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(54) **SYSTEM FOR MODULAR BUILDING TOLERANCE CONTROL**

(57) A method and system of assembling a modular building structure, the building structure comprising a first building module comprising at least one first male connector, a second building module comprising at least one second male connector, a connector plate comprising a first aperture arranged to receive the first male connector of the first building module, and a second aperture ar-

ranged to receive the second male connector on the second building module, such that upon receipt of the first and second male connectors the first and second building modules are coupled together, and corrective forces are exerted by the connector plate on the first and second building modules causing the first and second building modules to deform to meet predefined spatial tolerances.

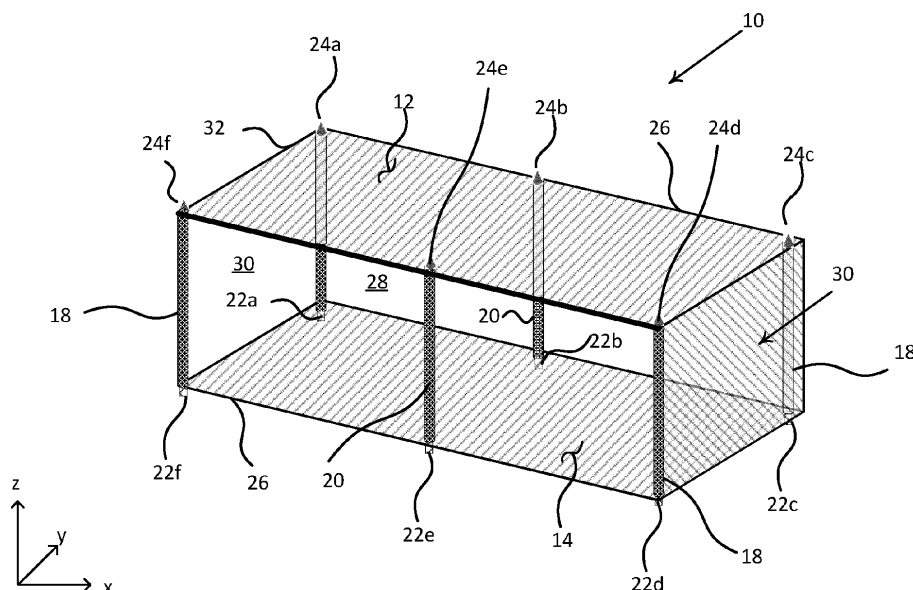


FIG. 1

Description

Background

[0001] Modular buildings comprise prefabricated building sections or modules assembled together to form a whole building structure. Building modules may comprise a load bearing structure, mechanical, electrical, or plumbing components, interior finishes, and exterior cladding, and may altogether form a whole room or storey of the building which may first be entirely or mostly constructed off-site (e.g. in a factory-controlled environment) and delivered to a building site for installation. The advantage of modular buildings lies within the fact that minimal construction is required on-site as building modules are pre-constructed, and therefore allow for increased construction efficiency, consistent building designs, and the ability to service remote locations. Furthermore, as modules may be constructed in factories, materials usage may benefit from economies of scale and the use of building materials and resources may be both recycled and utilised more effectively, leading to low material waste and environmental advantages.

[0002] The embodiments described below are provided by way of example only and are not limiting of implementations which solve any or all of the disadvantages of known modular building construction processes.

Summary

[0003] This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter.

[0004] According to an aspect of the invention, there is provided a method of assembling a modular building structure, comprising forming a first building layer comprising a plurality of building modules by positioning a first building module comprising at least one first male connector adjacent to another building module comprising at least one second male connector; engaging the at least one first and the at least one second male connectors with a first connector plate, wherein the connector plate comprises at least a first aperture arranged to receive the first male connector of the first building module and at least a second aperture arranged to receive the second male connector of the other building module, and wherein upon receipt of the at least one first and the at least one second male connectors by the connector plate the adjacent building modules are engaged together, and when corrective forces are exerted by a plurality of connector plates on the building modules forming the first building layer, deformation is distributed across the first building layer, causing the building modules of the first building layer to incrementally deform to meet pre-defined spatial tolerances for the male connectors of that

building layer to function as datum connection points for an upper building layer.

[0005] Optionally, the first building layer comprises at least one additional building module, wherein the method further comprises engaging an additional male connector of the additional building module and at least one male connector of any of the building modules in the first building layer with at least one additional connector plate, and wherein engaging the at least one additional connector plate exerts corrective forces on all of the building modules in the first building layer to distribute the deformation across the first building layer, causing all of the building modules in the first building layer to incrementally deform to meet the pre-defined spatial tolerances for the male connectors of that building layer.

[0006] Optionally, the method further comprises forming a second building layer on top of the first building layer by positioning another building module on top of one or more building modules of the first building layer, wherein the another building module of the second building layer comprises at least one female connector arranged to receive a male connector functioning as a datum connection point of any of the building modules of the first building layer such that the another building module of the second building layer is coupled together with the building module of the first building layer, and wherein upon coupling the male and female connectors the building module of the first building layer and the another building module of the second building layer are positionally aligned in two or three dimensions into a pre-defined position.

[0007] Optionally, one or more of the at least one first and second male connectors are conically shaped and wherein the taper ratio of the conically shaped male connectors comprise a ratio of between 1:3 and 1:25.

[0008] Optionally, the method further comprises applying a fastening means to secure the male and female connectors together, wherein the fastening means is applied via at least one pair of corresponding apertures in the male and female connectors after coupling the another building module of the second building layer, and wherein the apertures of the male and female connectors align with an access aperture of one or more of the building modules to allow the fastening means to be applied from externally to the building modules, and wherein the access aperture extends through a cavity in a column of the respective building module.

[0009] Optionally at least one of the apertures in the male and female connectors is threaded, and applying the fastening means comprises applying a capscrew arranged to engage with the threaded aperture to secure the male and female connectors together.

[0010] According to another aspect of the invention, there is provided a modular building structure, comprising a first building layer comprising: a first building module comprising at least one first male connector, at least one other adjacent building module comprising at least one second male connector, and a connector plate compris-

ing at least a first aperture arranged to receive the first male connector of the first building module, and at least a second aperture arranged to receive the second male connector of the at least one other building module, such that upon receipt of the first and second male connectors the first and second building modules are engaged together, and when corrective forces are exerted by a plurality of connector plates on the building modules forming the first building layer, deformation is distributed across the first building layer, causing the building modules of the first building layer to deform to meet pre-defined spatial tolerances for the male connectors of that building layer to function as datum connection points for an upper building layer.

[0011] Optionally, the modular building structure further comprises one or more additional building modules extending the first building layer, wherein an additional male connector of the additional building module and a male connector of any of the building modules in the first building layer are engaged with at least one additional connector plate, and wherein engaging the at least one additional connector plate exerts corrective forces on all of the building modules in the first building layer to distribute the deformation across the first building layer, causing all of the building modules in the first building layer to deform to meet pre-defined spatial tolerances for the male connectors of that building layer.

[0012] Optionally, the modular building structure further comprises a second building layer on top of the first building layer, the second building layer comprising another building module on top of one or more building modules of the first building layer, wherein the another building module of the second building layer comprises at least one female connector arranged to receive a male connector functioning as a datum connection point of any of the building modules of the first building layer such that the another building module of the second building layer is coupled together with the building module of the first building layer, and wherein upon coupling the male and female connectors the building module of the first building layer and the another building module of the second building layer and positionally aligned in two or three dimensions into a pre-defined position.

[0013] Optionally, one or more of the at least one first and second male connectors are conically shaped and wherein the taper ratio of the conically shaped male connectors comprise a ratio of between 1:3 and 1:25.

[0014] Optionally, a stiffness of the connector plate is higher than a stiffness of the building module.

[0015] Optionally, a material hardness of the male connectors is higher than a material hardness of the connector plate.

[0016] Optionally, the male and female connectors are secured together by a fastening means applied via at least one pair of corresponding apertures in the first and second connectors.

[0017] Optionally, the apertures of the male and female connectors align with an access aperture of one or more

of the building modules of the first or second building layers to allow the fastening means to be applied from externally to the building modules.

[0018] Optionally, the access aperture extends through a cavity in a column of the building module.

[0019] Optionally, at least one of the apertures in the male and female connectors is threaded, and the fastening means comprises a capscrew arranged to engage with the threaded apertures to secure the male and female connectors together.

[0020] Optionally, the first or second building modules comprise a pre-fabricated housing unit.

[0021] According to another aspect of the invention, there is provided a connection system for vertically connecting plurality of building modules to form a building structure comprising one or more building modules per storey, the connection system comprising a first building layer comprising at least one first building module, the at least one first building module comprising at least one male connector element, each male connector element having a configuration enabling it to be received by a female connector element having a corresponding configuration, the male connector element attached to the first building module and protruding away from the first building module, the male connector elements being fabricated as part of the infrastructure of the first building module; a second building layer comprising at least one second building module, the at least one second building module comprising at least one female connector element, each female connector element having a configuration enabling it to receive a male connector element having a corresponding configuration, the female connector element being formed integrally with the second building module, the female connector elements being fabricated as part of the infrastructure of the second building module; wherein the connector elements are positioned and configured to guide an upper one of the first or second building modules as it is lowered onto a lower one of the first or second building modules to positionally align the building modules along two or three dimensions.

[0022] According to another aspect of the invention, there is provided a self-positioning multi-storey building structure comprising a plurality of building modules, each building module comprising: a flexible frame comprising a plurality of beams and columns; a plurality of male connectors; a plurality of female connectors, wherein the male and female connectors of each building module are configured to cause the building module to which they are attached to deform and bring itself into alignment with one or more other building modules positioned at least partially under it as it is lowered onto the one or more building modules.

[0023] Optionally, the self-positioning multi-storey building structure further comprises a connector plate arranged to receive at least one male connector and at least one female connector to engage two or more adjacent building modules, wherein upon receipt of the at least one male connector and the at least one female

connector adjacent building modules are engaged together, and when corrective forces are exerted by a plurality of connector plates on the building modules, deformation is distributed across the engaged building modules, causing the engaged building modules to incrementally deform to meet pre-defined spatial tolerances.

[0024] According to another aspect of the invention, there is provided a building module for use in a multi-storey building structure as claimed.

[0025] The above features may be combined as appropriate, as would be apparent to a skilled person, and may be combined with any of the aspects of the examples described herein.

Brief Description of the Drawings

[0026] Examples will now be described in detail with reference to the accompanying drawings in which:

FIG. 1 is a schematic diagram of an example frame-based building module;

FIG. 2 shows schematically an exaggerated example of how the frame-based building module shown in FIG. 1 can distort under load;

FIG. 3 shows schematically an exaggerated example of manufacturing tolerances for an example building module;

FIG. 4 shows schematically an example connector system comprising male and female connector components between two building modules;

FIG. 5 is a schematic overhead plan view which illustrates an exaggerated example of lateral deviation and/or distortion between the upper and lower floors of an example building module;

FIG. 6A shows a schematic plan view of an example arrangement of a building storey comprising a plurality of example building modules placed in proximity to each other;

FIG. 6B is an enlarged schematic plan view of the central region joining the plurality of building modules shown in FIG. 6A;

FIG. 7A is a first schematic view of an example of a tie plate;

FIG. 7B is a second schematic view of the tie plate of FIG. 7A;

FIG.s 8A and 8B illustrates schematically stages of assembly an example building structure;

FIG. 9 illustrates an example of an example male

connector component;

FIG. 10A shows an example of a modular building structure according to an embodiment of the invention from a first side-ways perspective;

FIG. 10B shows the example modular building structure of FIG. 10A from a second side-ways perspective; and

FIG. 11A shows in more detail a first example of how a three-storey building structure can be linked using two building connector systems;

FIG. 11B shows in more detail a second example of how a three-storey building structure can be linked using two building connector systems;

FIG. 12 shows schematically in yet more detail two example building modules connected using a building connector system.

FIG. 13 shows schematically steps in an example method of positioning at least one example building module using an example connector system comprising male and female connector components;

FIG. 14 shows schematically steps in constructing an example method of constructing a multi-storey modular building structure comprising multiple building modules per storey; and

FIG. 15 shows schematically steps in an example method of controlling modular building construction.

[0027] The accompanying drawings illustrate various examples. The skilled person will appreciate that the illustrated element boundaries (e.g., boxes, groups of boxes, or other shapes) in the drawings represent one example of the boundaries. It may be that in some examples, one element may be designed as multiple elements or that multiple elements may be designed as one element. Common reference numerals are used throughout the figures, where appropriate, to indicate similar features.

Detailed Description

[0028] This disclosure relates to a system for modular building tolerance control. In particular, but not exclusively, to tolerance control which allows a building structure comprising two or more pre-fabricated building modules to be positioned on site in sufficient alignment with each other to allow for any pre-fabricated cladding or similar surface decoration to provide a substantially continuous undisturbed surface across both building modules. Such an effect can be achieved if the building modules are aligned sufficiently, usually within 2mm, but preferably

within 1mm or less of each other. In this manner, the join between the two building modules may not be visible to the naked eye when a person is viewing both building modules and/or the entire building structure.

[0029] The following description is presented by way of example to enable a person skilled in the art to make and use the invention. The present invention is not limited to the embodiments described herein and various modifications to the disclosed embodiments will be apparent to those skilled in the art.

[0030] Figure 1 illustrates a perspective view of a schematic representation of an example building module 10. As shown in Figure 1, the building module 10 is shown vertically aligned in a z-axis direction and the ceiling 12 and floor 14 of the building module 10 are aligned with the x-y plane. The example building module 10 shown in Fig. 1 comprises in addition to corner side columns 18, mid-side columns 20. It will be apparent to anyone of ordinary skill in the art that depending on construction dimensions and loads on the building module 10, mid-columns 20 may be omitted in some walls of example building modules (for example, as shown in FIG. 1 in side walls, 28 30. In other examples, more than one mid-column 20 may be provided (for example, if more load is to be supported by the building module 10).

[0031] Not visible in Fig. 1, is the interior of the columns 18, 20 which are constructed in some embodiments to allow access to lower connector elements 22 to fix the engagement of lower connector elements 22a,...22f to other connector elements (for example, corresponding connector elements of another (lower) building module or corresponding connector elements 24a, ...24f positioned at ground level to form a base module guiding layer - not shown in Fig. 1).

[0032] The corner columns 18 and mid-columns 20 shown in Fig. 1 together with upper and lower long beams 26 (only the top rear beam and front lower beam are labelled in Figure 1 for the sake of clarity) form a frame which together with suitable wall panels form the front and rear walls 28 of the building module shown in Fig. 1. Whilst the long beams 26 are shown as lines in Fig. 1, it will be appreciated that in reality they are three-dimensional load-bearing structures. The corner columns 18 and short beams 32 together with suitable wall panels form sidewalls 30 as shown in Figure 1. The ceiling 12 and floor 14 are formed from long beams 26 and short beams 32 which provide the support for and/or frame respective ceiling and floor panel(s).

[0033] In this example of a building module 10, the assembled module 10 forms a 3D volumetric space comprising an enclosed room or discrete unit of a building (as in four walls are described, although not all can be shown in Figure 1). In some embodiments, however, the 3D volumetric space is formed by an example module where one or more of the ceiling/floor/side/front/rear walls are omitted to open up the interior space so that a larger 3D volumetric space is formed on site by a plurality of building modules by positioning the building modules

adjacent to one or more other building module(s). Higher 3D volumetric spaces can be also formed by creating apertures formed in floor and ceiling layers, for example, to allow for double height building modules and/or to allow staircases and the like to be provided in some examples.

[0034] The example building module 10 shown schematically in Figure 1 omits for the sake of clarity any additional building features which would normally also be provided. Examples of such additional features include but are not limited to additional load bearing structures/components, mechanical, electrical, or plumbing (MEP) components, interior finishes, or exterior cladding.

[0035] In some embodiments, the example building module comprises a pre-fabricated housing unit or commercial premises unit such as may be provided for business premises.

[0036] Traditionally, such building units require construction on-site, i.e. construction at the final location of the building itself. However, modular construction allows the building module 10 to be pre-fabricated in a factory-controlled setting before being transported to the building site for installation. It is known to pre-fabricate building modules comprising a suitable frame together with the floor, ceiling and any walls of the building module, however, recent improvements in building construction techniques and improvements in manufacturing controls now allow more of the build process to be conducted off-site, for example, within a factory environment.

[0037] Buildings have been constructed using 3D volumetric modules for many years where the accuracy of module manufacture generally complies with normal construction tolerances of say +/-5mm. Whilst it is also known for building modules to be manufactured with better tolerances unless the assembly methods used on site are able to approach the manufacturing tolerances, limited benefits are achieved from this improved accuracy within the factory. This has in some instances deterred investment in equipment to improve such tolerances. For example, a typical assembly sequence such as will be familiar to someone of ordinary skill in the art is as follows:

A) Cranes lift a module, guide the module to its intended position with respect to the site location and any other building infrastructure at the site location. Known guidance techniques include the use of, for example, bumpers and cones to assist in landing the module in substantially the correct position. However, such known systems are positioned on site, rather than pre-positioned and integrated with the building module infrastructure during its manufacture. This results in a very loose tolerance and resulting potential mis-alignment of building module as they are positioned on site relative to each other.

B) Check the module for alignment with adjacent modules. Taking the weight on the crane, fine adjust position. Once position is OK, release the crane.

C) Lock the module to the adjacent module using a series of bolts and shims. Bolt down to modules underneath.

D) Proceed to install horizontally adjacent modules.

E) Once a whole storey level of modules has been installed, proceed to install the next storey level of modules;

F) Once a vertical face around the perimeter of a building has been established, use mast climbers to apply the cladding to the building. The cladding can be adjusted to suit the as-built dimensions.

[0038] The application of cladding on-site in the above known process is necessary, as the actual alignment of the building modules cannot be sufficiently controlled and so there is usually misalignment which exceeds 5mm or so per storey or within a storey between two modules. This known process creates a problem when one tries to complete as much of a building module as possible off-site in a factory environment. For example, to pre-attach cladding or similar surface finishes/treatments/decoration, the alignment needs to be in order of 2mm or less if no visible join is to be created between two pre-clad building modules when they are positioned adjacent to each other on site. The process is further complicated and slowed down by the need to check alignments between modules and to level using shims where necessary. The rate of assembly of a multi-storey building structure comprising one or more modules on each storey is typically slowed down to a single crane installing between 8 and 12 modules per 8-hour shift. The need to apply cladding at site afterwards to accommodate required "as-built" dimensions results in a significant amount of work related to the build process still being performed on site which further increases build time.

[0039] The invention seeks to reduce the amount of time it takes to construct building modules and also seeks to provide a more environmentally friendly way of constructing building modules by reducing the amount of construction work which occurs outside the controllable environment of a factory. By applying cladding off-site to building modules, it is possible to maintain a cleaner build environment with a much lower element of air-pollution. As the build process is much shorter, pollution caused by the usual dust and dirt associated with the construction process is also greatly reduced. Noise is also greatly reduced.

