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Inventor(s)	Pickering; Samuel Thomas et al.

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### Block transfer apparatus and improved clamping assembly for use therewith

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#### Abstract

A block transfer apparatus for transferring a block between an upstream and downstream clamps of a block delivery system. The apparatus includes: a frame pivotally mounted to a support; a clamping assembly mounted to the frame and linearly extendable relative thereto, and including a pair of gripper jaws for clamping opposing sides of the block. The apparatus receives a block in the gripper jaws in an approximate position; rotates to a drop position and releases the block allowing it to self-datum onto first and second orthogonal datum surfaces. The apparatus re-clamps the block after the drop by applying a clamping force to opposing sides of the block to register the block against a third datum surface to thereby datum the position of the block with respect to the clamping assembly; and presents the block clamped in the datumed position for transfer to the downstream clamp.

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<b>Inventors:</b>	<b>Pickering; Samuel Thomas (Kalamunda, AU), Newcombe; David James (Cottesloe, AU), Hauri; Rudolf Hans (City Beach, AU)</b>
<b>Applicant:</b>	<b>FASTBRICK IP PTY LTD (High Wycombe, AU)</b>
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<b>Assignee:</b>	<b>FASTBRICK IP PTY LTD (High Wycombe, AU)</b>
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*Primary Examiner:* Rodriguez; Saul

*Assistant Examiner:* Tighe; Brendan P

*Attorney, Agent or Firm:* Perkins Coie LLP

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## Background/Summary

### CROSS-REFERENCE TO RELATED APPLICATIONS

(1) The present application is a United States national phase entry of International Application No. PCT/AU2021/050361 titled “BLOCK TRANSFER APPARATUS AND IMPROVED CLAMPING ASSEMBLY FOR USE THEREWITH” and filed on April 22, 2022, which claims priority from Australian Provisional Application No. 2020901272 titled “BLOCK TRANSFER APPARATUS AND IMPROVED CLAMPING ASSEMBLY FOR USE THEREWITH” and filed on 22 Apr. 2020, the contents of which are hereby incorporated by reference in their entireties.

### BACKGROUND OF THE INVENTION

(2) The present invention relates to a block transfer apparatus and improved clamping assembly for use therewith. In one particular example, the block transfer apparatus and clamping assembly is suitable for use by a robotic block laying machine.

### DESCRIPTION OF THE PRIOR ART

(3) The reference in this specification to any prior publication (or information derived from it), or to any matter which is known, is not, and should not be taken as an acknowledgment or admission or any form of suggestion that the prior publication (or information derived from it) or known matter forms part of the common general knowledge in the field of endeavour to which this specification relates.

(4) Autonomous and semi-autonomous industrial robotic equipment is increasingly being used in outside work environments such as on construction sites, building sites, mining sites, and industrial sites. For example, WO 2007/076581 describes an automated brick laying system for constructing a building from a plurality of bricks comprising a robot provided with a brick laying and adhesive applying head, a measuring system, and a controller that provides control data to the robot to lay the bricks at predetermined locations. The measuring system measures in real time the position of the head and produces position data for the controller. The controller produces control data on the basis of a comparison between the position data and a predetermined or pre-programmed position of the head to lay a brick at a predetermined position for the building under construction. The controller can control the robot to construct the building in a course by course manner where the bricks are laid sequentially at their respective predetermined positions and where a complete course of bricks for the entire building is laid prior to laying of the bricks for the next course.

(5) In one example of a robotic construction robot developed by the applicant there is provided a telescoping articulated boom that is mounted on a truck, and a conveying system that transports bricks along the boom to an end effector known as the layhead, which lays the bricks at predetermined locations. When the brick arrives at the layhead via the boom, it is clamped while adhesive is applied and then it is rotated 180 degrees and presented for pickup by a robot arm that places the brick at a desired location, preferably with sub-mm accuracy. When a brick is laid, it is assumed that the brick is held in a certain pose with respect to the robot arm. In order for the robot arm to place a brick at the desired location, it must pick up the brick in the correct location from the clamp.

