

PREFABRICATED VOLUMETRIC MODULE DESIGN, FABRICATION, ASSEMBLY AND INSTALLATION METHOD

Technical Field

[001] Embodiments of the invention relate to Prefabricated Prefinished Volumetric Construction (PPVC) and more specifically to prefabricated volumetric modules comprising of prefabricated profiled wall panels, floor and ceiling slabs assembled by means of mechanical joints; and to a method of installing the same on a building under construction with conventional reinforced concrete structural frame and design to integrate the prefabricated volumetric modules for greater structural reliability and designers' and end-users' flexibility.

Background of Related Art

[002] Prefabricated Prefinished Volumetric Construction (PPVC) is a relatively new construction method introduced to the construction industry to enhance construction productivity and quality. This construction technique requires building modules to be fabricated and finished off-site in a factory, before they are delivered to the construction site for installation on a building under construction. After positioned in place, the building modules are connected and integrated as parts of the building with structural continuity transferring loads and providing structural stability to the building.

[003] A prefabricated volumetric module may comprise both structural and non-structural elements such as walls, columns, beams, slabs and/or façade. The walls, columns, beams and slabs can be constructed from materials such as concrete, Reinforced Concrete (RC), Steel-Concrete Composite (SCC), High Performance Cementitious Composite (HPCC), Ultra-High Performance Concrete (UHPC) or steel, while the façade can be constructed of cement-based panels, aluminium panels or curtain wall systems, as specified by the designer and/or end-user.

[004] Current technologies for fabricating the volumetric modules include (i) the use of conventional RC walls, columns, beams and/or slab which can be cast monolithically or in several operations with cold-joints to form the volumetric module, (ii) the use of RC walls, columns, beams, RC or SCC slab with walls infilled with prefabricated cement-

based or calcium silicate panels to form the volumetric module and (iii) the use of structural steel frame, RC or SCC slab with wall infilled with prefabricated cement-based or calcium silicate panels to form the volumetric module. A prefabricated volumetric module is typically completed with finishes for walls, floors and ceiling before it is delivered to the construction site for installation.

[005] Upon delivery to the construction site, the prefabricated volumetric module is hoisted using lifting equipment to position it on a building under construction, where it is connected and integrated as parts of the building with structural continuity transferring loads and providing structural stability to the building. In general, there are two methods for connecting and integrating these prefabricated volumetric modules with the building, namely through, (i) the use of steel connectors attached to the structural elements of the prefabricated volumetric modules and building; or (ii) the use of cement-based grout to bond over-lapping steel reinforcements and/or steel reinforcements spliced using steel connectors.

[006] Current technologies and methodologies for PPVC are often tedious with multiple steps and constraints in the fabrication of the volumetric module; and often require difficult and complex operations such as pressure grouting and fastening of concealed steel connectors, to connect and integrate the prefabricated volumetric modules structurally. Conventional RC PPVC modules can also weigh up to 35 tonnes requiring high capacity lifting equipment to position them on the building under construction. High capacity lifting equipment are costly to deploy and the maximum size of the prefabricated volumetric modules are often governed by the capacity of the lifting equipment to hoist them in place. Further, conventional RC PPVC modules typically relies on structural shear walls for connection and integration with the building and adjacent PPVC modules which provides little or no flexibility for designer and/or end-user to modify the layout of the unit.

[007] Recent innovations and patent applications of PPVC technologies and methodologies have focused on improving the connecting of adjoining PPVC units, such as the development of (i) a manufacturing process to cast PPVC modules' slab, wall and roof slab against the adjoining PPVC module completed earlier in series, to ensure these PPVC modules can be assembled on site with very small tolerances to overcome construction dimensional errors; and (ii) connectors between PPVC modules to integrate

them structurally with enhanced safety, reliability and ease of installation as discussed in Singapore patent application no. 10201610152Q.

[008] In view of the above and other problems, it is highly desirable to have improved prefabricated volumetric module that can be fabricated, assembled, connected and integrated structurally efficiently; is light-weight to maximise its dimensions for higher productivity and/or to reduce the costs for deploying high capacity lifting equipment; and provides greater flexibility for designer and/or end-user to modify the layout of the building unit layout.

