

A CONNECTING METHOD AND A CONNECTOR ASSEMBLY FOR A MULTI-STOREY MODULAR BUILDING

FIELD OF INVENTION

- 5 The present invention relates broadly to a connecting method and a connector assembly for a multi-storey modular building.

BACKGROUND

- 10 Any mention and/or discussion of prior art throughout the specification should not be considered, in any way, as an admission that this prior art is well known or forms part of common general knowledge in the field.

- Prefabricated Prefinished Volumetric Construction (PPVC) refers to a construction method in which free-standing volumetric modules (complete with finishes for walls, floors and ceilings) are constructed and assembled in an accredited fabrication facility, in accordance with any accredited fabrication method, and then installed in a building under building works
15 [<https://www.bca.gov.sg/BuildableDesign/ppvc.html>].

- Generally, the attractiveness of PPVC as a construction method lies in cost- and time-saving compared to conventional construction methods. Also, PPVC allows for much of the work to be done off-site in a controlled manufacturing environment, which is generally desirable to
20 raise construction productivity and quality. The off-site manufactured modules are then installed at the building site, which includes the lateral and horizontal interconnection of the modules. One of the challenges faced in PPVC construction relates to providing interconnection methods and connector assemblies for the modules that can provide or enhance the required structural integrity of the constructed building, while being as time-,
25 labour- and cost-efficient as possible. This is particularly relevant to the application of PPVC for multi-storey buildings.

Embodiments of the present invention seek to address at least one of the above challenges.

SUMMARY

- 30 In accordance with a first aspect of the present invention, there is provided a connecting method for assembly of a multi-storey modular building, the method comprising welding at least first and second coupling elements, at respective first ends thereof, to an end of a column of a first module for the modular building and, at respective second ends thereof, to ends of respective ceiling beams of the first module for the modular building; welding at least
35 third and fourth coupling elements, at respective first ends thereof, to an end of a column of a

second module for the modular building and, at respective second ends thereof, to ends of respective floor beams of the second module for the modular building; and sandwiching a gusset plate between vertically adjoining ends of the columns of the stacked first and second modules of the modular building such that the gusset plate extends between vertically adjoining ones of the coupling elements welded to the respective vertically adjoining ends of the columns of the stacked first and second modules of the modular building.

In accordance with a second aspect of the present invention, there is provided a connector assembly for a multi-storey modular building, the connector assembly comprising at least four coupling elements, each coupling element configured for welding, at a first end thereof, to an end of a column of a module for the modular building and, at a second end thereof, to an end of a beam of the module for the modular building; and a gusset plate configured for, in an assembled state of the connector assembly, sandwiching between vertically adjoining ends of columns of stacked modules of the modular building such that the gusset plate extends between vertically adjoining coupling elements welded to respective ones of the vertically adjoining ends of the columns of the stacked modules of the modular building.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

FIG. 1 shows an isotropic view of a steel chassis for a steel / steel-composite module.

FIG. 2 shows an isotropic view of eight box-shaped modules joined together as part of a multi-storey modular building.

FIG. 3 shows the plan view of different types of typical joints J required at different locations A-E (i.e. JA, JB, JC, JD, and JE in Fig. 3) in the assembly of a multi-storey modular building, with perspective views of the joints in the inlets. As used herein, the term "joint" is not intended to refer to specific elements making up the interconnection, but is intended to generally refer to the arrangement at the interconnection region.

FIG. 4 shows a haunch-shaped coupling element according to an embodiment.

FIG. 5 shows a haunch-shaped coupling element according to another embodiment.

FIG. 6 shows a corner joint of the ceiling beams within a module according to an example embodiment.

FIG. 7 shows a corner joint of the floor beams within a module according to an example embodiment.

FIGS. 8a) to c) show isotropic views of the ceiling corner of a module according to some embodiments.

FIG. 9 shows a gusset plate for joining adjacent modules at the same corner, i.e. at a JC joint, according to an example embodiment.

- 5 FIG. 10 shows an isotropic view of the common ceiling corner (i.e. JC joint) of adjacent box-shaped modules according to an example embodiment.

FIG. 11a) shows an isotropic view illustrating that, on top of the common corner shown in Figure 10, a gusset plate is attached for tying the laterally adjoining modules together in the horizontal direction, according to an example embodiment.

- 10 FIG. 11b) shows an isotropic view illustrating the extension of respective threaded bars connected to the respective columns, in particular coupling of the threaded bars to separate respective extension threaded bars, according to an example embodiment.

- FIGS. 12a) and b) show different isotropic views illustrating that after the extension of the threaded bars as illustrated in Figure 11b), additional, i.e. upper modules can be lowered
15 down to the top of the horizontally tied modules for vertical interconnection of the modules, according to example embodiments.

- FIGS. 13a) and 13b) show an isotropic view and a section view, respectively, of the internal bolted connections at a JC joint for facilitating horizontal and vertical interconnection, according to an example embodiment, with the floor and ceiling removed for improved
20 visualization.

FIG. 13c) shows an isotropic view, partly in section, of a non-grouted connection at a joint, according to an example embodiment.