(6) One problem is that the exact location of the brick with respect to the clamp in the layhead is not accurately known. It may be translated or rotated slightly away from an ideal pickup location of the robot arm. A camera-based vision system may be used to determine the exact 6 DOF location of the brick in space. However, this is a challenging task, as there are spatial constraints at the layhead to place cameras and sensors (without affecting the required functionality) and processing must be performed quickly (e.g. less than 2 seconds) to ensure rapid bricklaying. Further this task is made more difficult due to the varied range of outdoor conditions the robot is required to operate in—this includes temperatures ranging from 0-50° C., rain, dust, wind as well as full daylight, twilight and

dark night lighting conditions. This places significant demands on the vision system for determining the location of the brick to enable precise placement of the brick.

(7) There is thus a need to develop an improved system for clamping a brick or block such that its location with respect to the clamp is known without requiring vision-based processing techniques, or to at least provide a useful alternative to existing systems.

#### SUMMARY OF THE PRESENT INVENTION

(8) In one broad form, an aspect of the present invention seeks to provide a block transfer apparatus for transferring a block between an upstream clamp of a block delivery system and a downstream clamp of the block delivery system, the block transfer apparatus including: a) a frame pivotally mounted to a support; and, b) a clamping assembly mounted to the frame and linearly extendable relative thereto, the clamping assembly including a pair of gripper jaws for clamping opposing sides of the block; wherein, the block transfer apparatus is configured to: i) receive a block from the upstream clamp, wherein the block is initially clamped in the gripper jaws in an approximate position; ii) rotate to a drop position whereby the gripper jaws release the block and allow it to self-datum onto first and second orthogonal datum surfaces to thereby register an end and top or bottom face of the block in corresponding first and second orthogonal planes; iii) re-clamp the block after the drop by applying a clamping force to opposing sides of the block so as to register the block against a third datum surface defining a third plane orthogonal to both the first and second planes to thereby datum the position of the block with respect to the clamping assembly; and, iv) present the block clamped in the datumed position for transfer to the downstream clamp.

(9) In one embodiment, the first datum surface that registers an end of the block is provided as part of the clamping assembly at one of: a) a distal end of the gripper jaws; and, b) a proximal end of the gripper jaws to either the jaw or a jaw support structure.

(10) In one embodiment, the second datum surface that registers a top or bottom surface of the block is at least one of: a) provided as part of the clamping assembly along an upper lengthwise extending edge of the gripper jaws; and, b) provided as part of the frame in the form of a lengthwise extending bar or plate mounted to the support that is parallel to the gripper jaws.

(11) In one embodiment, the third datum surface is provided by a first of the two gripper jaws.

(12) In one embodiment, the first gripper jaw has a pair of spaced apart first gripper pads rigidly attached to an inner surface of the jaw.

(13) In one embodiment, the first gripper pads extend lengthwise along the first gripper jaw.

(14) In one embodiment, a second of the two gripper jaws includes a plurality of second gripper pads attached to flexible finger members spaced apart along the length of the jaw that allow the pads to flex laterally and compensate for variations in flatness of the side of the block along its length.

(15) In one embodiment, at least one row of second gripper pads of the second gripper jaw is located approximately midway between the pair of spaced apart first gripper pads such that when a clamping force is applied to the block it is urged into planar alignment with the third datum surface.

(16) In one embodiment, the gripper jaws are configured to accommodate blocks of varying length.

(17) In one embodiment, the gripper jaws are configured to one of: a) clamp blocks of varying length at different pre-defined positions along the length of the gripper jaws; and, b) clamp blocks of varying length at the same position along the length of the gripper jaws.

(18) In one embodiment, the drop position coincides with the clamping assembly being rotated to a relative angle to the ground of at least one of: a) between 30 to 60 degrees; b) between 35 to 55 degrees; c) between 40 to 50 degrees; and, d) approximately 45 degrees.

(19) In one embodiment, the support comprises a distal end of a boom used for transferring blocks therealong.

(20) In one embodiment, the upstream clamp forms part of a shuttle for delivering a block along the boom.

(21) In one embodiment, the downstream clamp is an end effector of a robotic block placement arm

that is programmed to place blocks during construction of a building structure.