[0040] Advantageously, the connector components, connector systems, and methods developed and described herein allow a sufficient increase in the amount of control over positioning of building modules on-site when constructing building structures to allow more of the build process to occur within the factory environment. The technology disclosed herein allows the tolerance which would otherwise need to be allowed for on-site

construction of a building structure using building modules to be reduced and benefits of this include:

a) reducing the installation time of multi-modular building structures, typically by more than half, so that, for example, the construction of building structures requiring 20+ modules to be installed can be completed by a single crane in a single 8-hour shift; and

b) the dimensional accuracy of the building structure exterior facade is good enough to permit cladding to be pre-installed at the factory.

[0041] These factors also greatly reduce the amount of dust and other pollution which might otherwise result from a prolonged building operation and also reduce the need for highly skilled labourers to travel to each construction site to effect an accurate installation, which can also benefit the environment by reducing the need for such skilled labour to travel to build sites across the country.

[0042] Returning to Figure 1, the example building module 10 shown is provided with a plurality of first, upper, connector components, shown as male connectors 24a, ..., 24f. The example building module 10 is also shown provided with a plurality of second, lower connector components, shown as female connectors 22a, ..., 22f. The connector components 24 and 22 are positioned in vertical alignment with floor to ceiling columns 18, 20. Aligning the connector components with columns 18, 20 allows concealment of a connector system formed by corresponding female and male connector components 22, 24. In some embodiments, the columns 18, 20 are hollow to allow internal access for fixing means (not shown in FIG. 1, but described later herein below) to be used to fix the engagement of connectors with each other. In this way, each lower connector 24 of the building module 10 shown in Fig. 1 can be fixedly attached to another, lower, building module (not shown in Figure 1) by accessing the interior of a column 18, 20 before another building module (not shown in Fig. 1) is lowered on top of it.

[0043] Preferably a building module 10 is provided with enough male connector components 24 to collectively reduce the tolerance of each degree of freedom the building module 10 can move within to below a desired level. Usually this level will be predetermined as a constraint imposed on a building module 10 or building structure 100 being constructed using one or more of such building modules 10.

[0044] Each building module 10 is manufactured to include connector components 22, 24. The connector components may be machined, joined, mounted or shaped into the building module framework itself, and therefore integral with the building module framework. In some examples, to ensure that the male and female cone connectors are integrated within the building infrastructure,

the columns that the connectors are integrated into are first formed, and then during the factory-based construction of the building module, precision engineering is used to position the location of each connector component 22, 24. For example, appropriate apertures for receiving a connector component 22, 24 may be drilled into each building module column using tooling equipment which is robotically controlled so that the tolerance in the position of these apertures is kept to a minimum. In some embodiments, each aperture then receives a male and/or female connector component, so that the building module constructed within the factory leaves the factory facility with the cone connector components already integrated into the frame infrastructure. Integrating the cones into the frame infrastructure allows forces which are applied to a male cone (e.g. by a tie-plate or by a female cone connector) or to a female cone (e.g. by a male cone connector) to be transferred to the beams and columns forming the frame which in turn alters the frame configuration.

[0045] In the example of a building module shown in Fig. 1, the building module 10 comprises six male connector components 24a, ..., 24f which are shown schematically as a male "cone" type structure at the upper end of a corner 18 or mid-column 20 and six corresponding female connector components 22a, ..., 22f which are shown schematically located at the lower end of the vertical corner 18 or mid-columns 20. Each male connector 24 is designed to form a modular building connector system by engaging in use with a corresponding "female" connector component 22 of another building module 10. It will be apparent that in some embodiments, the terms "male" connector and "female" connector may be interchanged, providing the appropriate functionality is maintained by the connector system. Moreover, it will also be apparent that whilst in this embodiment, male connectors engage with female connectors in a vertical position with the male connectors on top, in some embodiments the positions of the male and female connectors may be reversed. It is also possible in some embodiments for connectors to be used for joining adjacent building modules 10 laterally (for example, in addition to or instead of the connector plate mechanism described in more detail herein below).

[0046] Also shown schematically in Figure 1 as a basic cone, each male connector 24 in practice has a shape and/or 3D configuration which allows the first, male, connector 24 to provide at least two functions when constructing a building 100 from a plurality of building modules 10.

[0047] One function is to act as a guide for alignment of building modules 10 during the construction phase when multiple building modules 10 are being connected so that the amount of tolerance in the relative position of at least the adjoining exterior portions of adjacent building modules 10 which make up the exterior of a multi-module building structure 100 are maintained across all building modules to below a predetermined tolerance limit. The predetermined tolerance limit for the alignment is prefer-

ably less than 5mm and may be 2mm or less in some embodiments. Advantageously, by limiting the tolerance limit to, for example, 2mm or less, this allows for pre-attachment of cladding to the building modules at the factory, thereby saving on construction costs and time. The other function is to allow a connection to be formed after one building module 10 has been positioned to another building module 10 which in some embodiments allows fine tuning of stacked building modules 10 in the vertical direction. For example, the male connectors 24 of a building module may be exactly positioned within pre-defined tolerance limits during the construction process such as to function as datum connection points for an upper building module or building layer. In other words, the male connectors are exactly positioned to receive corresponding female connectors of an upper building module to be coupled according to a pre-defined spatial tolerance limit. The pre-defined spatial tolerance limit may be chosen according to current manufacturing capabilities such as to minimise misalignment of one or more aspects of the building structure. Another function provided by the connector is the ability to fix the connection so that one building module 10 is fixedly bound to at least one other building module 10.

[0048] In this way, each connector 22, 24 enables a plurality of building modules 10 to be aligned in both two and three dimensions as each male connector 24 engages with each female connector 22.

[0049] Different sizes and configurations of male connectors 24 (and corresponding female connectors 22) may be used in some embodiments for the same building module. Male connectors 24 which protrude more from a surface 12, 14, 28, 30, of a building module 10 may engage with reciprocal female connector 22 initially to allow two building modules 10 to be first aligned relative to each other with a large degree of tolerance over their relative positions. However, as the two building modules are moved together, male connectors 24 which have a smaller degree of protrusion may start to engage with reciprocating female connectors 22 to further reduce the level of tolerance as the two building modules 10 move together.

[0050] Returning now to Figure 1, each male connector 24 has the same configuration and comprises a suitably configured cone-shaped protrusion. Other configurations may be used providing this will allow the modules to self-align as they move together. As shown in Figure 1, male cone connectors 24a, 24c, 24d, 24f are located at the top of the corner columns 18 of the building module and male connectors 24b, 24e at the top of the mid-point columns 20 of the topmost long beams 26, however it will be appreciated that male connectors 24 may be located in any other suitable location on the building module 10. The example male connectors 24 may extend outwardly from any surface of the building module 10. In some embodiments, the male connectors 24 are conically-shaped, however it will be appreciated that other suitable shapes may be used, such as a conic frustum

or pyramidal frustum, providing the distal end of the male connectors is suitably configured to allow engagement with another building module in a manner which maintains or improves their alignment as the two building modules 10 move closer together.

[0051] The building module 10 shown in Figure 1 also comprises a number of reciprocating female connectors 22a, ..., 22f. Each female connector 22 has a three-dimensional configuration or shape and is manufactured in the building module 10 to ensure a high-level of accuracy over its position so as to enable it to at least initially engage with a corresponding male connector (for example, a male connector 24 attached to another, second, building module or appropriately set out at ground level (not shown)). The configuration and the positioning of the female connector 22 also supports the guidance and alignment function performed by the corresponding male connector 24 which is attached to another, second, building module 10 as the building modules 10 are moved together. In some embodiments, the female connectors 22 of a building module 10 are aligned with corner columns 18 and mid-columns 20 and each female connector 22 has a configuration designed to provide at least two functions. Firstly, to allow that building module 10 to be lowered onto corresponding male connectors 24 (for example, of a lower building module). The second function provided is to allow the upper building module 10 containing the female connectors 22 to be fixedly engaged with the corresponding male connectors 24 by using a fixing tool which gains access to the concealed connection system of each column 18, 20 via the male connector 24 located at the top of the column 18, 20 of the upper building module 10. In this manner, for example, the male and female connectors of adjacent modules can be bolted together in close alignment.

[0052] Accordingly, each female connector 22 comprises a cavity or hollow extending inwardly to the building module 100 and shaped to receive a corresponding male connector 24 to form a building module connection system. In the example embodiment shown in Figure 1, the female connectors 22 are located at the bottom of the corner columns 18 of the building module 10 and at the mid-point columns 20 of the lower-most long beams to enable two building modules to be vertically stacked on top of each other. As mentioned, however it will be appreciated that a female connector 22 may be in any other suitable location on the building module 10 and may extend inwardly from any surface of the building module 10. In some embodiments, the female connector 22 is conically-shaped, however it will be appreciated that other suitable shapes may be used which reciprocate and conform to the shape of the male connectors 24.

[0053] As mentioned above, by attaching male 24 and female 22 connectors to each building module, it is possible to use them to join together two building modules 10. This allows for quick and efficient construction on site of single or multi-storey building structures which comprise one or more building modules 10 on each storey.

It will also be appreciated that in order to successfully join two building modules via their male 24 and female 22 connectors with a suitably high level of alignment (for example, such as may allow certain exterior surface finishes (such as cladding) to be applied in a factory environment to maintain alignment when the building modules are deployed on site), the positions of the building modules 10 must be suitably aligned such that the male 24 and female 22 connectors are adequately positioned to receive each other. In some embodiments, the male 24 and female 22 connectors are accordingly located in matching positions on the top floor 12 and bottom floor 14 of their respective building modules 10. It will accordingly be appreciated that in some embodiments, it is feasible that the male 24 and female 22 connectors may be located elsewhere and/or other intra-modular connections may be formed for example using connector plates such as the connector plate 700 described in more detail with reference to at least Figures 6A, 6B and 7A, 7B.

[0054] In some embodiments, a building module is manufactured to comprise only one type of connector element per surface plane of the building module (for example, all male connectors 24 are shown as the upper connector components protruding from ceiling 12, and all female connectors 22 are shown recessed within floor 14). In some embodiments, however, a mix of male or female connectors may be provided on the same surface plane. For example, corner connector elements may be male connectors 24 in the ceiling plane 12 and female connectors 22 on the floor plane 14 of a building module 10 with the mid-columns having female connectors located instead at the upper end within the ceiling plane 12 and male connectors protruding from the floor base 14. In embodiments of building modules where lower male connectors are provided, the number of such lower male connectors is preferably sufficient to support the weight of the building module they are attached to without deforming unless other provisions are made for supporting the building module until the building module has been installed on site.

[0055] Also, for example, building modules may be manufactured with connector elements arranged according to their intended on-site location. For example, building modules 10 intended for use as top floor modules in a multi-storey building structure 100 may only be provided with lower connectors (e.g. with female connectors 22 if a lower building module has the module configuration shown in Fig. 1). Although the examples described herein mostly discuss male connectors engaging vertically upwards with downwards facing female connectors, it will be apparent that in some embodiments, the connectors may be differently oriented, for example, male connectors 24 may engage vertically downwards if male connectors 24 are provided in the floor 14 of a building module 10 and engage with female connectors 22 provided in the ceiling/top floor of another building module 10.

[0056] It will also be apparent that whilst the male con-

nectors protrude from the ceiling 12 of a building module as shown in the example of Figure 1 by a certain distance in the vertical direction (in this example, parallel to the z-axis shown in Fig. 1), the reciprocal female connectors 22 must be sufficiently recessed in the floor 14. In some embodiments, the floor depth may impose a constraint on the depth of certain or all of the female connectors 22 of a building module (and/or the corresponding distance a male connector 24 protrudes to engage with the female connectors 22). For example, if the connectors 22, 24 are too big and/or are not positioned within a wall 26, 28, 30 or column 18, 20 of a building module 10, they may be visible within the interior of the building module 10.

[0057] When fabricating panels such as wall panels, floor panels, or ceiling panels for installation in a frame of a building module 10, manufacturing inaccuracies may introduce small deviations in the dimensions, i.e. size and/or shape, of the panels. Furthermore, on-site construction inaccuracies may cause dimensional deviations. In addition, the positions of building module components may deviate when assembled and under load due to gravity, material stresses, tension, or other forces.

[0058] Figure 2 for example shows in an exaggerated form a lateral view of a distorted building module 10 to illustrate by way of example how a "true" wall shape 28a of a manufactured building module 10 may be deformed, for example, such as may happen when it is installed on site. In the example shown in Figure 1 the building module 10 has been installed in a way which has resulted in a distorted wall panel 28b (shown as a dashed outline in Figure 2). In the exaggerated example shown in Figure 2, the lower connector elements of the distorted wall panel 28b comprise female connectors 22a, 22b, 22c which are shown in alignment with "true" lower connectors, however, the upper connector elements of the distorted wall panel 28b (provided here by male connectors 40a, 40b, 40c) are shown as being displaced in 3 dimensions relative to the location of "true" male connectors 24a, 24b, 24c.

[0059] The building module panel which is distorted is shown in Figure 2 as a wall panel but it will be apparent that distorted, displaced, and deformed building components as well as the construction process on site could each or all, individually or collectively, cause at least a portion of part of the exterior of the building module to deviate from "true" where "true" exceeds either a theoretical ideal or predetermined amount of tolerance from such a theoretical idea. Examples of building components which can cause a building module to warp or deviate from its manufactured or "true" configuration include at least one or more of the following: pre-fabricated wall/floor/ceiling panels, load bearing columns or other internal or external structure, ducts for services, windows or any other aspect of a building module. Even if the each manufactured building module meets the manufacturing tolerance conditions for being "true", where the dimensional errors may only represent small deviations from the true intended size and/or shape of the component, a

building structure 100 comprising one or more such building modules 10 may still deviate from true by an unacceptable amount when assembled on-site.

[0060] Dimensional errors in a single panel can cause further misalignment of all other associated panels of a building module, and in some circumstances can impact the alignment of an entire neighbouring building module, thus leading to misalignments in the building itself.

[0061] In some scenarios, errors or deviations in dimensions of the components may impact the position of the male and/or female connectors of the building module. It will be appreciated that a misalignment between corresponding male and female connectors of two different building modules will prevent the building modules from joining together successfully. Building module components are therefore usually produced and assembled according to spatial tolerances, wherein the dimensions or positions of the components may be allowed to vary within an acceptable range.

[0062] Figure 3 shows lateral distortion of a floor plane 14b (dashed outline) relative to a manufactured "true" floor plane 14a (solid line) of a building module 10. The description below however can also be applied equivalently for lateral distortion in the ceiling plane 12 of a building module 10. In Figure 3, each distorted connector element 40a, ..., 40f has been displaced from its true position (indicated by connectors 24a, ..., 24f). A tolerance circle 42 having a diameter d_{tol} is shown in Figure 3 as a dotted circle centred on the theoretically perfect location of each connector's centre. Building modules are manufactured so that each connector element 22, 24 falls within the tolerance circle 42. It will be appreciated that in some embodiments, tolerance circle 42 may have a different configuration to allow for different tolerances in different directions (for example, it may take the form of an ellipse or otherwise vary from being a perfect circle).

[0063] In Figure 3, the acceptable range of positions that the centres of the male connectors 40a, ..., 40f of a factory manufactured building module 10 may take in order to satisfy spatial tolerance requirements is shown schematically. As can be seen, despite not being centred, the position of male connectors 40a, 40b, 40c, 40d, 40f of the manufactured panel 14 falls within the spatial tolerance range 42, and thus have acceptable dimensional errors as the error is not significant enough to cause substantial misalignment that would impact the rest of the building module. However, the position of male connector 42e of the 'realistic panel' falls outside of its spatial tolerance range 42, and thus the position of male connector 42 will require some correction such that it is within its spatial tolerance range 42 by adjustment on-site if not corrected in the manufacturing environment. Correct positioning of the male connectors 40a... 40f allows them to function as datum connection points for the female connectors of other engaging building modules, thereby ensuring incremental alignment of the building structure as it is constructed layer by layer.

[0064] Figure 4 shows schematically the configuration

of an example simple connector system comprising a male and female connector. In Figure 4, the example connector system comprises a protruding male connector 24 having substantially a solid cone configuration and a corresponding female connector 22 having a conforming configuration to that of the male connector. In some embodiments, such as are described later hereinbelow with reference to Figures 11A, 11B and 12 both of the connector elements have a configuration which allows them to be fixed to each other using a suitable fastening means such as the example fastening means 84, 98 shown in these Figures. Examples of a suitable fastening mechanism accordingly include providing each connector element with an internal bore which may be smooth or threaded, such that they can be fixed to each other using a suitable screw, bolt or other fixing mechanism. Figure 4 shows a lateral sectional view of such a connector system for vertically stacking a building module 10 having a lower connector component comprising a female connector 22 over a corresponding male connector 24 taken along a cross-section of the male connector 24 which passes through an axis of symmetry Z-Z' of the male connector 24. In the example connector system of Figure 4, male connector 24 is shown mounted on a lower connector support, such as, for example, may be provided by the ceiling layer 12 of a lower building module 10 or by some suitable foundation for a ground floor building module installation. In Figure 4 the female connector 22 mounted within the plane of the floor 14 of a second building module 10 has an internal recess/ aperture for receiving the male connector with a diameter d_{fc} and the male connector diameter is indicated as d_{mc} .

[0065] The configuration or shape of each male connector 24 is designed to provide a vertical guidance function by co-operating with a respective female connector 22 which provides vertical tolerance control. Each male connector 24 is also designed to co-operate with a connector plate 60 to provide lateral tolerance control.

[0066] To better explain the functionality of the connector system as regards providing vertical tolerance control, consider an example embodiment where one or more male connector components 24 protrude upwards from the roof 14 of a building module 10a. Another building module 10c which contains a corresponding number of female connectors 22 which will each have been manufactured to be centred within the tolerance levels required to receive a male connector of a building module such as building module 10a is to be lowered on top of building module 10a such that a two storey building structure is formed from the two building modules 10a, 10c.

[0067] The upper building module 10c is first lowered towards building module 10a such that all of the male connectors 24 of the lower building module 10a are able to enter the capture zones of their respective corresponding female connectors 22 in the upper building module 10c. Unless all of the connector components of the two building modules are perfectly aligned, at least some of the weight of the upper building module 10c will eventu-

ally start to act on some of the surface of at least one of the male cone connectors 24. The weight of the upper building module 10c will be deflected by the protruding male cone surface configuration. Providing the male cone connectors 24 are sufficiently strongly fixed to or integrated into the building framework infrastructure of the lower building module 10c, the weight of the upper building module 10c as it acts on the cone connectors 24 of the lower building module 10c will produce sufficiently strong forces on at least the building framework infrastructure of the upper building module 10c to cause its framework to flex in order to allow the male connectors to be more aligned and eventually fully received by the female connectors 22. Once all of the male cone connectors 24 are in full alignment with the female connectors 22, the upper building module 10c can be lowered fully onto the lower building module 10a which allows both the full weight of the upper building module 10c to fall onto the lower building module 10a. This ensures the two building modules are vertically in alignment to the extent that the manufacturing tolerances of the male 24 and female 22 connectors, and the building module frameworks allow. To ensure that the male and female connectors are sufficiently strongly integrated into the framework of the building modules 10a, 10c, they are ideally positioned in alignment with either steel long beams 26, short beams 32, and/or aligned with columns 18, 20.