FIG. 13d) shows an isotropic view, partly in section, of a non-grouted connection at a joint, according to an example embodiment.

- 25 FIG. 14 shows a plan view of a JC joint according to an example embodiment.

FIG. 15 shows a section view of the JC joint as indicated at A-A in FIG. 14, according to an example embodiment.

FIG. 16a) and Fig. 16b) show the bolt and screw pair employed for ease of connection according to some embodiments.

- 30 FIGS. 17a) to d) show the various configurations of gussets plates for different joints according to example embodiments.

- FIGS. 18a) and b) illustrate the use of corrugated pipes precast inside composite columns to obtain a rough surface for better bonding of high strength grout embedded inside the steel-composite columns during the vertical interconnection of the modules, according to an
35 example embodiment.

FIG. 19 shows a line drawing of a shear key element welded to an end plate of a column according to an example embodiment.

FIG. 20 shows a line drawing of a locking nut for locking a threaded bar to the shear key element of FIG. 19, according to an example embodiment.

- 5 FIG. 21 shows a drawing illustrating connection of a lifting connector to the shear key element of FIG. 19, according to an example embodiment.

FIG. 22 shows an isotropic view of a JC joint using non-haunch-shaped -shaped coupling elements, according to an example embodiment.

10 DETAILED DESCRIPTION

Example embodiments of the present invention described herein provide a connection method and system for horizontally and vertically joining modular units to construct a multi-storey building using PPVC. The connection method and system according to example
15 embodiments are applicable for both steel and steel-composite modular systems. In some embodiments, the modular units comprise of four corner columns, four steel-composite floor beams, and four steel ceiling beams. In more detail, for the steel-composite floor beams, the steel beams will act together with a concrete floor slab to achieve a composite action in resisting loading. For the steel ceiling beams, the steel beams will act together with a steel
20 ceiling deck in resisting loading. The types of steel cross-section for both the steel-composite floor beams and steel ceiling beams can vary among e.g. channel section, rectangular hollow section, universal H or I section, etc. in various embodiments.

For the corner columns, steel-composite columns may be used in example embodiments, i.e. the steel corner columns can be infilled or grouted with concrete to achieve a composite action in resisting loading. However, the corner columns can be (regular) steel columns in
25 other embodiments.

According to some embodiments, one end of a coupling element is welded to the corner columns, which can e.g. be a rectangular or tubular column, and the other end of the same coupling element is welded to a steel or steel-composite beam, e.g. to the steel ceiling beam and/or the steel-composite floor beam according to some embodiments.

30 In some embodiments, the modular units are connected vertically by interconnected threaded bars on the one hand, and by bolted connections extending across a gusset plate and the coupling elements on the other hand, as will be described in more detail below. Briefly, centred threaded bars extending from the corner columns of the lower modules, which are connected to extension threaded bars in the corner columns of the upper modules by couplers,
35 form part of the vertical interconnection. The coupled threaded bars as well as the bolted connections extending across the gusset plate and the coupling elements serve to take some of

the tensional forces from the columns when the modular building is under overturning moment resulting from lateral loads such as wind and seismic loads.

As mentioned above, the columns can be steel or steel-composite columns. That is, grouting for the threaded bars is not always needed, i.e. the threaded bars can be left un-grout within the steel columns. The un-grout threaded bars may be subject to corrosion and may need inspection periodically, which can be avoided if the grouting of the threaded bars is performed, as will be described in more detail below. When the column is subject to compression, the grout and the steel section of the steel-composite columns will act together to achieve a composite action to resist the compression force in such embodiments.

As mentioned above, another part of the vertical connection is provided by the gusset plate in some embodiments, which also functions to horizontally interconnect the modules. The gusset plate will be placed over shear keys welded to the top end plates of each corner column, the top end plates in turn being welded to the columns in some embodiments. A bolted connection will integrate the gusset plate, floor beam coupling elements and ceiling beam coupling elements together. This joining technique according to some embodiments can advantageously ensure or at least improve the durability and structural performance of the joints of a multi-storey modular building. Embodiments of the present invention can serve to achieve more economical, productive and safer construction of multi-storey buildings constructed from modular units.

In some embodiments, the joints between the modules advantageously do not need periodical inspection in humid climate because the bolted connections are embedded in grout using, for example, recesses in the horizontal concrete floor slabs, so the connections are advantageously not subjected to corrosion and therefore need not be subjected to inspection, as will be described in more detail below. However, it is noted that if e.g. stainless bolts and nuts are used in some embodiments, then no grouting may be needed, eliminating the need for, for example, recesses in the concrete floor slabs in such embodiments. As mentioned above, the joining technique according to example embodiments is applicable for both steel and steel-composite modular systems for multi-storey buildings.

Also, the bolted connections according to some embodiments of the present invention can be designed using slotted holes without the need for internal threads for bolting, as will be described in more detail below.

FIG. 1 shows an isotropic view of a steel chassis 100 for a steel / steel-concrete composite module. The following description and illustrations will focus on the connection of the major structural components according to some example embodiments and hence the internal finishes, walls, windows, and mechanical, electrical and plumbing (MEP), which are understood by a person skilled in the art, are not shown or described herein.