Summary of Invention

[009] The invention aims to provide a light-weight prefabricated volumetric module (aka PPVC module) that can be fabricated by producing discrete wall panels, floor and ceiling slabs and assembling them quickly using mechanical fasteners; a method of installing the same on a building under construction with greater tolerance to construction dimensional errors using simple concreting technique that is reliable and cost effective; and a structural system for connecting and integrating such PPVC modules with the building that provides greater flexibility for designer and/or end-user to modify the building unit layout.

[0010] According to the present invention, there is provided a method of manufacturing a PPVC module including the steps of:

- a) casting a profiled concrete floor slab, with cast-in anchor elements along its edges/perimeters for connection with a plurality of profiled concrete wall panels;
- b) casting a plurality of profiled concrete wall panels, with connecting holes along its edges/perimeter for connection with the profiled concrete floor slab and a profiled concrete ceiling slab;
- c) casting a profiled concrete ceiling slab, with connecting holes along its edges/perimeter for connection with the profiled concrete wall panels; and
- d) assembling the profiled concrete floor slab, the plurality of profiled concrete wall panels, profiled concrete ceiling slab to form a prefabricated volumetric module using mechanical connections.

[0011] Preferably, the profiled concrete floor slab is strengthened at the locations of the column and/or wall positions, with protruding connection loops and/or ties to facilitate structural tying and integrating of the PPVC module with the building, thereby ensuring horizontal continuity of the PPVC module floor slab with transfer of horizontal forces to the building lateral force resisting members.

[0012] Preferably, the profiled concrete wall panels are adapted to be part of a formwork system at the locations of the beam, column and/or wall positions to receive fresh concrete after such PPVC modules and reinforcements are positioned in place on the building. This ensures vertical and horizontal continuity of the PPVC modules with transfer of vertical and horizontal forces to the building foundations and lateral force resisting members, respectively. Segments of the profiled concrete wall panels may be designed to be removable at locations away from the columns and/or walls to provide greater flexibility for the designer and/or end-user to modify the building unit layout. The profiled concrete wall panels may be strengthened with steel sections to withstand the concrete hydrostatic pressure during casting, where necessary.

[0013] Preferably, the profiled concrete ceiling slab is adapted to be part of the formwork system at the locations of the beam, column and/or wall positions to receive fresh concrete after the PPVC modules and reinforcements are positioned in place on the building. This ensures vertical and horizontal continuity of the PPVC modules with transfer of vertical and horizontal forces to the building foundations and lateral force resisting members, respectively. The profiled ceiling slab is designed to withstand imposed construction loads before the upper PPVC module is positioned in place or to support the RC roof slab concreting works. The profiled concrete ceiling slab may be strengthened with steel sections to withstand the imposed construction loads, where necessary.

[0014] The concrete used in casting of the profiled floor slab, wall panels and ceiling slab may be RC, SCC, FRCC, HPCC or UHPC.

[0015] According to the present invention, there is provided a method of installing a PPVC module, to assemble, connect and integrate a plurality of PPVC modules on a building under construction. The method of installation including the steps of:

- a) preparing a supporting slab/floor with column and/or wall reinforcement splice bars to receive a plurality of PPVC modules;

- b) lifting and positioning a PPVC module with engaging means of the PPVC module slab engaged with the column and/or wall reinforcement splice bars;
- c) repeating step (b) for each successive PPVC modules on the same storey of the building;
- d) placing reinforcements for beams, columns and/or walls within a formwork defined by the assembled PPVC modules and the supporting slab/floor;
- e) casting of the beams, columns and/or walls to connect and integrate the PPVC modules with the building structurally using conventional concreting techniques; and
- f) repeating steps (b) to (e) until the uppermost storey of the PPVC modules installation is completed.

[0016] According to the present invention, there is provided a simplified structural framing system for a building constructed with PPVC modules using conventional slab, beam, wall and/or column system in lieu of proprietary connectors, to connect and integrate the PPVC modules structurally with a building including the steps of:

- a) connecting engaging means of a PPVC module floor slab to associated reinforcement splice bars of the lower portion of the storey columns and/or walls;
- b) connecting PPVC modules vertically using conventional reinforced concrete column and/or wall splicing details; and
- c) connecting the PPVC modules using horizontal elements such as concrete beams to integrate the PPVC modules as an overall floor slab to receive the next level of PPVC modules.

[0017] The connection of step a) above may achieved using protruding connection loops and/or ties overlapping columns' and/or walls' splice reinforcement bars.