[0068] In this manner, vertical tolerance control can be achieved by providing male connectors 24 which are received by female connectors 22 providing the two connector components 22, 24 have been manufactured to have conforming levels of tolerance relative to their positions in each building module. This allows control over the alignment of a building module 10c including one or more female connectors 22 as the building module 10c is lowered over one or more corresponding male connectors 22. In this way, two building modules may be coupled together to form two storeys in a multi-storey building structure 100 using at least one suitably configured connector assembly but preferably more than one connector assembly of a female connector 22 and male cone connector 24 as this will better constrain the position of the two modules relative to each other.

[0069] In the example shown in Figure 4, male cone connector 24 has a cylindrical base with diameter d_{mc} and as mentioned the cylinder at the top of the female connector 22 has a diameter d_{fc} . Providing $d_{fc} - d_{mc} \geq d_{tol}$, where d_{tol} is the diameter of the lateral manufacturing tolerance of the connector's positioning in the floor 14 and ceiling 12 of a building module, then all the female cones 22 of an upper module floor panel 14 will fit over the male connector 24 positioned below (for example, the male cone connectors located in ceiling panel 12 of the building module below). It should be noted that poor tolerances will tend to reduce the overall deviation of the centre of the floor area of the upper building module 10 relative to the centre of the area defined by the set of

lower male connectors of a lower module 10 as there is less relative movement possible between upper and lower building modules.

[0070] In Figure 4 the male connector 24 is illustrated as a conical frustum, however it will be appreciated that any other suitable shape may be used in practice. Similarly, female connector 22 is illustrated as being rectangular, however any other suitable shape may be used in practice. As can be seen, the female connector 22 is shaped to receive the male connector 24 to form a coupling between the two connectors 22, 24 so that it allows a second building module to be guided into its correct location relative to a first building module 10 during coupling process. In this way, adjacent building modules 10 may be joined together. Vertical stacking configurations are able to use gravity to force the engagement of the connectors in such a way that the building columns and walls of the module they are attached to flex sufficiently to reduce errors in alignment.

[0071] Whilst Figure 4 shows a coupling where the female connector 22 is positioned vertically over the male connector 24, however it will be appreciated that in other embodiments the male 24 and female 22 connectors may be positioned to receive each other horizontally or at any other angle, providing sufficient force can be applied to bring the two building modules together using the coupling of the male and female connector elements. The force to bring the two building modules together may be provided only by the weight of a coupling module in order to ensure minimum damage to the modules.

[0072] Figure 5 shows schematically an exaggerated level of distortion of a floor panel 14 relative to a "true" ceiling panel 12. In Figure 5 a plan view is provided which depicts an example of a laterally distorted (i.e. in the x-y plane) floor 14 of a building module 10 relative to a "true" ceiling 12 of the same building module 10 or another building module 10. Those of ordinary skill in the art will find it apparent that in some embodiments a similar plan view could be obtained by lateral distortion of the ceiling relative to a "true" floor and that in some embodiments both the ceiling 12 and the floor 14 of one or both building modules 10 may be distorted, although these embodiments will not be described for the sake of brevity herein. As shown in Figure 5, deviations are shown in terms of Δx , Δy to illustrate there is deviation in two dimensions. It will be apparent that if a three-dimensional deviation is present, this can be indicated by Δz using a conventional x, y, z Cartesian coordinate system.

[0073] It will be appreciated that some building structures may require multiple building modules per floor or storey of the building. For example, a single floor of a building may comprise a plurality of building modules positioned adjacently, with further building modules positioned above or below. The connector system which is formed from male and female connectors 24, 22 also allows, when used in conjunction with a suitably configured building module connector-plate, such as is known in the art as a tie-plate, to provide two-dimensional lateral

tolerance control across an entire storey or floor of a building structure 100. In embodiments where lateral tolerance control is being provided across a storey, one or more, but not necessarily all, of the connector systems in that storey will function as a three-dimensional tolerance adjustment mechanism.

[0074] Figure 6A shows schematically a roof-level plan view of a first building layer of an example building structure 100 comprising a plurality of building modules 10a, 10b, 10c, 10d positioned adjacent to each other to form a floor of the building structure 100. The arrangement of four building modules 10a, ..., 10d represent an example arrangement of building modules 10 to form a floor, layer, or storey of an example modular building 100 and many other arrangements modules 10 to form a floor or layer are possible. As is shown later in Figures 10A and 10B, in some embodiments, building modules are not stacked in alignment one about each other and it is possible for building modules 10 to be off set from each other so that the vertical stacking of building modules is staggered.

[0075] Returned now to the single storey or floor shown in Figure 6A, each building module 10a, ..., 10d has a plurality of upper connector elements shown in this example as male connectors 24a, ..., 24f which are suitably located in the ceiling/roof layer 14 of their respective building module at locations which align with structural corner and mid-column elements 18, 20. Also shown in Figure 6A is a cluster 68 of multiple connector elements. As shown in Figure 6A, four modules are joined at the point of cluster 68. To provide improved alignment and linkage between each of the four building modules 10a, 10b, 10c, 10d at the point of cluster 68, a connector plate such as tie-plate 60 is used in some example embodiments of a method of constructing a modular building.

[0076] As shown in Figure 6A, cluster 68 comprises four connector elements: 24d from building module 10a, 24f from building module 10b, 24a from building module 10c, and 24c from building module 10d. Figure 6B shows an enlarged view of the connector cluster region 68 which provides more detail of the connector plate 60.

[0077] Figure 6B show a cutaway plan view of the cluster 68 comprising the four connector elements, shown in this example as male connectors 24d, 24f, 24a, 24c which provides more detail than Figure 6A. Figure 6b shows that in fact the centres of at least one of the male connectors 24 is distorted from their manufacturing/theoretical "true" position. In this example, male connectors 24d, 24f, and 24a of building modules 10a, 10b, and 10c are in fact displaced and shown as displaced connector elements 40d, 40f, and 40a, and only connector element 24c is shown by way of example as located in its "true" location. Also shown in Figure 6B is the location of a connecting connector plate 60 which comprises a plurality of holes or apertures 66 indicated by the solid circles containing dashed crosses. As can be seen, errors or deviations exist between the actual positions of the displaced male connectors indicated by 40d, 40f, and 40a and the theoretically perfect positions of the male con-

nectors 24d, 24f, 24a which are here in fact indicated by the apertures 66a, 66b, 66c, 66d of the connector plate 60. This drawing assumes no other dimensional errors in any other components of the building modules 10a, ..., 10d and it will also be appreciated that the deviations shown are greatly exaggerated for clarity. Also shown in Figure 6B are arrows which show schematically for each displaced connector a direction of force which if exerted sufficiently could re-align the position of the displaced connectors 40d, 40f, and 40a with their respective true positions 24d, 24f and 24a.

[0078] These forces are provided in some embodiments by the use of a connector plate such as is shown by way of example in Figures 7A and 7B. Figures 7A and 7B show an example of a connector plate 60 with holes 66 of diameter d_p appropriate located to suit the 4-cone cluster shown in Figure 6B. Connector plate holes 66 are shown centred at the theoretically correct centres Z-Z' (see Figure 4) of each male connector 24 forming the cluster. It will be apparent that if connector plate 60 is suitably dimensioned for male cone connectors 24, then as the connector plate is forced down over the male cone connectors 24 these forces will be automatically generated to act on the male cone connectors 24 substantially at the same time. These corrective forces will then act to push or pull displaced male cone connectors 40d, 40f, and 40a as shown in Figures 6A and 6B towards their theoretically correct locations 24d, 24f, and 24a whilst maintaining male cone connector 24c in its correct position/within its tolerance for that correct position. It will be appreciated that as corrective forces are applied using a plurality of connector plates 60 on building modules 10a... 10d, deformation is distributed across the building layer, causing individual building modules to incrementally deform to meet the pre-defined spatial tolerances for the male connectors of that building layer. In this fashion, the male connectors 24 are then also correctly positioned to function as the datum connection points for receiving the female connectors of an upper building layer whilst ensuring alignment of each building module. The arrows shown in Figure 6B only show the direction of these corrective forces for the out-of-tolerances drawn, as the connector plate 60 is pushed down there may also be forces exerted on male cone connector 24c which are not shown.

[0079] Examples of how this misalignment is mitigated and/or eliminated are described later with reference to Figure 14 and 15 as well as Figures 7A and 7B. Figures 7A and 7B show a plan view (viewed in the vertical plane) and a perspective view respectively of a connector plate 60 arranged to couple the cluster of male connectors 24. As shown in Figures 7A and 7B, connector plate 60 comprises a top substantially planar surface element 62 and has sidewalls 64. A plurality of apertures 66 pass through the connector plate which are engineered to have positions conforming to the desired "true" locations of two or more male connectors 24 of a plurality of building modules 10. As shown in Figures 7A and 7B, connector plate

60 comprises four apertures 66a, 66b, 66c, 66d. Each connector plate is configured with at least one aperture 66 arranged to receive a male connector 24, 40 of a first building module 10 and at least one aperture 66 arranged to receive a male connector 24, 40 of a second building module 10. The apertures 66 are preferably circular in order to prevent locking of the connector plate 60 with the male connector 24, 40 during coupling of the two building modules 10 however it will be appreciated that other suitable shapes of aperture 66 may be used.

[0080] The connector plate 60 is appropriately dimensioned and has a composition to maintain the positions of the apertures 66 so they correspond to the theoretically ideal locations of the male connectors 24 of the building modules 10 as the modules 10 are coupled laterally together. For example, the clearances between apertures 66 of the connector plate 60 preferably corresponds to the ideal or "true" clearance desired between male connectors 24 of building modules which is aimed for during the factory assembly process.

[0081] In an example embodiment, the connector plate 60 is applied over the male connectors 24 of a first building module 10 and a second building module 10 comprising a first building layer. Preferably, the connector plate 60 is materially or structurally rigid, such that deformations to the connector plate 60 are negligible under load. In some examples, the connector plate 60 is made from hard steel, however any other suitable materials may be used, such as any suitably rigid metal alloy or plastic.

[0082] Upon application of the connector plate 60 over the male connectors, corrective forces are exerted by the connector plate 60 on the male connectors 24 which are fixed to first and second building modules 10 causing the first and second building modules 10 to at least partially deform in the region of the connector plate 60 and engage together. As the apertures 66 of the connector plate 60 are already fabricated in the theoretically ideal location, the forces exerted by the connector plate 60 on any displaced male connectors 40 act to push or pull the displaced male connectors 40 into similarly the theoretically correct position. In this way, spatial deviations in the positions of the male connectors away from the ideal location are corrected by the connector plate 66. As the male connectors are rigidly connected to the building modules, this in turn causes also the building module to incrementally deform, such that the deformation is distributed across the building modules forming the first building layer and such that spatial deviations in the building module are also corrected. Correction in this instance may be taken to mean the positions of the components of the building module are deformed in order to meet pre-defined spatial tolerances.

[0083] Figures 8A and 8B illustrates schematically stages of assembling a connector system for use in constructing building structure 100 comprising at least one storey (or building floor) constructed by joining a plurality of building modules 10 per storey or floor. The connector

system is formed by aligning two laterally adjacent building modules by using a connector plate 60 to adjust the lateral alignment of building modules 10 as they are assembled to form a floor of the building structure 100.

[0084] Figure 8A shows schematically a sideways view of a cross-section through a connector plate 60 which is correcting the locations of two adjacent building modules 10a, 10b by exerting forces on each building's male cone connectors (for example, male cone connectors 24c, and 24a of adjacent two building modules 10a, 10b as shown in Figure 6A). The connector plate 60 is made of a material or has a structure that is sufficiently rigid such that deformations under load are negligible.

[0085] Figure 8A shows the example connector plate 60 placed over two male connectors 24c, 24a that are too close together. In the example illustrated, male connector spacing A is a function of the theoretically optimal connector spacing B adjusted by the deviations Δx and Δy values (according to direction in the horizontal plane) of the two building modules 10a, 10b. As the connector plate 60 is forced down over the cone connectors 24a, 24c, the distance between the connector cones 24a, 24c increases as the cones pass through the apertures 66 of the connector plate 60 which push the connector cones apart towards their theoretically correct spacing B (see Figure 8B). In Figure 8B, the clearance between the connector plate apertures or holes 66 and the male connectors 24 given as $\Delta tp = d_{tp} - d_{mc}$. This means that each of the male connectors' centrelines Z-Z' will be able to differ from the theoretical ideal spacing B by this amount of clearance tolerance, i.e. A can be out by $\pm \Delta tp$. If the amount of tolerance $\Delta tp \geq \Delta x, \Delta y$ (the amount of deviation from true in the x, y plane) then little or no corrective forces in the x-y plane will be applied to the male connector cones 24 and inadequate corrective action will be achieved at each storey level in the module structure.

[0086] Figures 8A, 8B are drawn for a pair of cones. It will be apparent that if there is a 4-cone cluster such as is shown in Figures 6A, 6B and 7A, 7B then forces act in both the x and y directions, but that the effect is the same, i.e., to push or pull the cones to within Δtp of their theoretically correct distance from each other.

[0087] In some example building structures 100, multiple connector clusters are provided over each storey level and multiple connector plates 60 are used to couple the connector clusters together. For example, if 6 building modules 10 form a single building floor or layer then two four connector cluster plates 60 may be used to ensure the modules are all connected. In some examples, nine two cluster connector plates 60 may be used to connect 6 building modules, such that multiple connector plates can be used over any male connector to couple to the male connector to multiple different adjacent male connectors. Whilst the floors and ceilings of the building modules are shown in the Drawings as substantially rectangular, it will be appreciated that multiple shapes and configurations are possible. For example, triangular or pentagonal, or hexagonal shapes may be used. Similarly,

whilst the connector plates 60 are shown as being substantially rectangular, it will be appreciated that multiple shapes and configurations of connector plate may be used as appropriate, with more or less apertures as shown. Where more than one cluster connector plate 60 is used to couple the male connectors 24 on a building floor, as each connector plate 60 is installed, new corrective forces are applied to the male connectors 24. However, as some of the building modules are coupled using more than one connector plate, the forces propagate through the building modules. These forces act over the entire storey layer to correct the deviations resulting from each individual module's Δx and Δy . In this manner the upper male connectors are pulled or pushed back close to their theoretically correct position, allowing them to function as datum connection points for subsequent upper building modules. This ensures that subsequently placed building modules are correctly aligned, thereby achieving incremental correction as each building module is placed during construction.

[0088] The process described above is repeated at each storey level or building layer. The action of the connector plates causes the building layer to deform and pull or push the tops of each module towards their correct positions. Whilst the male connector at each storey level may deviate from theoretical, they are as accurate (if different) to the storey level below. The net effect is for the building to assemble with a high level of overall accuracy.

[0089] This provides a method of controlling the positioning of each building module to meet certain building tolerances by correcting for deviations Δx and Δy in the ceiling 12 and floor 14 of building modules 10. In practice there can also be deviations in the vertical direction, Δz . These may arise due to tolerances on column lengths or a general twisting of the module box. If Δz 's are corrected by bolting a module down at the column locations to the storey level below prior to installing connector plates, then one or more of the following undesirable effects may occur in some embodiments:

A) If there are vertical gaps resulting from module twisting, then closing these gaps by fixing the modules using a technique involving bolting will result in a small change to Δx and Δy . To ensure the values of spatial deviation in the x-y plane Δx and Δy do not increase as the gaps are closed bigger forces must be applied by the connector plate 60.

B) In some embodiments, the effect of locating the connector plates within the corner and mid-columns 18, 20 of a building module 10 means that vertical adjustment by bolting at these column locations will increase the flexural stiffness of the building module 10. This will also result in higher connector plate forces since a stiffer building module requires a greater force to be applied to move one of its male connectors 24 a given distance.

C) Once a column 18, 20 of a building module 10 has been bolted to adjust and hold its adjusted vertical position and alignment with the columns of another building module, it will not be able to slide horizontally even if a combination of corrective forces are applied and the dimensions of the male/female connector clearances allow for possible lateral movement. The result means that connector plate forces applied to the building module 10 will increase, which increases building module deformation.

[0090] To reduce or eliminate one or more or preferably all of the above three issues, in some embodiments the connector system allows a building module to be fixed to a building module 10 sited below that building module 10 by bolting the two modules together after the connector plates 60 have been installed over the male connectors (as will be explained in further detail later). In order to reduce activities and time at site, it is desirable to be able to do this with the male connectors 24 in the right position, for example, so they are correctly positioned on a foundation slab at ground level and/or for building modules which are to have one or more other building modules stacked above them.

[0091] In the embodiment of a coupling system shown in Figures 8A and 8B where two building modules 10a, 10b are being coupled, an example of a horizontal coupling between male connectors 24a, 24c and the connector plate 60 is shown schematically.

[0092] Whilst Figure 8A showed an example of first and second male connectors 24a, 24c being initially positioned too closely together resulting in x-y plane spatial deviations Δx and Δy from their correct or true positions, it will be apparent to anyone of ordinary skill in the art that a connector plate 60 is also capable of correcting first and second male connectors 24a, 24c which are initially positioned too far apart which also results in x-y plane spatial deviations Δx and Δy from the correct or true connector positions. If the positions of the male connectors do not fall outside the pre-defined spatial tolerance amount Δtp , however, then no corrective forces are applied by the connector plate 60 to push (or pull) the first and second male connectors 24a, 24c towards their correct positions within the pre-defined spatial tolerance. Advantageously, application of the connector plate 60 over the male connectors 24a, 24c of the building modules in such a fashion allows for positional deviations of the building modules to be quickly and efficiently corrected. Corrective action may therefore be efficiently achieved at each storey level, and in addition spatial deviations may be corrected without requiring substantial modification of each building module.

[0093] Advantageously, the connector plate 60 is coupled from outside of the building modules. This removes the requirement to access and correct spatial deviations of the building modules from inside of each building module, which can often be difficult owing to space and safety

limitations and prevents completion of the module internals.

[0094] Figure 9 shows a cross-section viewed in the horizontal plane of a male connector 24 in further detail. As previously mentioned, the male connectors may be conically-shaped such that the diameter or width of the top of the connector 78 is smaller than the diameter or width of the bottom of the connector 72. In some embodiments, the male connector is a conical frustum as shown in Figure 9. Advantageously, a conical shape facilitates efficient application of the connector plate over the connectors, as well as guide the receipt of a female connector such that two building modules may be coupled together in the correct position. The reduced diameter of the top sections of the connectors provide a larger clearance for the connector plate to be coupled, thereby aiding assembly. Furthermore, it will be appreciated that the angle 76 of the slant of the male connector 24 with respect to the x-y plane perpendicular to the Z-Z' cone axis 70 influences the ease of application of a connector plate 60. In some embodiments the slant exhibits a linear gradient, however it will also be appreciated that non-linear gradients may be used. In embodiments of the invention, the angle 76 of the slant of the male connector 24 with respect to the x-y plane perpendicular to the cone z axis 70 is such that it allows a gradual application of the corrective forces exerted by the connector plate 60 as it is coupled with the male connectors 24, thus reducing bending stresses exerted on the male connectors 24 and improving the efficiency with which the connector plates 60 are applied. The cone Z-Z' axis 70 may be defined as the straight line passing through the apex of each connector 24 through to its base about which the base (and the whole cone) has a circular symmetry in some embodiments.

