

APPARATUS, SYSTEMS AND METHODS FOR
MODULAR CONSTRUCTION

Related Application

[0001] This application claims priority to, and incorporates by reference in its entirety,
5 U.S. provisional application no. 61/570,656 filed 14 December 2011.

Technical Field

[0002] The invention relates to modular construction of buildings. Embodiments of the
invention provide volumetric construction modules, methods for assembling such
modules into buildings, and buildings and structural components of buildings constructed
10 from such modules.

Background

[0003] Modular building construction has many advantages over conventional building
construction. For example, prefabricated construction sections can be manufactured away
from construction sites at centralized factories, which may permit more productive use of
15 time, labour, material and equipment. Modular construction also presents fewer logistical
challenges than conventional construction by marshalling and assembling materials,
devices and equipment off site in factory conditions and thereby reducing the variety of
materials and components required during construction and by permitting efficient
division and scheduling of on-site construction tasks. Modular construction may also be
20 performed with less extensive site preparation, and can streamline the process of
obtaining engineering approval. These and other advantages of modular construction may
be especially pronounced in the construction of multi-story buildings. For instance,
modular construction may allow for a smaller construction site footprint, since arranging
just-in-time delivery of and storage for fewer and less various prefabricated construction
25 sections is simpler than for more diverse materials and components used in conventional
construction.

[0004] Additional economic advantages may be realized in modular construction by using prefabricated volumetric construction modules. For example, prefabricated volumetric construction modules may allow pre-installation (e.g., before delivery to the construction site or at the construction site before placement of the module in the building) of utility connections (e.g., plumbing, electricity wiring, HVAC, fire protection, etc.), interior finishing (e.g., kitchen fixtures, bathroom fixtures, cabinetry, drywall, curtain walls, etc.), and fenestration hardware (e.g., doors, windows, casings therefore, etc.). Prefabricated volumetric construction modules may also be configured to accord with the dimensions of intermodal shipping containers, thereby simplifying and economizing transportation, handling and assembly of the modules.

[0005] Building codes in much of the world require buildings to meet minimum structural strength criteria. In some areas of the world, building codes require buildings to meet structural strength and stiffness criteria sufficient to withstand the loads that occur during seismic events. It is a challenge to construct multi-story buildings that have adequate structural strength from prefabricated structural sections without incurring costs that extinguish the economic advantages of modular construction. The challenge of constructing multi-story buildings is especially daunting when using volumetric construction modules, due to the lack of continuity of the volumetric construction modules structural members.

[0006] Most modern residential high rise buildings are built with concrete reinforced with rebar. In these buildings it is conventional to provide reinforced concrete diaphragms that span shear walls and/or building frames. The concrete diaphragms transmit horizontal forces to the shear walls and/or building frames. Though it is possible to construct conventional buildings with rebar reinforced concrete walls and slab diaphragms around volumetric construction modules employing the modules as formwork, (such as is described in Published PCT Application no. WO 2009/061702), in general this is not cost efficient.

[0007] Another aspect of this challenge is the problem of providing vertical and lateral load bearing members that are sufficiently strong to support buildings having at least

several stories. Currently, it is conventional to provide reinforced concrete columns by encasing steel re-bar in concrete. This typically involves casting concrete in and around re-bar cages, which requires tying steel re-bar and assembling concrete formwork around the rebar on-site. For multi-story buildings, this requires tying steel-rebar, and placing
 5 and removing concrete forms at progressively higher floors. The connections of beams to columns are particularly challenging for rebar installation due to congestion of rebar required to counteract the forces concentrated at these locations. Setting, stripping, cleaning, rigging and resetting formwork is also time consuming and labour intensive particularly for concrete slab soffit forms.

10 **[0008]** There is accordingly need for volumetric construction modules, building systems and construction methods that facilitate construction of structurally strong multi-story buildings from prefabricated volumetric construction modules.

[0009] References in the general field of the technology include the following:

- CA 2,542,184 □BUILDING MODULES
- 15 • US 3,331,170 □PREASSEMBLED SUBENCLOSURES ASSEMBLED TO FORM BUILDING CONSTRUCTION
- US 3,514,910 □MODULAR BUILDING CONSTRUCTION
- US 4,599,829 □MODULAR CONTAINER BUILDING SYSTEM
- US 5,584,151 □EARTHQUAKE, WIND RESISTANT AND FIRE RESISTANT
- 20 PRE-FABRICATED BUILDING PANELS AND STRUCTURES FORMED THEREFROM
- US 7,827,738 □SYSTEM FOR MODULAR BUILDING CONSTRUCTION
- US 2003/0188507 □METHOD FOR CONSTRUCTING MODULAR SHELTERS USING RECYCLED LAND/SEA SHIPPING CONTAINERS
- 25 • US 2005/0223651 □BARRIER-PROTECTED CONTAINER
- US 2006/0185264 □PREFABRICATED BUILDING METHOD
- US 2008/0307729 □STRUCTURAL PANELS

- US 2007/0084135 □ CONSTRUCTION SYSTEM FOR STEEL-FRAME BUILDINGS
- US 2011/0036018 □ MOVABLE BUILDING
- WO 2009/061702 □ MODULAR BUILDING CONSTRUCTION UNIT, SYSTEM, AND METHOD
- WO 2009/132387 □ FIRE RATED, MULTI-STOREY, MULTI-DWELLING STRUCTURE AND METHOD TO CONSTRUCT SAME
- WO 2011/15836 □ MODULAR BUILDING AND FOUNDATION SYSTEM THEREFOR AND METHODS FOR THEIR CONSTRUCTION
- DE 3716795 □ FORMWORK FOR AN UNDERGROUND BOMB SHELTER
- FR 2710087 □ CONSTRUCTION COMPONENTS AND METHODS FOR MAKING THEM
- GB 8323946 □ PORTABLE BUILDING
- GB 2146053 □ PORTABLE BUILDING
- EP 1123449 □ VOLUMETRIC MODULAR BUILDING SYSTEM

[0010] The foregoing examples of the related art and limitations related thereto are intended to be illustrative and not exclusive. Other limitations of the related art will become apparent to those of skill in the art upon a reading of the specification and a study of the drawings.

20 Summary

[0011] The following embodiments and aspects thereof are described and illustrated in conjunction with systems, tools and methods which are meant to be exemplary and illustrative, not limiting in scope. In various embodiments, one or more of the above-described problems have been reduced or eliminated, while other embodiments are directed to other improvements.

[0012] An aspect of the invention provides a method of modular building construction comprising (a) providing a first volumetric construction module comprising a frame, the frame comprising a first segment; (b) defining a volume of a composite segment and

integrating the first segment with the volume; and (c) filling the volume with a curable material to cast the composite segment. The method may include, prior to step (b), step (a)(i) comprising providing a structure adjacent the first volumetric construction module, the adjacent structure comprising a second segment, and wherein step (b) comprises

5 integrating the first segment and the second segment with the volume. In step (b) the volume may contain at least a portion of the first and second segments. Step (b) may comprise defining a boundary of the volume with temporary formwork. Step (b) may comprise defining at least a portion of the boundary of the volume with the first and second segments. The adjacent structure may comprise a second volumetric construction

10 module comprising a frame including the second segment. The curable material may comprise a high strength curable material, such as carbon fibre reinforced polymer or high strength concrete.

[0013] The method may include, prior to step (b), step (a)(ii) comprising augmenting structural capacity of the composite segment. Step (a)(ii) may comprise coupling the first

15 segment and/or the second segment to a plurality of shear connectors extending into the volume. Step (a)(ii) may further comprise coupling a column reinforcement member to the plurality of shear connectors. Step (a)(ii) may comprise providing a column closure member opposite to the first segment and/or the second segment, the column closure member defining a portion of the boundary of the volume. The column closure member

20 may be coupled to a plurality of shear connectors extending into the volume. Step (a)(ii) may comprise providing a plurality of first and second reinforcement elements, the first and second reinforcement elements extending in transverse planes with respect to each other. The first reinforcement elements may comprise rebar rods and the second reinforcement elements comprise rebar stirrups. Step (a)(ii) may further comprise

25 providing a plurality of first and second reinforcement elements, wherein the second reinforcement elements engage the shear connectors. The first reinforcement elements may comprise rebar rods and the second reinforcement elements comprise rebar stirrups. Step (a)(ii) may comprise coupling the first segment and the second segment by wrapping the segments with fibre reinforced polymer wrap.

[0014] Each of the first and second volumetric construction modules may have an opening defined in its side that faces the other module, wherein the volume may comprise a space between the modules adjacent the openings. The volume may comprise a space between adjacent corners of the frame of the at least one of the first and second

5 volumetric construction modules. The volume may comprise a space adjacent an edge of the frame of at least one of the first and second volumetric construction modules. The first and second volumetric construction modules may be provided in laterally adjacent relation. The first and second volumetric construction modules in laterally adjacent relation may comprise providing the modules such that a side of one module is adjacent a
10 side of the other module, or such that an end of one module is adjacent a side of the other module, or such that an end of one module is adjacent an end of the other module. The frame of each of the first and second volumetric construction module may comprise a plurality of vertical posts, wherein the volume comprises a space between opposed posts of the modules. The frame of each of the first and second volumetric construction
15 module may comprise a horizontal rail, wherein the volume comprises a space between opposed rails of the modules. Each of the first and second volumetric construction module may comprise a panel section fastened to the frame, wherein the volume comprises a space between opposed panel sections of the modules.

[0015] Adjacent upper portions of the frames may be bridged with a structural member to
20 provide a bottom boundary of a slab volume. The structural member may comprise one or more upwardly extending shear connectors. The shear connectors may extend past the top of the frames. A plurality of rebar rods and rebar stirrups may be provided in the slab volume. The structural member may comprise a hot or cold rolled steel section, such as a plate, I beam or truss. A boundary of the slab volume may be partially defined by a
25 spacer installed above the first volumetric construction module and/or the second volumetric construction module. The top corners of the frame of each of the first and second volumetric construction modules may comprise corner fittings having upper orifices, wherein the spacer comprises at least one downward projection, and wherein installing the at least one spacer comprises mating the at least one downward projection
30 with one of the upper orifices. A curable material may be introduced to the slab volume.

An upper volumetric construction module may be provided above each of the first and second volumetric construction modules, each of the upper volumetric construction modules comprising a frame. At least bottom corners of the frame of each upper module may comprise corner fittings having lower orifices, wherein the spacer comprises at least one upward projection, and wherein providing the upper volumetric modules above the volumetric construction modules comprises mating the at least one upward projection with one of the lower orifices.

[0016] Each of the frames of the first and second volumetric construction modules may comprise a rectangular parallelepiped frame. The rectangular parallelepiped frame may comprise at least a part of a frame of an intermodal shipping container. The curable material may comprise concrete.

[0017] Another aspect of the invention provides a method of modular building construction comprising: (a) providing first and second volumetric construction modules in lateral relation, each module comprising a frame, the frame comprising a first segment; (b) providing a panel expansion member spanning opposing top rails of the frames and a floor frame between opposing bottom rails of the frame, the space between the panel expansion member and the floor frame defining an expansion space, wherein at least one of the panel expansion member and the floor frame comprise a second segment; (c) defining a volume of a composite segment, the volume integrating the first segment and the second segment; and (d) filling the volume with a curable material to cast the composite segment. In step (c) the volume may contain at least a portion of the first and second segments. Step (c) may comprise defining a boundary of the volume with temporary formwork. Step (c) may comprise defining at least a portion of the boundary of the volume with the first and second segments. The method may include, prior to step (d), a step (c)(i) comprising augmenting the structural capacity of the composite segment. Step (c)(i) may comprise coupling the first segment and/or the second segment to a plurality of shear connectors extending into the volume. Step (c)(i) may comprise providing a plurality of first and second reinforcement elements, the first and second reinforcement elements extending in transverse planes with respect to each other. The

first reinforcement elements may comprise rebar rods and the second reinforcement elements comprise rebar stirrups.

[0018] Each volumetric construction module may have an opening defined in its side that faces the expansion space, and wherein the volumes comprises a space between the modules and the expansion space adjacent the opening. The volume may comprise a space between adjacent corners of the frame of the at least one of the first and second volumetric construction modules. The volume may comprise a space adjacent an edge of the frame of at least one of the first and second volumetric construction modules. A side of the first volumetric construction module may be aligned with the side of the second volumetric construction module, with the expansion space located therebetween. A side of the first volumetric construction module may be aligned with an end of the second volumetric construction module, with the expansion space located therebetween. An end of the first volumetric construction module may be aligned with an end of the second volumetric construction module, with the expansion space located therebetween. The panel expansion member may partially define a bottom boundary of a slab volume above the modules and the expansion space. The panel expansion member may comprise a structural member at two side regions of the panel expansion member wherein spanning opposing top rails comprises resting at least a portion of the structural member on the top rails. The structural member may comprise a hot or cold rolled steel section, such as a plate, I beam or truss. The structural member may be provided with upwardly projecting shear connectors. Each of the frames of the first and second volumetric construction modules may comprise a rectangular parallelepiped frame. The rectangular parallelepiped frame may comprise at least a part of a frame of an intermodal shipping container. The panel expansion member may comprise at least a part of a panel of an intermodal shipping container. The floor frame may comprise at least a part of a floor frame of an intermodal shipping container. The curable material may comprise concrete.

[0019] Another aspect of the invention provides a method of modular building construction comprising: (a) providing a first volumetric construction module comprising a frame, the frame comprising a first segment; (b) providing a partially constructed

building comprising a frame comprising a second segment; (c) defining a volume of a composite segment, the volume integrating the first segment and the second segment; and (d) filling the volume with a curable material to cast the composite segment. In step (c) the volume may contain at least a portion of the first and second segments. Step (c) may
5 comprise defining a boundary of the volume with temporary formwork. Step (c) may comprise defining at least a portion of the boundary of the volume with the first and second segments. Prior to step (d), a step (c)(i) may comprise augmenting the structural capacity of the composite segment. Step (c)(i) may comprise coupling the first segment and/or the second segment to a plurality of shear connectors extending into the volume.
10 Step (c)(i) may further comprise providing a plurality of first and second reinforcement elements, the first and second reinforcement elements extending in transverse planes with respect to each other. The first reinforcement elements may comprise rebar rods and the second reinforcement elements may comprise rebar stirrups.

[0020] Another aspect of the invention provides a modular building diaphragm
15 comprising: roof panels of first and second volumetric construction modules in laterally adjacent relation; floor frames of third and fourth volumetric construction modules in laterally adjacent relation, the third and fourth modules above the first and second modules, respectively; a beam soffit member connected between upper portions of the first and second modules and having one or more shear connectors extending upwardly
20 between the third and fourth modules; and a continuous body of concrete in contact with at least a portion of each of the roof panels of the first and second modules, the laterally adjacent portions of the third and fourth modules, and the beam soffit member, the concrete bonded in composite action with the one or more shear connectors of the beam soffit member.

25 **[0021]** Another aspect of the invention provides a modular building diaphragm comprising: roof panels of first and second volumetric construction modules in laterally adjacent relation; floor frames of third and fourth volumetric construction modules in laterally adjacent relation, the third and fourth modules above the first and second modules and, respectively, bottom rails of the third and fourth modules rigidly connected

by at least one shear connector; a structural member connected between upper portions of the first and second modules; and at least one first reinforcing element extending in a direction parallel to a long axis of the bottom rails; a plurality of second reinforcing elements oriented in a plane transverse to the long axis of the bottom rails, each of the second reinforcing elements coupling the at least one shear connector to the at least one first reinforcing element; and a continuous body of concrete in contact with at least a portion of each of the roof panels of the first and second modules, the laterally adjacent portions of the third and fourth modules, the at least one first reinforcing element, the plurality of second reinforcing elements, and the structural member, the concrete bonded in composite action with the one or more shear connectors of the beam soffit member.

[0022] Another aspect of the invention provides a column in a modular building, the column comprising: a first panel section of a first volumetric construction module; a second panel section of a second volumetric construction module, the second panel section parallel to and spaced apart from the first panel section; at least one shear connector extending into a volume between the first panel section and the second panel section and attached to at least one of the first panel section and the second panel section; at least one column closure member closing lateral sides of the volume between the first panel section and the second panel section; and concrete in the volume bonded in composite action with the at least one shear connector. The first module may have an opening defined in part by an inward edge of the first panel section, wherein the second module has an opening defined in part by an inward edge of the second panel section, and wherein the at least one column closure member borders the openings in the first and second modules. At least one shear connector may be attached to the at least one column closure member, wherein the concrete is bonded in composite action with the at least one shear connector attached to the at least one column closure member.

[0023] Another aspect of the invention provides a column in a modular building, the column comprising: a first corner post section of a first volumetric construction module; a first vertically extending reinforcement member; a first plurality of shear connectors rigidly connecting the first corner post section to the first vertically extending

reinforcement member; a volume defined by temporary formwork, the volume surrounding and including the first corner post section, the first vertically extending reinforcement member, and the first plurality of shear connectors; and concrete in the volume encasing and bonding in composite action the first corner post section, the first vertically extending reinforcement member, and the first plurality of shear connectors.

The column may further comprise a second corner post section of a second volumetric construction module adjacent the first corner post section; a second vertically extending reinforcement member; a second plurality of shear connectors rigidly connecting the second corner post section to the second vertically extending reinforcement member;

wherein the volume additionally surrounds and includes the second corner post section, the second vertically extending reinforcement member, and the second plurality of shear connectors; and wherein the concrete in the volume additionally encases and bonds in composite action the second corner post section, the second vertically extending reinforcement member, and the second plurality of shear connectors.

[0024] Another aspect of the invention provides a column in a modular building, the column comprising: a first corner post section of a first volumetric construction module; a second corner post section of a second volumetric construction module adjacent the first corner post section; a first plurality of shear connectors rigidly connecting the first corner post section to the second corner post section; a volume defined by temporary formwork, the volume surrounding and including the first corner post section, the second corner post section, and the first plurality of shear connectors; and concrete in the volume encasing and bonding in composite action the first corner post section, the second corner post section, and the first plurality of shear connectors. The column may further comprise a third corner post section of a third volumetric construction module adjacent the first or second corner post section; a fourth corner post section of a fourth volumetric construction module adjacent the third corner post section; a second plurality of shear connectors rigidly connecting the third corner post section to the fourth corner post section; wherein the volume additionally surrounds and includes the third corner post section, the fourth corner post section, and the second plurality of shear connectors; and wherein the concrete in the volume additionally encases and bonds in composite action

the third corner post section, the fourth corner post section, and the second plurality of shear connectors.