[0018] Preferably, the simplified structural framing system for the PPVC building includes connecting beams in orthogonal directions cast together with the columns and/or walls to further enhance vertical and horizontal continuity of the PPVC modules to transfer vertical and horizontal forces to the building foundations and lateral force resisting members, respectively; as well as to further enhance building integrity for water-tightness.

[0019] The advantages of this invention include but are not limited to:

- a) higher productivity in fabrication of the prefabricated volumetric modules through assembly of discrete components using mechanical connections to form the prefabricated volumetric modules;
- b) reduction of prefabricated volumetric modules' weight for ease of logistic arrangements and reduced costs for deploying high capacity lifting equipment;
- c) greater construction tolerances with cast-in-situ structural elements in between PPVC modules to absorb dimensional variations due to both off-site prefabrication and on-site construction;
- d) simplification of the building structural design and elimination of complex processes during construction stage to enhance site productivity and minimise opportunity for errors; and
- e) provision of greater flexibility for designer and/or end-user to modify the building unit layout.

Brief Description of the Drawings

[0020] Embodiments of the invention are disclosed hereinafter with reference to the drawings, in which:

[0021] FIG. 1A is a perspective view of a prefabricated profiled floor slab according to one embodiment of the invention;

[0022] FIG. 1B is a top view of the prefabricated profiled floor slab of FIG. 1A;

[0023] FIG. 1C is a side view of the prefabricated profiled floor slab of FIG. 1A;

[0024] FIG. 1D is a front view of the prefabricated profiled floor slab of FIG. 1A;

[0025] FIG. 1E is a typical slab reinforcement of the prefabricated profiled floor slab of FIG. 1A;

[0026] FIG. 1F is a typical slab formwork for the prefabricated profiled floor slab of FIG. 1A;

[0027] FIG. 2A is a perspective view of a prefabricated profiled wall panel according to one embodiment of the invention;

[0028] FIG. 2B is a side view of the prefabricated profiled wall panel of FIG. 2A;

[0029] FIG. 2C is a top view of the prefabricated profiled wall panel of FIG. 2A;

[0030] FIG. 2D is a perspective view of a prefabricated profiled wall panel consisting of detachable prefabricated profiled wall panel segments according to one embodiment of the invention;

[0031] FIG. 2E is a connection detail along the edge of a detachable prefabricated profiled wall panel segment of FIG. 2D;

[0032] FIG. 2F is a prefabricated profiled end wall panel that can be used on a prefabricated volumetric module installed at the building edge with no adjoining prefabricated volumetric module;

[0033] FIG. 3A is a perspective view of a prefabricated profiled ceiling slab according to one embodiment of the invention;

[0034] FIG. 3B is a top view of the prefabricated profiled ceiling slab of FIG. 3A;

[0035] FIG. 3C is a side view of the prefabricated profiled ceiling slab of FIG. 3A;

[0036] FIG. 3D is a front view of the prefabricated profiled ceiling slab of FIG. 3A;

[0037] FIG. 4A is a perspective view showing sequence of the prefabricated volumetric module assembly in which the prefabricated profiled wall panels are connected to the prefabricated profiled floor slab first, followed by connecting of the prefabricated profiled ceiling slabs to the prefabricated profiled wall panels;

[0038] FIG. 4B is a perspective view of an assembled prefabricated volumetric module assembled using the prefabricated profiled floor slab, prefabricated profiled wall panels and prefabricated profiled ceiling slab of FIGs. 1A, 2A and 3A, respectively;

[0039] FIG. 4C is a side view of the prefabricated volumetric module of FIG. 4B;

[0040] FIG. 4D is a top view of the prefabricated volumetric module of FIG. 4B;

[0041] FIG. 4E is a front view of the prefabricated volumetric module of FIG. 4B;

[0042] FIG. 4F is a partial close-up view the connection between the prefabricated profiled wall panels and prefabricated profiled ceiling slab of FIG. 4B;

[0043] FIG. 4G is a partial close-up view of the connection between the prefabricated profiled wall panels and prefabricated profiled floor slab of FIG. 4B;

[0044] FIGs. 5A to 5J show a sequence of installation of a number of prefabricated volumetric modules on a building under construction, in which:

[0045] FIG. 5A is a construction floor designed to receive the prefabricated volumetric modules;

[0046] FIG. 5B is the installation of a first prefabricated volumetric module onto the construction floor of FIG. 5A;

[0047] FIG. 5C is a partial close-up view of the connection between the column and/or wall splicing reinforcement and prefabricated floor slab connection loops and/or ties;