[0095] Male connectors 24 with a taper ratio of between 1:10 and 1:20 provides the optimal balance between instantaneous corrective forces exerted by the connector plate 60 and bending stresses on the male connectors 24, wherein the taper ratio is defined as a ratio of the length of the slant with respect to the plane perpendicular to the cone axis 70 and a length of the slant with respect to the cone axis (e.g. 1mm of length horizontally for every 10mm of length vertically). Alternatively, this may be expressed as male connectors comprising a slant angle 76 of between approximately 84° degrees and 87° degrees with respect to a plane perpendicular to the cone axis. In some examples, the male connector comprises a taper ratio of 1:15, or a slant angle of approximately 86° with respect to a plane perpendicular to the cone axis. In some embodiments, taper ratios of between 1:3 and 1:25 may also be used.

[0096] In order to prevent locking of the connector plate as it is lowered over the male connectors, the connector plate needs to be lowered such that it remains level (i.e., a slope angle of the connector plate with respect to the plane perpendicular to the cone axis needs to be substantially perpendicular to the cone axis of the male con-

nector). In addition, analysis has shown that the slope angle of the connector plate should be kept within 25% of the slant angle of the connector slope in order to prevent locking. For example, if a taper ratio of connector slope is 1:20, then the slope ratio of the connector plate should be limited to 1:80 with respect to the plane perpendicular to the cone axis.

[0097] Technical considerations that the cone configuration of preferred embodiments address include the following:

If the slant of the male connector 24 is too steep (i.e., greater than a 1:20 or 1:25 ratio), then the height required of the male connector 24 to achieve an acceptable coupling between the male 24 connector and the female 22 connectors increases.

[0098] Furthermore, if the male connector 24 height increases, then the horizontal forces required to correct tolerances will act further up the male connector. This results in a higher bending force in the male connector 24, leading to material failure or a reduction in the maximum horizontal force that can be permitted before failure. Horizontal forces are also generated due to spatial deviations between male connectors 24 and female connectors 22 as the modules are lowered. If the slant of the male connector is too steep, then again these forces act at a greater height, thereby potentially causing material failure of the male connector 24.

[0099] A steeper slant of the male connector 24 also requires a larger base diameter and a taller connector, thereby increasing material costs.

[0100] The resistance to the installation of connector plate 60 and the coupling between male 24 and female 22 connectors is a function of the sum of material frictional forces and the vertical component of the direct reaction force of the male connector 24. As the slant 76 of the male connector 24 gets shallower, so the magnitude of this force increases. If it increases above a certain level, the weight of a building module being lowered onto the male connector 24 may be insufficient to overcome the resistance. In this circumstance the building module may lock during lowering, potentially damaging the module.

[0101] However, if the slant 76 of the connector is too shallow, then the cone height is too short to provide the necessary guidance for the female connector 22 and/or any other items that require to mate as the building modules are lowered.

[0102] In addition, as the slant angle 76 reduces, the contact area between the leading edge of the connector plate 60 and the male connector 24 also reduces. This coincides with an increase in the normal force. The result is a tendency for the leading edge of the connector plate 60 to bite into the surface, cutting through any lubricants provided to reduce friction.

[0103] The slant of the male connector 24 should therefore be selected so as to account for the technical considerations and mitigate one or more of the issues described above.

[0104] Figure 10A shows schematically a lateral view

of a cross-section thorough a modular multi-storey building structure 100 assembled according to an embodiment of the present invention, and according to the methods described above. Figure 10A illustrates first and second building modules 10a, 10b positioned adjacent to each other and comprising the first layer of a building structure 100 and third and fourth building modules 10c, 10d stacked vertically on top of the first and second building modules 10a, 10b and comprising the second layer of the building structure 100. The first and second building modules 10a, 10b comprise a plurality of male connectors 24. The third and fourth building modules 10c, 10d comprise a plurality of female connectors 22 arranged to couple with the male connectors 24. Also provided are connector plates 60. As discussed previously, the connector plates 60 are provided with one or more apertures 66 arranged to receive the male connectors 60. Connector plate 60 for example comprises at least a first aperture 66 arranged to receive a first male connector 24 of building module 10a, and a second aperture 66 arranged to receive a second male connector 24 of the second building module 10b.

[0105] Upon the connector plate 60 receiving the first and second male connectors 24, the first and second building modules 10a, 10b are engaged together and corrective forces may be exerted by the connector plate 60 on the first and second building modules 10a, 10b to cause deformation to be distributed across the first building layer, causing the building modules 10a, 10b of the first building layer to deform to meet pre-defined spatial tolerances. Such exertive forces may be applied for example by the weight of an upper building module 10c, 10d acting on top of the connector plate 60. As these forces are applied, the positions of the male connectors 24 of the first building layer will therefore be corrected, such that they are able to function as datum connection points for the second upper building layer. Third and fourth building modules 10c, 10d comprising the second building layer may then be positioned on top of the first and second building modules 10a, 10b to form the second storey of the building structure 100, wherein the female connectors 22 of the third and fourth building modules 10c, 10d are arranged to receive the first and second male connectors 24 such that the third and fourth building modules are also coupled together with the first and second building modules 10a, 10b. In this fashion, the building modules 10a... 10d of the first and second building layers are positionally aligned in two or three dimensions into a pre-defined position.

[0106] In some embodiments, additional spacer plates or single-apertured connector plates are provided in between the building modules 10a, 10b, 10c, 10d in order to ensure that the upper building modules 10c, 10d remain level. Single-apertured plates for example may be provided over the male connectors at the perimeter of a building module that are not horizontally adjacent to any other building module (and therefore do not require coupling to any other male connectors) in order to ensure

that further building modules stacked on top remain level and balanced. The spacer plates or single-apertured connector plates will therefore at least partially fill any remaining gaps after the connector plates 60 have been applied in between an upper and lower building module so as to support the upper building module. The spacer plates or single-apertured connector plates may be substantially the same height or thickness as the connector plates 60 and may be applied after positioning the connector plates 60 on the male connectors 24..

[0107] Although not illustrated, in some embodiments the first and second building modules 10a, b comprise female connectors 22 located towards the bottom section of the building modules. In these instances, the female connectors 22 of the first and second building modules 10a, 10b may be coupled to further male connectors 24 installed into the ground in order to anchor the first and second building modules in place.

[0108] Figure 10B shows a different lateral view of a schematic cross-section in the z-y plane of a modular building structure 100, which may be a different view of the example modular building structure shown in Figure 10A or a view of another example building structure 100. In Figure 10B first and second building modules 10a, 10b positioned adjacent to each other and comprising the first storey of the building, and a third building module 10c is positioned on top of both of the first and second building modules 10a, 10b to comprise a second storey of the building structure 100. In a similar fashion to as previously described, a connector plate 60 is arranged to receive the first and second male connectors 24 of the first and second building modules 10a, 10b such that the first and second building modules 10a, 10b are coupled together, and are deformed by the connector plate 60 to meet pre-defined spatial tolerances. A third building module 10c comprising a plurality of female connectors 22 is provided and arranged to couple with the male connectors 24. The third building module 10c is positioned on top of both of the first and second building modules 10a, 10b to form the second storey of the building structure 100. The female connectors 22 of the third building module 10c are arranged to receive the male connectors 24 of the first and second building modules 10a, 10b such that the third building module 10c is coupled together with the first and second building modules 10a, 10b. Advantageously, the application of a connector plate 60 over the building modules 10a, 10b comprising male and female connectors 24, 22 in the manner described above provides for an efficient method of correcting misalignments during the assembly of a modular building structure 100 on a storey-by-storey basis. It will be appreciated that whilst Figures 10A and 10B illustrates a vertical arrangement of the invention, the building modules 10a, 10b may also be arranged such that they are coupled in a horizontal orientation using similar connector components 22, 24. Advantageously, constructing a modular building structure 100 in the manner described herein mitigates the effects of misalignments resulting from poor manufacturing tol-

erances, as the misalignments are cancelled out through individual building modules 10a, 10b, 10c being deformed back towards their correct shapes and positions at each level. Whilst connector positions may be spatially different at each level as a result of the misalignments, these are corrected by the connector plate 60 fitting such that they will always lie within the same spatial tolerances as the level below. In this manner, the plan position of each building module 10a, 10b, 10c as a whole is controlled, and the building structure 100 does not deviate from its intended shape.

[0109] As mentioned above, in some embodiments of the connector system for building modules a fastening means such as bolt is used to secure the male 24 and female 22 connectors of two or more building modules 10 together once they have being aligned by the cone connector coupling system (and in some embodiments, laterally aligned using a connector plate 60). In some example embodiments, the fastening means may be applied via at least one pair of corresponding apertures in the first and second connectors. The corresponding apertures in the first and second connectors may comprise internal bores which may be smooth or threaded, and are shaped to receive a fastening means 84, 98.

[0110] A detailed example embodiment of a fastening mechanism will now be described with reference to Figures 11A and 11B of the drawings. It may be desirable to be able to fix or bolt an upper building module 10 to a lower building module 10 positioned below it after all connector tie plate(s) 60 have been installed.

[0111] Figures 11A and 11B shows two variants of a fastening system for bolting building modules 10 together, where the fastening system is accessed from an access aperture on the top of the upper module 10c. Figure 11A on the left hand side shows a fastening tool comprising removable long Allen key 80. This passes through a threaded aperture in male cone 24, down the inside a co-axial access cavity of column 18, 20 and is guided into the socket of capscrew 84 by guide cone 82. Capscrew 84 passes through a hat assembly 86 which is an integral part of the female cone 22. Rotating Allen key 80 causes cap screw 84 to engage with the threads on the interior surface of male connector of lower building module 10a, thus fastening or fixing lower and upper modules together.

[0112] In some embodiments, the column of a building module may be constructed by fixing in position at one end of the column a female connector, and at the other end of the column a corresponding male connector, and then boring a cavity along the column through the fixed male and female connectors.

[0113] The example fastening system shown in Figure 11B on the right hand side shows a long bolt variant of the example fixing system of Figure 11A which allows the use of a short Allen key 90. The long bolt assembly comprises of a cavity containing a tube 96, Allen key socket 94 and bolt 98. These items are securely fitted together to resist the high torques encountered as the

bolt 98 is tightened. A guide 92 is provided to ensure that Allen key socket 98 is sufficiently aligned with the short Allen key 90 to ensure engagement.

[0114] Figure 12 shows an enlarged view of the cones and hat detail of Figures 11A and 11B with an exaggerated radial clearance between the male connector element 24 and female connector element 22. The detail shown ensures that capscrew 84 does not cross thread in the top of male connector cone 24 and does not have large bending forces induced in it during final torqueing. The aperture or hole in hat 86 has a diameter d_{hat} which is set to be greater than the thread diameter of the capscrew 84 added to the male cone 24 and female cone 22 clearance ($d_{\text{fc}} - d_{\text{mc}}$) added to any other tolerance resulting from the method of manufacture. Where $d_{\text{hat}} >$ permissible hole diameter under the head of the capscrew 84, a washer plate 106 is used to reduce capscrew head stresses.

[0115] To help guide capscrew 84 into the cone thread 116 a conical lead-in 110 is provided coupled with a cylindrical length 112. The diameter of the cylindrical length 112 is closely toleranced to the outside diameter of the capscrew thread. The length of the cylindrical section 112 is sufficient to set the capscrew axis parallel to the thread axis, in some embodiments this is typically half the diameter of the capscrew thread.

[0116] The use of long Allen key 90 to torque cap screw 84 results in significant torsional deformation of the Allen key 90 and storage of strain energy may be significant. The degree of rotation also means that more conventional impact type torque tools are not effective. In some embodiments, a direct drive tool is required to both torque the cap screw 84 and unload the stored energy in the Allen key 90. To react the tightening torque and enable the male connector 24 to be screwed into the top of the column, two flat surfaces 114 are machined onto opposing sides of the male connector element (for example, into the male connector's cone surface). Since the torque reaction from the direct drive tool acts to undo cone thread 118, male cone 24 is tightened such that the tightening torque applied to thread 118 is sufficiently larger than the cap screw torque, for example, the tightening torque is greater than 1.5x cap screw torque in some example embodiments. The thread is also treated with a proprietary thread locking compound in some embodiments.

[0117] In some embodiments, a fastening system is provided which together with the configuration of the male and female connector elements forming the connector system and/or the configuration and adjusting forces exerted by one or more connector plates, provides a three-dimensional adjustable fastening mechanism. Some embodiments of the fastening system are configured according to one or more constraints, for example:

[0118] To correct spatial deviations Δx and Δy in the x-y plane of a male connector from its true position, a building module 10 may need to be deformed back towards its true form. The magnitude of the spatial devia-

tions Δx and Δy which result from manufacture of the building module 10 must accordingly be small enough to allow the building module 10 to deform under appropriate corrective forces, i.e. to accommodate the corrective deformation without damage to the integrity of its structure or its finishes. Analysis has shown target Δx and Δy values of less than 5mm may be used, however target Δx and Δy values of less than 1mm are preferable. Target Δx and Δy values of less than 2mm are particularly acceptable for ensuring no damage is done to the integrity of the structure or its finishes.

[0119] To balance the tolerances and clearances so that building modules can always be suitably stacked or landed on top of each other, ($d_{\text{fc}} - d_{\text{mc}} \geq d_{\text{tol}}$). If $d_{\text{fc}} - d_{\text{mc}}$ is much greater than d_{tol} , an issue arises in that the centre of area of vertically adjacent modules 10 can drift out of position since guidance from the connector system would be too low (the male and female connectors would engage in too loose a manner). This increases the corrective deformation imposed on the modules. It also increases the size of potential steps between module edges at the perimeter of the building. Since $d_{\text{fc}} - d_{\text{mc}}$ is directly related to the manufacturing accuracy of the floor and ceiling panels, it is necessary to limit how much greater $d_{\text{fc}} - d_{\text{mc}}$ is than the expected manufacturing tolerance range. Analysis has suggested that $d_{\text{tol}} < (d_{\text{fc}} - d_{\text{mc}}) \leq 1.5 d_{\text{tol}}$, where d_{tol} is selected based on the accuracy of the manufactured floor or ceiling panel. In some embodiments, d_{tol} is typically 1mm.

[0120] As a connector plate 60 is pushed down, it generates horizontal forces on the male cone connectors 24 of the building module the connector plate 60 is coupling together. For example, if the male connector elements 24 comprise cones which have too steep a cone slope surface and if the positional tolerances on the connector cone locations are poor (as in not small enough), then high lateral forces are applied at the top of the cones which induces high bending stresses. This becomes a design requirement for the cones. Analysis suggests constraining the cone slope so that $1:10 < \text{cone slope} < 1:20$ gives the optimal balance between module capture and cone forces.

[0121] The connector plate clearance relative to Δx and Δy needs to be controlled if each storey layer is to be adequately corrected. Analysis suggests that Δt_p should be between 10% and 30% of the anticipated values of Δx and Δy . In some embodiments, the connector plate clearance Δt_p is typically circa 0.25mm.

[0122] A high amount of force is generated within and using the tie plate 60. To prevent the connector plate 60 locking onto the male connector elements 24 as it is lowered and the male connectors 24 pass through the apertures 66 of the connector plate 60, in some embodiments the connector plate is forced or pushed down so that it remains level (perpendicular to cone axis) to within 25% of the cone slope. In some example embodiments, the male connector elements 24 have a configuration where, if the cone slope is 1 in 20, the upper surface 62

of the connector plate 60 should push down within 1 in 80 of level.

[0123] In some embodiments, it is desirable to be able to fasten or fix (e.g. by bolting) one building module 10 to one or more other building modules 10 below after connector plates 60 have been installed on the lower floor where the building modules 10 are located. Since an upper storey level of one or more building modules 10 would block access to the column-column junctions of the building module 10 below (e.g. corner column 18 of the upper building module 10 would block access to the corner column 18 of the lower building module 10 (and potentially similarly if mid-columns 20 are also vertically aligned for two adjacent stacked building modules 10) it is necessary to be able to effect the bolting at the bottom of one building module 10 from the top of that building module 10, for example, via an access aperture in the roof or the building module.

[0124] In some example embodiments, for the Allen key 90 to pass through the minor diameter of the male cone internal thread 116, the minor diameter of the internal thread 116 must be greater than the across tips dimension of the corresponding Allen key 80, 90. This may require the internal minor thread diameter 114 to be increased. In this case, however, there is a resultant loss of thread bearing area which in some embodiments is compensated for by increasing the length of thread engagement. A working example combination is an M24 coarse thread and 19 A/F Allen key. This example requires the minor diameter of the internal thread 116 to be increased to 22mm and to compensate for the resultant loss in thread bearing area, the minimum thread engagement length is increased to 1.5 x bolt thread diameter in some embodiments.

[0125] In some embodiments, the long bolt assembly comprising bolt 94, tube 96 and Allen socket 94 shown in Figure 11B is retained in the centre of the column by guide 92. The length of the long bolt assembly and guide 92 shown in Figure 11B satisfy at least two criteria in some example embodiments:

[0126] Firstly, the criterion that with the long bolt assembly raised so that it touches the underside of male cone connector element 24, the thread of bolt 94 should engage at least 10mm into the hole in hat 86. This is an example of how the length of the long bolt assembly in some embodiments can be determined. Secondly, with the long bolt assembly lowered so that the head of bolt 84 is sitting on hat 86 (or washer plate 106 if fitted), the Allen key socket 98 should engage a minimum 5mm into guide 92. This is an example of how the length of the guide 22 in some embodiments can be determined.

[0127] For some embodiments, so that the connector plates 60 do not dig in and catch on the male connector elements 24, it is necessary for the male connector surface to comprise a substance or material which is significantly harder than the substance forming the connector plate 60. In some embodiments, in terms of yield strength, F_y , connector $\geq 1.6 \times F_y$, connector plate. In some em-

bodiments, a lubricant is provided between the surfaces of the male connector 24 and the connector plate 60 to ease application of the connector plate 60 to the male connector 24.

[0128] The above example embodiments of a fastening system for fastening a connector system comprising female and male connector elements 22, 24 allows a multi-storey modular building structure 100 to be constructed. Where more than one building module 10 is provided per storey in the building structure 100, additional lateral alignment of the building modules 10 forming each storey of the building structure 100 is provided in some embodiments by using a connector plate connector 60.

[0129] More generally, the embodiment shown in Figures 10A and 10B11A and 11B each show how three or more building modules 10 can be fastened together. Figure 11 shows how a column 18, 20 of a building module 10 includes a suitable access cavity which extends from an access opening in the top section of the building module 10 through the building module 10 interior to an aperture in a female connector 24. In Figures 11A, 11B and 12 accordingly, each of the male and female connectors is ring-like and has an interior aperture into which a fastening means 84, 98 may be applied using a fastening tool such as the long and short Allen keys 80, 90 in order to apply a suitable torque to fasten the male and female connectors 24, 22 to each other. The male connector 24 coupled to the female connector 22 comprises a corresponding aperture to the aperture in the female connector 22 which is arranged to receive the fastening means or Allen key 80, 90.