[0025] Another aspect of the invention provides a column in a modular building, the column comprising: a first corner post section of a first volumetric construction module;
5 at least one first reinforcing element extending in a direction parallel to a long axis of the first corner post section; at plurality of second reinforcing elements oriented in a plane transverse to the long axis of the first corner post section, each of the second reinforcing elements surrounding both the first corner post section and the at least one first reinforcing element; and a volume defined by temporary formwork, the volume
10 surrounding and including the first corner post section, the at least one first reinforcing element and the plurality of second reinforcing elements; and concrete in the volume encasing and bonding in composite action the first corner post section, the at least one first reinforcing element and the plurality of second reinforcing elements. The column may further comprise a second corner post section adjacent the first corner post section,
15 wherein each of the second reinforcing elements surround the second corner post section, wherein the volume surrounds and includes the second corner post section, and wherein the concrete in the volume encases and bonds in composite action the first corner post section, the second corner post section, the at least one first reinforcing element and the plurality of second reinforcing elements. The at least one first reinforcing element may
20 comprise a rebar rod, and the plurality of second reinforcing elements comprise rebar stirrups.

[0026] Another aspect of the invention provides a beam in a modular building, the beam comprising: a first horizontal rail of a first volumetric construction module; a second horizontal rail of a second volumetric construction module, the second horizontal rail
25 parallel to and spaced apart from the first rail; at least one shear connector extending into a volume between the first rail and the second rail and attached to at least one of the first rail and the second rail; a beam soffit member below the first rail and the second rail, the beam soffit member having one or more shear connectors extending into the volume between the first rail and the second rail; and concrete in the volume between the first rail

and the second rail, the concrete bonded in composite action with the at least one shear connector attached to at least one of the first rail and the second rail and with the one or more shear connectors of the beam soffit member. The first module may have an opening defined above the first rail, wherein the second module has an opening defined above the second rail, and wherein an upper face of the concrete borders the openings in the first and second modules.

[0027] Another aspect of the invention provides a beam in a modular building, the beam comprising: a first horizontal rail of a first volumetric construction module; a second horizontal rail of a second volumetric construction module, the second horizontal rail parallel to and spaced apart from the first rail; at least one shear connector extending between the first rail and the second rail and attached to at least one of the first rail and the second rail; at least one first reinforcing element extending in a direction parallel to a long axis of the first and second horizontal rail; at plurality of second reinforcing elements oriented in a plane transverse to the long axis of the first and second horizontal rail, each of the second reinforcing elements coupling the at least one shear connector to the at least one first reinforcing element; and a structural member below the first rail, the second rail, the at least one first reinforcing element, and the plurality of second reinforcing elements; and concrete in a volume defined between the first rail and the second rail, the concrete bonded in composite action with the at least one shear connector, the at least one first reinforcing element, and the plurality of second reinforcing elements. The structural member may be comprise a hot or cold rolled steel section, such as a plate, I beam or truss. The plurality of second reinforcing elements may be substantially U-shaped, wherein end regions of the U-shape engage the at least one shear connector, and a middle region of the U-shape engages the at least one first reinforcing element. The at least one first reinforcing element may comprise a rebar rod, and the plurality of second reinforcing elements comprise rebar stirrups.

[0028] Another aspect of the invention provides a shear wall in a modular building, the shear wall comprising: a shear wall panel; at least a portion of one end or side of a volumetric construction module; at least one connector rigidly fixed to and extending

between the shear wall panel and the portion of the one end or side; concrete in a volume defined between the shear wall panel and the portion of one end or side. The shear wall panel may comprise repurposed intermodal shipping container wall material.

[0029] Another aspect of the invention provides a volumetric construction module

5 comprising: a frame having opposed ends and opposed sides extending between the ends; and one or more shear connectors projecting outwardly from the frame. The frame may comprise at least part of a rectangular parallelepiped frame of an intermodal shipping container. The one or more shear connectors may extend between adjacent corners of the frame. The one or more shear connectors may comprise an array of stud-type shear
10 connectors. The one or more shear connectors may comprise at least one strip-type shear connector. The one or more shear connectors may be located adjacent an edge of the frame. The edge may comprise an edge between one of the ends of the frame and one of the sides of the frame. The frame may comprise a plurality of vertical posts, and wherein at least one of the one or more shear connectors is attached to one of the posts. The
15 module may comprise a panel section coupled to the frame, wherein at least one of the one or more shear connectors is attached to the panel section. The edge may comprise an edge between a bottom of the frame and one of the sides of the frame. The edge may be located along the top of one of the ends. The frame may comprise a horizontal rail, and at least one of the one or more shear connectors may be attached to the rail. The frame
20 may have an opening in one of its sides, wherein at least one of the shear connectors extends along an edge of the opening.

[0030] Another aspect of the invention provides a method for making a volumetric construction module, the method comprising: providing an intermodal shipping container; installing one or more shear connectors on the outside of the container. The
25 method may comprise removing a portion of a side panel of the container to define an opening in a side of the container. The method may comprise detachably fastening the removed portion of the side panel to the container. Installing the one or more shear connectors may comprise: attaching the one or more shear connectors to the removed portion of the side panel; and laminating the removed portion of the side panel to a

remaining portion of the side panel of the container. Installing the one or more shear connectors may comprise installing one or more shear connectors between adjacent corners of the container. Installing the one or more shear connectors may comprise installing an array of stud-type shear connectors. Installing the one or more shear connectors may comprise installing at least one strip-type shear connector. Installing the one or more shear connectors may comprise installing the one or more shear connectors adjacent to an edge of the container. The edge may comprise an edge between an end of the container and a side of the container. Installing the one or more shear connectors may comprise attaching at least one of the one or more shear connectors to a post of the container. Installing the one or more shear connectors may comprise attaching at least one of the one or more shear connectors to a panel of the container. The edge may comprise an edge between a bottom of the container and a side of the container. The edge may comprise an edge between a top of the container and an end of the container. Installing the one or more shear connectors may comprise attaching at least one of the one or more shear connectors to a horizontal rail of the container. Installing the one or more shear connectors may comprise welding at least one of the one or more shear connectors to the container. Installing the one or more shear connectors may comprise adhesively bonding at least one of the one or more shear connectors to the container. Installing the one or more shear connectors may comprise mechanically coupling at least one of the one or more shear connectors to the container.

[0031] Another aspect of the invention provides a building comprising: two volumetric construction modules in adjacent relation, each module comprising: a frame having opposed ends and opposed sides extending between the ends, and one or more first shear connectors coupled to the frame and extending toward the other module; at least one first closure member closing lateral sides of a first volume between the modules that includes the one or more first shear connectors; and concrete occupying the first volume. Each module may have an opening defined in its side that faces the other module, and wherein the first volume is adjacent the openings. Each of the modules may comprise one or more second shear connectors, and wherein the building comprises: at least one second first closure member closing lateral sides of a second volume between the modules that

includes the one or more second shear connectors; and concrete occupying the second volume, wherein the second volume is spaced apart from the first volume and adjacent the openings in the modules. The frame of each module may comprise at least part of a rectangular parallelepiped frame of an intermodal shipping container.

- 5 **[0032]** Another aspect of the invention provides a building comprising: a first volumetric construction module comprising a frame, the frame comprising a first segment; a volume of a composite segment, the volume integrating the first segment; and concrete occupying the volume. The building may comprise a structure adjacent the first volumetric construction module, the adjacent structure comprising a second segment, wherein the
- 10 volume integrates the first segment and the second segment. The adjacent structure may comprise a second volumetric construction module, an expansion space, and/or a partially constructed building. The volume may contain at least a portion of the first and second segments, wherein boundaries of the volume are formed by temporary formwork. The building may comprise a base isolation system.
- 15 **[0033]** In addition to the exemplary aspects and embodiments described above, further aspects and embodiments will become apparent by reference to the drawings and by study of the following detailed descriptions.

Brief Description of Drawings

[0034] The accompanying drawings show non-limiting example embodiments.

- 20 **[0035]** Figure 3 is an isometric view of a volumetric construction module according to an example embodiment.

[0036] Figure 3A is an isometric view of a volumetric construction module according to an example embodiment.

- 25 **[0037]** Figure 4 is an isometric view of panel sections of the volumetric construction module of Figure 3.

[0038] Figure 4A is a detail isometric view of an angle member installed on a panel section shown in Figure 4.

[0039] Figure 5 is a side elevation view of the volumetric construction module of Figure 3.

5 [0040] Figure 6 is a top plan view of the top of the volumetric construction module of Figure 3.

[0041] Figure 7A is an opening end elevation view of the volumetric construction module of Figure 3.

10 [0042] Figure 7B is a closed end elevation view of the volumetric construction module of Figure 3.

[0043] Figure 8A is an isometric view of a column closure member according to an example embodiment.

[0044] Figure 8B is an isometric view of a column closure member according to another example embodiment.

15 [0045] Figure 8C is an isometric view of a column reinforcement member according to an example embodiment.

[0046] Figure 9 is an isometric view of a beam soffit member according to an example embodiment.

20 [0047] Figure 9A is an isometric view of a panel expansion member according to an example embodiment.

[0048] Figure 10 is an isometric view of a spacer according to an example embodiment.

[0049] Figure 11 is an isometric view of a slab edge form member according to an example embodiment.

[0050] Figure 12 is an isometric view of an assembly according to an example embodiment comprising the volumetric construction module of Figure 3, the members of
5 Figures 8A, 8B and 9, the spacer of Figure 10 and the edge form member of Figure 11.

[0051] Figure 13 is a flow chart of a construction method according to an example embodiment.

[0052] Figure 14 is an isometric view of an assembly illustrating stages of construction according to an example implementation of the method of Figure 13.

10 [0053] Figure 15 is a detail isometric view of a corner of four adjacent modules assembled according to an example implementation of the method shown in Figure 13.

[0054] Figure 16 is a cross-section through a composite beam according to an example embodiment.

15 [0055] Figure 17 is a cross-section through a composite beam according to another example embodiment.

[0056] Figure 18 is a cross-section through a composite beam according to a further example embodiment.

[0057] Figure 19 is a cross-section through a composite beam according to a further example embodiment.

20 [0058] Figure 20 is a cross-section through a composite beam according to a further example embodiment.

[0059] Figure 21 is an isometric view of a spacer according to an example embodiment.

[0060] Figure 22 is an isometric view of an assembly according to an example embodiment comprising the volumetric construction module of Figure 3, the members of Figures 8B and 9, and the spacer of Figure 21.

5 [0061] Figure 23 is a flow chart of a construction method according to an example embodiment.

[0062] Figure 24 is an isometric view of an assembly illustrating stages of construction according to an example implementation of the method of Figure 23.

[0063] Figure 24A is a close up isometric view of a portion of the assembly of Figure 24.

[0064] Figure 25 is an end view cross-section of a portion of the assembly of Figure 24.

10 [0065] Figure 26 is a cross-section through a composite beam according to a further example embodiment.

[0066] Figure 27 is a cross-section through a composite beam according to a further example embodiment.

15 [0067] Figure 27A is a detail isometric view of a corner of four adjacent modules assembled according to an example implementation of the method shown in Figure 23.

[0068] Figure 28 is an isometric view of a multi-story building according to an example embodiment.

[0069] Figure 29 is a floor plan of the building shown in Figure 28, shown with modules removed.

20 [0070] Figure 30 is a floor plan of the building shown in Figure 28 with modules shown.

[0071] Figure 31 is a side elevation view of the building core of the building shown in Figure 28.

[0072] Figure 32 is a schematic plan view cross-section through a column formed in part by four corner adjacent opening end corner posts.

[0073] Figure 33 is a schematic plan view cross-section through a column formed in part by four corner adjacent closed end corner posts.

5 **[0074]** Figure 34 is a schematic plan view cross-section through a column formed in part by two laterally adjacent closed end corner posts.

[0075] Figure 35 is a schematic plan view cross-section through a column formed in part by two facing adjacent opening end corner posts.

10 **[0076]** Figure 36 is a schematic plan view cross-section through a column formed in part by two laterally adjacent opening end corner posts.

[0077] Figure 37 is a schematic plan view cross-section through a column formed in part by one opening end corner post.

[0078] Figure 38 is a schematic plan view cross-section through a column formed in part by four corner adjacent opening end corner posts.

15 **[0079]** Figure 39 is a schematic plan view cross-section through a column formed in part by two corner adjacent facing closed end corner posts.

[0080] Figure 40 is a schematic plan view cross-section through a column formed in part by one closed end corner post.

20 **[0081]** Figure 41 is a schematic plan view cross-section through a shear wall according to an example embodiment.

[0082] Figure 42 is a schematic plan view cross-section through a column formed in part by two facing adjacent opening end corner posts according to an example embodiment.

[0083] Figure 43 is a schematic plan view cross-section through a column formed in part by an opening end corner posts according to an example embodiment.

[0084] Figures 44 and 44A are isometric and cross section views, respectively, through a composite beam according to an example embodiment.

5 [0085] Figure 45 is a cross section through a composite beam according to an example embodiment.

[0086] Figure 46 is a cross section through a composite beam according to an example embodiment.

10 [0087] Figure 47 is a cross section through a composite beam according to an example embodiment.

Description

[0088] Throughout the following description specific details are set forth in order to provide a more thorough understanding to persons skilled in the art. However, well known elements may not have been shown or described in detail to avoid unnecessarily obscuring the disclosure. Accordingly, the description and drawings are to be regarded in
15 an illustrative, rather than a restrictive, sense.

[0089] In some embodiments of the invention, volumetric construction modules are integrated with concrete and/or other curable materials having high-compressive strength to form composite segments (e.g., columns, beams, slabs, diaphragms, etc. comprising
20 steel and concrete). In particular, in some embodiments, one or more segments (e.g. corner posts, end rails, side rails, etc.) of volumetric construction modules may be integrated with a curable material to form the composite segment. Shear connections or other means (e.g. fibre reinforced polymer wraps) may be provided in particular
embodiments to augment the structural capacity of the composite segment while in other
25 particular embodiments such augmentation is not provided (i.e., structural capacity is derived solely from the segments integrated with the high strength curable material). For

simplicity of exposition, a volumetric construction module and various components according to an example embodiment are introduced first, and this is followed by an explanation of how the module and components may be combined in a building according to an example embodiment.

- 5 **[0090]** Volumetric construction modules according to some example embodiments comprise at least some parts of intermodal shipping containers. Presently, intermodal shipping containers can be obtained in developed countries at relatively low prices (in some cases less than the cost of their component materials) due to global trade imbalances. Embodiments which comprise intermodal shipping containers may reap cost
- 10 advantages from the availability of low-cost intermodal shipping containers. Such embodiments may also reap advantages associated with ease of transporting these containers, as well as with the standard dimensions, tight tolerances and specified structural capacities to which these containers are built. In some embodiments, the volumetric construction module may comprise other suitable modules including purpose
- 15 built modules. The shape of the volumetric construction module may be rectangular or any other shape suitable for the particular application.

[0091] Figure 1 is an isometric view of an intermodal shipping container 10. Figure 2 is a partially-exploded isometric view of container 10. Container 10 comprises an International Standards Organization (ISO) high cube 20 foot container. Container 10 is

20 6058 mm (19 feet 10 $\frac{1}{2}$ inches) long, 2438mm (8 feet) wide and 2896 mm (9 feet 6 inches) high. Container 10 is made from weathering steel (e.g., COR-TEN $\frac{1}{2}$ weathering steel).

[0092] Container 10 comprises a volumetric parallelepiped frame 12. Frame 12 comprises a rectangular opening end frame 22 at its opening end 20, a rectangular closed end frame 32 at its closed end 30, and rectangular side frames 42L and 42R at its left and

25 right sides 40L and 40R, respectively. Side frames 42L and 42R may be referred to collectively or generally herein as side frames 42. The terms "opening end" and "closed end" are used herein to denote the different ends of example containers and shipping modules for convenience only, and it will be understood that different container and

modules not having opening and closed ends may be used in embodiments of the invention.

[0093] Opening end frame 22 comprises a top opening end rail 24, bottom opening end rail 26, left opening end corner post 28L and right opening end corner post 28R. Opening end corner posts 28L and 28R may be referred to collectively or generally herein as corner posts 28. Closed end frame 32 comprises a top closed end rail 34, bottom closed end rail 36, left closed end corner post 38L (not shown in Figure 1; see Figure 2) and right closed end corner post 38R. Closed end corner posts 38L and 38R may be referred to collectively or generally herein as corner posts 38.

[0094] Corner fittings 14 are located at each of the corners of opening end frame 20 and closed end frame 30. Corner fittings 14 have orifices 16 on their exposed faces for connecting, lifting and lashing container 10 during transport and handling. Side rails extend between opposite corner fittings 14 of opening end frame 22 and closed end frame 32. More particularly:

- top left side rail 44L extends between corner fitting 14 at the top left corner of opening end frame 22 and corner fitting 14 at the top left corner of closed end frame 32;
- top right side rail 44R extends between corner fitting 14 at the top right corner of opening end frame 22 and corner fitting 14 at the top right corner of closed end frame 32;
- bottom left side rail 46L (not shown in Figure 1; see Figure 2) extends between corner fitting 14 at the bottom left corner of opening end frame 22 and corner fitting 14 at the bottom left corner of closed end frame 32; and
- bottom right side rail 46R extends between corner fitting 14 at the bottom right corner of opening end frame 22 and corner fitting 14 at the bottom right corner of closed end frame 32.

[0095] Left side frame 42L comprises left opening corner post 28L, left closed corner post 38L, top left side rail 44L, and bottom left side rail 46L. Right side frame 42R comprises right opening corner post 28R, right closed corner post 38R, top right side rail 44R, and bottom right side rail 46R. As described above, corner posts 28 and 38 are, respectively, also components of opening and closing end frames 22 and 32. Top side rails 44L and 44R may be referred to collectively or generally herein as top side rails 44. Bottom side rails 46L and 46R may be referred to collectively or generally herein as top side rails 46.

[0096] End frames 22 and 32, and side frames 42 are closed by either corrugated steel panels or by doors in the case of opening end frame 22. Doors 52 hingedly connected to opening end corner posts 28 are pivotable to selectively close opening end frame 22. When closed, doors 52 span opening end corner posts 28, top opening end rail 24 and bottom opening end rail 26. An end panel 54 closes closed end frame 32. A left side panel 56L closes left side frame 42L. A right side panel 56R closes right side frame 42R.