[0048] FIG. 5D is the installation of the last prefabricated volumetric module onto the construction floor of FIG. 5A;

[0049] FIG. 5E is a partial close-up view of the sealed gap between the PPVC modules;

[0050] FIG. 5F is the installation of prefabricated column reinforcement cages into position;

[0051] FIG. 5G is the installation of the prefabricated beam reinforcement cage and slab reinforcement mesh into position;

[0052] FIG. 5H is the installation of the wall reinforcement mesh into position and closing of end prefabricated volumetric module end wall formwork (if the prefabricated end wall panel is not used);

[0053] FIG. 5I is the concreting of the slab, beams, walls and/or columns;

[0054] FIG. 5J is the installation of the prefabricated volumetric modules onto the completed prefabricated volumetric modules at the lower floor(s);

[0055] FIG. 6 is a lifting frame for lifting the PPVC module onto the construction floor;

[0056] FIG. 7 is the various configurations and arrangement of the PPVC modules that can be adapted for a typical unit of a residential development; and

[0057] FIG. 8 is the structural elements of a building constructed with the prefabricated volumetric modules.

Detailed Description of Preferred Embodiments of the Invention

[0058] In the following description, numerous specific details are set forth to provide a thorough understanding of the embodiments of the invention. It should be understood, however, to one skilled in the art, that embodiments of the invention may be practiced without some or all of these specific details. In other instances, well known process operations are not described in detail in order not to unnecessarily obscure pertinent aspects of embodiments being described. It should be understood that the embodiments as set forth are intended to be illustrative and are not to limit the scope of the invention in any way. In the drawings, like reference numerals refer to same or similar functionalities or features throughout the several views.

Fabrication of PPVC Module

[0059] With reference to FIGs. 1A-1F, the method of casting profiled floor slab 20 of PPVC module 10 includes the steps of:

- a) setting up a profiled floor slab formwork 27 based on the required PPVC module layout;
- b) setting slab reinforcement 26, protruding connection loops and/or ties 22 and splice reinforcements 23 into the floor slab formwork (where applicable);
- c) setting cast-in anchor bolts 21 into the profiled floor slab formwork;
- d) pouring concrete into the profiled floor slab formwork 27; and
- e) allowing profiled floor slab 20 to set and cure.

[0060] The profiled floor slab formwork 27 includes any suitable formwork configurations for the intended PPVC module 10 with recessed profiles 24 at the column and/or wall positions, kerb profiles 25 and pre-formed holes 28 for inserting cast-in anchor bolts 21 along the edge/perimeter of profiled floor slab 20 (where applicable) to receive the profiled wall panels 30 and façade (where applicable).

[0061] With reference to FIGs 1A-1F, the resultant floor slab 20 can have varying thickness dimensions and profiles to meet any particular requirement of the project and is characterised with the protruding steel connection loops and/or ties 22 and splice reinforcements 23 for connection and integration with the building structural system; and cast-in anchor bolts 21 for connection with the profiled wall panels 30 and façade (where applicable).

[0062] With reference to FIGs 2A-2F, the method of casting the profiled wall panels 30, profiled wall panels segments 31a, 31b, 31c and profiled end wall panels 31d of PPVC module 10 includes the steps of:

- a) setting up a profiled wall panel formwork;
- b) setting wall reinforcement into the profiled wall panel formwork (where applicable);
- c) pouring concrete into the profiled wall panel formwork; and
- d) allowing profiled wall panels 30, profiled wall panel segments 31a, 31b, 31c and profiled end wall panel 31d to set and cure.

[0063] To elaborate, step b) may not be necessary for example when profiled wall panel 30, profiled wall panels segments 31a, 31b, 31c and profiled end wall panels 31d are cast from UHPC.

[0064] The profiled wall panel formwork includes any suitable formwork configurations for the intended PPVC module 10 with recessed profile 33 at the column and/or wall positions, recessed profile 34 at the beam positions, rib profiles 35, opening profile 36 and inserts and/or block-outs to form connecting holes along the edge/perimeter of the profiled wall panels 30, profiled wall panels segments 31a, 31b, 31c, profiled end wall panel 31d for connection with profiled floor slab 20, profiled ceiling slab 40 and adjacent profiled wall panels (where applicable).