[0130] In some examples of the embodiments depicted in Figures 11A and 11B of a fastening mechanism, the male and female connectors 24, 22 are positioned directly above and below one or more corner column 18 of a building module 10, and thus the access apertures extend vertically through the corner column of the building module (i.e. as cavities within the corner columns). However, it will be appreciated that the male connectors 24 and female connectors 22, and the access apertures may be positioned at any suitable column location in each building module, such as at the mid-points of each building module 10. Preferably the columns, male connectors 24 and female connectors 22 are located around the perimeter of a building module.

[0131] In the embodiments shown in Figures 11A, 11B and 12 the fastening means comprises a bolt 84, 98 which is tightened using a fastening tool such as an Allen key to which torque is applied via the access cavities and apertures in the male 24 and female 22 connectors in order to secure the male and female connectors 24, 24 are fastened or fixed together. Whilst Figures 11B and 12 illustrate the fastening means as a threaded bolt, it will be appreciated that any other suitable fastening or locking means may be used in other embodiments. In some embodiments where the fastening means 84, 98 is applied via the access cavities of the building module

10, a suitable fastening tool, such as an Allen key or other direct drive tool, is used. This provides a method for securing the male and female connectors 24, 22 together from outside of the building modules 10 and thus removes the need to secure the building modules from the inside.

[0132] Applying the fastening means 98, 100 in this manner facilitates a method of quick and efficient on-site construction. There is no need to perform installation work from inside any of the building modules 10 and the fastening process is in some embodiments performed in-step with construction, i.e. directly after the connector plates 60 are installed.

[0133] In some embodiments the fastening means 98, 100 are similarly removed via the cavities in each building module's vertical columns 18, 22 via the roof of the building module 10 in order to facilitate efficient disassembly of the building structure 100.

[0134] Figure 13 shows an example embodiment of a method of positioning or aligning a building module by forming a connector system comprising male and female connector elements 24, 22. In Figure 13, an example first step (200) comprises positioning one or more, for example, male cone connector elements 18 such that they can engage with corresponding female cone connector elements 22 attached to a building module 10. The male cone connector elements may be sited at ground level or attached to a lower building module 10. Connector plates 60 may be applied to the male connectors 24 to provide corrective displacement forces on the male connectors 24. Building module 10 comprising the female cone connector elements 22 is then positioned over the male connector elements (step 210), within the relevant tolerance levels so that the building module 10 can be lowered towards the male connectors to cause the male cone connectors 24 to engage with the female cone connectors 22 and form a connector system (step 220). Once the connectors 22, 24 have engaged with each other, the upper building module 10 is fastened to the lower connector elements 24 via an access aperture in the upper building module 10 using a fastening mechanism such as is shown in Figures 11A, 11B, and 12 of the accompanying drawings. It will be appreciated that the fastening mechanism may be applied at any time, for example after engaging two or more building modules, or after placing all of the building modules of the building structure. As the building module 10 is being lowered, unless all of the connector components are perfectly aligned, at least some of the weight of the building module 10 will eventually start to act on some of the surface of at least one of the male connectors 24. The weight of the building module 10 will be deflected by the protruding male surface configuration. Providing the male connectors 24 are sufficiently strongly fixed, the weight of the upper building module 10 as it acts on the connectors will produce sufficiently strong forces on at least the building framework infrastructure of the module 10 to cause its framework to flex in order to allow the male connectors to be more aligned and eventually fully received by the female con-

nectors 22. Once all of the male cone connectors 24 are in full alignment with the female connectors 22, the building module 10 can be lowered fully. In cases where two or more building modules are to be vertically stacked over each other to form additional storeys (optionally shown as step 240), the method effectively returns to step 210 as the upper module 10 is positioned over the male connectors 24 of the lower building module 10 (step 210), and as each building module is lowered onto one or more building modules beneath it, the building module being lowered is guided into position by the male and female connectors forming the connection system (220), and the upper module is then fastened to a lower building module using a suitable fastening mechanism in step 230 such as was described referring to Figures 11A, 11B, and 12 of the accompanying drawings. In this way, the vertical alignment of the building modules relative to each other can be controlled even where the building structure comprises multiple-storeys of say three or more building modules, the vertical limit being imposed by the load which the lower building modules 10 can bear resulting from the collective weight of the building modules stacked above them.

[0135] Figure 14 shows another example embodiment of a method of aligning a plurality of building modules forming a floor in a building structure 100 comprising one or more floors. In Figure 14, the building modules 10 forming a building storey or building layer are first positioned adjacent to each other in step 300 so that at least one cluster 68 of connector elements 22, 24 is formed, in this example, a cluster of male cone connectors 24. A connector plate 60 is then lowered on top of the connectors 24 forming each cluster 68 so that the male cone connectors 24 pass through the apertures 66 of the connector plate 60 as the connector plate is lowered into position. If the male connectors are not aligned within predetermined tolerance levels, the lowering of the connector plate 60 applies corrective forces to the building modules 10 to which each male connector 24 is attached which causes deformation to be distributed across the building modules 10 such that the building modules 10 deform to move the male connectors 24 into alignment (step 310). After the connector plate 60 has been lowered into place and the male connectors 24 positioned with desired tolerance level(s) of their ideal or true position, another building module can be positioned over the lower building module 10 and lowered so that its female cone connector elements 22 engage with portions of at least one male connector element 24 that has passed through an aperture 66 of a connector plate 60.

[0136] Figure 15 shows another example method of constructing a building structure comprising at least two aligned building modules 10 forming a first building layer. In the example shown in Figure 15, the method comprises: positioning a first building module comprising at least one first male connector adjacent to a second building module comprising at least one second male connector (step 410), coupling a connector plate to the first and

second male connectors (420), exerting corrective forces by the connector plate on the first and second building modules (430) of the first building layer, the corrective forces arranged to distribute deformation across the first building layer; and causing (440) the first and second building modules to deform to meet pre-defined spatial tolerances for the male connectors of the first building layer to function as datum connection points for a second upper building layer using the exerted corrective forces. The connector plate 60 in this example comprises a first aperture arranged to receive the first male connector of the first building module and a second aperture arranged to receive the second male connector of the second building module and upon receipt of the first and second male connectors by the connector plate, the first and second building modules are coupled together. The corrective forces exerted by the connector plate on the first and second building modules which cause the first and second building modules to deform to meet pre-defined spatial tolerance will only be generated if the cone connectors 24 are out of the range of tolerance provided for their spatial deviation (for example, their spatial deviation Δx , Δy in the x-y plane if the coupling direction is in the z-axis direction perpendicular to their lateral spatial deviation).

[0137] In this way, an example method of assembling a modular building by the application of connector plates pushed down over cones such that corrective forces and displacements are applied to the top of each module to substantially correct for module tolerance deviations is shown. The cone positions at each storey level are thus brought back to a common tolerance condition ready for the installation of the next storey level. Repeating the process at each storey level controls overall building tolerances.

[0138] Embodiments of the disclosed technology relate generally to a method of assembling a building structure comprising a plurality of three-dimensional (3D) volumetric modules (essentially boxes) such that each building module can be lifted into position and immediately detached from the crane lifting it without the need for first performing any manual setting operation for aligning the module position. In some embodiments, a level of accuracy achieved during the alignment process is such that building modules can have cladding attached in the factory. This level of accuracy is achieved in some example embodiments by one or more of: manufacturing building modules to repeatable dimensions and to close an initial tolerance; managing the tolerances of building modules even if accurately built by providing fastening and/or connector systems as described herein below to correct tolerances at each storey by applying small distortions to the modules, where the distortions are elastic and are tolerated without damage to module finishes; applying corrective distortions to modules by forcing accurate tie plates over cone clusters where each cone in a cluster is on a separate but adjacent module. The cones are the key module datum points; recognising that correcting out of tolerances in the above manner brings the position of

key module datum points over an entire storey floorplate back towards a consistent geometry.

[0139] Moreover, whilst there may be random variations in the actual male connector positions across a connector plate, a large number of corrected (reduced) random deviations leads to positive and negative tolerances cancelling each other out. It is accordingly possible, as a result, for the assembly of a plurality of building modules to have a natural tendency to self-correct positionally as the building modules are stacked to form a multi-storey building structure.

[0140] In some embodiments, assembling multiple modules using tie plates at each level to 'correct' plan geometry results in an accurate overall building structure.

[0141] Throughout the description references to male or female cone connectors should be interpreted as references to "male" or "female" connectors which have any similar functional shape, including frusto-conical and pyramidal as mentioned above.

[0142] According to a first embodiment of the invention, there is provided a method of assembling a modular building structure, comprising: positioning a first building module comprising at least one first male connector adjacent to a second building module comprising at least one second male connector, coupling a connector plate to the first and second male connectors, wherein the connector plate comprises a first aperture arranged to receive the first male connector of the first building module and a second aperture arranged to receive the second male connector of the second building module, and wherein upon receipt of the first and second male connectors by the connector plate the first and second building modules are coupled together, and corrective forces are exerted by the connector plate on the first and second building modules causing the first and second building modules to deform to meet pre-defined spatial tolerances.

[0143] According to another embodiment of the invention, there is provided a modular building comprising a first building module comprising at least one first male connector; a second building module comprising at least one second male connector; a connector plate comprising a first aperture arranged to receive the first male connector of the first building module, and a second aperture arranged to receive the second male connector on the second building module, such that upon receipt of the first and second male connectors the first and second building modules are coupled together, and corrective forces are exerted by the connector plate on the first and second building modules causing the first and second building modules to deform to meet pre-defined spatial tolerances.

[0144] One preferred embodiment of a building module is constructed to have male/female connector components at key datum points on each module, where the male cone has a shallow taper to guide modules into position and develop the lateral forces necessary to correctively distort the modules.

[0145] Preferably the clearances within the male and female connector cone system allow for small, random variations in length due to limits on manufacturing accuracy so that the two opposite types of connector elements can be lowered into position without undue resistance (e.g., friction) as the male 24 and female 22 cones engage.

[0146] Preferably clearances between apertures or holes 66 in a connector plate 60 and the male connector elements (e.g. male cone connectors) 24 are such that the forces required to push the connector plate 60 down over the male connectors 24 are acceptable whilst maintaining sufficient plan accuracy.

[0147] Examples of embodiments of the technology disclosed herein accordingly provide a system for three-dimensional tolerance control to be exerted in a modular building structure to bring about alignment in both a vertical direction between stacked building modules and in a lateral direction through the use of an appropriate connecting plate. Although the building modules are large structures and have significant inertia, they are each formed with a flexible and/or distortable framework comprising horizontal beams and vertical columns into which guiding (or realigning) elements are positioned. Each column is manufactured first to align its guiding or re-aligning elements (for example, guiding elements provided as male and female cone connectors at opposite ends of the column), and then the remaining frame elements of the building module are fixed to the column to form the basic framework. In this way, movement of the guiding elements results in strain on the framework, enabling the framework to be brought back to a desired tolerance level (e.g. within 2mm of true). The remaining internal and external infrastructure of the building module can then be completed inside the factory environment. The completed building module can then be delivered on site. The cone-like connector system is arranged to transfer the weight of the building module to its framework and/or to the framework of any building module below when the connector system at floor level engages with the connector system immediately below (provided in some embodiments by reciprocating cone-connector elements located either at position datums at ground level or in other embodiments provided by the building module immediately below).

[0148] As the cone-connector system is integral to the building module framework, it causes the building frame to distort back towards its intended "true" configuration upon engagement. In this way, a building structure comprising two or more pre-fabricated building modules is provided with modules which are positioned relative to each other on site with sufficient vertical alignment with each other to allow for any pre-fabricated cladding or similar surface decoration to be presented as a substantially continuous surface vertically across both building modules. Such a visual effect can be achieved if the building modules are aligned sufficiently, usually within 2mm of each other. Moreover, horizontal tolerance levels are

controlled when more than one building module is positioned horizontally adjacent to each other through the use of a connector plate as disclosed herein. Sufficient horizontal alignment between two or more building modules can be provided using such a connector plate together (together with a suitable spacer or side-edge support to level off the height of the connector plate) to also allow for any pre-fabricated cladding or similar surface decoration to be presented as a substantially continuous surface horizontally across both building modules. Such a visual effect can be achieved if the building modules are aligned sufficiently, usually within 2mm of each other when viewed by a person at a sufficient distance, for example, at a distance where at least the entire building structure and/or an individual building module is within the person's field of view.

[0149] Example embodiments of the disclosed technology achieve these high levels of alignment by firstly using building modules built in a manufacturing environment which allows for precision machining and correspondingly precise positioning of cone-type guidance elements within the columns forming each building modules frame. Each building module framework is configured to allow its protruding (male) cone-type guidance element to connect with a reciprocally configured (e.g. inverted cone) female element within very low tolerance limits for misalignment. At ground level, male cone-connector elements (or in some example embodiments, inverted female cone-connector elements) are provided at precise datum points on a supporting base or foundation so as to guide the first storey building module(s) into position. Each building module which forms a higher storey can be simply lowered into position over a lower building module, or modules if the modules are to be staggered and an appropriate cone configuration is provided to allow this. As each building module is lowered into position on-site, usually using a crane, the corresponding cone/inverted cone connectors of the lower building module eventually engage. The forces exerted by the cone connectors engaging are controlled at least in part by the configuration of the cone structures. The surface slope (and possibly texture) controls how the weight of the upper building module is transferred onto the lower building module.

[0150] Some example embodiments of building structures are also disclosed where each storey comprises a plurality of building modules which are placed adjacent to each other. Such building structures may also require additional tolerance control in a lateral direction. Another technique to achieve tolerance control which is disclosed herein uses a system of one or more tie-plates which engage with the cone-connectors which provide the horizontal tolerance control in a manner which allows all of the building modules forming a single lateral level to be collectively aligned across that level. Additional support is provided along perimeter edges of each building module's roof/floor which has the same thickness as the connector plate to keep the building modules level.

[0151] Some example embodiments of the invention accordingly provide a method of constructing a self-aligning modular building structure comprising a plurality of one or more building modules. The modules are provided with particular features and tolerances within the factory environment and by jointing them with appropriately toleranced connector (e.g. tie) plates on site, an upper building module is locked down to the lower building module in close alignment. In this manner, even poor manufacturing tolerances resulting in deviations from a true (or 'perfect') building module configuration (e.g. tolerances which exceed 5mm in individual building modules as they leave the factory) are cancelled out on site using the tie-plate technique. By deforming each individual module in a building storey back towards its true or 'perfect' shape using the tie-plate, the cone positions of each building module after tie-plate fitting for the entire storey will all be more spatially correct than before. This means that even if cone connector positions are spatially different within each completed level, they will always lie within the same spatial tolerances as the level below. In other words, the starting condition at each level is nominally identical to the level below. In this manner the plan position of modules at each level is always under control, and the building does not deviate from its intended shape. This effect can be achieved with no other on-site surveying requirement than the datum point positioning of the ground level connectors. Any range or device value given herein may be extended or altered without losing the effect sought, as will be apparent to the skilled person.

[0152] It will be understood that the benefits and advantages described above may relate to one embodiment or may relate to several embodiments. The embodiments are not limited to those that solve any or all of the stated problems or those that have any or all of the stated benefits and advantages.

[0153] The steps of the methods described herein may be carried out in any suitable order, or simultaneously where appropriate. The arrows between boxes in the figures show one example sequence of method steps but are not intended to exclude other sequences or the performance of multiple steps in parallel. Additionally, individual blocks may be deleted from any of the methods without departing from the spirit and scope of the subject matter described herein. Aspects of any of the examples described above may be combined with aspects of any of the other examples described to form further examples without losing the effect sought.

[0154] The applicant hereby discloses in isolation each individual feature described herein and any combination of two or more such features, to the extent that such features or combinations are capable of being carried out based on the present specification as a whole in the light of the common general knowledge of a person skilled in the art, irrespective of whether such features or combinations of features solve any problems disclosed herein. In view of the foregoing description it will be evident to a person skilled in the art that various modifica-

tions may be made within the scope of the invention.

Claims

1. A method of assembling a modular building structure, comprising:

forming a first building layer comprising a plurality of building modules by positioning a first building module comprising at least one first male connector adjacent to another building module comprising at least one second male connector;

engaging the at least one first and the at least one second male connectors with a first connector plate, wherein:

the connector plate comprises at least a first aperture arranged to receive the first male connector of the first building module and at least a second aperture arranged to receive the second male connector of the other building module, and

wherein upon receipt of the at least one first and the at least one second male connectors by the connector plate the adjacent building modules are engaged together, and when corrective forces are exerted by a plurality of connector plates on the building modules forming the first building layer, deformation is distributed across the first building layer, causing the building modules of the first building layer to incrementally deform to meet pre-defined spatial tolerances for the male connectors of that building layer to function as datum connection points for an upper building layer.

2. The method of claim 1, wherein the first building layer comprises at least one additional building module, wherein the method further comprises engaging an additional male connector of the additional building module and at least one male connector of any of the building modules in the first building layer with at least one additional connector plate, and wherein engaging the at least one additional connector plate exerts corrective forces on all of the building modules in the first building layer to distribute the deformation across the first building layer, causing all of the building modules in the first building layer to incrementally deform to meet the pre-defined spatial tolerances for the male connectors of that building layer.
3. The method of claims 1 or 2, further comprising forming a second building layer on top of the first building layer by positioning another building module on top

of one or more building modules of the first building layer, wherein the another building module of the second building layer comprises at least one female connector arranged to receive a male connector functioning as a datum connection point of any of the building modules of the first building layer such that the another building module of the second building layer is coupled together with the building module of the first building layer, and wherein upon coupling the male and female connectors the building module of the first building layer and the another building module of the second building layer are positionally aligned in two or three dimensions into a pre-defined position.

4. The method of any preceding claim, wherein one or more of the at least one first and second male connectors are conically shaped and wherein the taper ratio of the conically shaped male connectors comprise a ratio of between 1:3 and 1:25.
5. The method of any preceding claim, further comprising applying a fastening means to secure the male and female connectors together, wherein the fastening means is applied via at least one pair of corresponding apertures in the male and female connectors after coupling the another building module of the second building layer, and wherein the apertures of the male and female connectors align with an access aperture of one or more of the building modules to allow the fastening means to be applied from externally to the building modules, and wherein the access aperture extends through a cavity in a column of the respective building module.
6. The method of claim 5, wherein at least one of the apertures in the male and female connectors is threaded, and applying the fastening means comprises applying a capscrew arranged to engage with the threaded aperture to secure the male and female connectors together.
7. A modular building structure, comprising:
a first building layer comprising:
a first building module comprising at least one first male connector,
at least one other adjacent building module comprising at least one second male connector, and
a connector plate comprising at least a first aperture arranged to receive the first male connector of the first building module, and at least a second aperture arranged to receive the second male connector of the at least one other building module, such that upon receipt of the first and second male connectors the first and second building modules are engaged together, and when corrective forces are exerted by a plurality

of connector plates on the building modules forming the first building layer, deformation is distributed across the first building layer, causing the building modules of the first building layer to deform to meet pre-defined spatial tolerances for the male connectors of that building layer to function as datum connection points for an upper building layer.