The top face of container 10 is closed by a top panel 58.

[0097] The bottom of container 10 comprises a floor frame 62 comprising left and right bottom side rails 46L and 46R, opening end bottom rail 26 and a closed end bottom rail 36 (not shown in Figure 1; see Figure 2). Floor frame 62 is spanned by spaced transverse joists 68. Floor joists 68 are coupled at their ends to bottom side rails 46. A plywood panel 70 above floor frame 62 is fastened to joists 68, bottom side rails 46, opening bottom rail 64, and closed bottom rail 66. Tubular forklift pockets 72 intermediate bottom end rails 26 and 36 span bottom side rails 46.

[0098] Container 10 is designed and built to be loaded and stacked on container ships. A twenty foot ISO standard intermodal shipping container 10 has a tare weight of 2,220 kilograms (4,894 lbs.), can be loaded to a gross weight up to 30,480 kilograms (67,197 lbs.), and can be stacked 9 high (i.e., can support the weight of 8 loaded containers weighing a total of 244 metric tonnes). In modern intermodal shipping container designs all components participate in the container's structural integrity, and the specified level of structural capability is assured only when all walls, floors and roofs are in place and

doors are closed. Removing any portion of an intermodal shipping container (e.g., to provide windows or doors, or to open up rooms), will compromise structural integrity. Since windows, doors, and open rooms are practical necessities for habitable buildings, construction of multi-story buildings from intermodal shipping containers requires
5 additional support to carry vertical and lateral loads present in these buildings.

[0099] Some parts of intermodal shipping containers are stronger than others. For example, floor frame 62 and corner posts 28 and 38 of container 10 are relatively strong. More particularly:

- 10 • floor frame 62 of container 10 comprises bottom side rails 46, which are constructed of steel C-channel beams to withstand longitudinal tensile loads, floor joists 68, which are constructed of steel C-channel beams to withstand transverse tensile loads, and bottom end rails 26 and 36, which are constructed of steel box sections; and
- 15 • corner posts 28 and 38 are constructed from steel C-channel sections closed with welded steel plate.

[0100] Some embodiments of the invention provide volumetric construction modules adapted to integrate the relatively strong parts of container 10 into composite structural members (e.g., columns, beams, slabs and diaphragms). Example embodiments of volumetric construction modules and buildings constructed therefrom using containers
20 such as container 10 are described below. It is to be understood that the features and techniques disclosed herein could also be applied to other types of containers or other types of volumetric construction modules.

[0101] Figures 3, 4, 4A, 5, 6, 7A and 7B show a volumetric construction module 100, or at least portions thereof, according to an example embodiment. More particularly:

- 25 • Figure 3 is an isometric view of module 100;
- Figure 4 is an isometric view of panel sections of the module 100;

- Figure 4A is a detail isometric view of an angle member installed on a removable panel section of module 100;
- Figure 5 is a side elevation view of module 100;
- Figure 6 is a top plan view of module 100;
- 5 • Figure 7A is an opening end elevation view of module 100; and
- Figure 7B is a closed end elevation view of module 100.

[0102] Module 100 comprises parts of an intermodal shipping container. Those parts are identified using the same reference numerals used to identify like parts of container 10, and are not described again here. Like container 10, module 100 is laterally symmetric.

10 For convenience, laterally symmetric features of module 100 are described generally with reference to reference numbers indicating these features on the lateral side of module 100 whose outward surface is visible in Figure 3 (which side corresponds to left side 40L of container 10). Modules according to some embodiments of the invention are not laterally symmetric.

15 **[0103]** Module 100 comprises frame 12. A first opening 22A is defined by opening end frame 22, which in container 10 was selectively closable with doors 52. A second opening 32A defined by closed end frame 32, which in container 10 was closed by closed panel 54.

20 **[0104]** Module 100 comprises opposed side openings 102. Openings 102 are defined in part by panel sections 128 and 138 located on the sides 40 of module 100 adjacent the opening end 20 and closed end 30, respectively, of module 100. The top and bottom sides of panel sections 128 and 138 are attached, respectively, to top side rail 44 and bottom side rail 46. Panel section 128 is attached along one side to opening end corner post 28. Panel section 138 is attached along one side to closed end corner post 38.

25 **[0105]** Openings 102 correspond to removable panel sections 104 shown in Figure 4. Figure 4 shows the doors 52, end panel 54 and panel sections 104 removed from an intermodal shipping container to create openings 22A, 32A, and 102 of module 100. In

some embodiments, one or more of doors 52, end panel 54 and panel sections 104 is detachably fastened to module 100 to cover a corresponding opening in module 100, so as to be optionally detachable before and/or after module 100 is used in constructing a building. Some non-limiting example uses of detachable doors, panels and panel sections include:

- protecting the interior of module 100 during pre-fabrication of internal components of module 100 and/or transportation of module 100,
- providing selectable building configurations,
- acting as shoring or formwork during construction of buildings incorporating module 100,
- providing structural reinforcement to other panel sections of module 100 (e.g., by laminating a detachable panel section onto another panel section coupled to frame 12 by welding, heat bonding, adhesive, mechanical connection and/or other suitable laminating techniques),
- using them as a slab soffit for a composite concrete slab extending between container modules,
- and
- the like.

[0106] In Figure 4, panel sections 128 and 138 are shown positioned according to their locations on module 100 in order to illustrate how they and panel sections 104 may be obtained from side panels 56 of a container 10.

[0107] Figure 4A is an isometric view of a portion of one of panel sections 104. Panel sections 104 comprise lengths of steel angle 90 along their top edges 104T. A vertical leg of angle 90 is fastened along top edge 104T. A horizontal leg of angle 90 extends perpendicular to panel section 104 and is generally aligned with top edge 104T. Angle 90 may be used for detachably fastening wall section 104 to top side rail 44, such as by tack welds, mechanical fasteners, or the like. Panel sections 104 also comprise lengths of steel angle 96 along their bottom edges 104B. Angle 96 is similar to angle 90 and may be

used for fastening panel sections 104 to bottom side rails 46. In similar fashion, closed end panel 54 comprises lengths of steel angle (not specifically identified in the Figures) along its top and bottom edges, which may be used to fasten end panel 54 to close opening 54A of module 100. In some embodiments, module 100 comprises connector components (e.g., lengths of steel angle, mechanical fastener components, etc.) to facilitate fastening of panel sections 104 and end panel 54 to module 100.

[0108] Module 100 comprises a plurality of shear connectors 110 coupled to frame 12. As described in further detail below, shear connectors 110 may facilitate integration of module 100 and components thereof into composite structural members. In the illustrated embodiment, arrangement of shear connectors 110 is laterally symmetric, but this is not necessary.

[0109] Sides 40 of module 100 comprises shear connector arrays 112O and 112C. Shear connector arrays 112O and 112C each extend between adjacent corners of frame 12. Shear connector arrays 112O and 112C are adjacent opening end 20 and closed end 30, respectively, of module 100. In the illustrated embodiment, shear connector arrays 112O and 112C comprise outwardly projecting shear connectors 110 arrayed on panel sections 128 and 138, respectively. More particularly, arrays 112O and 112C each comprise a plurality (3) of vertical columns of spaced apart, laterally-extending headed steel shear studs. In array 112O, the shear studs 110 of the outward vertical column are rigidly connected to opening end corner post 28, through panel section 128, and the shear studs 110 of the inward vertical columns are rigidly connected to panel section 128. Similarly, in array 112C, the shear studs 110 of the outward vertical column are rigidly connected to closed end corner post 38, through panel section 138, and the shear studs 110 of the inward vertical columns are rigidly connected to panel section 138.

[0110] Sides 40 of module 100 also comprise shear connector arrays 114. Each shear connector array 114 comprises outwardly projecting shear connectors 110 adjacent the bottom of module 100. In the illustrated embodiment, each array 114 comprises a single row of spaced apart, laterally-extending headed steel shear studs. The shear studs 110 of arrays 114 are rigidly connected to bottom side rails 46.

[0111] The angular section at the top face 50 of module 100 comprises a shear connector array 116. Shear connector array 116 comprises outwardly projecting shear connectors 110 adjacent the top of opening end opening 22A. More particularly, array 116 comprises a single row of spaced apart headed steel shear studs welded to the angular portion. The shear studs 110 of array 116 are rigidly connected to top opening end rail 24.

[0112] Opening end 20 of module 100 comprises a shear connector array 118O. Shear connector array 118O comprises outwardly projecting shear connectors 110 adjacent the bottom of first opening 22A. In the illustrated embodiment, array 118O comprises a single row of spaced apart headed steel shear studs. The shear studs 110 of array 118O are rigidly connected to opening end bottom rail 26. In some embodiments, module 100 may not have shear connector array 118O (e.g., in embodiments where opening end 20 of module 100 forms part of an outward face of a building).

[0113] Closed end 30 of module 100 comprises a shear connector array 118C. Shear connector array 118C comprises outwardly projecting shear connectors 110 adjacent the bottom of second opening 32A. In the illustrated embodiment, array 118C comprises a single row of spaced apart headed steel shear studs. The shear studs 110 of array 118C are rigidly connected to closed end bottom rail 36. Shear connector arrays 118O and 118C may be referred to interchangeably or collectively herein as shear connector arrays 118.

[0114] Though shear connectors 100 in the illustrated embodiment comprise headed steel shear studs, in other embodiments any suitable type (or combination of types) of shear connectors may be provided. Non-limiting examples of other types of shear connectors that may be used in embodiments include:

- shear bolts;
- deformed bar anchors;
- ties, threaded rods or bolts fastened to opposing members with nuts;
- perforated, oscillated, waveform and profiled strips,

- T connectors,
- Hilti □ HVB connectors;
- Hambro □ top cord elements; and
- the like.

5 [0115] A row or column of shear connector arrays 112O, 112C, 114 116 and/or 118 may comprise as few as one shear connector. For example, in some embodiments, arrays 112O and 112C each comprise three parallel, spaced apart, vertically-oriented strip-type shear connectors. In some embodiments, a few as one shear connector may extend between adjacent corners of frame 12. For example, array 114, 116 and/or array 118 may
10 comprise a single strip-type shear connector that extends between adjacent corners of frame 12. Though arrays 112O, 112C, 114, 116 and 118 of the illustrated embodiment comprise rectangular arrays, this is not necessary. Arrays of shear connectors need not exhibit regular spacing between adjacent shear connectors, and may comprise rows and/or columns having different numbers of (and different types of) shear connectors.
15 Arrays of shear connectors may exhibit other geometric patterns, such as triangles, diamonds, arcs, circles and the like, for example.

[0116] In some embodiments, at least some shear connectors are arranged on module 100 to be staggered with respect to counterpart shear connectors located on an opposite side or end of module 100. This may enable shear connectors of laterally adjacent modules
20 100 to pass each other in overlapping fashion when the modules 100 are placed in close laterally adjacent relation.

[0117] As will become more apparent from the discussion below, the type, dimensions arrangement, and spacing of shear connectors may be selected to provide a desired degree of composite action between module 100 and a curable material integrated with the shear
25 connectors. In some embodiments, shear connectors may be located in different locations than in the example embodiment illustrated by module 100. For example, one or more structural members of module 100 that have shear connectors attached to them may not have shear connectors attached to them in other embodiments. In some embodiments,

shear connectors may be attached to structural members of a volumetric construction module that do not have shear connectors in module 100 (e.g., adjacent the top of closed end opening 32A, across top panel 58, on joists 68, etc.).

5 [0118] Shear connectors 110 may be rigidly connected to parts of module 100 using any suitable type of connection, such as welding, mechanical connection (e.g., captive threaded, nut-retained threaded, riveted, interlocking tab and slot, twist-lock, etc.), adhesive, heat bonding, or the like, for example. In some embodiments, shear connectors 110 may be configured to be installed on module 100 on-site. For example, structural members of module 100 (such as corner posts 28 and 38, and bottom side rails 46, for 10 example) may comprise mechanical fastener components (e.g., holes, threaded apertures, slots, etc.) configured to mate with cooperating fastener components provided on shear connectors 110 (e.g., matched studs, threaded studs, notched tabs, etc.). In a particular example embodiment, shear connectors 110 comprise Nelson[®] weld studs manufactured by Nelson Stud Welding, and may be installed by a drawn arc stud welding process, such 15 as with a Nelson[®] Ferrule Shooter.

[0119] Figure 3A is an isometric view of module 100¹ according to an example embodiment. Module 100¹ is similar to module 100 except that shear connector arrays 112O¹, 112C¹, 114¹, 116¹, and 118C¹ comprises shear bolts instead of headed studs, shear connector arrays 112O¹ and 112C¹ each comprise a single column of shear connectors 20 instead of three columns of shear connectors, and each row of shear connector arrays 114¹, 116¹, and 118C¹ comprises fewer numbers of shear connectors. Note in Figure 3A that the corner post has been cut from the side panel leaving a portion of the heavier gauge cold rolled C shape member on the exterior of the hot rolled C channel making up the corner post, i.e. the corner post has been cut off to improve the aspect ratio of the 25 column and because it would otherwise add considerable concrete volume to the column with low steel content. The heavier gauge strip of steel from the corner post may be left on the corrugated side panel to add rigidity to the panel in a reuse function, such as the expansion panel member described further below.

[0120] Some embodiments of the invention comprise one or more components that facilitate the interconnection of modules 100, the integration of modules 100 into composite structural members, and/or the creation of a volumetric space between laterally aligned modules 100. Figures 8A, 8B, 8C, 9, 9A, 10 and 11 show non-limiting examples of such components.

[0121] Figure 8A, 8B and 8C are isometric views of column closure members 150 and 160 and column reinforcement member 165 according to example embodiments. As described in further detail below, members 150, 160 and 165 may be used to provide a structural connection between adjacent modules, and as part of an encasement for a composite structural column integrated with modules 100 and to strengthen the column. The cross-section of steel in the enclosure members may vary to meet the demand of the specific column. Column closure member 150 comprises a steel C channel 152 having a plurality of shear connectors 154 projecting from the base of the channel 152. Column closure member 160 comprises a steel C channel 162 having a plurality of shear connectors 164 projecting opposite the flange of channel 162. Column reinforcement member 165 comprises a steel C channel 167 having a plurality of holes 169 arranged in the web of channel 167 to receive shear connectors of the modules or other components.

[0122] Column closure member 160 comprises a steel C channel section 162 having a plurality of shear connectors 164 projecting opposite the web of channel section 162. Shear connectors 164 may be arranged on channel section 162 so that shear connectors 164 of closure member 160 are staggered with respect to those of an inverted closure member 160. This may enable shear connectors 164 of closure members 160 having complementary orientations (i.e., one inverted, one not inverted) to pass each other in overlapping fashion when the closure members 160 are placed in close opposition.

[0123] Figure 9 is an isometric view of a beam soffit member 170 according to an example embodiment. As described in further detail below, beam soffit member 170 may be used to limit the deflection of the bottom side rail 46 of column 100, to provide a structural connection between adjacent modules 100, and to integrate modules the floor

frames of modules 100 into a structural diaphragm. Member 170 comprises a steel plate 172 having a plurality of shear connectors 174 projecting from a major side thereof.

[0124] Figure 9A is an isometric view of a panel expansion member 175 according to an example embodiment. As described in further detail below, panel expansion members
5 may be used to create an expansion space between laterally aligned modules 100. Panel expansion member 175 comprises a pair of beam soffit members 170 coupled to opposite end regions of a panel member 177. Shear connectors 174 of beam soffit members 170 may project through corresponding holes in panel member 177 or the shear studs may be welded through the panel members to the beam soffit members with special ferrules as
10 manufactured by Nelson Stud Welding□. Panel member 177 may for example comprise corrugated side wall steel of an intermodal shipping container.

[0125] Figure 10 is an isometric view of a spacer 180 according to an example embodiment. As explained in further detail below, spacer 180 may be used to align and space vertically and laterally adjacent modules 100 in buildings according to example
15 embodiments. Spacer 180 comprises a steel box section 182 closed on five sides, including end side 182E. Spacer 180 comprises a first pair of projections 184A and 184B on a top side 182T of box section 182 that are opposite a second pair of projections 184C and 184D on a bottom side 182B of box section 182. In the illustrated embodiment, projections 184 are configured to be received in the orifices 16 of corner fittings 14 of
20 ISO standard intermodal shipping containers. A shear connector array 188 extends upwardly from box section 182 between projections 184A and 184B. Shear connectors 188A and 188B also extend from opposite ends of box section 182.

[0126] In the illustrated embodiments, shear connectors of column closures 150 and 160, diaphragm anchoring plate 170 and spacer 180 comprise headed steel shear studs, but any
25 other suitable type (or combination of types) of shear connector may be used instead of or in addition to headed steel shear studs.

[0127] Figure 11 is an isometric view of a slab edge form member 190 according to an example embodiment. As described in further detail below, slab edge form member 190

may be used as a form for an edge of a slab of curable material (e.g., concrete). Form member 190 comprises a length of angle steel 192. A vertical leg 192V of angle steel 192 is folded at its top edge 192T toward horizontal leg 192H to form an inclined flap 194. Member 190 comprises a strap 196 attached to flap 194 and extending downwardly to a foot 198. An aperture 196A is defined through strap 196 and flap 194. Foot 198 is parallel to and spaced apart from horizontal leg 192H. An aperture 198A is defined through foot 198.

[0128] Figure 12 is an isometric view of an assembly 200 according to an example embodiment. Assembly 200 partially defines a plurality of volumes into which curable material (e.g., concrete) may be introduced to form composite structural members (e.g., beams, columns, slabs, etc.). Assembly 200 comprises:

- volumetric construction module 100;
- a plurality of column closure members 150 and 160 (individually identified in Figure 12 as column closure members 150O, 150C, 160O and 160C);
- a beam soffit member 170;
- a plurality of spacers 180 (individually identified in Figure 12 as spacers 180O and 180C); and
- a plurality of slab edge form members 190 (individually identified in Figure 12 as slab edge form members 190O and 190C).

[0129] For convenience, features of the aforementioned components are identified using the same reference numerals as in their descriptions.

[0130] In assembly 200, column closure members 150O and 160O are generally perpendicular to and abut opposite edges of panel section 128 to close vertically-extending sides of opening end column volume 228. In like fashion column closure members 150C and 160C are generally perpendicular to and abut opposite edges of panel section 138 to close vertically-extending sides of closed end column volume 238. As described in further detail below, the open vertically-extending sides of column volumes

228 and 238 (opposite panel sections 128 and 138, respectively) may be closed by an adjacent volumetric construction module or another column closure member, so that column volumes 228 and 238 are laterally enclosed.