FIG. 2 shows an isotropic view of eight box-shaped modules, four top modules e.g. 100a, 100b and four bottom modules e.g. 100c, 100d corresponding to the module 100 as shown in FIG. 1, joined together as part of a multi-storey modular building 102. This configuration is

applicable for low-rise, mid-rise and high-rise modular buildings in various embodiments. In addition, the layout of the modules may be varied to suit the architectural plan in various embodiments. It is noted that the modules 100a-d are interchangeable as top or bottom modules, and each can serve as a bottom module relative to an upper module and/or as an upper module relative to a lower module in a multi-storey building.

FIG. 3 shows the different types of joints J that typically occur at different locations A-E (i.e. JA, JB, JC, JD, and JE in Fig. 3) of a multi-storey modular building 300. Depending on their locations and module layout, the joints of a multi-storey modular building 300 usually have different configurations. The most complex joint is a JC joint, which directly connects eight modules at the same location. JC joint will be used for illustration purposes in the following description of some embodiments. However, it will be appreciated by a person skilled in the art that the other joint types can be readily implemented according to various embodiments based on the components used for a JC joint according to the described embodiments.

FIG. 4 and FIG. 5 show haunch-shaped coupling elements 400 and 500 according to respective embodiments, i.e. with and without stiffeners e.g. 502 (Fig. 5). Stiffeners e.g. 502 may be desired depending on the stiffness and the strength requirements of the joints according to various embodiments. For clearer illustration, only the haunch-shaped coupling elements 400 without stiffeners are shown in and described with reference to the remaining figures.

The haunch-shaped coupling elements 400 that are welded to a steel column 600 (here having rectangular hollow sections) according to an example embodiment are shown in FIG. 6 and FIG. 7. FIG. 6 shows a corner joint of the ceiling beams 602, 604 within a standard module, while FIG. 7 shows a corner joint of the floor beams 702, 704 within a standard module.

For each haunch-shaped coupling element e.g. 601, the first and second ends 603, 605 are configured, in the assembled state, to transfer forces from the beam e.g. 602 to a cross-section of the column e.g. 600. The second end 605 has a size matched to a size of the end of the column 600, the first end 603 has a size matched to a size of the end of the beam 604. It is noted that the first end second ends do not need to have a size matched to the column and beam respectively, and may only change such that one side is larger than the other. Also, If the beam and column have the same widths, then the two sides of the coupling element can have the same widths (which may be referred to as a non-haunch-shaped haunch-shaped coupling element) in different embodiments.

For example, it is possible to use a non- haunch-shaped coupling element with the sizes of the two sides equal to one another and e.g. the same as the beam, even if the beams and columns do not have that the same width in different embodiments, as shown in FIG. 22. Specifically, FIG. 22 shows a configuration for a JC joint according to an example embodiment in which non- haunch-shaped coupling elements e.g. 2200 can be used to connect rectangular hollow section (RHS) floor beams e.g. 2201 having the same width as the non- haunch-shaped coupling elements e.g. 2200, and the columns e.g. 2203 having a larger width than the non-

haunch-shaped coupling elements e.g. 2200. The RHS ceiling beams e.g. 2202 are also connected to the columns e.g. 2204 with non- haunch-shaped coupling elements e.g. 2205.

Returning to FIG. 6 and FIG. 7, each haunch-shaped coupling element e.g. 601 comprises first and second plate elements 607, 609 extending between the first and second ends 603, 605, with a space defined therebetween.

Each haunch-shaped coupling element e.g. 601 comprises of a third plate element 611 extending between the first and second ends 603, 605 and between the first and second plate elements 607, 609 such that, in the assembled state, the third plate element 611 forms a wall defining the space between the first and second plate elements 607, 609 open to the interior of the module.

As shown in FIG. 6, on top of the column 600, there is an end plate 606 welded to the column 600, and with a shear key 608 welded to the end plate 606, in some embodiments. The end plate 606 has a through hole aligned with the hole in the shear key 608 for concrete grouting. One function of the shear key 608 is to attach a lifting connector 2100 by locking on to the shear key 608 on top of the plate 606 of the column 600, as shown in FIG. 21. A detailed view of the shear key 608 welded to end plate 606 according to some embodiments is also shown in FIG. 19. Returning to FIG. 6, the shear key 608 can advantageously also serve as a guide to position the upper module according to some example embodiments, as will be described in more detail below. The beam section of the beams 602, 604, (and 702, 704 in FIG. 7) used for the purpose of illustration is a channel section according to some embodiments. Advantageously, embodiments of the present invention enable various steel beam cross-section types to be used depending on the structural and architectural requirements of the module design. That is, the channel cross-section can be replaced by other standard steel cross-sections such as rectangular hollow section, universal H or I section, etc. in various embodiments.

Embodiments of the present invention can significantly strengthen both the floor beam-to-column joint (Fig. 7) and the ceiling beam-to-column joint (Fig. 6) within each single module by using the coupling elements, for example the haunch coupling elements 400. Unlike existing systems such as the one described in KR10123359B1 and KR101409231B1, the beam 602, 604, 702, 704 sections are not limited to C-section beams. The haunch coupling elements 400 help to transfer the forces from the beam 602, 604, 702, 704 to the larger column 600 section, which can prevent premature local failure at the plate e.g. 605 facing the column 600.

