the second and third levels 556, 558 is provided between the first vertical sections 548b-c and bays 560b-c of second and third levels 556, 558.

- 5 Figure 5c shows an exploded perspective view of the split-level building discussed with reference to figure 5a. Figure 5d shows an exploded perspective view of the split-level building with enclosed-cast horizontal sections discussed with reference to figure 5b.

10 Figure 5e illustrates an exploded perspective view of another arrangement 500 of building sections 502. Each building section 502 comprises at least one wall/column section and at least one floor/ceiling section. Each building section can be cast in turn using the method of constructing a building described previously with reference to figures 1 to 3. An in the example described with reference to figures 5b and 5d, the method comprises arranging a plurality of mould volumes to define wall sections and floor sections of the building such that at least part of the building has a split-level, open-  
15 section construction. The resultant building has a multi-level structure. The arrangement of the plurality of mould volumes is such that the cast structures interlock, or tessellate, to define a plurality of separate units 504, 506, 508 within the building structures 502. Two example building sections are described in detail below.

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A first building section 502 has a horizontal section 510 defining a floor 512/ceiling 514 and a vertical wall section 516 that extends downwards from the ceiling 514 of the horizontal section 510 along a side 518 of the horizontal section 502.

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A second building section 520 has a horizontal section 522 defining a floor 524/ceiling 526, a first vertical wall section 528 and a second vertical wall section 530. The second wall section 530 extends only from the floor 524 of the horizontal section 522. The first wall section extends from both floor 524/ceiling 526 of the horizontal section 522. The first wall section extends a first distance along a side 530 of the horizontal section 522.

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The second wall section 530 extends a second distance along an opposing side 534 of the horizontal section 522. The first distance is greater than the second distance. The horizontal section 522 comprises a first portion adjacent to the first wall section 528 and a second portion adjacent to the second wall section 530. The first portion has a width equal to the first distance and the second portion has a width equal to the second  
35 distance. In this way, a split-level is defined by an opening in the horizontal section 522 of the second building section 520. The wall sections of adjacent third and fourth building sections 540, 542 co-extend with the walls of the second section 520.

Figure 6a illustrates an exploded perspective view of another tessellating building structure having two sets of repeated building sections. Each set comprises at least one unit of a first orientation and the least one unit of a reverse, mirror image, orientation. A first set comprises first, second and third building sections 602, 604, 606. The first building section 602 is the same as the third building section 606. The second building section 604 is the reverse of the first building section 602. A second set comprises fourth, fifth and sixth building sections 608, 610, 612. The fourth building section 608 is the same as the sixth building section 612. The fifth building section 610 is the reverse of the fourth building section 608.

The first building section 602 comprises a first horizontal section 614 disposed between a first vertical section 616 and a second vertical section 618, and a second horizontal section 620 disposed between the second vertical section 618 and the third vertical section 624. The first vertical section 616 extends from the top surface of the horizontal section 614. The third vertical section 624 extends from a top surface of the second horizontal section 620. The first and second horizontal sections 614, 620 are at different height levels and are separated by a first part of the second vertical section 618. The first part of the second vertical section 618 extends from the top surface of the first horizontal section 614 and from a bottom surface of the second horizontal section 620. The first and third vertical sections 616, 624 and the first part of the second vertical section 618 extend along the entire length of the first and second horizontal sections 614, 620. The second part of the second vertical section 618 extends along less than the length of the horizontal sections 614, 620.

The fourth building section 608 is provided on the same level as the first building section 602. The fourth building section 608 has a horizontal section 626 disposed between a first vertical section 628 and an opposing second vertical section 630. The second vertical section 630 is aligned and engaged with the third vertical section 624 of the first building section 602. The first vertical section 630 of the fourth building section 608 extends a first distance along a side of the horizontal section 626. The second vertical section 628 extends a second distance along an opposing side of the horizontal section 626. The first distance is greater than the second distance. The horizontal section 626 comprises a first portion adjacent to the first wall section 628 and a second portion adjacent to the second wall section 630. The first portion has a width equal to the first distance and the second portion has a width equal to the second distance. In this way, a

split-level structure is formed in a similar manner to that described with reference to figure 5e.

5 The second building section 604 is provided on the same level as the fifth building section 610. The fifth building section 610 is substantially below the first building section 602 and has a first vertical section aligned and engaged with the first vertical section 616 of the first building section 602. The second building section 604 is substantially below the fourth building section 608, and has a first vertical section aligned and engaged with the first vertical section 628 of the fourth building section 608.

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The third building section 606 is provided on the same level as the sixth building section 612. The sixth building section 612 is substantially below the second building section 604 and has a first vertical section aligned and engaged with the first vertical section of the second building section 604. The third building section 606 is substantially below the  
15 sixth building section 612, and has a first vertical section aligned and engaged with the first vertical section of the sixth building section 612.

The joint casting of horizontal and vertical members allows free positioning of the construction joint as will be appreciated from the embodiments described above with  
20 reference to figures 5b, 5d, 5e and 6; this in turn enables the improvement or optimisation of the construction sequence to achieve a more productive subdivision of the structure instead of the conventional level-based subdivision. A multi-unit building can be erected around a conventionally cast access shaft, as depicted in the arrangement 650 of figure 6b. In this example indentations are provided in the building  
25 sections in order to accommodate the access shaft.

## Claims

1. A method of casting a concrete material comprising concrete and metal fibres using a mould volume comprising an open section and a closed section, the closed section having a substantially horizontal top shutter portion defining an upper extent of the closed volume and the open section having an opening, the method comprising introducing the concrete material into the mould volume such that the concrete material displaces vertically within the open section and laterally within the closed section to define an upper surface against the top shutter.
2. The method of claim 1 in which the metal fibres are mutually aligned by lateral displacement of the concrete material within the closed section.
3. The method of claim 1 or claim 2 in which the concrete is self-compacting concrete.
4. The method of any preceding claim in which the closed section is in fluid communication with the open section for lateral displacement of the concrete material from the open section to the closed section.
5. The method of any preceding claim in which the mould volume of the closed section is at least as large as the mould volume of the open section.
6. The method of any preceding claim in which a linear lateral dimension of the closed section is greater than a corresponding linear lateral dimension of the open section.
7. The method of any preceding claim including ventilating the closed section through at least a part of the substantially horizontal top shutter portion.
8. The method of claim 7 in which ventilating the closed section is carried out through a permeable lining to the top shutter portion.
9. The method of claim 7 in which the top shutter of the closed section comprises a removable plug, the method further comprising controlling ventilation of the closed section using the removable plug.

10. The method of any preceding claim further including deploying a coating to reduce surface tension on the inside surface of the top shutter portion.
11. The method of any preceding claim in which the mould comprises an insulating layer.
12. The method of any preceding claim further comprising preheating the concrete material before casting.
13. The method of any preceding claim further comprising using a heating system within the mould to heat the concrete material.
14. The method of any preceding claim further comprising using ohmic heating to heat the concrete material by applying an electric current through the concrete.
15. The method of any preceding claim in which the concrete material is introduced into the mould volume in a single casting operation.
16. An apparatus configured to automatically perform the method of any preceding claim.