5 [0131] Column closure members 160O and 160C also close vertically-extending front and rear ends, respectively of a beam volume 246. One vertically-extending side of beam volume 260 is closed by bottom side rail 46. As described in further detail below, the other vertically-extending side of beam volume 246 (opposite bottom side rail 46) may be partially closed by an adjacent volumetric construction module or another beam closure member, so that beam volume 246 is laterally enclosed.

10 [0132] Opening end slab edge form member 190O and opening end spacer 180O form a wall that closes the vertically-extending side of slab volume 260 below opening end 20 of module 100. Closed end slab edge form member 190C and closed end spacer 180C and form a wall that closes the vertically-extending side of slab volume 260 below closed end 30 of module 100. One projection (not visible in Figure 11) of each of spacers 180O and 15 180C is engaged with a corresponding orifice 16 of one of corner fittings 14. As described in further detail below, the unengaged projections of spacers 180O and 180C may be mated with the orifices of the corner fittings 14 of other modules, such as a module below module 100 whose roof closes the bottom of slab volume 260, for example.

20 [0133] Beam soffit member 170 is below and spaced apart from bottom side rail 46 and closes a portion of the bottom side of a slab volume 260. More particularly, plate 172 of beam soffit member 170 is level with the bottoms of spacers 180O and 180C. The ends of beam soffit member 170 are aligned with column closure members 150O and 150C. Shear connectors 174 of beam soffit member 170 extend through slab volume 260 into 25 beam volume 246.

[0134] It may be observed from Figure 12 that each of column volumes 228 and 238 is closed on at least three vertically-extending sides by steel plate having shear connectors projecting into the volumes. In particular:

- column volume 228 is closed on:
 - a first side by C-channel beam 162 of column closure member 160O and includes shear connectors 164 that project therefrom,
 - a second side by C-channel beam 152 of column closure member 150O and includes shear connectors 154 that project therefrom, and
 - a third side by panel section 128 and includes shear connectors 110 of array 112O that project therefrom; and

- column volume 238 is closed on:
 - a first side by C-channel beam 152 of column closure member 150C and includes shear connectors 152 that project therefrom,
 - a second side by C-channel beam 162 of column closure member 160C and includes shear connectors 164 that project therefrom, and
 - a third side by panel section 138 and includes shear connectors 110 of array 112C that project therefrom.

[0135] When the vertically extending outward sides of column volumes 228 and 238 are closed by posts and/or panels of a laterally adjacent module and/or other closure members, all vertically-extending sides of each of column volumes 228 and 238 are closed and the volumes are accordingly laterally enclosed.

[0136] It may also be observed from Figure 12 that column volumes 228 and 238, beam volume 246 and slab volume 260 are all continuous with each other, and that neighbouring ones of these volumes include shear connectors rigidly connected to the same structural member. In particular:

- shear connectors 110 of shear connector array 114 on bottom side rail 46 project into column volumes 228 and 238 and beam volume 246;
- spacers 180O and 180R have shear connectors 186 that project into column volumes 228 and 238 and shear connectors 188 that project into slab volume 260; and

- shear connectors 174 of beam soffit member 170 extend through slab volume 260 into beam volume 246.

[0137] Figure 13 is a flow chart of a construction method 300 according to an example embodiment. Figure 14 is an isometric view of an assembly 400 of four volumetric

5 construction modules 100 (individually identified in Figure 14 as 400A, 400B, 400C and 400D) illustrating stages of construction according to an example implementation of method 300. Modules 400A, 400B and 400C are part of a first floor and module 400D is located on top of module 400A as part of a second floor. Figure 14 shows concrete poured after installation of a fifth module 100 on top of module 400B and adjacent to
10 module 400D; the fifth module is not shown in order to expose features of assembly 400 that would otherwise be obscured. Modules 400A, 400B, 400C and 400D are shown without doors 52, closed panels 54 and detachable sections 104 in Figure 14 to avoid obscuring features of assembly 400. In some embodiments, one or more of these components is left in place at one or more of the illustrated stages of construction (e.g.,
15 for hoarding and/or shoring until concrete has cured, for permanently dividing adjacent modules, for providing exterior walls, etc.).

[0138] Step 302 of method 300 comprises enclosing a slab volume. A slab volume enclosed in step 302 may be defined in part by the roofs of the volumetric construction modules (e.g., volumetric construction module 100), for example. Or the slab soffit may
20 be enclosed by a repurposed corrugated panel from the wall of a shipping container. In the illustrated embodiment, step 302 comprises enclosing a slab volume defined in part by the roofs of volumetric construction modules in spaced laterally adjacent relation, and includes steps 304 and 306.

25 [0139] Step 304 comprises enclosing lateral sides of the slab volume. Enclosing lateral sides of a slab volume may comprise installing spacers 180 and slab edge closures 190 above the top rails of a single module, or above the perimeter top rails of a plurality of adjacent modules, for example. Figure 14 shows an example of this in slab volume 460

which is partially laterally enclosed by slab edge closures 190D, which are installed along the top opening end rail, top side rail and top closed end rail of module 400D, and spacers 180D, which are installed into the adjacent top orifices of corner fittings of module 400D. Slab volume 460D includes shear connector array 116 located along top opening end rail of module 400D.

[0140] Step 306 comprises enclosing the space between upper portions of the adjacent sides of laterally adjacent modules. Figure 14 shows one example of step 306 in beam soffit member 470, which is installed atop top side rails 44 of modules 400C and 400B to enclose the space between upper portions of the adjacent sides of modules 400B and 400C.

[0141] Step 308 comprises introducing curable material, such as concrete, for example, to the slab volume enclosed in step 302. Figure 14 shows an example of this in composite slab 406, which is visible above module 400B but spans the roofs of modules 400A and 400B. Composite slab 406 comprises concrete integrated with shear connector arrays 116 of modules 400A and 400B (not visible in Figure 14) and shear connectors 474 of a beam soffit member between modules 400A and 400B (not visible in Figure 14). The concrete of composite slab 406 conforms to the corrugated roofs of modules 400A and 400B (not visible in Figure 14). In some embodiments, curable material introduced to a slab volume may be further integrated with the roof(s) the module(s) in order to engage the steel of the modules in composite action, such as with adhesive, embosses, shear connectors, welded wire mesh and/or the like.

[0142] Step 310 of method 300 comprises providing two modules in spaced laterally adjacent relation, each module having one or more shear connectors extending toward the other module. This is illustrated in Figure 14 by the laterally adjacent relation of modules 400A and 400B, and the laterally adjacent relation of modules 400B and 400C. Step 310 may comprise placing orifices 16 of adjacent corner fittings 14 of the modules onto projections of spacers 180 of previously placed modules or onto projections installed in a foundation or the like, for example.

[0143] Step 312 of method 300 comprises enclosing vertically-extending sides of one or more volumes between the modules provided in step 310, which volume(s) includes one or more shear connectors of the modules. In the illustrated embodiment, step 312 comprises steps 314 and 316.

- 5 [0144] Step 314 comprises laterally enclosing a beam volume. In some embodiments, step 314 comprises closing vertically extending sides of a beam volume whose other vertically extending sides are defined by bottom side rails 46. For example, step 314 may comprise installing column closure members, such as members 160, for example, between adjacent modules 100. The differences between beam volume 446BC and beam
10 volume 446AB exemplify step 314. Beam volume 446BC is closed on two of its vertically extending sides by adjacent bottom side rails of modules 400B and 400C, but is open on its other vertically-extending sides. Beam volume 446AB is closed on two of its vertically-extending sides by adjacent bottom side rails of modules 400A and 400B and closed another of its other vertically-extending sides by column closure member 160AB.
15 The remaining vertically extending side of beam volume 446AB is closed by a column closure member not visible in the view shown in Figure 14, so that beam volume 446AB is laterally enclosed.

- [0145] It will be appreciated that where step 310 comprises providing two modules in spaced laterally adjacent relation above a slab (e.g., a slab formed in step 308), the slab
20 may close a bottom side of a beam volume between the modules (e.g., in Figure 14 the top of composite slab 406 is level with the bottoms of the bottom side rails of module 400D). In this connection, it may be observed that step 314 may comprise closing vertically extending sides of a beam volume that includes shear connectors embedded in a slab below the beam volume. This is exemplified in Figure 14 by shear connectors 474
25 of beam soffit member 470, which extend above the top of concrete slab 406, and into the beam volume that may be formed above beam soffit member 470.

[0146] Step 316 comprises laterally enclosing one or more column volumes. In some embodiments, step 316 comprises closing vertically extending sides of a column volume. For example, step 316 may comprise installing column closure members, such as

members 150 and 160, for example, between adjacent modules. The differences between column volume 428BC and column volume 428AB exemplify step 316. Column volume 428BC has two vertically-extending sides closed by opposed panel sections 128 of modules 400B and 400C, and includes shear connector arrays 112O of modules 400B and 400C. The other two vertically-extending sides of column volume 428BC are open. Column volume 428AB has two vertically-extending sides closed by opposed panel sections 128 of modules 400A and 400B, and includes shear connector arrays of modules 400A and 400B (not visible in Figure 14). The other two vertically-extending sides of column volume 428AB are closed by column closure members 150AB and 160AB, so that column volume 428AB is laterally enclosed.

[0147] In some embodiments, steps 310, 312, 314 and/or 316 may be combined. For example, column closure members may be attached to a first module before the module is placed in spaced laterally adjacent relation with a second module. For another example, installing column closures 316 may simultaneously constitute all or part of both steps 314 and 316.

[0148] Step 318 comprises introducing curable material, such as concrete, for example, into a laterally-enclosed volume between the modules placed in laterally adjacent relation in step 310. In the illustrated embodiment, step 318 comprises steps 320 and 322.

[0149] Step 320 comprises introducing curable material to a beam volume enclosed in step 314. Figure 14 shows an example of step 320 in composite beam 404. Composite beam 404 is closed on all but one of its vertically extending sides by a bottom side rail 46 of module 400D (not visible in Figure 14) and column closure members 160DO and 160DC, and closed on its bottom side by composite slab 406. Ordinarily beam 404 would be closed on its remaining vertically-extending side, such as by the bottom side rail of a module above module 400B. The concrete of beam 404 may have been formed according to step 320 by introducing concrete to the form defined by the components closing the vertically-extending sides of beam 404. Composite beam 404 comprises concrete integrated with shear connectors (not visible in Figure 14) of a diaphragm beam

anchoring member (not visible in Figure 14) that bridges the space between modules 400A and 400B.

[0150] Step 322 comprises introducing curable material, such as concrete, for example, to a column volume enclosed in step 316. Figure 14 shows examples of step 322, namely:

- 5 • column volume 428AB, which is located between the opposed panel sections 128 of modules 400A and 400B, is laterally enclosed and filled with concrete (concrete not visible in Figure 14) to form a composite column 402AB,
- column volume 428D, which closed on all but one of its vertically extending sides by panel 128 of module 400D (this panel not visible in Figure 14) and column
10 closure members 150DO and 160DO, is filled with concrete visible through an open side of volume 428D to form a composite column 402D, and
- column volume 438D, which is closed on all but one of its vertically extending sides by panel 138 of module 400D (this panel not visible in Figure 14) and
15 column closure members 150DC and 160DC, is filled with concrete visible through an open side of volume 438D to form a composite column 403D.

[0151] It will be appreciated that the open sides of column volumes 428D and 438D are open for illustrative purposes, and would ordinarily be closed on their remaining vertically-extending sides, such as by panel sections 128 and 138, respectively, of a module laterally adjacent to module 400D. The concrete of columns 402D and 403D may
20 have been formed according to step 322 by introducing concrete to the forms defined by the components closing the vertically-extending sides of columns 402D and 403D.

[0152] In some embodiments, two or more of steps 308, 318, 320 and 322 are combined. For example, curable material forming a slab and a beam may be introduced after the upper modules 100 whose bottom side rails 46 define the beam volume have been placed
25 above the slab volume. In such embodiments, the bottom of floor frame 62 of the module 100 above the slab may be left open to permit curable material to enter the space between floor joists 68, or it may be closed (in whole or in part) to prevent curable material from filling (at least some of) the space in floor frame 62. In some embodiments, concrete is

introduced into forklift pockets 72 and/or between pairs of joists 68 (such as through holes defined in a bottom side rail 46 and/or floor panel 70) to form transverse beams. In some such embodiments, slabs may not be provided between floors of the building (e.g., transverse beams acting in composite with the module floor may alone provide sufficient strength in the diaphragm to carry lateral forces to shear walls). In some embodiments, curable material is introduced between modules in step 318 to form continuous walls (e.g., detachable panel sections 104 may not be removed from modules 100).

[0153] As the arrangement of modules 400A, 400B and 400C in Figure 14 shows, method 300 may be practiced with more than two side-by-side adjacent modules. Method 300 may also be practiced with modules provided in spaced end-to-end adjacent relation, end-to-side adjacent relation, and various combinations of spaced side-by-side adjacent, end-to-end adjacent, and/or end-to-side adjacent modules.

[0154] Method 300 may be repeated to construct higher floors of a building. Where this is done, step 310 may comprise placing modules 100 of an upper floor above the modules of an immediately lower floor (e.g., in the manner of module 400D above module 400A). In some embodiments, an upper module may be mounted above a lower module so that the orifices 16 of the upper module's lower corner fittings 14 receive the projections of spacers mated with the orifices 16 of corresponding upper corner fittings 14 of the lower module.

[0155] Advantageously, the use of spacers 180 to separate vertically adjacent modules may permit method 300 to be repeated for a higher floor without waiting for the concrete poured in the lower floor to cure. In multi-story reinforced concrete construction, the usual practice is to shore a freshly placed floor on a previously cast floor. The sequence and rate of erection is governed by the loads placed on the supporting floor(s) by the weight of the wet concrete and formwork, and by the time required to allow the concrete to cure, remove formwork and shoring from the cured concrete and then reinstall the formwork and shoring for the next floor. Method 300 may be performed in a manner that eliminates at least some of these delays. For example, where spacers 180 placed on the top corner fittings 14 of the lower modules 100 are at least equal in height to the depth of

a slab to be poured over the roofs of the lower modules 100, the next, higher floor of modules 100 may be installed and concrete for that floor poured without shoring before the concrete of the lower floor has completely cured, since the spacer 180 will transfer the weight of the upper modules 100 to the lower modules 100 without putting pressure on the slab in an early stage of curing.

[0156] Figure 15 is an isometric view of a corner 500 of four adjacent modules 100 (individually identified as 500A, 500B, 500C and 500D) assembled according to an example implementation of method 300. Corner 500 includes components previously introduced, and like numbers are used to indicate like components without further elaboration. In Figure 15, components are layered to expose the internal elements of composite columns 502, composite beam 504 and composite slab 506, and to show detail of a composite diaphragm 508 formed by the method 300. Diaphragm 508 may be viewed as a "sandwich" having:

- a bottom that includes plate 172 of beam soffit member 170, and top panels 58 and top opening end rails 24 of modules 500A and 500B;
- a middle that includes shear connectors 174 of beam soffit member 170, shear connector arrays 116 of modules 500A and 500B, and composite slab 506; and
- a top of that includes beam 504 and floors 60 of modules 500C and 500D (floors 60 and beam 504 being structurally integrated by opposed shear connector arrays 114 on adjacent bottom side rails 46 of modules 500C and 500D).

[0157] Diaphragm 508 may also be seen as including a grid of composite beams that span the full height of diaphragm 508. The beams' cross-sections are defined in part by beam soffit members 170 and bottom side rails 46, and the beams include the full lengths of shear connectors 174 of beam soffit members 170. Under gravity loads, plates 172 of beam soffit member 170 acts as tension flanges of the beams, while bottom side rails 46 and the concrete encasing shear connectors 174 act as compression members.

[0158] The layers of diaphragm 508 are anchored to one another by shear connectors. In particular, shear connector arrays 116 of modules 500A and 500B are embedded in

composite slab 506 to anchor the bottom of diaphragm 508 to the middle of diaphragm 508, and shear connectors 174 of beam soffit member 170 anchor the bottom, middle and top of diaphragm 508 together. Anchored as such, the top of diaphragm 508, which includes bottom side rails 46, floor joists 68 and plywood panels 70 of modules 500C and 500D, provides ductile strength against lateral loads and the middle and bottom of diaphragm 508 (e.g., concrete slab 506 and top panels 58) provide rigidity.

Advantageously, diaphragm 508 provides this combination of ductile strength and rigidity in a shallow floor section and with a beam structure in the same plane as the floors 60 of modules 100. In some embodiments, diaphragm 508 is structurally connected to a building core (e.g., see building 1000 of Figures 28-31), and carries lateral forces to the core to continue the load path through the core to the foundation.

[0159] Figure 15 also shows how column closure members 150 and 160, panel section 128 and corner posts 28 encase the column concrete to form composite column 502.

Each of the aforementioned structural components is further integrated with the column concrete by rigidly connected shear connector arrays (e.g., shear connector array 112O, which is visible in Figure 15), which bond with the column concrete. In the composite structural members column 502, beam 504, slab 506 and diaphragm 508, the steel of modules 500 and column closure members 150 and 160 provide ductility and tensile strength for withstanding lateral loads, and the concrete provides structural rigidity and compressive strength for withstanding gravity loads. The bonding of the steel and concrete with shear connectors combines the structural advantages of both materials to deliver structural performance that exceeds the performance of the individual materials acting alone.

[0160] The encasement of concrete by steel plates in columns 502 and beam 504 provides advantages over conventional reinforced concrete. In a conventional reinforced concrete column or beam the concrete is retained by embedded steel rebar stirrups closely spaced along steel rebar. When a reinforced concrete column or beam is loaded to failure the concrete spalls away from the rebar stirrups, the rebar bends and the column or beam fails. By contrast, in an encased composite concrete column or beam, ductile steel, which

is well adapted to withstand lateral tensile loads (such as occur during seismic event), is provided on the exterior of rigid concrete, which is well adapted to withstand vertical compressive loads. When the column or beam concrete is loaded to failure, it is confined by the steel confining it and will continue to carry compressive loads even as it begins to fail. An additional advantage is provided by anchoring the encasing steel plate to the confined concrete with shear connectors. This anchoring arrangement holds the steel encasement flush against the envelope of the concrete, and thereby provides additional resistance to buckling.