Embodiments of the present invention can also significantly strengthen both the floor beam-to-column joint and the ceiling beam-to-column joint at lower cost within each module by using a standard material, i.e. steel, coupling element. Another existing system described in US20160002909A1 instead utilizes cast-iron connectors for strengthening the beam ends, which is costly in some countries, as will be appreciated by a person skilled in the art. Furthermore, the cast-iron connectors described in that document also include a short column tube, requiring the column to be cut.

FIG. 8a) to d) show the isotropic views of the ceiling corner of a module according to some embodiments. This sequence of figures show how a threaded bar 800 is locked to the top of the module/corner column 802 and how a gusset plate 804 is positioned over it. There is a recess 806 at the corner of the ceiling of the module near the corner column 802 as shown in FIG. 8.a). The recess 806 can be formed, for example, by punching of the steel deck 807 at the corner region. Another example of formation of the recess 806 can include welding of horizontal and vertical plate portions at a cut out in the steel deck 807 in the corner region. This recess 806 advantageously serves as a formwork for concrete grouting if the joint is to be cast with concrete in some embodiments. If the joint does not need to be cast with concrete, then the recess 806 need not be provided in different embodiments.

As shown in FIG. 8.a), a drilled hole 808 on a shear key 810 allows the threaded bar 800 for vertical interconnection to go through, the hole 808 on the shear key 810 being threaded for locking the threaded bar 800 using a locking nut 812 (also shown in Fig 8b and FIG. 20) as shown in FIG. 8.b). Specifically, the threaded bar 800 protrudes beyond the shear key 810 with a gap between the threaded bar 800 and the opening in the shear key 810 to allow grout to be inserted. That is, the threaded bar is not directly in threaded engagement with the shear key 810. Once the grout has been inserted, then the locking nut 812 locks the threaded bar 800 to the shear key 810 by mutual threaded engagement with the threaded bar 800 and the shear key 810. As shown in FIG. 8.c), the gusset plate 804 is positioned over the shear key 810 after the locking of the threaded bar 800. It is noted that since FIG. 8 is based on a joint JA according to an example embodiment, the gusset plate 804 is, for example, only $\frac{1}{4}$ the size of a gusset plate 900 used at a JC joint in a different embodiment as shown in FIG. 9.

FIG. 9 shows the gusset plate 900 for joining the adjacent modules at the same corner, i.e. at the JC joint, according to an example embodiment. The gusset plate 900 includes four rectangular holes e.g. 902 in this embodiment around the centre for receiving the respective shear keys protruding from the columns of the lower modules, for horizontal interconnection of the lower modules. However, it is noted that the holes e.g. 902 can have different shapes and sizes in different embodiments, so as to match different possible shapes and sizes of the shear keys. There are also bolting holes e.g. 904 for bolted connections to tie the floor beam coupling elements of the upper module and the ceiling beam coupling elements of the lower modules together, as part of the vertical interconnection, as will be described below with reference to FIG. 13.

FIG. 10 shows an isotropic view of the common corner at the ceiling (i.e. the JC joint) of adjacent box-shaped modules 1001-1004. FIG. 11a) shows that, on top of this common corner, the gusset plate 900 is attached to the top of the four modules 1001-1004 for tying the modules 1001-1004 together in the horizontal direction. Each threaded bar e.g. 1005 is locked to the shear keys e.g. 1006 of each column respectively by a locking nut e.g. 1008 being threaded to each threaded bar e.g. 1005 and into the shear keys e.g. 1006, as described above with reference to FIG. 8. Grout can be poured in through the holes of the shear keys e.g. 1006 (compare 808 in FIG. 8a) before locking the threaded bars e.g. 1005 in some embodiments. This advantageously provides bonding between the precast concrete filled column and the

threaded bar e.g. 1005 in such an embodiment FIG. 11b) shows the extension of the respective threaded bars e.g. 1005 by using threaded couplers e.g. 1010, for coupling of the threaded bars e.g. 1005 to extension threaded bars e.g. 1012.

It is noted that grouting of the corner columns is used in order to cover the exposed threaded bar connection inside the corrugated pipe (which will be described with reference to FIG. 18a) and FIG. 18b) below) and to provide bonding of the threaded bars to the precast or partially precast concrete filled columns in some embodiments. However, the grout does not need to be set before stacking of the upper modules; therefore, this process does not significantly slow down the module assembly speed in such embodiments.

Referring to FIG. 12a) and Fig. 12b), after the extension of the threaded bars, the upper modules 1200, 1202, 1204, 1206 can be lowered down to the top of the lower modules e.g. 1002, 1003. In this embodiment, four lower and four upper modules are interconnected at the JC joint.