(22) In one embodiment, the block transfer apparatus includes a distance range sensor for use in determining the proximity between the clamping assembly and the block held by the upstream clamp.

(23) In another broad form, an aspect of the present invention seeks to provide a block delivery system for delivering blocks for placement during construction of a building structure, the block delivery system including: a) a boom for transferring blocks therealong; b) an upstream clamp forming part of a shuttle that delivers blocks along the boom; c) a downstream clamp associated with an end effector of a robotic block placement arm that is programmed to place blocks during construction of the building structure; and, d) a block transfer apparatus for transferring a block between the upstream clamp and the downstream clamp, the block transfer apparatus including: i) a frame pivotally mounted to a distal end of the boom; and, ii) a clamping assembly mounted to the frame and linearly extendable relative thereto, the clamping assembly including a pair of gripper jaws for clamping opposing sides of the block; wherein, the block transfer apparatus is configured to: (1) receive a block from the upstream clamp, wherein the block is initially clamped in the gripper jaws in an approximate position; (2) rotate to a drop position whereby the gripper jaws release the block and allow it to self-datum onto first and second orthogonal datum surfaces to thereby register an end and top or bottom face of the block in corresponding first and second orthogonal planes; (3) re-clamp the block after the drop by applying a clamping force to opposing sides of the block so as to register the block against a third datum surface defining a third plane orthogonal to both the first and second planes to thereby datum the position of the block with respect to the clamping assembly; and, (4) present the block clamped in the datumed position for transfer to the downstream clamp.

(24) In another broad form, an aspect of the present invention seeks to provide a clamping assembly for clamping a block, the clamping assembly including a pair of gripper jaws including datum surfaces in first and second orthogonal planes to locate the block relative thereto, the clamping assembly configured to locate an end and top or bottom face of the block in the first and second orthogonal planes and then apply a clamping force to opposing sides of the block so as to locate the block in a third plane orthogonal to both the first and second planes to thereby datum the position of the block with respect to the clamping assembly.

(25) In one embodiment, the datum surfaces form a V-shaped wedge into which the block is located.

(26) In one embodiment, each gripper jaw includes at least one first datum surface extending at least partially between top and bottom surfaces of the gripper jaw and towards the opposing gripper jaw for locating an end of the block.

(27) In one embodiment, the at least one first datum surface is provided by one of: a) a surface integral with each gripper jaw; and, b) a plate element mounted to a surface integral with each gripper jaw.

(28) In one embodiment, each gripper jaw includes at least one second datum surface that is parallel to a top or bottom surface of the gripper jaw and projects towards the opposing gripper jaw for locating the top or bottom surface of the block.

(29) In one embodiment, the at least one second datum surface is provided by one of: a) the top or bottom surface of each gripper jaw; and, b) plate elements mounted to the top or bottom surfaces of each gripper jaw.

(30) In one embodiment, the at least one second datum surface is discontinuous.

(31) In one embodiment, the gripper jaws are configured to accommodate blocks of varying length.

(32) In one embodiment, the gripper jaws are configured to clamp blocks of varying length at different pre-defined positions along the length of the gripper jaws.

(33) In one embodiment, each gripper jaw includes a plurality of first datum surfaces spaced apart along a lengthwise direction thereof.