[0161] The strength of the encasement of columns and beams in method 300 will depend on the strength of the connection between the members that form the encasement. In some embodiments, members that form encasements are continuously bonded at their adjacent edges, such as by welding, adhesive or the like, to provide additional strength to columns. In some embodiments, members are joined at spaced apart locations (i.e., non-continuously), such as by tack welds, adhesives and/or mechanical connection, for example. In some embodiments, members are not permanently joined, and clamps or other devices are used to hold the members together while the curable material they contain has not cured.

[0162] In some embodiments, ties or stringers may be installed between opposed encasing members. For example, stringers may be welded between the opposed surfaces of adjacent panels 128 and 138 and/or between opposed column members 150 and 160. For another example, a tie comprising a headed bolt with a threaded shank may be inserted through matched holes on opposed encasing members, so that the head and the end of the shank are on the outsides of the opposed members, and a nut threaded on the end of the shank to prevent the members from moving laterally apart from each other. Ties and/or stringers installed between opposed encasing members may function as both shear connectors and encasement reinforcement.

[0163] Many variations on the construction of column 502, beam 504, slab 506, diaphragm 508 and the interconnection of column 502 and beam 504 are possible. The particular construction of the column, beam, slab and diaphragm and interconnection

between column and beam shown in Figure 15 are non-limiting examples. The construction of column 502, beam 504, slab 506, diaphragm 508 and the interconnection of column 502 and beam 504 shown in Figure 15 may be modified to satisfy design criteria. Figures 16, 17 and 18 show composite beams according to other example
5 embodiments.

[0164] Figure 16 is a cross-section through a composite beam 604 according to another example embodiment. Beam 604 is formed at the interface of four modules 600A, 600B, 600C and 600D. Beam 604 differs from beam 504 in that beam soffit member 670 of beam 604 is supported by a ledger angle 614 fastened below the top side rails 44 of lower
10 modules 600A and 600B. As a result, steel plate 672 of beam soffit member 670 is flush with the top of top side rails 44 of lower modules 600A and 600B, which provides further lateral stability.

[0165] Figure 16 demonstrates that a beam soffit member may be lowered further. This may be done, for example, by providing modules 100 with side wall panels that extend
15 along and below the top side rails. In the context of a module based on an intermodal shipping container, this may be effected by removing side panel sections that do not extend up to the top side rails, for example.

[0166] Figure 17 is a cross-section through a beam 704 according to a further example embodiment. In this embodiment, a beam soffit member 770 comprises a steel I-beam
20 772 having shear studs 774 extending from its upper flange 776. Lower flange 778 of I-beam 772 is supported on ledger angles 714 fastened to the upper portions of side walls 708 of lower modules 700A and 700B. I-beam 772 is dimensioned so that its upper flange 776 rests atop top side rails 44 of lower modules 700A and 700B. Shear studs 774 extend upward from top flange 776 through concrete slab 706 into the space between
25 bottom side rails 46 of upper modules 700C and 700D. As compared with beams 504 and 604, beam 704 has greater strength and may allow for longer spans and/or heavier floor loads.

[0167] Figure 18 is a cross-section through a beam 804 according to a yet another example embodiment. In this embodiment, a beam soffit member 870 comprises a steel I-beam 872. Lower flange 874 of I-beam 872 is supported on ledger angles 814 fastened to the upper portions of side walls 808 of lower modules 800A and 800B. The web 876 of I-beam 872 extends through concrete slab 810 and into beam 804. The upper flange 878 of I-beam 872 is located in the space between opposed bottom side rails 46 of upper modules 800C and 800D. Upper flange 878 of I-beam 872 acts as a shear connector to bond concrete in beam 804 to I-beam 872. Web 876 and/or upper flange 878 of I-beam 872 may be perforated, embossed, or provided with tabs, for example, to further integrate it in composite action with the concrete of beam 804. As compared with beams 504, 604 and 704, beam 804 has greater strength and may allow for longer spans and/or heavier floor loads. Alternative encased steel joist designs (e.g., castigated beams or trussed joists) may also be employed in the manner of I-beams 772 and 872.

[0168] Figure 19 is a cross-section end view of a composite beam 604 according to another example embodiment. Beam 604 is a long beam formed between modules 600C and 600D parallel to the side rails of the modules. Beam 604 differs from beam 604 in that, like beam 504, beam soffit member 670 of beam 604 is supported by top side rails 44 of lower modules 600A and 600B. Shear studs 674 of beam soffit member 670 extend into beam 604. Further composite action is provided by shear bolt 680 extending between the bottom side rails 46 of upper modules 600C and 600D.

[0169] Figure 20 is a cross-section end view of a composite beam 604 according to another example embodiment. Beam 604 is a short beam formed between modules 600C and 600D. Beam soffit member 670 of beam 604 is supported by top end rails 12,24 of lower modules 600A and 600B. Shear studs 674 of beam soffit member 670 extend into beam 604. Further stability is provided by shear bolt 680 extending between the bottom end rails 26,36 of upper modules 600C and 600D.

[0170] Figure 21 is an isometric view of a spacer 980 according to another example embodiment. Whereas spacer 180 is configured for aligning and spacing up to four adjacent modules 100, spacer 980 is configured for aligning and spacing two vertically

adjacent modules. Spacer 980 comprises a steel box 982 which may be closed on all sides or open on two sides to allow concrete to enter the void there by providing composite connection. Spacer 980 comprises a first projection 984A on one side of box 982 that is opposite a second projection 984B on the opposite side of box 982. In the illustrated
5 embodiment, projections 184 are configured to be received in the orifices 16 of corner fittings 14 of ISO standard intermodal shipping containers. Shear connector 988A and 988B also extend from opposite side of box 982 between projections 984A and 984B.

[0171] Figure 22 is an isometric view of an assembly 900 according to an example embodiment. Assembly 900 partially defines a plurality of volumes into which curable
10 material (e.g., concrete) may be introduced to form composite structural members (e.g., beams, columns, slabs, etc.). Assembly 900 comprises:

- volumetric construction module 100;
- a plurality of column closure members 950 and 960 (individually identified in Figure 22 as column closure members 950O, 950C, 960O and 960C), each of
15 which is identical to column closure member 150;
- a beam soffit member 970, which is a shorter version of beam soffit member 170; and
- a plurality of spacers 980

[0172] Assembly 900 also comprises components of assembly 200, which are not
20 described again here. For convenience, features of the aforementioned components are identified using the same reference numerals as in their descriptions above, and are not described again here.

[0173] In assembly 900, column closure members 950O and 950C are generally perpendicular to and abut inward edges of panel sections 128 and 138, respectively.

25 Column closure members 960O and 960C are generally parallel to and abut outward edges of panel sections 128 and 138, respectively. Column closure members 950O and 960O close vertically-extending sides of opening end column volume 928. In like fashion

column closure members 950C and 960C close vertically-extending sides of closed end column volume 938. The open vertically-extending sides of column volumes 928 (opposite panel section 128 and column closure member 960O) and 938 (opposite panel section 138 and column closure member 960C) may be closed by an adjacent volumetric construction module or another column closure member, so that column volumes 928 and 938 are laterally enclosed.

[0174] Column closure member 960O extends above a beam volume 946. One vertically-extending side of beam volume 946 is closed by opening end bottom rail 26. Beam volume 946 includes shear connector array 118O, which projects from rail 26. The vertically-extending side of beam volume 946 opposite rail 26 may be closed, such as by a bottom rail of another module (e.g., an end bottom rail of a module in end-adjacent relation with module 100 of assembly 900, etc.). A beam soffit member 970 is below and spaced apart from opening end bottom rail 26. One end of beam soffit member 970 is aligned with column closure members 960O. Shear connectors 974 of beam soffit member 970 extend into beam volume 946. It will be appreciated that beam volume 946 is continuous with beam volume 246 defined by assembly 200 (see Figure 12), and that a grid of continuous composite beams may be provided by arranging modules 100 in a rectangular array and introducing curable material to these beam volumes.

[0175] Figure 23 is a flowchart of a construction method 300 according to an example embodiment. Figures 24 is an isometric view of an assembly 400 of six volumetric construction modules 100 (individually identified in Figure 24 as 400A, 400B, 400C, 400D, 400E, and 400F) illustrating stages of construction according to an example implementation of method 300. Modules 400A, 400B, 400C, and 400D are part of a first floor. Modules 400E and 400F are located on top of modules 400A and 400C respectively, as part of a second floor. Modules 400A, 400B, 400C, 400D, 400E, and 400F are shown without doors 52, closed panels 54 and detachable sections 104 in Figure 24 to avoid obscuring features of assembly 400. In some embodiments, one or more of these components is left in place at one or more of the illustrated stages of

construction (e.g., for hoarding and/or shoring until concrete has cured, for permanently dividing adjacent modules, for providing exterior walls, etc.).

[0176] The first floor of assembly 400 also comprises an expansion space 450A in a side-by-side arrangement between modules 400A and 400B, and an expansion space 450B in a side-by-side arrangement between modules 400C and 400D. Expansion spaces 450A and 450B are illustrated with a width equal to that of the modules. In other embodiments expansion spaces 450A and 450B may be narrower or wider than the modules. An expansion space provides assembly 400 with additional interior space at a lower cost than adding a module. Expansion spaces may for example be provided in sections of assembly 400 where structural requirements can be met without the need for adding modules.

[0177] Figure 25 shows a portion of assembly 400. Panel expansion member 475 is supported by and spans corresponding top side rails 44 of modules 400A and 400B to partly define expansion space 450A. Figure 26 is a close up view of panel expansion member 475 being supported by top side rail 44 of module 400A. As shown in Figure 25, a supplemental floor frame 462 between the floor frames 62 of modules 400A and 400B partly defines expansion space 450A. Figure 26 is a close up view of supplemental floor frame 462 of an expansion space 450C built above expansion space 450A wherein supplemental floor frame 462 is tied to floor frame 62 of adjacent module 400E by shear bolts of shear connector array 114. Supplemental floor frame 462 of expansion space 450A may be tied in a similar manner to floor frames 62 of modules 400A and 400B in Figure 25. Supplemental floor frame 462 may be similar in construction to floor frame 62.

[0178] In other embodiments, expansion spaces may be provided in an end-to-end arrangement between modules, for example as shown in close up in Figure 27 which illustrates a partial view of two stacked modules 410A and 410C on the left of the figure and two stacked expansion spaces 415A and 415B on the right of the figure. Panel expansion member 475 spans from top opening end rail 24 of module 410A to a top end rail of module 410B (not shown). Floor frame 462 of expansion space 415B is

5 tied to floor frame 62 of module 410C by bolts of shear array 118O. Plywood flooring 495 covers floor frame 62 and 462. Method 300 may also be practiced with expansion spaces between modules provided in spaced end-to-end adjacent relation, end-to-side adjacent relation, and various combinations of spaced side-by-side adjacent, end-to-end adjacent, and/or end-to-side adjacent modules.

10 [0179] Figure 25 also shows column reinforcement members 465 extending from base regions of corner posts 28,38 to mid-elevation regions of the second floor of assembly 400 (as also shown in Figure 24). The columns of assembly 400 differ from the columns of assembly 400 in that they include column reinforcement members 465 which, together with corner posts 28,38, are encased in a curable material such as concrete to form composite columns. Example configurations of column reinforcement members 465 and column posts 28,38 within composite columns are shown in Figures 35-37 and 40. Concrete on the exterior of the composite columns adds a fire rating to assembly 400 and further adds strength to the columns' axial, shear and bending capacity.

15 [0180] As shown in Figure 25, formwork 480 may be positioned to define the column volume and to contain the curable material, such as concrete, until it cures. Shoring 490 may also be temporarily positioned along the center of the modules to support the top panels 58 of the modules, and along the center of the expansion spaces to support the expansion panel member 475 while curable material for composite slab 406 is poured and cured above. Formwork 480 and shoring 490 are not shown in Figures 24 and 24A for simplicity and clarity.

20 [0181] Construction method 300 as illustrated in Figure 23 is similar to construction method 300 of Figure 13 except that construction method 300 contemplates (i) including expansion spaces (e.g. expansion spaces 450A, 450B, 450C, 450D, 415A, 415B) between one or more pairs of laterally aligned modules and/or (ii) increasing strength of the assembly by forming composite columns with additional column closure members embedded within formed columns of curable material (e.g. high-strength concrete, carbon

fibre reinforced polymer (CFRP), and the like). In particular, differences between construction method 300 and construction method 300 may include the following:

- 5

 - step 304 where the perimeter of an assembly includes one or more expansion spaces, enclosing the lateral sides of a slab volume may additionally comprise installing slab edge closures 190 above the perimeter edges of panel expansion members. When an expansion space is adjacent a module and there are no other adjacent modules, then a spacer 980 instead of a spacer 180 may be installed on the top orifice of the corner fitting of the module to allow vertical stacking of additional modules.
- 10

 - step 306 panel expansion members of expansion spaces are sized so that their side edges abut the top panel edges of laterally adjacent modules so no additional bridging is necessary. See for example the arrangement of panel expansion member 475 and top panels 58 in Figure 24A.
- 15

 - step 308 the composite slab may alternatively or additionally span the roofs of modules and expansion spaces. The composite concrete slab may additionally comprise shear connectors of panel expansion members. The curable material of the composite concrete slab conforms to the corrugated top panels of the modules and the corrugated top surface of panel expansion members of the expansion spaces. See for example in Figures 24A, 26 and 27 the integration of the shear
- 20

 - connectors of panel expansion members 475 with slab 406. In some embodiments, curable material introduced to a slab volume may be further integrated with the panel expansion members in order to engage the steel of the expansion spaces in composite action, such as with adhesive, embosses, shear connectors, welded wire mesh and/or the like.
- 25

 - step 310 this step may alternatively or additionally comprise providing an expansion space between two laterally aligned modules, as shown for example in Figure 25. Step 310 therefore can comprise spanning top side rails of laterally aligned and spaced apart modules with a panel expansion member, and installing between the bottom side rails of the modules a supplemental floor frame, to define
- 30

 - an expansion space. Instead of the side-by-side configuration shown in Figure 25,

an expansion space may be provided in an end-to-end configuration, as partially shown in Figure 27 and described above. Orifices of corner fittings of modules adjacent an expansion space would be placed on projections of spacers 180 or 980 of previously placed modules or onto projections installed in a foundation or the like, for example.

- step 312□□ this step may alternatively or additionally comprise enclosing vertically-extending sides of one or more volumes between modules and expansion spaces.
- step 314□□laterally enclosing a beam volume may alternatively or additionally comprise closing vertically extending sides defined on one side by a bottom side rail or bottom end rail of a module and on the other side by a bottom side rail or bottom end rail of a supplemental floor frame of an expansion space. The ends of the beam volume may be closed by formworks for a column instead of a column closure member as in step 314. Where a slab closes a bottom side of a beam volume between a module and expansion space (e.g. in Figure 24A, the top of composite slab 406□is level with the bottoms of the bottom side rail of second floor module 400F□and the bottom side rail of supplemental floor frame of second floor expansion space 450D□), step 314□would include comprise closing vertically extending sides of a beam volume that includes shear connectors of panel expansion member 475□extending through the top of slab 406□into the beam volume. This is shown with long (i.e., side) beam volume 446□in Figure 26 and short (i.e., end) beam volume 447□in Figure 27.
- step 316□□laterally enclosing a column volume may alternatively or additionally comprise temporarily positioning formworks along one, two, three or all four vertically extending sides of a column of an assembly. For example, Figure 25 illustrates formworks 480□temporarily positioned on two sides of each of the four columns illustrated. Formworks 480□for the other two sides (i.e., the ends) are not shown. Each column also comprises column reinforcement member 465□In some embodiments column reinforcement members 465□are bolted with shear bolts to corner posts of the modules. Example configurations of column

reinforcement members with shear connectors of the module corner posts within the columns are shown in Figures 35-37 and 40.

- step 318□- this step comprises introducing curable material, such as concrete, for example, into a laterally-enclosed slab volume between the modules and expansion spaces placed in laterally adjacent relation in step 310□
- step 320□□this step comprises introducing curable material, such as concrete, to a beam volume enclosed in step 314□ Beam 446□and 447□in Figures 26 and 27 are examples of cured beam volumes.
- step 322□□this step comprises introducing curable material, such as concrete, to a column volume enclosed in step 316□ Column 402 in Figures 24 and 24A are examples of cured column volumes.
- step 324□□formworks and shoring are removed once curing material has cured.

[0182] Method 300□may be repeated to construct higher floors of a building. Where this is done, step 310□may comprise placing modules 100 of an upper floor above the modules of an immediately lower floor (e.g., in the manner of module 400E□above module 400A□) and placing expansion spaces of an upper floor above expansion spaces of an immediately lower floor (e.g. in the manner of expansion space 450C□above expansion space 450A□). In some embodiments, an upper module may be mounted above a lower module so that the orifices 16 of the upper module's lower corner fittings 14 receive the projections of spacers mated with the orifices 16 of corresponding upper corner fittings 14 of the lower module.

[0183] Figure 27A is an isometric view of a corner 500□of four adjacent modules assembled according to another example implementation of method 300□without any expansion spaces. Curable material is introduced into formwork to form column 502□during step 322□of an initial cycle of method 300□for construction of the floor beneath the four adjacent modules. Subsequently, curable material is introduced to form slab 506□during step 308□of a subsequent cycle of method 300□for construction of the floor comprising the four adjacent modules. Next, curable material is introduced to form beams 504□during step 320□the same subsequent cycle of method 300□

[0184] Figure 28 is an isometric view of a multi-story building 1000 according to an example embodiment. Building 1000 comprises core walls 1002 (which are shear walls positioned in a square or rectangular arrangement around stair and or elevator shafts in the region of the center of the building; see Figure 41 for an example embodiment of a shear wall). Core walls 1002 protrude through the roof as is common in mid-rise and high-rise buildings. The first floor 1004 of building 1000 is a concrete substructure (e.g., a commercial structure, a parking garage, a foundation at grade, etc.). Modules 1006 are stacked twelve stories high and surround core walls 1002 on three sides. Columns, beams and diaphragms formed in part by modules 1006 and they are structurally connected to one another and lateral loads are carried to core walls 1002 then through the core walls to the foundation. Modules 1006 have windows 1008 at their opening ends. Columns between outward ends of adjacent modules 1006 are hidden by a building envelope 1010.