Referring to FIG. 13a) and FIG. 13b), an isotropic view and a section view, respectively, of the internal joints according to an example embodiment, after removing the concrete slab and steel ceiling for better clarity are shown. As shown, sixteen coupling elements in the form of haunch-shaped coupling elements e.g. 1302, 1308 are provided, each coupling element configured for welding, at a first end thereof, to an end of a column e.g. 1303, 1305 of a module for the modular building and, at a second end thereof, to an end of a beam e.g. 1304, 1310 of the module for the modular building. A gusset plate 1306 is sandwiched between vertically adjoining ends of columns e.g. 1303, 1305 of stacked modules of the modular building such that the gusset plate 1306 extends between vertically adjoining coupling elements e.g. 1302, 1308 welded to respective vertically adjoining ends of the columns e.g. 1303, 1305 of the stacked modules of the modular building.

As can be seen, the bolted connections e.g. 1300 that connect the top haunch-shaped coupling elements e.g. 1302 of the floor beams e.g. 1304, the gusset plate 1306 and the bottom haunch-shaped coupling elements e.g. 1308 of the ceiling beams e.g. 1310 are completed at the internal of the modules. Two non-limiting example options for the bolted connection to be completed according to some embodiments are:

Option 1, the bolted connection e.g. 1300 can be completed at the internal of each connected steel-composite module through the openings e.g. 1207 at the corners of the floor concrete slab of the upper modules e.g. 1206, as shown in FIG. 12b). The size of the openings e.g. 1207 are preferably designed such that enough workable space is provided for the bolted connection to be completed, including fastening of the bolts. After the bolted connection has been completed, the opening e.g. 1207 at the corners of the floor concrete slabs can then be grouted, using e.g. concrete or high strength grout, with the recesses e.g. 1201 in the ceiling steel decks of the lower modules e.g. 1003 advantageously serving as the formwork and preferably designed such that enough workable space is provided for ease of grouting, as shown in FIG. 12a).

Option 2, the steel deck for the ceiling of the module can be designed with a removable corner portion, e.g. in the form of a steel plate, that can be temporarily removed from the remaining ceiling deck. The removable corner portion can be in the area corresponding to the recess in the ceiling steel deck for option 1. In option 2 no concrete casting may be needed for joining the modules together, i.e. the floor concrete slabs 1312, 1314 do not need to have openings requiring filling by concrete casting, as shown in FIG. 13c). In the example embodiment shown in FIG. 13c), the concrete slabs 1312, 1314 have a thickness that is the same as the vertical distance of the top and bottom flanges of the horizontal beams 1316, 1318 in the peripheral regions 1320, 1322 of the slabs 1312, 1314, for support of the slabs 1312, 1314 by the horizontal beams 1316, 1318 by resting on the bottom flanges. However, it is noted that the support of the concrete slabs can be implemented differently in different embodiments, for example by using rebars welded to the web of the horizontal beams and the couplings elements for support, or by using angles welded to the web of the horizontal beams and the couplings elements for support. In another example embodiment shown in FIG 13d) plates e.g. 1330 are welded to the coupling elements e.g. 1332 under the concrete slab 1334 for support in the corner area. The remaining peripheral part of the concrete slab 1334 can directly rest on the bottom flange of the horizontal beam (not shown), similar to the example embodiment as shown in the FIG. 13c).

Some embodiments of the present invention can advantageously remove the necessity for periodic inspection of the joints after completion of the modular buildings, because the bolted connections can have better durability (anti-corrosion) and fire performances as they are protected by the grout according to some embodiments, for example Option 1 above. This can free the residents in modular buildings from being disturbed by periodic inspections. The joining technique and system according to some embodiments of the present invention utilizes the recesses at the top of the ceilings and the recesses at the floors as formworks to allow for grouting after the completion of the bolted connections. The grout advantageously eliminates periodic inspection required, making steel/steel-composite modular construction more attractive.

Additionally, such embodiments of the present invention can provide 100% internal finishes of the module walls (which, for example, is a requirement for PPVC construction in Singapore), while existing techniques such as the one described in US20160002909A1 require openings on the module walls.

Also, if periodical inspection is allowed/convenient, other embodiments of the present invention can be designed to be connected without grouting at the beam-column connection regions.

FIG. 14 shows a plan view of a JC joint connection and FIG. 15 shows a section view of the JC joint connection as indicated at A-A in FIG. 14, according to an example embodiment. For a steel-composite column, the column e.g. 1400 can be precast in the factory by infilling it with concrete. In one embodiment, a large portion 1800 of the casting inside the column 1802 is done in the factory, using a corrugated pipe 1804 positioned at a centre of the column 1802

as formwork, as shown in FIG. 18a) and Fig. 18b). In such an embodiment, grouting on site is only needed in the region within the corrugated pipe 1804. Also, the corrugated pipes 1804 precast inside the columns 1802 advantageously provide a rough surface according to some embodiments, which can provide improved bonding strength between the high strength grout used for vertical continuity/bonding to the threaded bars and the precast concrete 1800 inside the columns 1802. Specifically, the corrugated pipes 1804 will bond with the precast concrete 1800 inside the columns 1802 and the on-site grout in the regions within the corrugated pipe 1804.

Alternatively, the whole steel column can be grouted on-site. In such an embodiment, no corrugated pipe is needed, noting that increasing the quantity of grouting on-site may slow down the speed of on-site module connection in such embodiments.