[0065] With reference to FIGs 2A-2F, the profiled wall panels 30, wall panels segments 31a, 31b, 31c, end wall panels 31d can have varying thickness, dimensions and profiles to meet any particular requirement of the project and is characterised with the connecting holes 37 along its edge/perimeter for connection with profiled floor slab 20, profiled ceiling slab 40, adjacent profiled wall panels and façade (where applicable). Profiled wall panels 30, profiled wall panel segments 31a, 31b, 31c, end wall panels 31d are further characterised by its design to act as formwork for columns and/or walls and beams when positioned in place on the building under construction to resist the fresh concrete hydrostatic pressure during the concreting works. Profiled wall panel segments 31b are further characterised by its design to be removable by undoing the mechanical connections 21, 32, 41 along their edge/perimeter, to allow flexibility for the designer and/or end-user to modify the building unit layout.

[0066] Preferably, profiled wall panel 31d is to be used for PPVC modules at the end wall of the building where there is no adjacent PPVC module to form an enclosed formwork for the column and/or wall casting. Alternatively, conventional formwork can be used to construct the cast-in-situ end wall against the PPVC module profiled wall panel 30, 31a, 31b, 31c to connect and integrate the PPVC module structurally with the building.

[0067] For clarity, it should be noted that profiled wall panel 31a, 31b, 31c and 31d are subsets of profiled wall panel 30; and where profiled wall panel 30 is referred hereafter in this write-up, it includes its subsets of profiled wall panel 31a, 31b, 31c and 31d, wherever applicable.

[0068] With reference to FIGs 3A-3D, the method of casting the profiled ceiling slab 40 of PPVC module 10 includes the steps of:

- a) setting up a profiled ceiling slab formwork;
- b) setting slab reinforcement into the profiled ceiling slab formwork (where applicable);
- c) pouring concrete into the profiled ceiling slab formwork; and
- d) allowing profiled ceiling slab 40 to set and cure.

[0069] For instance, step b) may not be necessary when profiled wall ceiling slab 40 is cast from UHPC.

[0070] The profiled ceiling slab formwork includes any suitable formwork configurations for the intended PPVC module 10 with recessed profile 42 at the beam position and block-outs to form connecting holes 43 along the edge/perimeter of the profiled ceiling slab 40 for connection with profiled wall panels 30, profiled wall panel segments 31a, 31b, 31c, profiled end wall panel 31d and façade (where applicable).

[0071] With reference to FIGs 3A-3D, profiled ceiling slab 40 can have varying thickness, dimensions and profiles to meet any particular requirement of the project and is characterised with the connecting holes 43 along its edge/perimeter for connection with profiled wall panels 30, profiled wall panel segments 31a, 31b, 31c, profiled end wall panel 31d and façade (where applicable). Where the structural framing system for the PPVC building includes connecting beams in orthogonal directions cast together with the columns and/or walls, profiled ceiling slab 40 is further characterised by its design to act as formwork for the beams when positioned in placed on the building under construction to resist the fresh concrete hydrostatic pressure during the concreting works.

[0072] With reference to FIGs 4A and 4B, the method of assembling prefabricated profiled floor slab 20, prefabricated profiled wall panels 30, prefabricated profiled ceiling slab 40 and façade (where applicable) to form PPVC module 10 includes the steps of:

- a) setting prefabricated profiled floor slab 20;

- b) assembling and securing prefabricated profiled wall panels 30 and façade (where applicable) together with prefabricated profiled floor slab 20 using mechanical connections 21 such as bolts and nuts; and
- c) assembling and securing prefabricated profiled ceiling slab 40 together with prefabricated profiled wall panels 30 and façade (where applicable) using mechanical connections 41 such as bolts and nuts.

[0073] When assembled and connected mechanically, prefabricated profiled floor slab 20, prefabricated profiled ceiling slab 40, prefabricated profiled wall panels 30 and façade (where applicable) are rigidly connected and allow minimum movements between the individual components.

[0074] When the prefabricated profiled wall panels 30 and profiled ceiling slab 40 are constructed of UHPC, the weight of the PPVC module 10 can be reduced significantly compared to PPVC modules constructed of RC. The assembly of PPVC module 10 is preferably performed off-site.