[0185] Figure 29 is a floor plan 1100 of multi-story building 1000, shown without modules 1006 and certain interior elements of building 1000 in order to expose the location of core walls 1002, columns 1102 and beams 1104. Columns 1102 are arranged in a grid, which provides open spans suitable for various architectural applications. Beams 1104 show the rectangular grid of the floor diaphragm 1106 which carries lateral loads to the concrete core walls 1102. Though floor plan 1100 shows columns 1102 between every module, in other embodiments, some columns may be eliminated (e.g., columns may be provided between only every second module or every third module). Where columns are eliminated, more robust beam designs may be used to support longer spans between columns.

[0186] Figure 30 is a floor plan 1200 of a floor of multi-story building 1000, shown with modules, interior finishing and fenestration hardware. In floor plan 1200, modules 1006 are arranged to provide hallways 1210, studio apartments 1220, and building core 1240.

[0187] Hallways 1210 comprise hall modules 1212 in spaced end-wise adjacent relation. Hall modules 1212 comprise frames of 20 foot intermodal shipping containers.

[0188] Studio apartments 1220 comprise pairs of long side adjacent room modules 1222. Room modules 1222 comprise frames of 20 foot intermodal shipping containers. Room modules 1222 of each apartment 1220 are connected by openings 1224. Dividing walls 1226 are provided between pairs of room modules 1222. Dividing walls 1226 may be formed by introducing curable material between opposed closed sides of adjacent modules room modules 1222 of adjacent apartments 1220. Envelope walls 1228 are provided at the exterior sides and ends of room modules 1222.

[0189] In each studio apartment 1220, curtain walls 1230 are installed to create a bathroom and kitchen space and doors 1232 are fitted in openings of interior walls 1214 for entry from hallway 1210 to open living spaces of apartments 1220.

[0190] Building core 1240 comprises three core units 1244, 1246 and 1248. First core unit 1244 comprises four upright core modules 1242A in spaced laterally adjacent relation. Core modules 1242A comprise the frames of 20 foot intermodal shipping containers. Second core unit 1246 and third core unit 1248 each comprise a core module 1242B. Each core module 1242B comprises the frame of a 40 foot intermodal shipping container. Second core unit 1246 and third core unit 1248 confine opposite sides of first core unit 1244.

[0191] Core walls 1002 are provided between core units 1244, 1246 and 1248, and on the outward sides of core units 1244, 1246 and 1248. Core walls may be made more robust, such as by increasing their thickness, installing rebar mats, providing shear connectors or bolts between panels of core modules 1242 (e.g., by covering an entire side panel with shear connectors), and/or laminating additional panels (e.g., detachable panel sections removed from room modules 1222) onto them, for example.

[0192] Core modules 1242B of second core unit 1246 and third core unit 1248 are provided with top and bottom openings. In second core unit 1246, elevator shafts 1254 are provided through these openings. In third core unit 1248, stairwells 1256 are provided in these openings.

[0193] Figure 31 is a cross-section through core 1002 of building 1000. As can be seen from Figure 31, core modules 1242B of second core unit 1246 and third core unit 1248 are provided for every floor, and are integrated with diaphragms 1260 of their respective floors. Core modules 1242A of first core unit 1244 are end-wise vertically stacked, and each first core unit 1244 spans 3 and 2/3 floors. Vertical core walls 1002 between the adjacent core units are visible in Figure 30.

[0194] It will be appreciated that the variety of configurations in which shear connectors may be provided on modules, closure components, and expansion space components (e.g. panel expansion members and supplemental floor frames), combined with the variety of configurations in which modules, expansion space components, closure components, and reinforcement members may be arranged provides virtually limitless freedom in the design of composite structure components. Figures 32-34 show three example columns that illustrate how different configurations of modules, shear connectors and closure components may be used to provide different column designs. The columns shown in Figures 32 to 34 may for example be utilized in assembly 400. Figures 35-40 show six example columns that illustrate how different configurations of modules, shear connectors and reinforcement members may be used to provide different column designs. The columns shown in Figures 35-40 may for example be utilized in assembly 400□

[0195] Figure 32 is a schematic plan view cross-section through a column 1400 according to an example embodiment. Column 1400 is formed in part by four corner adjacent opening end corner posts (individually enumerated as 1410A, 1410B, 1410C and 1410D, referred to collectively herein as corner posts 1410) of different modules (not shown). Each of corner posts 1410 has a plurality of shear connectors 1412 extending outwardly from it. In Figure 32, it may be observed that opposite ones of shear connectors 1412 of adjacent ones of corner posts 1410 are vertically staggered. More particularly, in the close laterally adjacent relation of corner posts 1410 in column 1400, shear connectors 1412 of opposing shear connector arrays pass by each other in overlapping fashion.

[0196] Corner posts 1410 partially laterally enclose a volume 1420. Curable material is not shown in volume 1420 in order to avoid obscuring features of column 1400. The lateral sides of volume 1420 not enclosed by corner posts 1410 are enclosed by column closure members (individually enumerated as 1430A, 1430B, 1430C and 1430D, referred to collectively herein as column closure members 1430). Each of column closure members 1430 has a plurality of shear connectors 1432 extending from one of its major sides. In Figure 32, it may be observed that the shear connectors 1432 of column closure members 1430A and 1430D are vertically staggered with respect to the shear connectors 1412 of the corner posts 1410 to which column closure members 1430A and 1430D are adjacent. More particularly:

- shear connectors 1432 of column closure member 1430A overlap at right angles the shear connectors 1412 of shear connector arrays of corner posts 1410A and 1410B, which are bridged by column closure member 1430A; and
- shear connectors 1432 of column closure member 1430D overlap at right angles to the shear connectors 1412 of shear connector arrays of corner posts 1410C and 1410D, which are bridged by column closure member 1430D.

[0197] In Figure 32, it may also be observed that shear connectors 1432 of opposing shear connector arrays of column closure members 1430B and 1430C pass by each other in overlapping fashion.

[0198] Figure 33 is a schematic plan view cross-section through a column 1500 according to an example embodiment. Column 1500 is formed in part by four corner adjacent closed end corner posts (individually enumerated as 1510A, 1510B, 1510C and 1510D, referred to collectively herein as corner posts 1510) of different modules (not shown). Each of corner posts 1510 has a plurality of shear connectors 1512 extending outwardly from it. In Figure 33, it may be observed that opposite shear connectors 1512 of adjacent ones of corner posts 1510 are vertically staggered. More particularly, in the close laterally adjacent relation of corner posts 1510 in column 1500, shear connectors

1512 of opposing shear connector arrays of corner posts 1510 pass by each other in overlapping fashion.

[0199] Corner posts 1510 partially laterally enclose a volume 1520. Curable material is not shown in volume 1520 in order to avoid obscuring features of column 1500. The lateral sides of volume 1520 not enclosed by corner posts 1510 are enclosed by column closure members (individually enumerated as 1530A, 1530B, 1530C and 1530D, referred to collectively herein as column closure members 1530). Each of column closure members 1530 has a plurality of shear connectors 1532 extending from one of its major sides. In Figure 26, it may be observed that opposing shear connectors 1532 of opposite ones of column closure members 1530 are vertically staggered. More particularly, shear connectors 1532 of opposing shear connector arrays pass by each other in overlapping fashion. In Figure 26, it may also be observed that the shear connectors 1532 of column closure members 1530 are vertically staggered with respect to the shear connectors 1512 of the corner posts 1510 to which column closure members 1530 are adjacent. More particularly:

- shear connectors 1532 of column closure member 1530A overlap at right angles the shear connectors 1512 of shear connector arrays of corner posts 1510A and 1510B, which are bridged by column closure member 1530A;
- shear connectors 1532 of column closure member 1530B overlap at right angles the shear connectors 1512 of shear connector arrays of corner posts 1510A and 1510D, which are bridged by column closure member 1530B;
- shear connectors 1532 of column closure member 1530C overlap at right angles the shear connectors 1512 of shear connector arrays of corner posts 1510B and 1510D, which are bridged by column closure member 1530B; and
- shear connectors 1532 of column closure member 1530D overlap at right angles the shear connectors 1512 of shear connector arrays of corner posts 1510C and 1510D, which are bridged by column closure member 1530D.

[0200] Figure 34 is a schematic plan view cross-section through a column 1600 according to an example embodiment. Column 1600 is formed in part by two laterally adjacent closed end corner posts (individually enumerated as 1610A and 1610B, referred to collectively herein as corner posts 1610) of different modules (not shown). Each of corner posts 1610 has a plurality of shear connectors 1612 extending from one of its major sides. In Figure 34, it may be observed that opposite shear connectors 1612 of corner posts 1610 are vertically staggered. More particularly, in the close laterally adjacent relation of corner posts 1610 in column 1600, shear connectors 1612 of opposing shear connector arrays of corner posts 1610 pass by each other in overlapping fashion.

[0201] Corner posts 1610 partially laterally enclose a volume 1620. Curable material is not shown in volume 1620 in order to avoid obscuring features of column 1600. The lateral sides of volume 1620 not enclosed by corner posts 1610 are enclosed by column closure members (individually enumerated as 1630A, 1630B and 1630C, referred to collectively herein as column closure members 1630) and laminated panel section 1640. Each of column closure members 1630 has a plurality of shear connectors 1632 extending from one of its major sides. Laminated panel section 1640 comprises two panel sections 1640A and 1640B which have been laminated together. A plurality of shear connectors 1642 extend from one side of panel section 1640.

[0202] In Figure 34, it may be observed that the shear connectors 1632 of column closure members 1630 are vertically staggered with respect to the shear connectors 1612 of the corner posts 1610 to which column closure members 1630 are adjacent. More particularly:

- shear connectors 1632 of column closure member 1630A overlap at right angles the shear connectors 1612 of shear connector arrays of corner posts 1610A and 1610B, which are bridged by column closure member 1630A; and
- shear connectors 1632 of column closure member 1630B overlap at right angles to the shear connectors 1612 of a shear connector array of corner post 1610A; and

- shear connectors 1632 of column closure member 1630C overlap at right angles to the shear connectors 1612 of a shear connector array of corner post 1610B.

[0203] In Figure 34, it may also be observed that shear connectors 1642 of panel section 1640 are vertically staggered with respect to opposed shear connectors 1612 of corner posts 1610 and with respect to opposed shear connectors 1632 of column closure member 1630A. More particularly:

- shear connectors 1642 of panel section 1640 pass by shear connectors 1612 of opposed shear connector arrays of corner posts 1610 in overlapping fashion; and
- shear connectors 1642 of panel section 1640 pass by shear connectors 1632 of the opposed shear connector array of column closure member 1630A in overlapping fashion.

[0204] Figure 35 is a schematic plan view cross-section through a column 1500 according to an example embodiment. Column 1500 includes two adjacent opening end corner posts facing each other (individually enumerated as 1510A and 1510B) of different modules (not shown). Each of corner posts 1510A, 1510B has a plurality of shear connectors 1512 extending outwardly from it. Shear connectors 1512 are received in holes of corresponding column reinforcement members 1565A, 1565B and bolted. Column 1500 is formed by pouring curing material into a column volume 1520 enclosed by formwork (not shown).

[0205] Figure 36 is a schematic plan view cross-section through a column 1600 according to an example embodiment. Column 1600 includes two adjacent opening end corner posts in a side-by-side configuration (individually enumerated as 1610A and 1610B of different modules (not shown). One of corner posts 1610A, 1610B has a plurality of shear connectors 1612 extending outwardly from it, while the other of corner posts 1610A, 1610B has holes for receiving shear connectors 1612 and creating a bolted connection. Alternatively, both corner posts may have a plurality of holes for receiving a plurality of separate shear connectors and creating bolted connections. Column 1600 is

formed by pouring curing material into a column volume 1620 enclosed by formwork (not shown).

[0206] Figure 37 is a schematic plan view cross-section through a column 1700 according to an example embodiment. Column 1700 includes an opening end corner posts 1710. Corner post 1710 has a plurality of shear connectors 1712 extending outwardly from it and received in holes of a column reinforcement member 1765. Column 1700 is formed by pouring curing material into a column volume 1720 enclosed by formwork (not shown).

[0207] Figure 38 is a schematic plan view cross-section through a column 1800 according to an example embodiment. Column 1800 includes two pairs of corner adjacent opening end corner posts (individually enumerated as 1810A , 1810 B, 1810C and 1810D of different modules (not shown). One of the corner posts from each pair of corner posts has a plurality of shear connectors 1812 extending outwardly from it, while the other one of the corners posts from each pair has holes for receiving shear connectors 1812 and creating a bolted connection. Alternatively, all of corner posts may have a plurality of holes for receiving a plurality of separate shear connectors and creating bolted connections. Column 1800 is formed by pouring curing material into a column volume 1820 enclosed by formwork (not shown).

[0208] Figure 39 is a schematic plan view cross-section through a column 1900 according to an example embodiment. Column 1900 includes two facing closed end corner posts (individually enumerated as 1910A and 1910B of different modules (not shown). One of corner posts 1910A, 1910B has a plurality of shear connectors 1912 extending outwardly from it, while the other of corner posts 1910A, 1910B has holes for receiving shear connectors 1912 and creating a bolted connection. Alternatively, both corner posts may have a plurality of holes for receiving a plurality of separate shear connectors and creating bolted connections. Column 1900 is formed by pouring curing material into a column volume 1920 enclosed by formwork (not shown).

[0209] Figure 40 is a schematic plan view cross-section through a column 2000 according to an example embodiment. Column 2000 includes a closed end corner posts 010. Corner post 2010 has a plurality of shear connectors 2012 extending outwardly from it and received in holes of a column reinforcement member 2065. Column 2000 is formed by pouring curing material into a column volume 2020 enclosed by formwork (not shown).

[0210] The structural capacity of any building's design is highly influenced by its height and aspect ratio; further, modern building codes dictate standards for seismic resistance based on probability and site soil conditions. Most reinforced high rise designs combine core walls with robust beam to column connections to absorb, transfer and dissipate lateral loads, therefore axial and lateral forces are linked through these structures. The modular structural systems described here provides axial load capacity for gravity loads, however, the systems decouple gravity loads and lateral loads. When applied in a traditional architectural schemes as described in this disclosure, the system will have sufficient inherent lateral load capacity to resist moderate wind and seismic loads, however, in areas where the structure is expected to experience high earthquake or wind loads, the system can be augmented to increase the load capacity of the structure by transferring, isolating and/or dissipating lateral forces. There are several methods to deal with this as set out below:

1. Add a seismic force resisting system such as moment frame, shear wall, braced frame, dampers, or base isolation to the structure. Excessive lateral loads can be resisted by adding dedicated shear walls or braced frames to the structure. (The lateral loads will be transferred through the floor diaphragms as lateral forces to the shear walls or braced frames and ultimately to the foundation. Figure 41 is a schematic plan view cross-section through a shear wall 2100 according to an example embodiment. Shear wall 2100 includes a shear wall volume 2160 defined by a shear wall panel 2104 on one side and on the other side a module 2110, beam 2046, and an expansion space 2150. Shear wall panel 2104 may comprise repurposed container wall material. A plurality of connectors 2112, such as ties or stringers, rigidly tie shear wall panel 2104 to corresponding panels

or posts of module 2110 and expansion space 2150. Shear wall volume 2160 may additionally include reinforcing material such as rebar (not shown).

2. Augment the beam to column connections to transfer the moment resulting from the lateral loads to the length of the columns and beams, for example:

- 5 a) using gusset plates to create haunches at the beam to column connection and/or
- b) adding steel reinforcements within the concrete to make the beam to column connection a moment connection.

3. Add base isolation devices to isolate the structure from the foundation. Dedicated base isolation devices can be used to absorb most of the earthquake energy and limit the lateral forces to be transferred to the modular structural system.

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[0211] Shear walls are a practical method of combining structural stability, architectural segregation and fire separation between areas of a building and can be employed efficiently in architectural applications such as residential apartments, hospitals, prison cells and the like.

15 **[0212]** Augmenting the beam to column connections is also a practical seismic solution. It limits the need for walls and provides open plan architectural opportunities but increases the size and weight of the structure which will increase foundation costs.

[0213] Base isolation provides the most sustainable opportunity as these buildings are earthquake resistant because lateral forces are absorbed in the isolators rather than by compromising the structure, which is the case for all code prequalified seismic force resisting systems. The modular structural system described here provides a stiff structure which is ideal for base isolation. Buildings of the present invention may accordingly incorporate suitable base isolation systems.

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[0214] Figure 42 is a schematic plan view cross-section through a column 2200 according to an example embodiment. Column 2200 includes two adjacent opening end corner posts facing each other (individually enumerated as 2200A and 2200B) of different modules (not shown). Corner posts 2200A and 2200B have a plurality of shear stirrups 2212 (rebar bent into a rectangular loop with lapping splice hooks at the end) enclosing the corner posts on one side of the column and vertical rebar reinforcement members 2210A, 2210B, 2210C, 2210D and 2210F on the opposing side of the column. Column 2200 is formed by pouring curing material into a column volume 2220 enclosed by formwork (not shown). Similar to column reinforcement member 465 (see Figure 25) the vertical rebar reinforcement may extend to midlevel of the floor above for splicing to additional members extending to the elevation above. Splicing the vertical members at mid floor elevation stiffens the column as it terminates at an alternative location away from the beam column connection and it adds shear strength to the beam to column connection.

[0215] Figure 43 is a schematic plan view cross-section through a column 2300 according to an example embodiment. Column 2300 includes an opening end corner post 2300A. Corner post 2300A has a plurality of shear stirrups 2312 enclosing the corner posts on one side of the column and vertical rebar reinforcement members 2310A, 2310B and 2310C on the opposing side of the column. Column 2300 is formed by pouring curing material into a column volume 2320 enclosed by formwork (not shown). Similar to column reinforcement member 465 (see Figure 25) the vertical rebar reinforcement may extend to midlevel of the floor above for splicing to additional members extending to the following elevation.

[0216] Columns 2200 and 2300 can be implemented in place of column 402 shown in Figure 24, with adjacent expansion space. Further columns 2200 and 2300 may be implemented to integrate the volumetric modular system described here, to a conventional reinforced concrete building or to a steel structure with Q deck, etc. It should be further noted that shear stirrups shown with hooks in Figures 42 and 43 may be spliced with mechanical connectors, for example Lenton Quick Wedge or Lenton

Interlock rebar splice. By employing these fittings the shear stirrups may be more open or in two or more pieces. This allows the substitution of shear stirrups in place of the shear bolts demonstrated in Figures 35 and 36 on columns 1500 and 1600.