As shown and described above, some embodiments of the present invention do not require additional horizontal connection elements, unlike existing systems such as described in KR10123359B1 and KR101409231B1. Instead, module to module horizontal connections are realized by the gusset plate e.g. 1306 as shown in FIG. 13a) and Fig. 13b. This includes the advantage that no bolt holes are required on the web, i.e. the vertical plates of connectors/beams, according to such embodiments. The connection according to such embodiments of the present invention does therefore preferably use fewer bolts. The tolerances can also be less stringent than for existing systems, because fewer bolts can be used in example embodiments since the bolted connection is performed only in the horizontal plane (i.e. interconnecting the floor coupling element flange, gusset plate, and ceiling coupling element flanges), whereas KR10123359B1 and KR101409231B1 require bolted connections to be performed in both the vertical plane (webs) and horizontal plane (flanges).

On the other hand, unlike in other existing systems such as in described in US 2014/0123573 A1, in which the floor beams of the upper modules and ceiling beams of the lower modules are not bolted together and thus the integrity of the modules is weak and limited to hollow section beams, the connection according to example embodiments of the present invention can provide better integrity and enable the connected joints of each modules to act together to resist both gravity and horizontal forces.

One-way bolted connection according to some embodiments of the present invention will now be described.

FIG. 16a) and Fig. 16b) show the bolting technique for ease of connection according to some embodiments. With this design, the bolted connections can be easily completed by clamping the end 1600 of the bolts 1602 and by applying torque on the nuts 1604, preferably using washers 1606, 1608 in some embodiments.

The bolted connection according to some embodiments allows for tightening the bolts 1602 at one side only as the designed bolts 1602 can be clamped at one side 1600 while tightening the bolts 1604 at the same side. Instead, existing systems such as described in US20160002909A1 use long bolts and internal threaded holes for bolted connections. The

strength of those bolted connections largely depends on the quality and requires manufacturing tolerances to be small, which can increase costs associated with the manufacturing, as will be appreciated by a person skilled in the art. Once there is a tolerance issue in such bolted connection, due to the rigidity of the block, it is required to send the module back to the factory. In contrast, the joining technique according to some embodiments of the present invention can be designed using slotted holes in the coupling elements without internal threads for bolting.

Referring to FIGS. 17a) to d), the various configurations for gussets plates 1701-1704 for different joints according to example embodiments are shown.

Figure 23 shows a flow-chart 2300 illustrating a connecting method for assembly of a multi-storey modular building, according to an example embodiment. At step 2302, at least first and second coupling elements are welded, at respective first ends thereof, to an end of a column of a first module for the modular building and, at respective second ends thereof, to ends of respective ceiling beams of the first module for the modular building. At step 2304, at least third and fourth coupling elements are welded, at respective first ends thereof, to an end of a column of a second module for the modular building and, at respective second ends thereof, to ends of respective floor beams of the second module for the modular building. At step 2306, a gusset plate is sandwiched between vertically adjoining ends of the columns of the stacked first and second modules of the modular building such that the gusset plate extends between vertically adjoining ones of the coupling elements welded to the respective vertically adjoining ends of the columns of the stacked first and second modules of the modular building.

For each coupling element, the first and second ends may be configured for transferring forces from the beam to a cross-section of the column. The second end may have a larger size than the first end. The second end may have a size matched to a size of the end of the column. The first end may have a size matched to a size of the end of the beam.

The second end may have substantially the same size as the first end.

Each coupling element may comprise first and second plate elements extending between the first and second ends, with a space defined therebetween.

Each coupling element may comprise a third plate element extending between the first and second ends and between the first and second plate elements such that, in the assembled state, the third plate elements forms a wall defining the space between the first and second plate elements away from an interior of the module. The method may further comprise one or more stiffener elements extending between the first and second plate elements in the space therebetween.

The method may further comprise vertically connecting the vertically adjoining ones of the coupling elements welded to respective ones of the vertically adjoining columns of the stacked first and second modules of the modular building using the gusset plate. The gusset

plate may comprise a plurality of holes for receiving engagement elements for vertically connecting the vertically adjoining coupling elements welded to respective ones of the vertically adjoining ends of the columns of the stacked first and second modules of the modular building. Each engagement element may comprise a bolt and a nut, and the method
5 may comprise tightening the nut from one end of the bolt while arresting the bolt against rotating at the same one end of the bolt. The method may further comprise horizontally connecting adjoining ones of the coupling elements welded to respective ones of horizontally adjoining ends of columns of horizontally adjoining modules of the modular building using the gusset plate.

10 The method may further comprise attaching a shear key element to an upper end of the column of the first module of the modular building, wherein the gusset plate comprises at least one shear hole for receiving the shear key element so as to abut the upper end of the column of the first module in the assembled state. The method may further comprise locking
15 a threaded bar protruding the upper end of the column of the first module to the shear key element and coupling the threaded bar to an extended threaded bar, and receiving the extended threaded bar inside the column of the second module for the modular building. The method may further comprise grouting the threaded bar inside the column of the first module for bonding.