8. The modular building structure of claim 7, further comprising one or more additional building modules extending the first building layer, wherein an additional male connector of the additional building module and a male connector of any of the building modules in the first building layer are engaged with at least one additional connector plate, and wherein engaging the at least one additional connector plate exerts corrective forces on all of the building modules in the first building layer to distribute the deformation across the first building layer, causing all of the building modules in the first building layer to deform to meet pre-defined spatial tolerances for the male connectors of that building layer.
9. The modular building structure of claims 7 or 8, further comprising a second building layer on top of the first building layer, the second building layer comprising another building module on top of one or more building modules of the first building layer, wherein the another building module of the second building layer comprises at least one female connector arranged to receive a male connector functioning as a datum connection point of any of the building modules of the first building layer such that the another building module of the second building layer is coupled together with the building module of the first building layer, and wherein upon coupling the male and female connectors the building module of the first building layer and the another building module of the second building layer and positionally aligned in two or three dimensions into a pre-defined position.
10. The modular building structure of any of claims claim 7-9, wherein one or more of the at least one first and second male connectors are conically shaped and wherein the taper ratio of the conically shaped male connectors comprise a ratio of between 1:3 and 1:25.
11. The modular building structure of any of claims 7-10, wherein a stiffness of the connector plate is higher than a stiffness of the building module.
12. The modular building structure of any of claims 7-11, wherein a material hardness of the male connectors is higher than a material hardness of the connector plate.

13. The modular building structure of any of claims 9-12, wherein the male and female connectors are secured together by a fastening means applied via at least one pair of corresponding apertures in the first and second connectors. 5
14. The modular building structure of claim 13, wherein the apertures of the male and female connectors align with an access aperture of one or more of the building modules of the first or second building layers to allow the fastening means to be applied from externally to the building modules. 10
15. The modular building structure of claim 14, wherein the access aperture extends through a cavity in a column of the building module. 15

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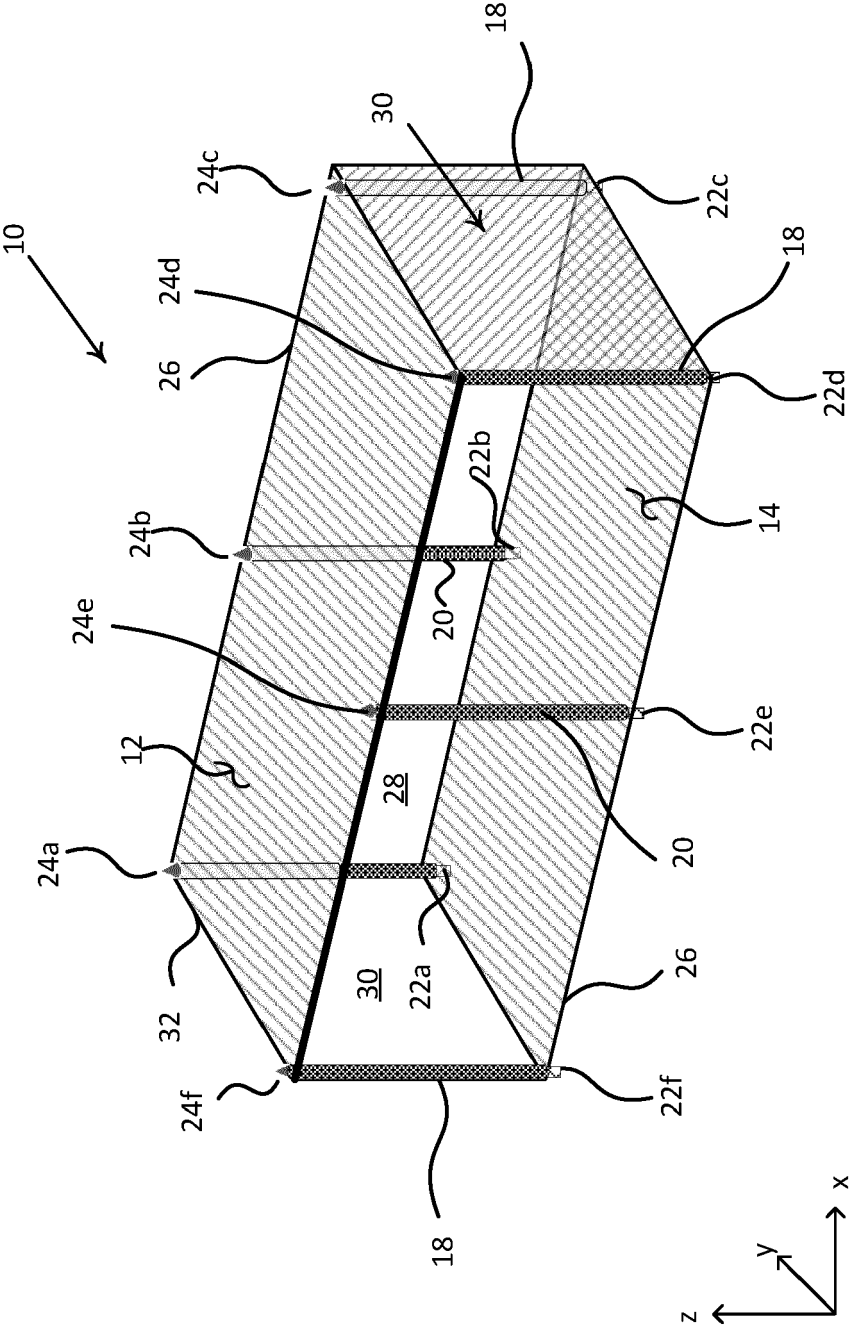


FIG. 1

Distorted and/or Displaced Building Element ----- Undistorted and/or non-displaced Building Element _____