[0217] The demonstration of headed studs, shear bolts or shear stirrups as shear connectors across columns is not intended to be limiting in that other methods of providing shear connection across columns may be employed such as carbon-fiber-reinforced polymer wrap as used in seismic upgrading columns, etc. may be employed to integrate the corner posts of volumetric construction modules in columns.

[0218] Figure 44 is an isometric view of a composite beam 4404 according to another example embodiment. Beam 4404 is a long beam formed between modules 600C and 600D (see Figure 16) parallel to the side rails of the modules. Beam 4404 differs from beam 604 in that the beam soffit member 670 is replaced by a non-structural soffit form 4471 straddling the top side rails 44 of the adjacent modules to contain the curable material and two lengths of structural rebar 4470 are installed a spaced above the soffit form 4471 to provide a concrete cover under the rebar for fire rating. Shear stirrups 4474 are U-shaped with hooks at both ends. The lower horizontal portion of the U shaped shear stirrup 4474 passes below the two lengths of structural rebar 4470 and the two vertical portions extend into the upper section of beam 4404. Further confinement of the concrete and composite action in the beam is provided by shear bolt 680 extending between the bottom side rails 46 of upper modules 600C and 600D and the vertical portions of shear stirrup 4474 with the hooked ends around shear bolt 680.

[0219] Figure 44A is a cross section end view of composite beam 4404.

[0220] Figure 45 is a cross section end view of composite beam 4504 according to a further example embodiment. Beam 4504 is a long beam formed between module 600C and a panel expansion member with a supplemental floor frame. Beam 4504 is similar to beam 446 of Figure 26 except there is no beam soffit member below the expansion panel. Instead there are two lengths of structural rebar 4470 spaced above the panel

expansion member to provide a concrete cover under the rebar for fire rating. Shear stirrups 4474 are employed in the same manner as in beam 4404.

[0221] Figure 46 is a cross section end view of composite beam 4604 according to a yet further example embodiment. Beam 4604 is an alternative short beam formed between module 600A and 600B of Figure 20. Beam 4604 differs from beam 604 in that beam soffit member 670 is replaced by a non-structural form 4671 straddling the top end rails of the adjacent modules to contain the curable material. Two lengths of structural rebar 4670 are spaced above the soffit form 4671 to replace the structural contribution of beam soffit member 670 and provide a concrete cover over the rebar for fire rating. Shear stirrups 4674 are U shaped with hooks at both ends. The lower horizontal portion of the U-shaped shear stirrup 4674 passes below the two lengths of structural rebar 4670 and the two vertical portions extend into the upper section of beam 4604. Further confinement of the concrete and composite action in the beam is provided by shear bolt 680 extending between the bottom end rails of the upper modules 600C and 600D and the vertical portions of shear stirrup 4474 with the hooked ends around shear bolt 680.

[0222] Figure 47 is a cross section end view of composite beam 4704 according to an example embodiment similar to Figure 27 in that the beam is closed on one side by the bottom end rail of a module and on the other by a framed floor above an expansion panel. Beam 4704 differs from Figure 27 in that instead of a beam soffit member, there are two lengths of structural rebar 4470 installed at a spaced distance above the an expansion panel to allow a concrete cover under the rebar for fire rating. Shear stirrups 4774 are U shaped with hooks at both ends. The lower horizontal portion of the U shaped shear stirrup 4774 passes below the two lengths of structural rebar 4770 and the two vertical portions extend into the upper section of beam 4704. Further confinement of the concrete and composite action in the beam is provided by shear bolts 680 extending between the bottom rails of the upper modules and the vertical portions of shear stirrup 4474 with the hooked ends around shear bolt 680. It should be noted that a similar beam configuration

may employed between facing expansion panels and floor frames or with a bottom side rail of a module on one side only, for example, at the edge of a building.

[0223] The capacity of the columns and beams described in Figures 42 to 47 may be adapted to the buildings structural demand by varying the cross section of concrete, the size and quantity of vertical rebar members and the size, quantity, location and spacing of the shear stirrups. Further, the capacity of the beam to column connection may be augmented by employing standard lapped rebar details with hooked stirrups employing engineering methods that are well understood by those familiar with the art.

[0224] Where a component or feature is referred to above (e.g., container, frame, rail, post, joist, panel, C-channel, plate, module, shear connector, etc.), unless otherwise indicated, reference to that component (including a reference to a "means") should be interpreted as including as equivalents of that component any component which performs the function of the described component (i.e., that is functionally equivalent), including components which are not structurally equivalent to the disclosed structure which performs the function in the illustrated exemplary embodiments of the invention.

[0225] Unless the context clearly requires otherwise, throughout the description and the claims, the words "comprise," "comprising," and the like are to be construed in an inclusive sense, as opposed to an exclusive or exhaustive sense; that is to say, in the sense of "including, but not limited to." Where the context permits, words in the above description using the singular or plural number may also include the plural or singular number respectively. The word "or," in reference to a list of two or more items, covers all of the following interpretations of the word: any of the items in the list, all of the items in the list, and any combination of the items in the list.

[0226] The above detailed description of example embodiments is not intended to be exhaustive or to limit this disclosure and claims to the precise forms disclosed above. While specific examples of, and examples for, embodiments are described above for illustrative purposes, various equivalent modifications are possible within the scope of the technology, as those skilled in the relevant art will recognize.

[0227] These and other changes can be made to the system in light of the above description. While the above description describes certain examples of the technology, and describes the best mode contemplated, no matter how detailed the above appears in text, the technology can be practiced in many ways. As noted above, particular

5 terminology used when describing certain features or aspects of the system should not be taken to imply that the terminology is being redefined herein to be restricted to any specific characteristics, features, or aspects of the system with which that terminology is associated. In general, the terms used in the following claims should not be construed to limit the system to the specific examples disclosed in the specification, unless the above
10 description section explicitly and restrictively defines such terms. Accordingly, the actual scope of the technology encompasses not only the disclosed examples, but also all equivalent ways of practicing or implementing the technology under the claims.

[0228] Particular structural characteristics (e.g., cross-sectional shape, material composition, etc.) ascribed to components (e.g., frames, rails, joists, posts, panels, etc.) of
15 example embodiments described herein are not necessary in all embodiments. Accordingly, components should not be interpreted as being limited to having particular structural characteristics ascribed to them in example embodiments.

[0229] From the foregoing, it will be appreciated that specific examples of apparatus and methods have been described herein for purposes of illustration, but that various
20 modifications, alterations, additions and permutations may be made without departing from the practice of the invention. The embodiments described herein are only examples. Those skilled in the art will appreciate that certain features of embodiments described herein may be used in combination with features of other embodiments described herein, and that embodiments described herein may be practised or implemented without all of
25 the features ascribed to them herein. Such variations on described embodiments that would be apparent to the skilled addressee, including variations comprising mixing and matching of features from different embodiments, are within the scope of this invention.

[0230] As will be apparent to those skilled in the art in light of the foregoing disclosure, many alterations and modifications are possible in the practice of this invention without departing from the spirit or scope thereof. For example:

- 5 • As an alternative or addition to shear connectors, some embodiments may couple segments (i.e., frame components such as the corner posts, side rails, end rails, etc.) by wrapping them with Fibre Reinforced Polymer (FRP). FRP may include carbon FRP, glass FRP, and the like.
- 10 • Columns, beams, and slabs may be made arbitrarily thick or thin.
- 10 • The number of shear connectors shown in the illustrated embodiments is not meant to be specific. The quantity, type, size and the like of shear connectors required may be specific to a particular column or building and the illustrated representation of type and quantity are exemplary only.
- 15 • Lengths of column closures and beam soffit members may be varied. For example, a column closure may span two or more vertically arranged modules.
- 15 • Vertically adjacent column closures (e.g., enclosing different portions of a column that spans two or more floors of a building) may be joined together, such as by a butt weld, lap joint and/or the like, for example.
- 20 • Column closures need not have shear connectors.
- 20 • Column closures may have shear connectors projecting from both major sides, such as for integrating end-wise adjacent modules, for example.
- 25 • A single column closure may close two or more sides of a column volume. For example, a column closure may comprise an I-beam whose flanges each close an opposite side of a column volume (e.g., similar to I-beam 772).
- 25 • Spacers may be configured for aligning and spacing eight adjacent modules (i.e., four corner-adjacent upper modules and four corner-adjacent lower modules).
- Spacers need not engage orifices of corner fittings. For example, spacers may be welded to top and/or bottom rails intermediate corners of frames.
- Volumetric construction modules may incorporate parts of intermodal shipping containers of various sizes.

- For example, volumetric construction modules may incorporate parts of intermodal shipping containers having lengths of 12192 mm (40 feet), 2991 mm (10 feet), 9125 mm (30 feet), 13716 mm (45 feet), 14630 mm (48 feet), and 17154 mm (53 feet).
- 5 ○ For another example, volumetric construction modules may incorporate parts of intermodal shipping containers having widths greater than 8 feet.
- For a further example, volumetric construction modules may incorporate parts of standard height intermodal shipping containers having, which are
10 2591 mm (8 feet 6 inches) high.
- Columns need not be formed at the ends of modules. For example, where a module incorporates a 17154 mm (53 foot) intermodal shipping container frame, structurally strong corner posts will be located approximately 6.5 feet inward from the ends of the module. Shear connectors may be secured to these corner
15 posts, and columns that include these shear connectors formed adjacent to the posts.
- Volumetric construction modules need not incorporate parts of intermodal shipping containers. Components of intermodal shipping containers used in descriptions of example embodiments may be substituted with any functionally
20 equivalent component, feature or combination of components and/or features.
- Volumetric construction modules may comprise corner fittings that, unlike the corner fittings of intermodal shipping containers, are fabricated from sheet steel or the module may have a corner post perforated for ease of interconnection with handling equipment or other modules.
- 25 • Modules of different dimensions may be integrated in the same building, on different floors or on the same floor.
- Buildings may comprise modules which differ in one or more of height, length, width and orientation.
- Differences in dimension and/or orientation among modules in a building may be
30 accommodated by dimensional differences among columns, beam and slabs of the building.

- Modules need not have floors and/or top panels.
- Components assembled with example modules in described example embodiments (e.g., column closure members, beam soffit members, edge slab closures, spacers, etc.) may be formed, fabricated or otherwise integrated with the module (e.g., at the factory, on site but before modules are placed in spaced adjacent relation, etc.).
- Components assembled with example modules in described example embodiments may be integrated with one another (e.g., one or more spacers and one or more slab edge closures may be provided as single unit, column closure for enclosing a single column volume may be provided as a single unit, etc.).
- Modules, frames and components may comprise materials other than steel. Non-limiting examples of other suitable materials include:
 - metals other than steel;
 - wood;
 - engineered wood composites (e.g., comprising wood fibre and adhesives, etc.);
 - carbon fibre composites;
 - plastics; and
 - the like.
- Curable materials other than concrete may be introduced into the structural volumes (e.g., to form composite columns, beams and/or slabs). Examples of other suitable curable materials include fibre reinforced polymers, magnesia cement based materials (e.g., concrete made with magnesium silicate cement, such as Carbon Negative Cement made by Novacem Limited of London, United Kingdom), and the like. In some embodiments, shear connectors are not used where high-strength curable materials such as Carbon Fibre Reinforced Polymer (CFRP) or high strength concrete (e.g. concrete reinforced with steel filings) are used and temporary formwork used to encase the segments (i.e., corner posts, side rails, etc.) with these curable materials.

- Fire rating material, such as intumescent paint, furring and gypsum board sprayed insulation or the like, for example, may be provided to protect the exposed structural steel in volumetric construction modules from heat due to fire.

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- Volumetric construction modules of the present invention may be adapted to augment any building structure to provide pre-manufactured highly finished areas. For example, volumetric construction modules containing kitchens and bathrooms may be stacked floor by floor and form a portion of the building structure in a high rise reinforced concrete building and the modules can be spaced vertically to match the story elevations floor to floor.

10

[0231] While a number of exemplary aspects and embodiments have been discussed above, those of skill in the art will recognize certain modifications, permutations, additions and sub-combinations thereof. It is therefore intended that the following appended claims and claims hereafter introduced are interpreted to include all such modifications, permutations, additions and sub-combinations as are within their true spirit

15

and scope.

Claims

WHAT IS CLAIMED IS:

1. A method of modular building construction comprising:

5 (a) providing a first volumetric construction module comprising a frame,
the frame comprising a first segment;

(b) defining a volume of a composite segment and integrating the first
segment with the volume; and

(c) filling the volume with a curable material to cast the composite
segment.

10 2. A method according to claim 1 further comprising prior to step (b), step (a)(i)
comprising providing a structure adjacent the first volumetric construction module, the
adjacent structure comprising a second segment, and wherein step (b) comprising
integrating the first segment and the second segment with the volume.

15 3. A method according to claim 2, wherein in step (b) the volume contains at least a
portion of the first and second segments.

4. A method according to claim 3, wherein step (b) comprises defining a boundary
of the volume with temporary formwork.

5. A method according to claim 2, wherein step (b) comprises defining at least a
portion of the boundary of the volume with the first and second segments.

20 6. A method according to any one of claims 2 to 5, wherein the adjacent structure
comprises a second volumetric construction module comprising a frame including the
second segment.

7. A method according to claim 6, comprising prior to step (b), step (a)(ii) comprising augmenting structural capacity of the composite segment.

8. A method according to claim 7, wherein step (a)(ii) comprises coupling the first segment and/or the second segment to a plurality of shear connectors extending into the
5 volume.

9. A method according to claim 8 wherein step (a)(ii) further comprises coupling a column reinforcement member to the plurality of shear connectors.

10. A method according to claim 7 wherein step (a)(ii) comprises providing a column closure member opposite to the first segment and/or the second segment, the column
10 closure member defining a portion of the boundary of the volume.

11. A method according to claim 10 wherein the column closure member is coupled to a plurality of shear connectors extending into the volume.

12. A method according to claim 7 wherein step (a)(ii) comprises providing a plurality of first and second reinforcement elements, the first and second reinforcement
15 elements extending in transverse planes with respect to each other.

13. A method according to claim 12, wherein the first reinforcement elements comprise rebar rods and the second reinforcement elements comprise rebar stirrups.

14. A method according to claim 8 wherein step (a)(ii) further comprises providing a plurality of first and second reinforcement elements, wherein the second reinforcement
20 elements engage the shear connectors.

15. A method according to claim 14, wherein the first reinforcement elements comprise rebar rods and the second reinforcement elements comprise rebar stirrups.

16. A method according to any one of claims 6 to 15 wherein each of the first and second volumetric construction modules has an opening defined in its side that faces the other module, and wherein the volume comprises a space between the modules adjacent the openings.

5 17. A method according to any one of claims 6 to 16 wherein the volume comprises a space between adjacent corners of the frame of the at least one of the first and second volumetric construction modules.

10 18. A method according to any one of claims 6 to 16 wherein the volume comprises a space adjacent an edge of the frame of at least one of the first and second volumetric construction modules.

19. A method according to any one of claims 6 to 18 wherein the first and second volumetric construction modules are provided in laterally adjacent relation.

15 20. A method according to claim 19 wherein providing the first and second volumetric construction modules in laterally adjacent relation comprises providing the modules such that a side of one module is adjacent a side of the other module, or such that an end of one module is adjacent a side of the other module, or such that an end of one module is adjacent an end of the other module.

20 21. A method according to any one of claims 6 to 20 wherein the frame of each of the first and second volumetric construction module comprises a plurality of vertical posts, wherein the volume comprises a space between opposed posts of the modules.

22. A method according to any one of claims 6 to 20 wherein the frame of each of the first and second volumetric construction module comprises a horizontal rail, wherein the volume comprises a space between opposed rails of the modules.

23. A method according to any one of claims 6 to 20 wherein each of the first and second volumetric construction module comprises a panel section fastened to the frame, wherein the volume comprises a space between opposed panel sections of the modules.

24. A method according to any one of claims 6 to 20 comprising bridging adjacent upper portions of the frames with a structural member to provide a bottom boundary of a slab volume.

25. A method according to claim 24 wherein the structural member comprises one or more upwardly extending shear connectors.

26. A method according to claim 25 wherein the shear connectors extend past the top of the frames.

27. A method according to claim 24 wherein a plurality of rebar rods and rebar stirrups are provided in the slab volume.

28. A method according to any one of claims 24 to 27 wherein the structural member comprises a hot or cold rolled steel section.

29. A method according to claim 6 to 28 wherein a boundary of the slab volume is partially defined by a spacer installed above the first volumetric construction module and/or the second volumetric construction module.

30. A method according to claim 29 wherein at least the top corners of the frame of each of the first and second volumetric construction modules comprise corner fittings having upper orifices, wherein the spacer comprises at least one downward projection, and wherein installing the at least one spacer comprises mating the at least one downward projection with one of the upper orifices.

31. A method according to any one of claims 24 to 30 comprising introducing a curable material to the slab volume.

32. A method according to any one of 29 to 31 comprising providing an upper volumetric construction module above each of the first and second volumetric construction modules, each of the upper volumetric construction modules comprising a frame.

5 33. A method according to claim 32 wherein at least bottom corners of the frame of each upper module comprise corner fittings having lower orifices, wherein the spacer comprises at least one upward projection, and wherein providing the upper volumetric modules above the volumetric construction modules comprises mating the at least one upward projection with one of the lower orifices.

10 34. A method according to any one of claims 6 to 33 wherein each of the frames of the first and second volumetric construction modules comprises a rectangular parallelepiped frame.

35. A method according to claim 34 wherein the rectangular parallelepiped frame comprises at least a part of a frame of an intermodal shipping container.

15 36. A method according to any one of claims 6 to 35 wherein the curable material comprises concrete.

37. A method of modular building construction comprising:

(a) providing first and second volumetric construction modules in lateral relation, each module comprising a frame, the frame comprising a first segment;

20 (b) providing a panel expansion member spanning opposing top rails of the frames and a floor frame between opposing bottom rails of the frame, the space between the panel expansion member and the floor frame defining an expansion space, wherein at least one of the panel expansion member and the floor frame comprise a second segment;

(c) defining a volume of a composite segment, the volume integrating the first segment and the second segment; and

(d) filling the volume with a curable material to cast the composite segment.

5 38. A method according to claim 37, wherein in step (c) the volume contains at least a portion of the first and second segments.