20 The method may further comprise providing a recess in the ceiling of the first module at or near the column of the first module and providing an opening in the floor of the second module at or near the column of the second module. The method may further comprise grouting using the recess and the opening as formwork, for protection of the connection between the first and second modules.

25 According to an example embodiment, a connector assembly for a multi-storey modular building is provided, the connector assembly comprising at least four coupling elements, each coupling element configured for welding, at a first end thereof, to an end of a column of a module for the modular building and, at a second end thereof, to an end of a beam of the module for the modular building; and a gusset plate configured for, in an assembled state of the connector assembly, sandwiching between vertically adjoining ends of columns of
30 stacked modules of the modular building such that the gusset plate extends between vertically adjoining coupling elements welded to respective ones of the vertically adjoining ends of the columns of the stacked modules of the modular building.

For each coupling element, the first and second ends may be configured for, in the assembled state, transferring forces from the beam to a cross-section of the column. The second end may
35 have a larger size than the first end. The second end may have a size matched to a size of the end of the column. The first end may have a size matched to a size of the end of the beam.

The second end may have substantially the same size as the first end.

Each coupling element may comprise first and second plate elements extending between the first and second ends, with a space defined therebetween. Each coupling element may

comprise a third plate element extending between the first and second ends and between the first and second plate elements such that, in the assembled state, the third plate elements forms a wall defining the space between the first and second plate elements open to an interior of the module. The connector may further comprise one or more stiffener elements extending between the first and second plate elements in the space therebetween.

The gusset plate may be configured for vertically connecting the vertically adjoining coupling elements welded to respective ones of the vertically adjoining ends of the columns of the stacked modules of the modular building. The gusset plate may comprise a plurality of holes for receiving engagement elements for vertically connecting the vertically adjoining coupling elements welded to respective ones of the vertically adjoining ends of the columns of the stacked modules of the modular building. Each engagement element may comprise a bolt and a nut and is configured such that the nut can be tightened from one end of the bolt while the bolt can be arrested against rotating at the same one end of the bolt. The gusset plate may be further configured for horizontally connecting adjoining ones of the coupling elements welded to respective ones of horizontally adjoining ends of columns of horizontally adjoining modules of the modular building.

The connector may further comprise a shear key element for attachment to a lower one of the vertically adjoining ends of the columns of the stacked modules of the modular building, wherein the gusset plate comprises at least one shear hole for receiving the shear key element so as to abut the upper end of the column of the first module in the assembled state. The connector assembly may further comprise a threaded bar protruding the upper end of the column of the first module and configured for being locked to the shear key element and for being coupled to an extended threaded bar for being received inside the column of the second module, in an assembled state.

The above description of illustrated embodiments of the systems and methods is not intended to be exhaustive or to limit the systems and methods to the precise forms disclosed. While specific embodiments of, and examples for, the systems components and methods are described herein for illustrative purposes, various equivalent modifications are possible within the scope of the systems, components and methods, as those skilled in the relevant art will recognize. The teachings of the systems and methods provided herein can be applied to other processing systems and methods, not only for the systems and methods described above.

The elements and acts of the various embodiments described above can be combined to provide further embodiments. These and other changes can be made to the systems and methods in light of the above detailed description.

In general, in the following claims, the terms used should not be construed to limit the systems and methods to the specific embodiments disclosed in the specification and the claims, but should be construed to include all processing systems that operate under the claims. Accordingly, the systems and methods are not limited by the disclosure, but instead the scope of the systems and methods is to be determined entirely by the claims.

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 a sense of "including, but not limited to." Words using the singular or plural number also include the plural or singular number respectively. Additionally, the words "herein," "hereunder," "above," "below," and words of similar import refer to this application as a whole and not to any particular portions of this application. When the word "or" is used in reference to a list of two or more items, that word 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.

CLAIMS

1. A connecting method for assembly of a multi-storey modular building, the method comprising

welding at least first and second coupling elements, at respective first ends thereof, to
5 an end of a column of a first module for the modular building and, at respective second ends thereof, to ends of respective ceiling beams of the first module for the modular building;

welding at least third and fourth coupling elements, at respective first ends thereof, to
an end of a column of a second module for the modular building and, at respective second
ends thereof, to ends of respective floor beams of the second module for the modular
10 building; and

sandwiching a gusset plate between vertically adjoining ends of the columns of the
stacked first and second modules of the modular building such that the gusset plate extends
between vertically adjoining ones of the coupling elements welded to the respective vertically
adjoining ends of the columns of the stacked first and second modules of the modular
15 building.

2. The method of claim 1, wherein, for each coupling element, the first and second ends
are configured for transferring forces from the beam to a cross-section of the column.

3. The method of claim 2, wherein the second end has a larger size than the first end.

4. The method of claims 2 or 3, wherein the second end has a size matched to a size of
20 the end of the column.

5. The method of claim 4, wherein the first end has a size matched to a size of the end of
the beam.

6. The method of claims 1 or 2, wherein the second end has substantially the same size
as the first end.

7. The method of any one of claims 1 to 6, wherein each coupling element comprises
first and second plate elements extending between the first and second ends, with a space
defined therebetween.