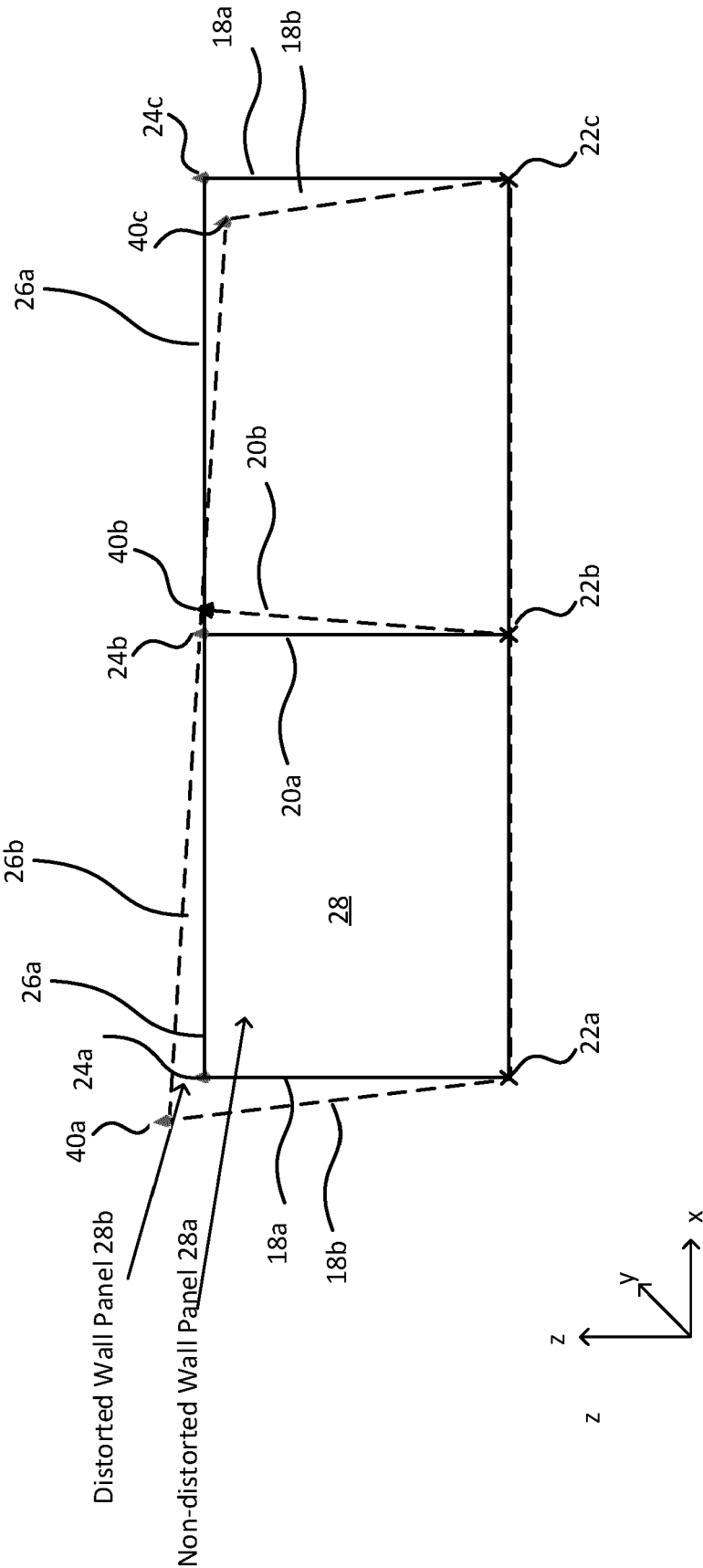


FIG. 2

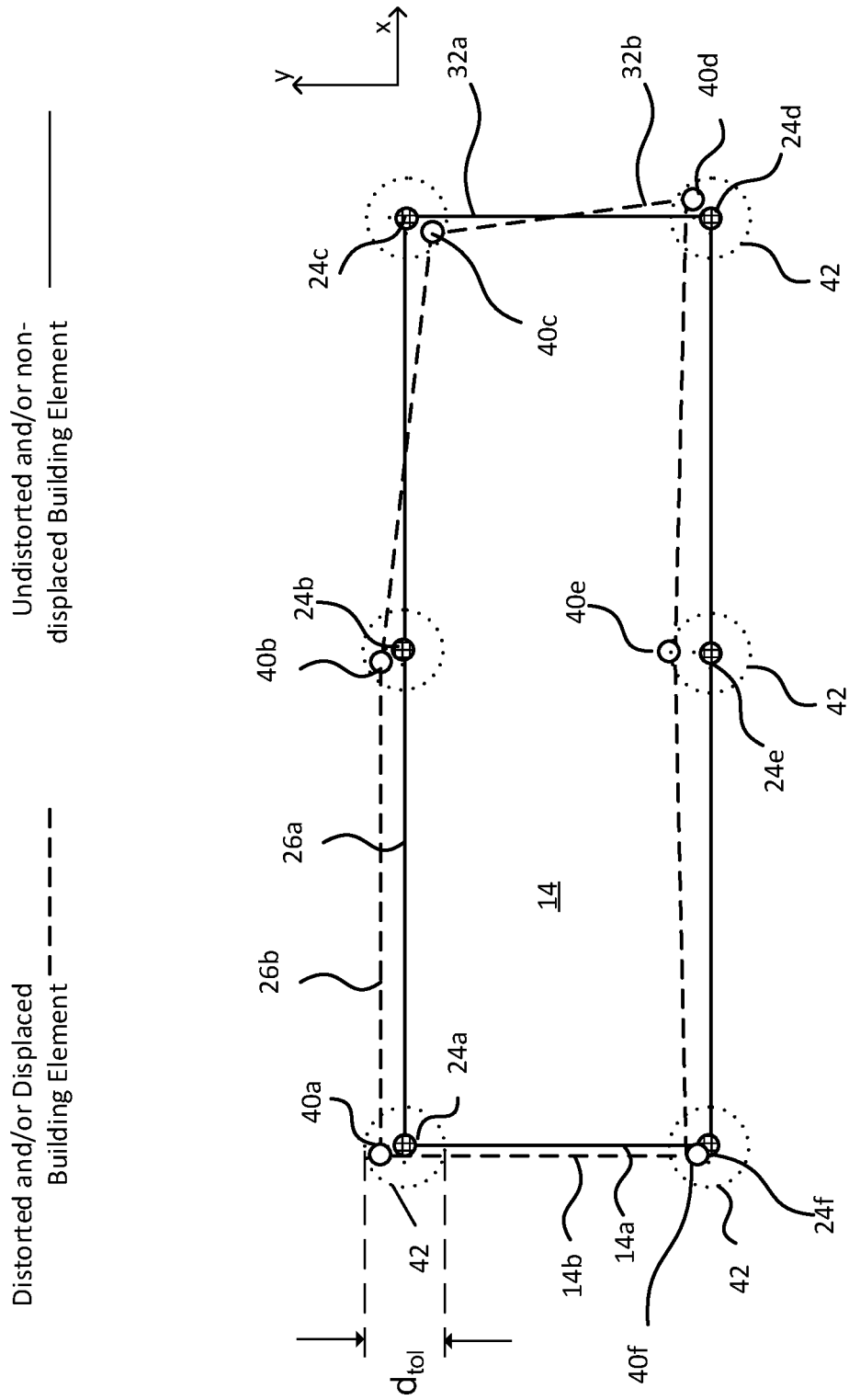


FIG. 3

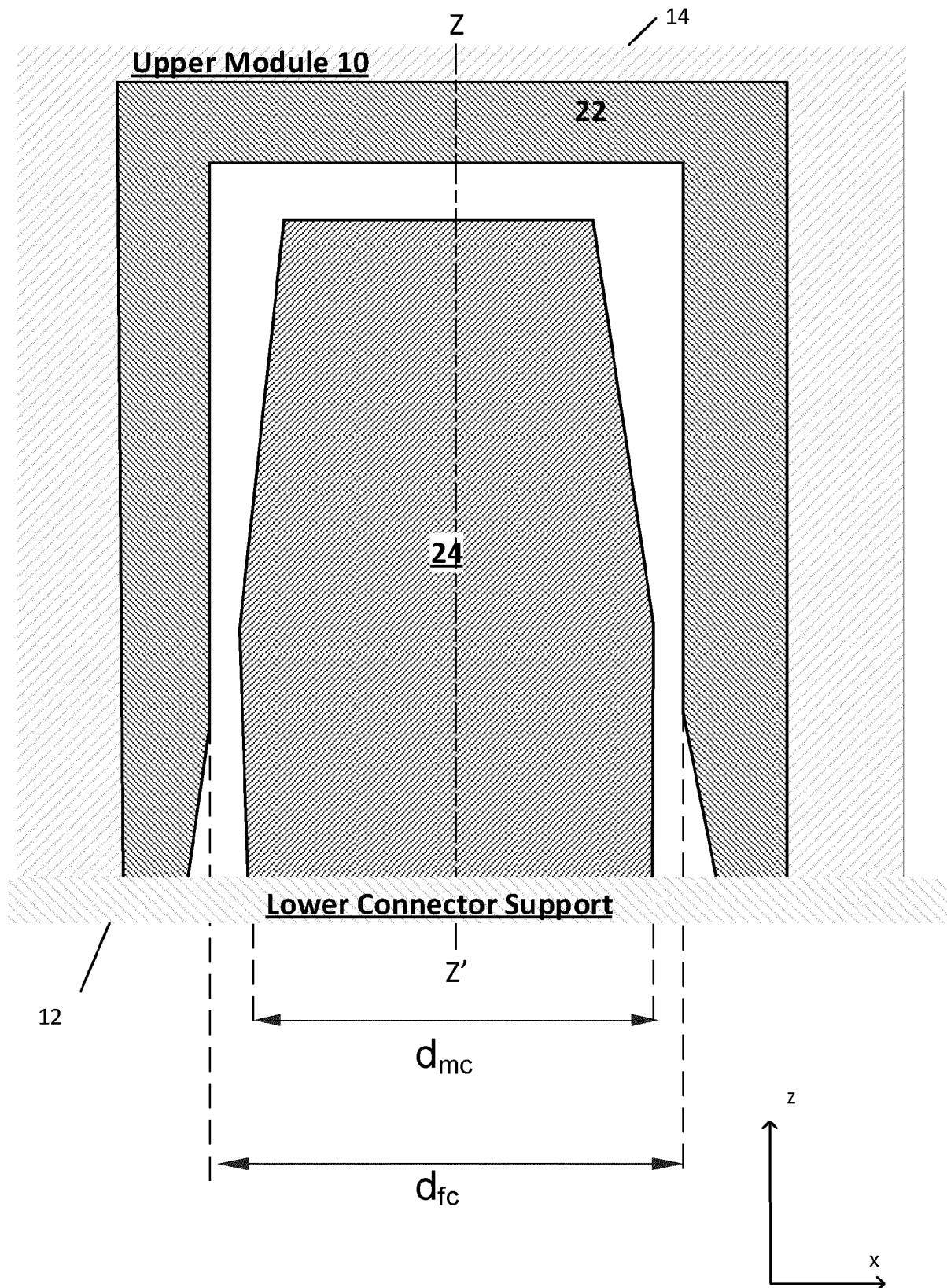


FIG. 4

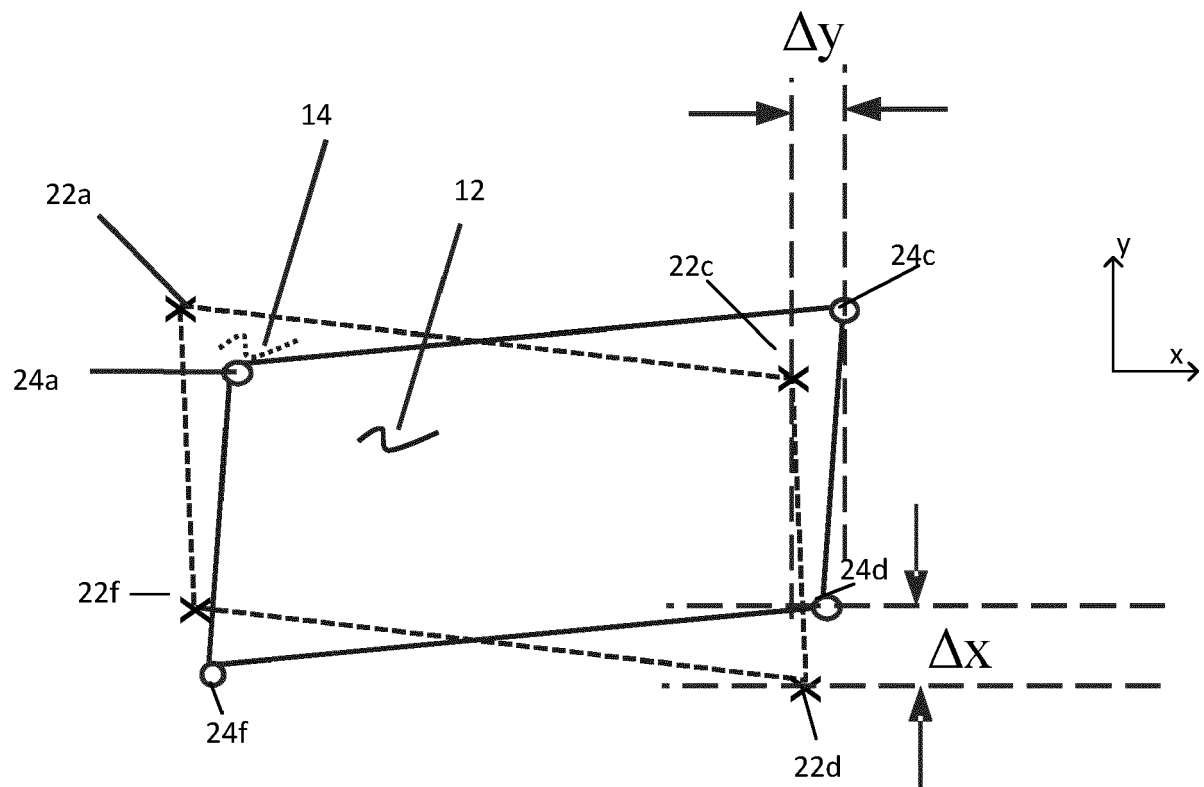
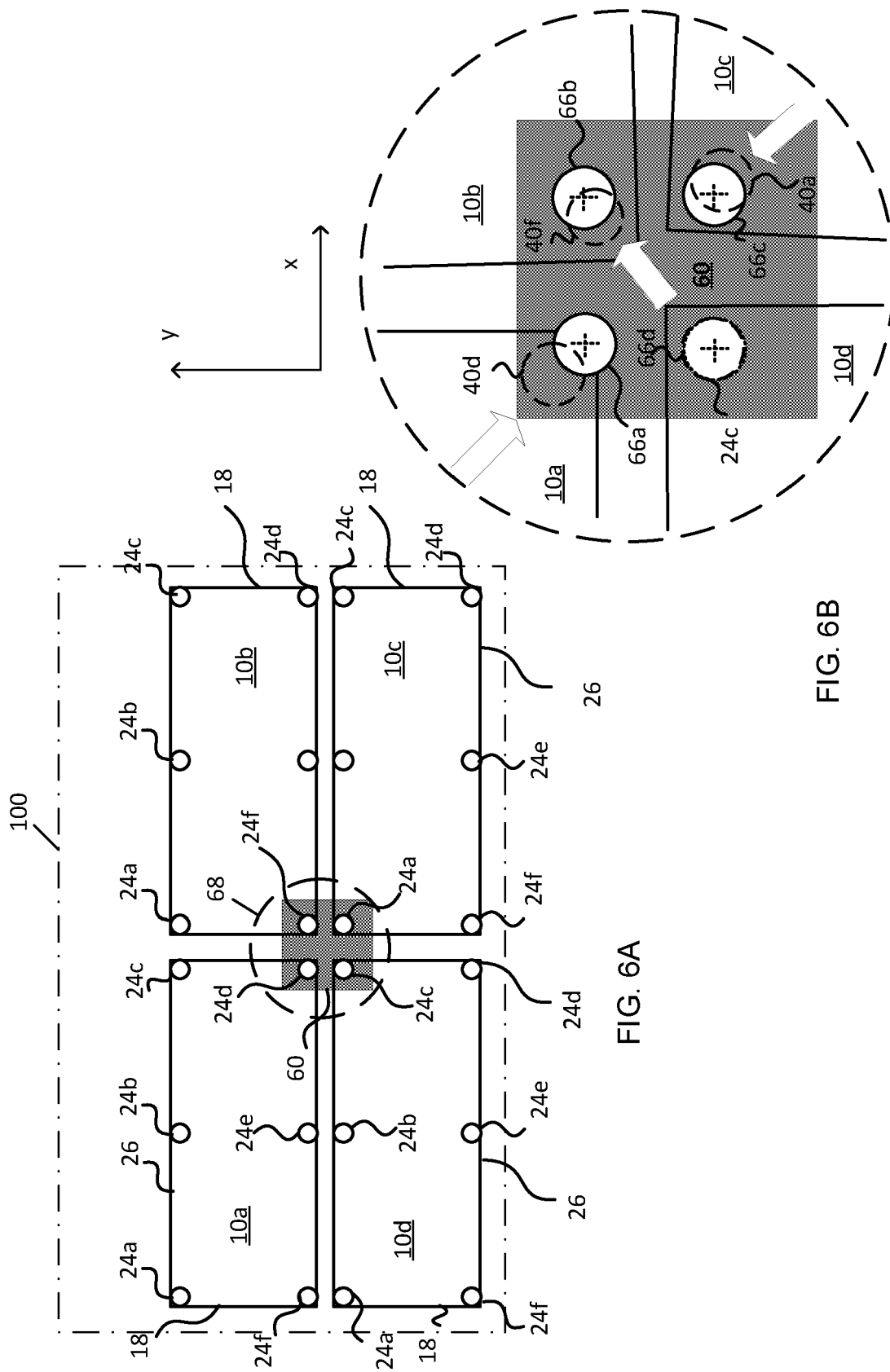