Assembly and Installation of PPVC Modules on Building Under Construction

[0075] The method of installing a first level of PPVC modules on a building under construction as shown in FIGs 5A-5J includes the steps of:

- a) preparing a structural floor plate 51 to receive successive layers of PPVC modules with columns and/or walls reinforcement splicing bars 52 protruding from the top of structural floor plate 51;
- b) lifting a first PPVC module 10 using lifting frame 60 pulling lifting cable 61 over structural floor plate 51 and lowering PPVC module 10 into position with protruding connection loops and/or ties 22 looping through columns and/or walls reinforcement splicing bars 52 and floor slab splice reinforcements 23 anchoring to the columns, walls, beams and/or slab;
- c) repeating step (b) to position all PPVC modules of the same floor level in place as required for the construction sequence;
- d) sealing of gaps between the PPVC modules by means of backer rod 58a, gasket 58b, sealant 58c and cement grout 59 or the like;

- e) placing prefabricated columns and/or walls steel reinforcements 53 in the space defined by adjoining PPVC modules' recessed profile 33 followed by prefabricated beams steel reinforcements 54 in the space defined by adjoining PPVC modules' recessed profile 34, 42 and slab reinforcements 55 (where applicable);
- f) placing of end wall steel reinforcement 56 and end wall external formwork 57 on PPVC modules that form external walls of the building (if profiled wall panel 31d is not used);
- g) casting of the columns, walls, beams and/or slab (where applicable) in spaces defined by adjoining PPVC modules' recessed profile 33, 34, 42, supporting slab and external walls; and
- h) repeating steps (b) to (g) until the top storey of PPVC modules are constructed.

[0076] Successive floors are added following essentially the steps of b) to g) except that the PPVC modules of successive floors are aligned and stacked on top of an installed PPVC module.

[0077] As shown in Fig 6, upon delivered to the building construction site, PPVC module 10 may be lifted using lifting cable 61 connected to profiled floor slab 20 and lifting frame 60 anchoring the lifting cable away from PPVC module 10 to avoid exerting any direct force on profiled wall panels 30 and profiled ceiling slab 40, to mitigate damages to PPVC module 10 and the finishes installed within it.

[0078] The above-described installation method for the PPVC modules uses simple conventional concrete construction method and does not involve complex operations such as pressure grouting and fastening of concealed steel connectors to connect and integrate the PPVC modules structurally. In-situ concrete casting operations are also limited to the key structural elements such as beams, columns and/or walls which do not require large volume of concrete, hence limiting the amount of labour-intensive works on site.

[0079] In-situ concrete casting operations to key structural elements such as columns and/or walls, beams and/or slabs between the prefabricated modules 10 provide greater construction tolerances to rectify dimensional variations due to off-site prefabrication as well as on-site construction works; while ensuring building integrity and water-tightness.

[0080] Preferably, with prefabricated profiled wall panel segments 31b designed as removable panels, profiled wall panel segments 31b can be removed easily by the designer and/or end-users to create wall openings in between adjacent PPVC modules.

[0081] According to the present invention, the PPVC module 10 can be adapted with different configurations and arrangements by varying the recess profiles 24, 33, 34, 42 as shown in FIG. 7 to suit the different layouts of a building and requirements of the designers.

Structural Analysis and Design of PPVC Building

[0082] According to the present invention following the method of manufacturing, assembly and installation of PPVC modules 10, the structural analysis and design of the PPVC building are simplified and do not require complex analysis and/or testing for joints connecting and integrating the PPVC modules 10 structurally with the building under construction, as the structural joints are constructed with conventional cast-in-situ beams, slabs, columns and/or walls as shown in FIG 8.

[0083] With the invention, the profiled floor slab 20, profiled wall panels 30, profiled wall panel segments 31a, 31b, 31c, profiled end wall panel 31d, profiled ceiling slab 40 and/or façade of a prefabricated volumetric module can be prefabricated as individual components and assembled off-site using mechanical fasteners to form the PPVC module 10 to reduce production time and costs.

[0084] The prefabricated profiled wall panels 30, wall panels segments 31a, 31b, 31c, end wall panel 31d and prefabricated profiled ceiling slab panels 40 are designed to act as permanent formwork upon assembly of the PPVC modules on site, further enhancing construction productivity and reducing construction costs. The recessed profiles defined by the PPVC modules allow steel reinforcements to be put in place directly for conventional cast-in-situ concrete casting of the structural elements such as columns and/or walls 81, beams 82, cast-in-situ slabs 83 and PPVC module slab 20, to connect and integrate the PPVC modules 10 together to form parts of the building structural system 80. The prefabricated profiled wall panel segments 31b at the non-structural column and/or wall locations are non-structural elements that are also designed to be removable to provide the designer and/or end-user with greater flexibility to modify the layout of the unit.