8. The method of claim 7, wherein each coupling element comprises a third plate
element extending between the first and second ends and between the first and second plate
30 elements such that, in the assembled state, the third plate elements forms a wall defining the
space between the first and second plate elements away from an interior of the module.

9. The method of claim 8, further comprising one or more stiffener elements extending
between the first and second plate elements in the space therebetween.

10. The method of any one of claims 1 to 9, further comprising vertically connecting the
35 vertically adjoining ones of the coupling elements welded to respective ones of the vertically

adjoining columns of the stacked first and second modules of the modular building using the gusset plate.

11. The method of claim 10, wherein the gusset plate comprises a plurality of holes for receiving engagement elements for vertically connecting the vertically adjoining coupling elements welded to respective ones of the vertically adjoining ends of the columns of the stacked first and second modules of the modular building.

12. The method of claim 11, wherein each engagement element comprises a bolt and a nut, and the method comprises tightening the nut from one end of the bolt while arresting the bolt against rotating at the same one end of the bolt.

13. The method of any one of claims 10 to 12, further comprising horizontally connecting adjoining ones of the coupling elements welded to respective ones of horizontally adjoining ends of columns of horizontally adjoining modules of the modular building using the gusset plate.

14. The method of any one of claims 1 to 13, further comprising attaching a shear key element to an upper end of the column of the first module of the modular building, wherein the gusset plate comprises at least one shear hole for receiving the shear key element so as to abut the upper end of the column of the first module in the assembled state.

15. The method of claim 14, further comprising locking a threaded bar protruding the upper end of the column of the first module to the shear key element and coupling the threaded bar to an extended threaded bar, and receiving the extended threaded bar inside the column of the second module for the modular building.

16. The method of claims 14 or 15, further comprising grouting the threaded bar inside the column of the first module for bonding.

17. The method of any one of claims 1 to 16, further comprising providing a recess in the ceiling of the first module at or near the column of the first module and providing an opening in the floor of the second module at or near the column of the second module.

18. The method of claim 17, further comprising grouting using the recess and the opening as formwork, for protection of the connection between the first and second modules.

19. A connector assembly for a multi-storey modular building, the connector assembly comprising

at least four coupling elements, each coupling element configured for welding, at a first end thereof, to an end of a column of a module for the modular building and, at a second end thereof, to an end of a beam of the module for the modular building; and

a gusset plate configured for, in an assembled state of the connector assembly, sandwiching between vertically adjoining ends of columns of stacked modules of the modular building such that the gusset plate extends between vertically adjoining coupling elements

welded to respective ones of the vertically adjoining ends of the columns of the stacked modules of the modular building.

20. The connector assembly of claim 19, wherein, for each coupling element, the first and second ends are configured for, in the assembled state, transferring forces from the beam to a cross-section of the column.

21. The connector assembly of claim 20, wherein the second end has a larger size than the first end.

22. The connector assembly of claims 20 or 21, wherein the second end has a size matched to a size of the end of the column.

23. The connector assembly of claim 22, wherein the first end has a size matched to a size of the end of the beam.

24. The connector assembly of claims 19 or 20, wherein the second end has substantially the same size as the first end.

25. The connector assembly of any one of claims 19 to 24, wherein each coupling element comprises first and second plate elements extending between the first and second ends, with a space defined therebetween.

26. The connector assembly of claim 25, wherein each coupling element comprises a third plate element extending between the first and second ends and between the first and second plate elements such that, in the assembled state, the third plate elements forms a wall defining the space between the first and second plate elements open to an interior of the module.

27. The connector assembly of claim 26, further comprising one or more stiffener elements extending between the first and second plate elements in the space therebetween.

28. The connector assembly of any one of claims 19 to 27, wherein the gusset plate is configured for vertically connecting the vertically adjoining coupling elements welded to respective ones of the vertically adjoining ends of the columns of the stacked modules of the modular building.

29. The connector assembly of claim 28, wherein the gusset plate comprises a plurality of holes for receiving engagement elements for vertically connecting the vertically adjoining coupling elements welded to respective ones of the vertically adjoining ends of the columns of the stacked modules of the modular building.

30. The connector assembly of claim 29, wherein each engagement element comprises a bolt and a nut and is configured such that the nut can be tightened from one end of the bolt while the bolt can be arrested against rotating at the same one end of the bolt.

31. The connector assembly of any one of claims 28 to 30, wherein the gusset plate is further configured for horizontally connecting adjoining ones of the coupling elements

welded to respective ones of horizontally adjoining ends of columns of horizontally adjoining modules of the modular building.

32. The connector assembly of any one of claims 19 to 31, further comprising a shear key element for attachment to a lower one of the vertically adjoining ends of the columns of the stacked modules of the modular building, wherein the gusset plate comprises at least one shear hole for receiving the shear element so as to abut the upper end of the column of the first module in the assembled state.

33. The connector assembly of claim 32, further comprising a threaded bar protruding the upper end of the column of the first module and configured for being locked to the shear key element and for being coupled to an extended threaded bar for being received inside the column of the second module, in an assembled state.