39. A method according to claim 38, wherein step (c) comprises defining a boundary of the volume with temporary formwork.

10 40. A method according to claim 37, wherein in step (c) comprises defining at least a portion of the boundary of the volume with the first and second segments.

41. A method according to any one of claims 37 to 40, comprising prior to step (d) a step (c)(i) comprising augmenting the structural capacity of the composite segment.

15 42. A method according to claim 41, wherein step (c)(i) comprises coupling the first segment and/or the second segment to a plurality of shear connectors extending into the volume.

43. A method according to claim 41, wherein step (c)(i) comprises providing a plurality of first and second reinforcement elements, the first and second reinforcement elements extending in transverse planes with respect to each other.

20 44. A method according to claim 43, wherein the first reinforcement elements comprise rebar rods and the second reinforcement elements comprise rebar stirrups.

45. A method according to any one of claims 37 to 44 wherein each volumetric construction module has an opening defined in its side that faces the expansion space,

and wherein the volumes comprises a space between the modules and the expansion space adjacent the openings.

46. A method according to any one of claims 37 to 44 wherein the volume comprises a space between adjacent corners of the frame of the at least one of the first and second volumetric construction modules.

47. A method according to any one of claims 37 to 46 wherein the volume comprises a space adjacent an edge of the frame of at least one of the first and second volumetric construction modules.

48. A method according to any one of claims 37 to 46 wherein a side of the first volumetric construction module is aligned with the side of the second volumetric construction module, with the expansion space located therebetween.

49. A method according to any one of claims 37 to 46 wherein a side of the first volumetric construction module is aligned with an end of the second volumetric construction module, with the expansion space located therebetween.

50. A method according to any one of claims 37 to 46 wherein an end of the first volumetric construction module is aligned with an end of the second volumetric construction module, with the expansion space located therebetween.

51. A method according to any one of claims 37 to 50 wherein the panel expansion member partially defines a bottom boundary of a slab volume above the modules and the expansion space.

52. A method according to claim 51 wherein the panel expansion member comprises a structural member at two side regions of the panel expansion member wherein spanning opposing top rails comprises resting at least a portion of the structural member on the top rails or on opposing sides of the modules

53. A method according to claim 52 wherein the structural member comprises a hot or cold rolled steel section.

54. A method according to claim 52 or 53 wherein the structural member is provided with upwardly projecting shear connectors.

5 55. A method according to any one of claims 37 to 54 wherein each of the frames of the first and second volumetric construction modules comprises a rectangular parallelepiped frame.

56. A method according to claim 55 wherein the rectangular parallelepiped frame comprises at least a part of a frame of an intermodal shipping container.

10 57. A method according to claim 37 to 56 wherein the panel expansion member comprises at least a part of a panel of an intermodal shipping container.

58. A method according to any one of claims 37 to 57 wherein the floor frame comprises at least a part of a floor frame of an intermodal shipping container.

15 59. A method according to any one of claims 37 to 58 wherein the curable material comprises concrete.

60. A method of modular building construction comprising:

(a) providing a first volumetric construction module comprising a frame, the frame comprising a first segment;

20 (b) providing a partially constructed building comprising a frame comprising a second segment;

(c) defining a volume of a composite segment, the volume integrating the first segment and the second segment; and

(d) filling the volume with a curable material to cast the composite segment.

61. A method according to claim 60, wherein in step (c) the volume contains at least a portion of the first and second segments.

5 62. A method according to claim 61, wherein step (c) comprises defining a boundary of the volume with temporary formwork.

63. A method according to claim 60, wherein step (c) comprises defining at least a portion of the boundary of the volume with the first and second segments.

10 64. A method according to any one of claims 60 to 63, comprising prior to step (d) a step (c)(i) comprising augmenting the structural capacity of the composite segment.

65. A method according to claim 64, wherein step (c)(i) comprises coupling the first segment and/or the second segment to a plurality of shear connectors extending into the volume.

15 66. A method according to claim 64 wherein step (c)(i) further comprises providing a plurality of first and second reinforcement elements, the first and second reinforcement elements extending in transverse planes with respect to each other.

67. A method according to claim 66, wherein the first reinforcement elements comprise rebar rods and the second reinforcement elements comprise rebar stirrups.

68. A modular building diaphragm comprising:

20 roof panels of first and second volumetric construction modules in laterally adjacent relation;

floor frames of third and fourth volumetric construction modules in laterally adjacent relation, the third and fourth modules above the first and second modules, respectively;

5 a beam soffit member connected between upper portions of the first and second modules and having one or more shear connectors extending upwardly between the third and fourth modules; and

10 a continuous body of concrete in contact with at least a portion of each of the roof panels of the first and second modules, the laterally adjacent portions of the third and fourth modules, and the beam soffit member, the concrete bonded in composite action with the one or more shear connectors of the beam soffit member.

69. A modular building diaphragm comprising:

roof panels of first and second volumetric construction modules in laterally adjacent relation;

15 floor frames of third and fourth volumetric construction modules in laterally adjacent relation, the third and fourth modules above the first and second modules and, respectively, bottom rails of the third and fourth modules rigidly connected by at least one shear connector;

a structural member connected between upper portions of the first and second modules; and

20 at least one first reinforcing element extending in a direction parallel to a long axis of the bottom rails;

a plurality of second reinforcing elements oriented in a plane transverse to the long axis of the bottom rails, each of the second reinforcing elements coupling the at least one shear connector to the at least one first reinforcing element; and

a continuous body of concrete in contact with at least a portion of each of the roof panels of the first and second modules, the laterally adjacent portions of the third and fourth modules, the at least one first reinforcing element, the plurality of second reinforcing elements, and the structural member, the concrete bonded in composite action with the one or more shear connectors of the beam soffit member.

70. A column in a modular building, the column comprising:

a first panel section of a first volumetric construction module;

a second panel section of a second volumetric construction module, the second panel section parallel to and spaced apart from the first panel section;

at least one shear connector extending into a volume between the first panel section and the second panel section and attached to at least one of the first panel section and the second panel section;

at least one column closure member closing lateral sides of the volume between the first panel section and the second panel section; and

concrete in the volume bonded in composite action with the at least one shear connector.

71. The column of claim 70 wherein the first module has an opening defined in part by an inward edge of the first panel section, wherein the second module has an opening defined in part by an inward edge of the second panel section, and wherein the at least one column closure member borders the openings in the first and second modules.

72. The column of claim 71 comprising at least one shear connector attached to the at least one column closure member, wherein the concrete is bonded in composite action with the at least one shear connector attached to the at least one column closure member.

73. A column in a modular building, the column comprising:

a first corner post section of a first volumetric construction module;

a first vertically extending reinforcement member;

5 a first plurality of shear connectors rigidly connecting the first corner post section to the first vertically extending reinforcement member;

a volume defined by temporary formwork, the volume surrounding and including the first corner post section, the first vertically extending reinforcement member, and the first plurality of shear connectors; and

10 concrete in the volume encasing and bonding in composite action the first corner post section, the first vertically extending reinforcement member, and the first plurality of shear connectors.

74. The column of claim 73 further comprising:

a second corner post section of a second volumetric construction module adjacent the first corner post section;

15 a second vertically extending reinforcement member;

a second plurality of shear connectors rigidly connecting the second corner post section to the second vertically extending reinforcement member;

20 wherein the volume additionally surrounds and includes the second corner post section, the second vertically extending reinforcement member, and the second plurality of shear connectors; and

wherein the concrete in the volume additionally encases and bonds in composite action the second corner post section, the second vertically extending reinforcement member, and the second plurality of shear connectors.

75. A column in a modular building, the column comprising:

5 a first corner post section of a first volumetric construction module;

a second corner post section of a second volumetric construction module adjacent the first corner post section;

a first plurality of shear connectors rigidly connecting the first corner post section to the second corner post section;

10 a volume defined by temporary formwork, the volume surrounding and including the first corner post section, the second corner post section, and the first plurality of shear connectors; and

15 concrete in the volume encasing and bonding in composite action the first corner post section, the second corner post section, and the first plurality of shear connectors.

76. The column of claim 75, further comprising

a third corner post section of a third volumetric construction module adjacent the first or second corner post section;

20 a fourth corner post section of a fourth volumetric construction module adjacent the third corner post section;

a second plurality of shear connectors rigidly connecting the third corner post section to the fourth corner post section;

wherein the volume additionally surrounds and includes the third corner post section, the fourth corner post section, and the second plurality of shear connectors; and

5 wherein the concrete in the volume additionally encases and bonds in composite action the third corner post section, the fourth corner post section, and the second plurality of shear connectors.

77. A column in a modular building, the column comprising:

a first corner post section of a first volumetric construction module;

10 at least one first reinforcing element extending in a direction parallel to a long axis of the first corner post section;

at plurality of second reinforcing elements oriented in a plane transverse to the long axis of the first corner post section, each of the second reinforcing elements surrounding both the first corner post section and the at least one first reinforcing element;

15 a volume defined by temporary formwork, the volume surrounding and including the first corner post section, the at least one first reinforcing element and the plurality of second reinforcing elements; and

20 concrete in the volume encasing and bonding in composite action the first corner post section, the at least one first reinforcing element and the plurality of second reinforcing elements.

78. A column according to claim 77, comprising a second corner post section adjacent the first corner post section, wherein each of the second reinforcing elements surround the second corner post section, wherein the volume surrounds and includes the second corner post section, and wherein the concrete in the volume encases and bonds in

composite action the first corner post section, the second corner post section, the at least one first reinforcing element and the plurality of second reinforcing elements.

79. A column according to claim 77 or 78, wherein the at least one first reinforcing element comprises a rebar rod, and the plurality of second reinforcing elements comprise rebar stirrups.

80. A beam in a modular building, the beam comprising:

a first horizontal rail of a first volumetric construction module;

a second horizontal rail of a second volumetric construction module, the second horizontal rail parallel to and spaced apart from the first rail;

at least one shear connector extending into a volume between the first rail and the second rail and attached to at least one of the first rail and the second rail;

a beam soffit member below the first rail and the second rail, the beam soffit member having one or more shear connectors extending into the volume between the first rail and the second rail; and

concrete in the volume between the first rail and the second rail, the concrete bonded in composite action with the at least one shear connector attached to at least one of the first rail and the second rail and with the one or more shear connectors of the beam soffit member.

81. The beam of claim 80 wherein the first module has an opening defined above the first rail, wherein the second module has an opening defined above the second rail, and wherein an upper face of the concrete borders the openings in the first and second modules.

82. A beam in a modular building, the beam comprising:

a first horizontal rail of a first volumetric construction module;

a second horizontal rail of a second volumetric construction module, the second horizontal rail parallel to and spaced apart from the first rail;

5 at least one shear connector extending between the first rail and the second rail and attached to at least one of the first rail and the second rail;

at least one first reinforcing element extending in a direction parallel to a long axis of the first and second horizontal rail;

10 at plurality of second reinforcing elements oriented in a plane transverse to the long axis of the first and second horizontal rail, each of the second reinforcing elements coupling the at least one shear connector to the at least one first reinforcing element; and

a structural member below the first rail, the second rail, the at least one first reinforcing element, and the plurality of second reinforcing elements; and

15 concrete in a volume defined between the first rail and the second rail, the concrete bonded in composite action with the at least one shear connector, the at least one first reinforcing element, and the plurality of second reinforcing elements.

83. A column according to claim 82, wherein the structural member comprises a hot or cold rolled steel section.

20 84. A column according to claim 82 or 83, wherein the plurality of second reinforcing elements are substantially U-shaped, wherein end regions of the U-shape engage the at least one shear connector, and a middle region of the U-shape engages the at least one first reinforcing element.

85. A column according to any one of claims 82 to 84, wherein the at least one first reinforcing element comprises a rebar rod, and the plurality of second reinforcing elements comprise rebar stirrups.

86. A shear wall in a modular building, the shear wall comprising:

5 a shear wall panel;

at least a portion of one end or side of a volumetric construction module;

at least one connector rigidly fixed to and extending between the shear wall panel and the portion of the one end or side;

10 concrete in a volume defined between the shear wall panel and the portion of the one end or side.

87. A shear wall according to claim 86 wherein the shear wall panel comprises repurposed intermodal shipping container wall material.

88. A volumetric construction module comprising:

15 a frame having opposed ends and opposed sides extending between the ends; and

one or more shear connectors projecting outwardly from the frame.

89. A volumetric construction module according to claim 88 wherein the frame comprises at least part of a rectangular parallelepiped frame of an intermodal shipping container.

20 90. A volumetric construction module according to claim 88 or 89 wherein the one or more shear connectors extend between adjacent corners of the frame.

91. A volumetric construction module according to any one of claims 88 to 90 wherein the one or more shear connectors comprises an array of stud-type shear connectors.

5 92. A volumetric construction module according to any one of claims 88 to 91 wherein the one or more shear connectors comprises at least one strip-type shear connector.

93. A volumetric construction module according to any one of claims 88 to 92 wherein the one or more shear connectors is located adjacent an edge of the frame.

10 94. A volumetric construction module according to claim 93 wherein the edge comprises an edge between one of the ends of the frame and one of the sides of the frame.

95. A volumetric construction module according to claim 93 or 94 wherein the frame comprises a plurality of vertical posts, and wherein at least one of the one or more shear connectors is attached to one of the posts.

15 96. A volumetric construction module according to any one of claims 93 to 95 comprising a panel section coupled to the frame, and wherein at least one of the one or more shear connectors is attached to the panel section.

97. A volumetric construction module according to claim 93 wherein the edge comprises an edge between a bottom of the frame and one of the sides of the frame.

20 98. A volumetric construction module according to claim 93 wherein the edge is located along the top of one of the ends.

99. A volumetric construction module according to claim 97 or 98 wherein the frame comprises a horizontal rail, and wherein at least one of the one or more shear connectors is attached the rail.

100. A volumetric construction module according to any one of claims 88 to 99 wherein the frame has an opening in one of its sides, and wherein at least one of the shear connectors extends along an edge of the opening.

101. A method for making a volumetric construction module, the method comprising:

5 providing an intermodal shipping container;

 installing one or more shear connectors on the outside of the container.

102. The method of claim 101 comprising removing a portion of a side panel of the container to define an opening in a side of the container.

10 103. The method of claim 102 comprising detachably fastening the removed portion of the side panel to the container.

104. The method of claim 102 or 103 wherein installing the one or more shear connectors comprises:

 attaching the one or more shear connectors to the removed portion of the side panel; and

15 laminating the removed portion of the side panel to a remaining portion of the side panel of the container.

105. The method of any one of claims 101 to 104 wherein installing the one or more shear connectors comprises installing one or more shear connectors between adjacent corners of the container.

20 106. The method of any one of claims 101 to 105 wherein installing the one or more shear connectors comprises installing an array of stud-type shear connectors.

107. The method of any one of claims 101 to 106 wherein installing the one or more shear connectors comprises installing at least one strip-type shear connector.

108. The method of any one of claims 101 to 107 wherein installing the one or more shear connectors comprises installing the one or more shear connectors adjacent to an
5 edge of the container.

109. The method of claim 108 wherein the edge comprises an edge between an end of the container and a side of the container.

110. The method of claim 109 wherein installing the one or more shear connectors comprises attaching at least one of the one or more shear connectors to a post of the
10 container.

111. The method of claim 109 or 110 wherein installing the one or more shear connectors comprises attaching at least one of the one or more shear connectors to a panel of the container.

112. The method of claim 111 wherein the edge comprises an edge between a bottom
15 of the container and a side of the container.

113. The method of claim 111 wherein the edge comprises an edge between a top of the container and an end of the container.

114. The method of claim 112 or 113 wherein installing the one or more shear connectors comprises attaching at least one of the one or more shear connectors to a
20 horizontal rail of the container.

115. The method of any one of claims 101 to 114 wherein installing the one or more shear connectors comprises welding at least one of the one or more shear connectors to the container.

116. The method of any one of claims 101 to 115 wherein installing the one or more shear connectors comprises adhesively bonding at least one of the one or more shear connectors to the container.

5 117. The method of any one of claims 101 to 116 wherein installing the one or more shear connectors comprises mechanically coupling at least one of the one or more shear connectors to the container.

118. A building comprising:

two volumetric construction modules in adjacent relation, each module comprising:

10 a frame having opposed ends and opposed sides extending between the ends, and

one or more first shear connectors coupled to the frame and extending toward the other module;

15 at least one first closure member closing lateral sides of a first volume between the modules that includes the one or more first shear connectors; and

concrete occupying the first volume.

119. The building of claim 118 wherein each module has an opening defined in its side that faces the other module, and wherein the first volume is adjacent the openings.

20 120. The building of claim 119 wherein each of the modules comprises one or more second shear connectors, and wherein the building comprises:

at least one second first closure member closing lateral sides of a second volume between the modules that includes the one or more second shear connectors; and

concrete occupying the second volume,

wherein the second volume is spaced apart from the first volume and adjacent the openings in the modules.

121. The building of claim 118 wherein the frame of each module comprises at least
5 part of a rectangular parallelepiped frame of an intermodal shipping container.

122. A building comprising:

a first volumetric construction module comprising a frame, the frame
comprising a first segment;

10 a volume of a composite segment, the volume integrating the first
segment; and

concrete occupying the volume.

123. A building according to claim 122, comprising a structure adjacent the first
volumetric construction module, the adjacent structure comprising a second segment,
wherein the volume integrates the first segment and the second segment.

15 124. A building according to claim 122, wherein the adjacent structure comprises a
second volumetric construction module.

125. A building according to claim 122, wherein the adjacent structure comprises an
expansion space.

20 126. A building according to claim 122, wherein the adjacent structure comprises a
partially constructed building.

127. A building according to any one of claims 123 to 126, wherein the volume contains at least a portion of the first and second segments, wherein boundaries of the volume are formed by temporary formwork.

5 128. A building according to any one of claims 123 to 127 further comprising a base isolation system.

129. A method according to claim 4 wherein the adjacent structure comprises a second volumetric construction module comprising a frame including the second segment.

10 130. A method according to claim 129 wherein the adjacent structure comprises a second volumetric construction module comprising a frame including the second segment.

131. A method according to any one of claims 1-4, 129 and 130 wherein the curable material comprises a high strength curable material.

132. A method according to claim 131 wherein the curable material comprises carbon fibre reinforced polymer or high strength concrete.

15 133. A method according to claim 7, wherein step (a)(ii) comprises coupling the first segment and the second segment by wrapping the segments with fibre reinforced polymer wrap.