[0085] While specific embodiments have been described and illustrated, it is understood that many changes, modifications, variations and combinations thereof could be made to the present invention without departing from the scope of the present invention. For example, the light-weight PPVC module of the present invention may be cast monolithically.

CLAIMS

1. A prefabricated profiled concrete wall panel 30 for use in the assembly of a PPVC module 10, the wall panel 30 having opposing exterior and interior vertical faces generally parallel to one another bounded along their perimeter by a pair of vertical side edges and a pair of horizontal top and bottom edges, end flange on the bottom edge,

wherein the profile of the concrete wall panel defines at least one recessed channel 33 spanning vertically between the horizontal top and bottom edges on its exterior vertical face, the recessed channel 33 partly defining a space to receive prefabricated column and/or wall reinforcement and the exterior vertical face of the wall panel 30 is adapted to be part of a permanent formwork for casting-in-situ concreting operation when the assembled PPVC module 10 is positioned in place on the building.

2. The prefabricated profiled concrete wall panel 30 of claim 1 whereby the recessed channel 33 is located on one side of the wall panel.
3. The prefabricated profiled concrete wall panel 30 of claim 1 whereby the recessed channel 33 is located at the centre section of the wall panel.
4. The prefabricated profiled concrete wall panel 30 according to any one of claims 1-3 further comprising a plurality of supporting rib profiles 35.
5. The prefabricated profiled concrete wall panel 30 of according to any one of claims 1-4 having a series of traverse bolt holes along the end flange extending from its bottom edge and a series of traverse bolt holes extending horizontally near its top edge.
6. The prefabricated profiled concrete wall panel 30 of according to any one of claims 1-5 wherein the concrete wall panel is cast from RC, SCC, FRCC, HPCC or UHPC.

7. The prefabricated profiled concrete wall panel 30 according to any one of claims 1-6 comprises one or more detachable segments 31a, 31b, 31c.
8. The prefabricated profiled concrete wall panel 30 according to any one of claims 1-6 reinforced with reinforcement cast in the concrete.
9. The prefabricated profiled concrete wall panel 30 according to any one of claims 1-6 comprising recessed profile 34 along the top edge defining a space to receive prefabricated beam reinforcement.
10. A prefabricated profiled concrete ceiling slab 40 for use in the assembly of a PPVC module 10, the ceiling slab 40 having opposing top and bottom horizontal faces generally parallel to one another, generally quadrilateral dimensions, one or more of its four sides arranged to be adjoined with a matching PPVC module 10 comprising:

end flanges extending downwardly from the one or more of its four sides for connecting to associated profiled concrete wall panels 30, the end flanges each partly defining a recessed channel to receive prefabricated beam reinforcement and adapted to be part of a permanent formwork for casting-in-situ concreting operation when the assembled PPVC module is positioned in place on the building; and

recessed profile 42 extending generally parallel to the remaining sides not arranged to be adjoined with another PPVC module 10, the recessed profile 42 defining a channel to receive prefabricated beam reinforcement and adapted to be part of a permanent formwork for casting-in-situ concreting operation when the assembled PPVC module 10 is positioned in place on the building.
11. The prefabricated profiled concrete ceiling slab 40 of claim 10 reinforced with slab reinforcement.
12. The prefabricated profiled concrete ceiling slab 40 of claims 10 or 11 having a series of traverse bolt holes along the end flanges.

13. The prefabricated profiled concrete ceiling slab 40 of according to any one of claims 10-12 wherein the concrete ceiling slab is cast from RC, SCC, FRCC, HPCC or UHPC.
14. A prefabricated profiled concrete floor slab 20 for use in the assembly of a PPVC module 10, the floor slab 20 having opposing top and bottom horizontal faces generally parallel to one another, generally quadrilateral dimensions, one or more of its four sides arranged to each be connected to an associated prefabricated profiled concrete wall panel 30 comprising:
- end flanges extending upwardly along the one or more of its four sides;
- anchoring means extending upwardly from the end flanges for anchoring of associated prefabricated profiled concrete wall panels 30;
- one or more recesses 24 along the edge of the one or more of its four sides, each recess matching to the recessed channel 33 of the associated prefabricated profiled concrete wall panel 30 to receive prefabricated column or wall reinforcement and such sides adapted to be part of a permanent formwork for casting-in-situ concreting operation when the assembled PPVC module 10 is positioned in place on the building; and
- first engaging means 22 extending horizontally from the recessed channel edges, for engagement with the prefabricated column or wall splicing reinforcement.
15. The prefabricated profiled concrete floor slab 20 of claim 14 further comprising second engaging means 23 extending horizontally from one or more sides not arranged to be connected to an associated prefabricated profiled concrete wall panel 30, for connection and integration with the building structural system.
16. The prefabricated profiled concrete floor slab 20 of claims 14 or 15 further comprising slab reinforcement.