FIGURE 5



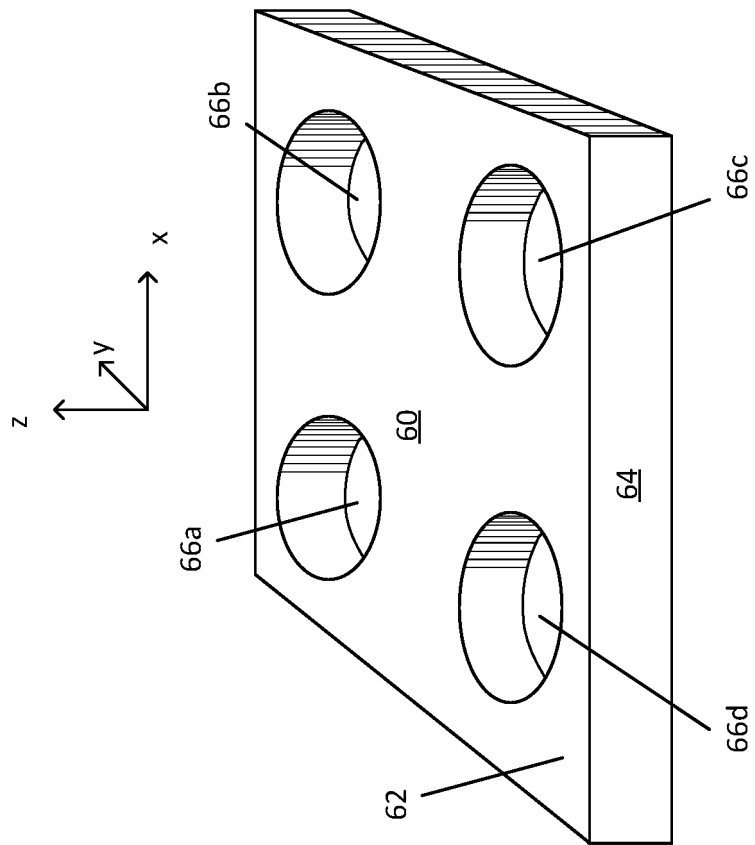


FIG. 7B

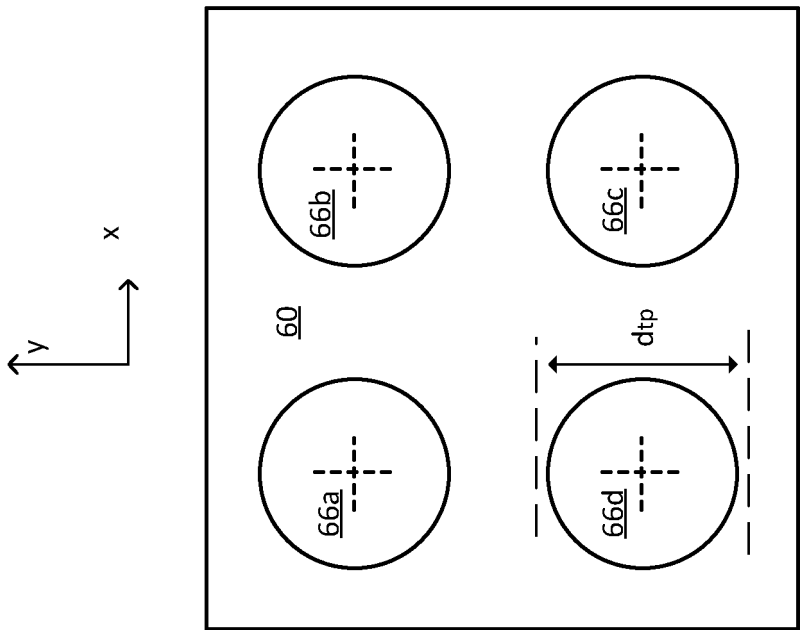


FIG. 7A

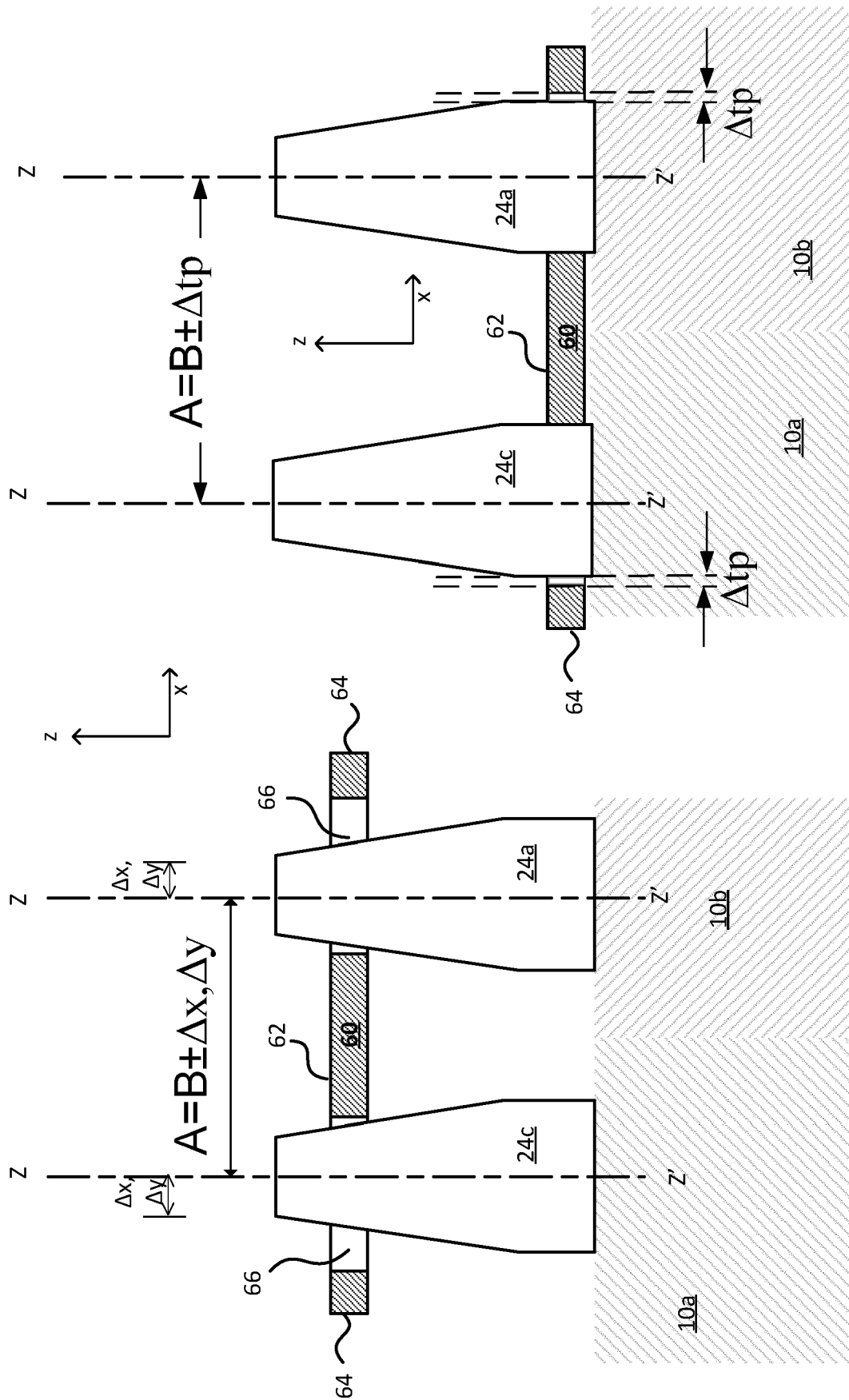


FIG. 8B

FIG. 8A

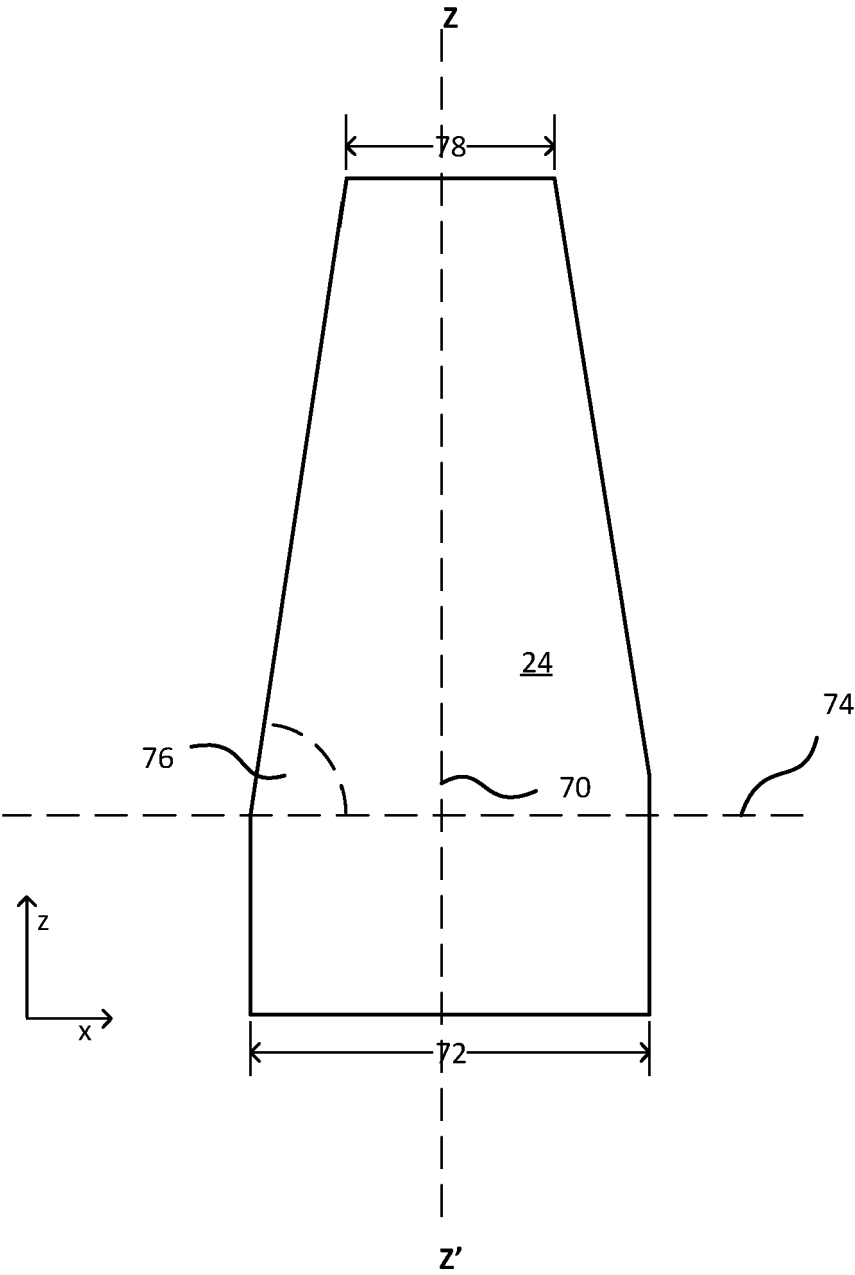


FIG. 9

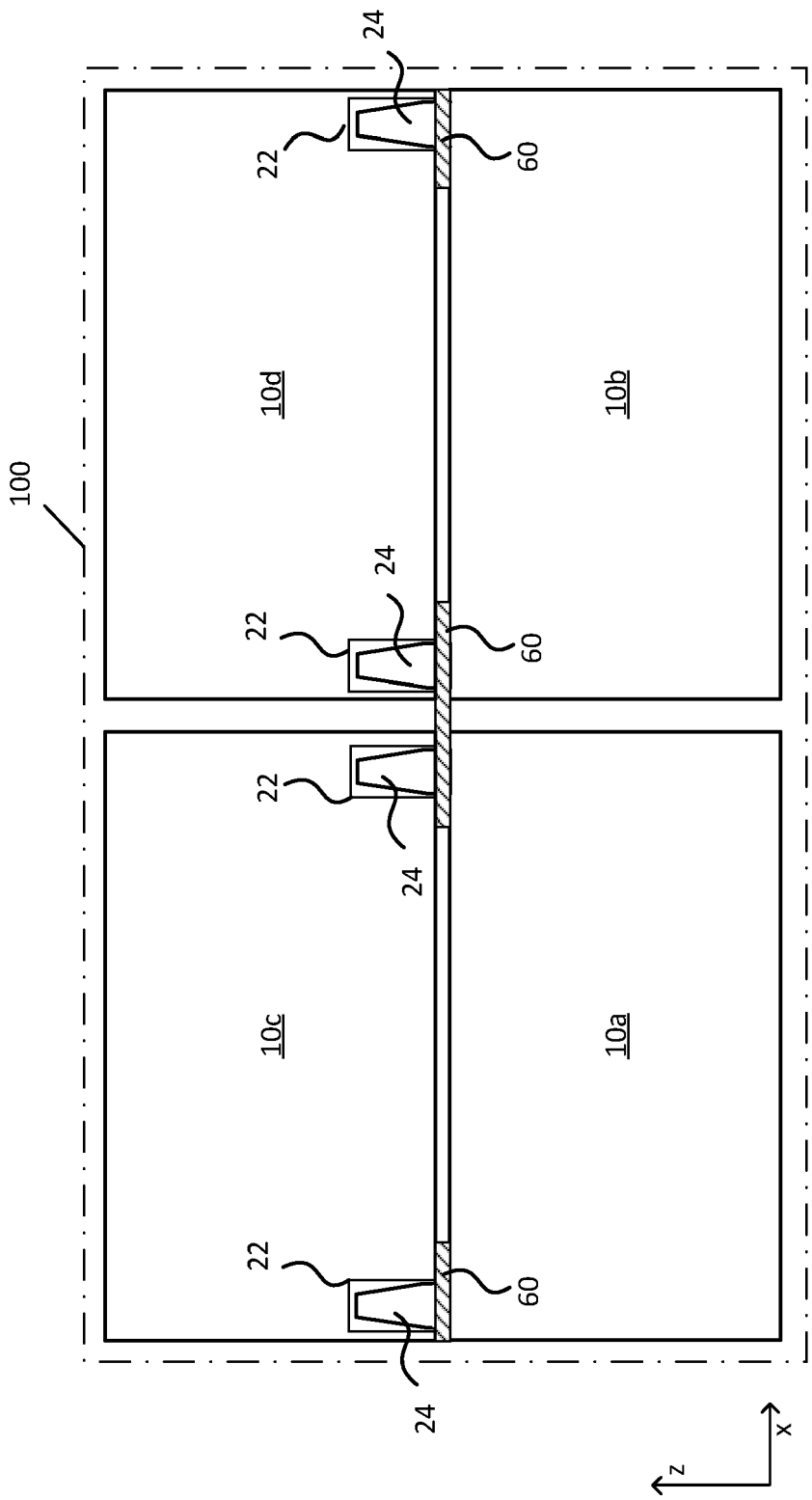


FIG. 10A

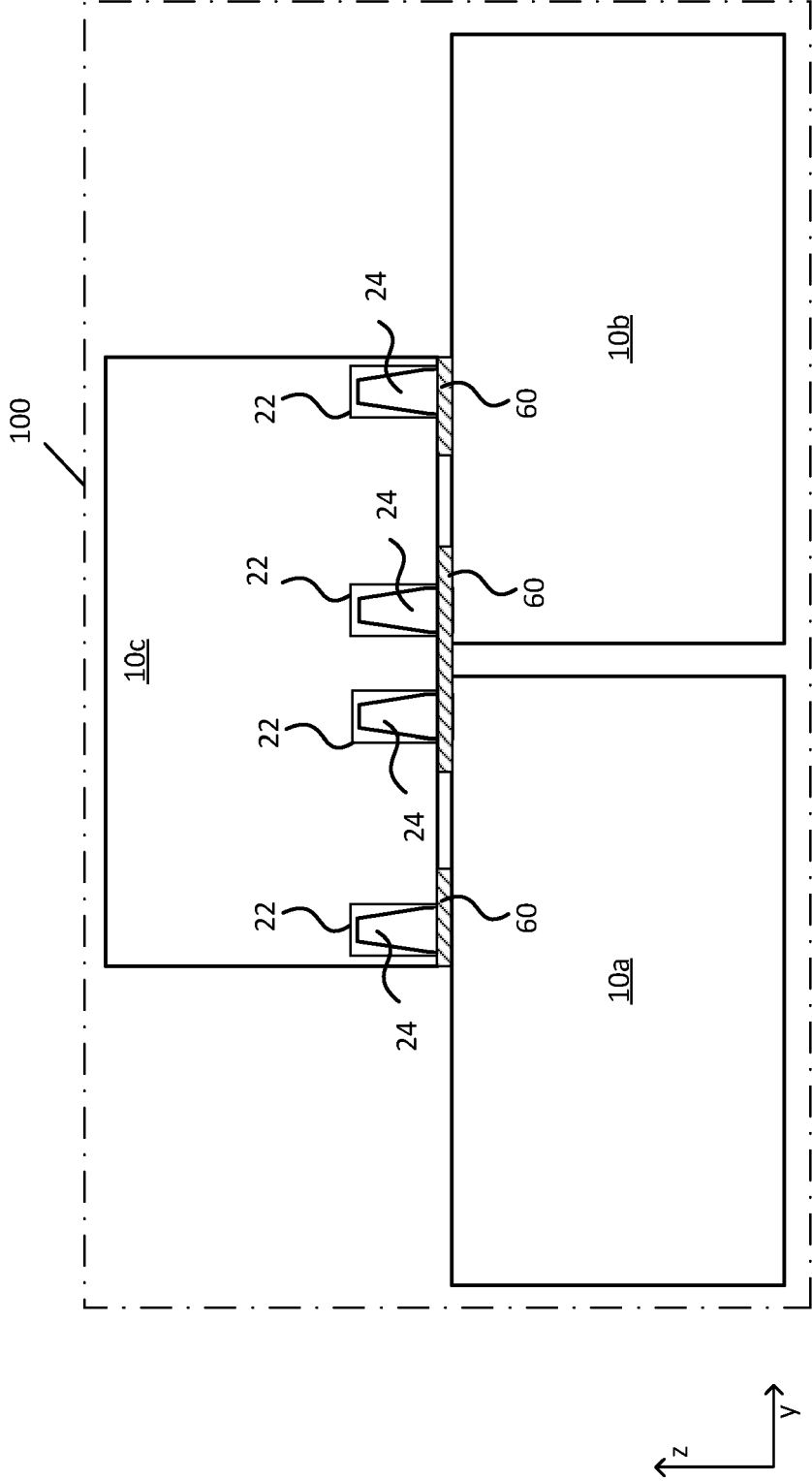


FIG. 10B

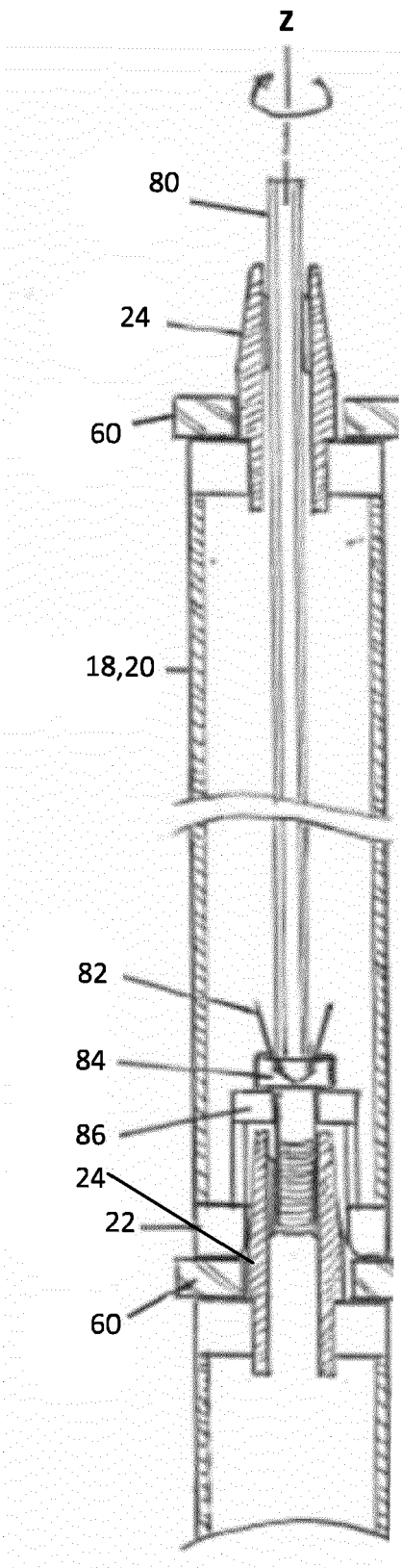


FIG. 11A

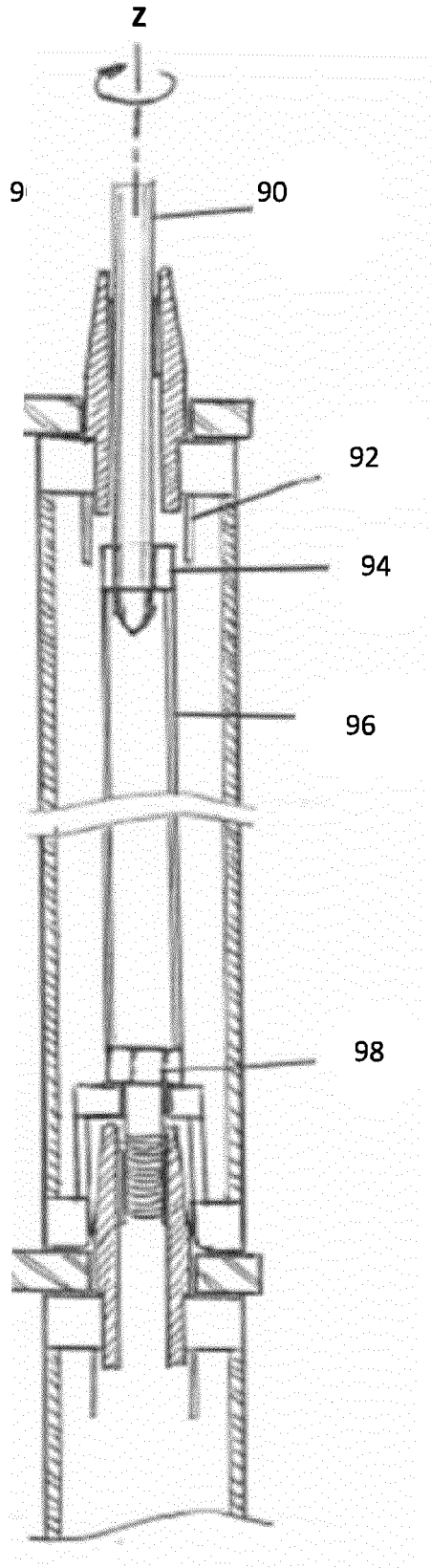


FIG. 11B

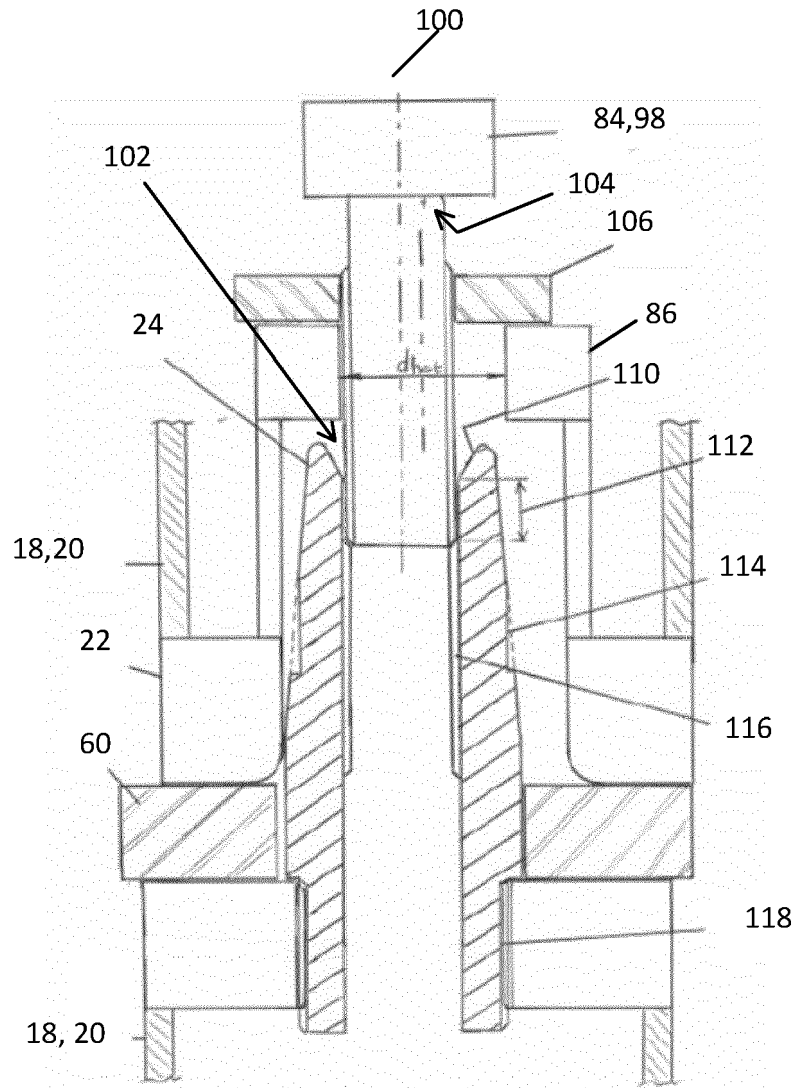


FIG. 12

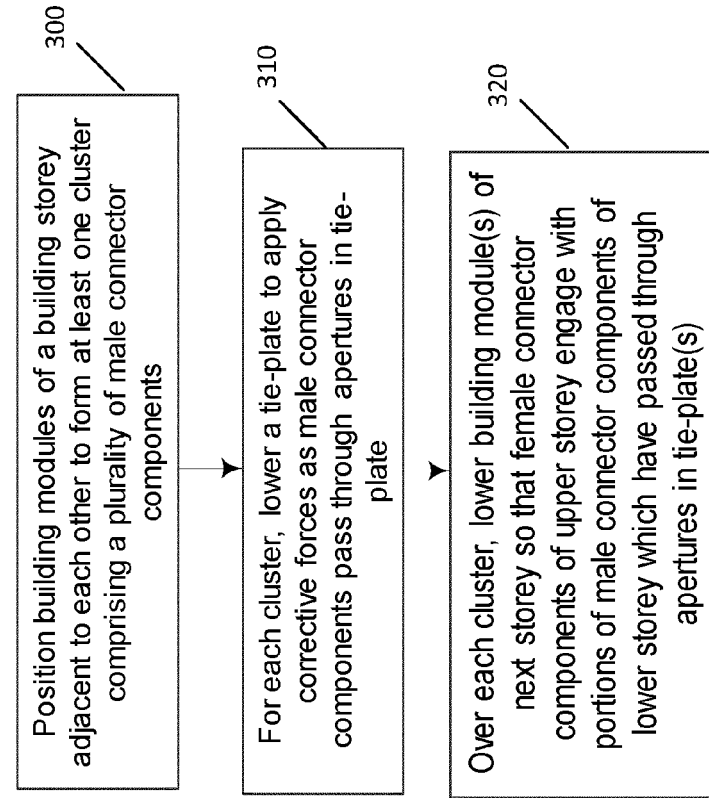


FIG. 14

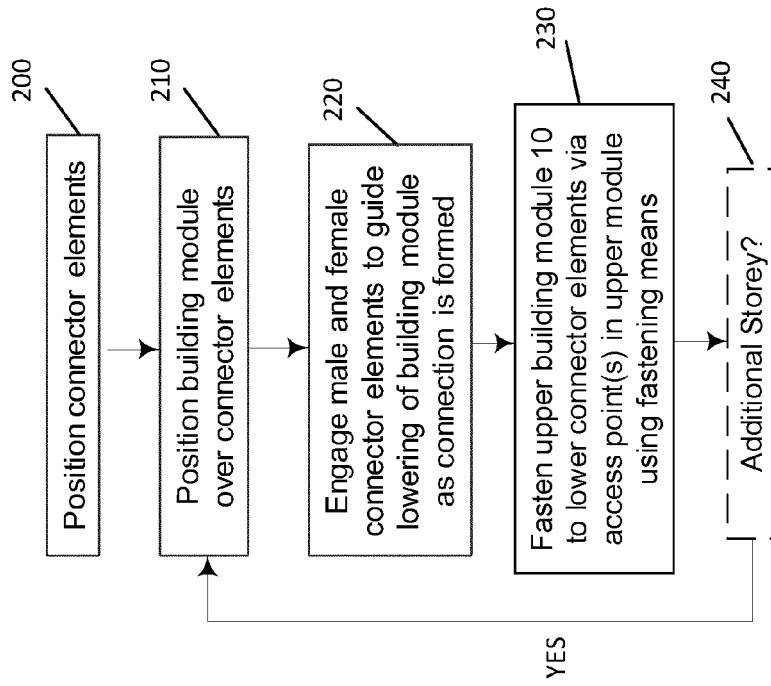


FIG. 13

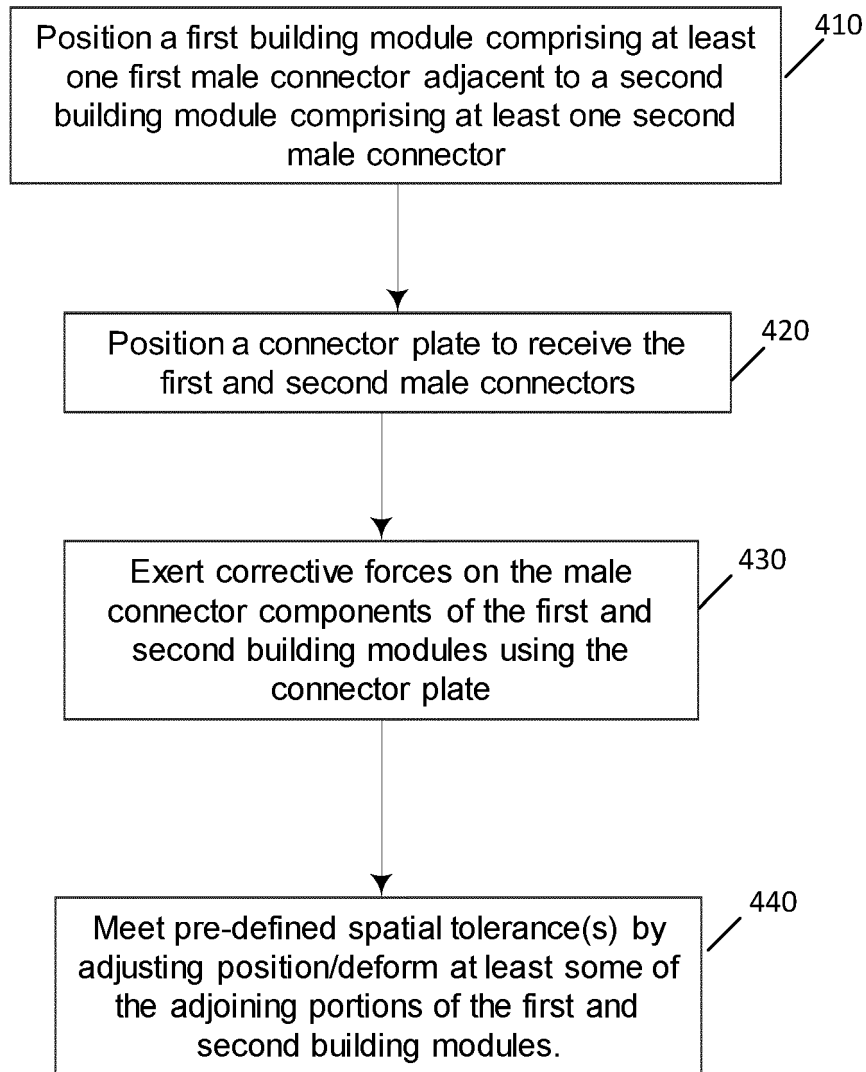


FIG. 15



EUROPEAN SEARCH REPORT

Application Number
EP 21 17 2836

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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	US 3 722 714 A (MORRIS J ET AL) 27 March 1973 (1973-03-27) * column 1, lines 22-42; figures 1-8 * * column 2, line 37 - column 4, line 36 * -----	1-15	INV. E04B1/348
A	GB 2 439 864 A (BIG STEPS LTD [GB]) 9 January 2008 (2008-01-09) * abstract; figures 1-18 * -----	1-15	
A	US 3 824 750 A (ANTONIOU A) 23 July 1974 (1974-07-23) * abstract; figures 1-8 * -----	1-15	
			TECHNICAL FIELDS SEARCHED (IPC)
			E04B
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 19 October 2021	Examiner Couprie, Brice
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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EPO FORM 1503 03/82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 21 17 2836

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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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19-10-2021

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US 3722714	A	27-03-1973	NONE
GB 2439864	A	09-01-2008	NONE
US 3824750	A	23-07-1974	NONE

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EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82