17. The prefabricated profiled concrete floor slab 20 according to any one of claims 14-16 wherein the first engaging means 22 includes connection loops and/or ties cast in the concrete.
18. The prefabricated profiled concrete wall panel floor slab 20 of according to any one of claims 14-17 wherein the prefabricated profiled concrete floor slab 20 is cast from RC, SCC, FRCC, HPCC or UHPC.
19. A PPVC module 10 for a building assembled from:
 - one or more prefabricated profiled concrete wall panels 30 according to any one of claims 1-9;
 - a prefabricated profiled concrete ceiling slab 40 according to any one of claims 10-13; and
 - a prefabricated profiled concrete floor slab 20 according to any one of claims 14-18.
20. A PPVC module 10 for a building of claim 19 wherein the one or more recess channels 33 of the prefabricated concrete profiled wall panel 30 register with the recess 24 of the prefabricated profiled concrete floor slab 20 forming uninterrupted recessed channels spanning vertically from the top and bottom of the PPVC module 10.
21. A PPVC module 10 for a building of claim 19 wherein an opening profile 36 in the prefabricated profiled concrete wall panel 30 registers with the recessed profile 42 of the prefabricated profiled concrete ceiling slab 40 forming an uninterrupted recessed channel along a top edge of the PPVC module 10.
22. A PPVC module 10 for a building according to any one of claims 19-21 wherein the prefabricated profiled concrete wall panels 30, prefabricated profiled concrete ceiling slab 40 and prefabricated profiled concrete floor slab 20 are connected using mechanical fasteners.
23. A PPVC module 10 according to any one of claims 19-22 comprising a façade that can be constructed of cement-based panels, aluminium panels or curtain wall systems.

24. A PPVC module arrangement for a building comprising a plurality of PPVC modules 10 according to any one of claims 19-23 placed on a building under construction wherein columns and/or walls splicing reinforcements are engaged with the first engaging means of the profiled floor slab 20.
25. A PPVC module arrangement for a building according to claim 24, wherein reinforcement for the building columns, walls, beams and slabs can be placed in position directly within the PPVC module arrangement for in-situ concrete casting of the structural elements comprising columns, walls, beams and/or slabs.
26. The PPVC module arrangement for a building according to claim 24, wherein the prefabricated profiled wall panels 30 and prefabricated profiled ceiling slab 40 act as formwork for in-situ concrete casting of the structural elements comprising columns, walls, beams and/or slabs.
27. A PPVC module arrangement for a building according to claim 24 further comprising PPVC modules 10 according to any one of claims 19-23 placed on top of one another and connected and integrated as part of the building.
28. A PPVC module arrangement for a building according to any one of claims 24-27 that allows the designer of the building to analyse and design the building structural system using conventional design and construction methods.
29. The method of installing a first level of a plurality of PPVC modules 10 according to any of claims 19-23 on a building under construction comprising the steps of:
- a) preparing a structural floor plate with columns and or walls reinforcement splicing bars protruding from the top of structural floor plate to receive the PPVC modules 10;
 - b) lifting a first PPVC module 10 and lowering said first PPVC module 10 into position with first engaging means 22 of the profiled concrete floor slab 20 of the PPVC module 10 engaged through the columns and or walls reinforcement splicing bars;

- c) lifting and lowering the remaining PPVC modules 10 into position with first engaging means 22 of the concrete floor slab 20 of the PPVC module 10 engaged through the columns and or walls reinforcement splicing bars as required for the construction sequence;
- d) sealing of gaps formed between end flanges of the profiled wall panels 30 of adjacent PPVC modules 10 and gaps formed between end flanges of adjacent PPVC modules 10;
- e) placing prefabricated columns and/or walls reinforcements in the space defined by the recessed channels of adjacent PPVC modules 10 followed by prefabricated beams reinforcements in the space defined by adjoining PPVC modules 10 recessed profile;
- f) casting of the columns, walls, beams in spaces defined by the recessed profiles of adjoining PPVC modules 10.