- (34) In one embodiment, the plurality of spaced apart first datum surfaces are further stepped apart laterally with respect to each gripper jaw so as not to overlap in the lengthwise direction thereof.
- (35) In one embodiment, an end of blocks of varying length are each located on one of the plurality of first datum surfaces of each gripper jaw.
- (36) In one embodiment, a first of the pair of gripper jaws has a plurality of first gripper pads arranged to define the third plane for locating a side face of the block when clamped.
- (37) In one embodiment, a second of the pair of gripper jaws has a plurality of second gripper pads arranged co-linearly in a lengthwise direction thereof such that when a clamping force is applied to the block the plurality of second gripper pads act to urge the block into planar alignment with the third plane defined by the plurality of first gripper pads.
- (38) In one embodiment, the plurality of first gripper pads comprise a pair of spaced apart rows of first gripper pads extending in a lengthwise direction of the first gripper jaw and wherein the second gripper pads are located on the second gripper jaw approximately midway between the spaced apart rows of first gripper pads.
- (39) In one embodiment, the first and second gripper pads are arranged on stepped surfaces of each gripper jaw so that each different length of block clamped by the assembly is contacted by a different plurality of first and second gripper pads.
- (40) In one embodiment, any block clamped by the assembly will be in contact with at least four first gripper pads and at least two second gripper pads when a clamping force is applied.
- (41) In one embodiment, the block is allowed to drop into the wedge under gravity to locate onto the datum surfaces defining the first and second orthogonal planes.
- (42) In one embodiment, the clamping assembly is pivotable and the drop is performed when the gripper jaws have been pivoted to a relative angle to the ground of at least one of: a) between 30 to 60 degrees; b) between 35 to 55 degrees; c) between 40 to 50 degrees; and, d) approximately 45 degrees.
- (43) In one embodiment, the block is: a) initially clamped in the gripper jaws in an approximate position; b) rotated to a drop position whereby the gripper jaws release the block and allow it to drop into the wedge; and, c) re-clamped when the block is located in the wedge so that the block is located in a datumed position.
- (44) In another broad form, an aspect of the present invention seeks to provide a block transfer apparatus for transferring a block between an upstream clamp of a block delivery system and a downstream clamp of the block delivery system, the block transfer apparatus including: a) a frame pivotally mounted to a support; and, b) a clamping assembly mounted to the frame and linearly extendable relative thereto, the clamping assembly including a pair of gripper jaws including datum surfaces in first and second orthogonal planes to locate the block relative thereto, wherein the clamping assembly is configured to at least: i) receive a block from the upstream clamp, wherein the block is initially clamped in the gripper jaws in an approximate position; ii) rotate to a drop position whereby the gripper jaws release the block and allow it to drop into a V-shaped wedge formed by the datum surfaces to thereby locate an end and top or bottom face of the block in the first and second orthogonal planes; iii) re-clamp the block after the drop by applying a clamping force to opposing sides of the block so as to locate the block in a third plane orthogonal to both the first and second planes to thereby datum the position of the block with respect to the clamping assembly. iv) present the block clamped in the datumed position for transfer to the downstream clamp.
- (45) In one embodiment, the support comprises a distal end of a boom used for transferring blocks therealong.
- (46) In one embodiment, the upstream clamp forms part of a shuttle for delivering a block along the boom.
- (47) In one embodiment, the downstream clamp is an end effector of a robotic block placement arm that is programmed to place blocks during construction of a building structure.

(48) In one embodiment, the block transfer apparatus includes a distance range sensor for use in determining the proximity between the clamping assembly and the block held by the upstream clamp.

(49) In yet a further broad form, an aspect of the present invention seeks to provide a block delivery system for delivering blocks for placement during construction of a building structure, the block delivery system including: a) a boom for transferring blocks therealong; b) an upstream clamp forming part of a shuttle that delivers blocks along the boom; c) a downstream clamp associated with an end effector of a robotic block placement arm that is programmed to place blocks during construction of the building structure; and, d) a block transfer apparatus for transferring a block between the upstream clamp and the downstream clamp, the block transfer apparatus including: i) a frame pivotally mounted to a distal end of the boom; and, ii) a clamping assembly mounted to the frame and linearly extendable relative thereto, the clamping assembly including a pair of gripper jaws including datum surfaces in first and second orthogonal planes to locate the block relative thereto, wherein the clamping assembly is configured to at least: (1) receive a block from the upstream clamp, wherein the block is initially clamped in the gripper jaws in an approximate position; (2) rotate to a drop position whereby the gripper jaws release the block and allow it to drop into a V-shaped wedge formed by the datum surfaces to thereby locate an end and top or bottom face of the block in the first and second orthogonal planes; (3) re-clamp the block after the drop by applying a clamping force to opposing sides of the block so as to locate the block in a third plane orthogonal to both the first and second planes to thereby datum the position of the block with respect to the clamping assembly; and, (4) present the block clamped in the datumed position for transfer to the downstream clamp.

(50) It will be appreciated that the broad forms of the invention and their respective features can be used in conjunction and/or independently, and reference to separate broad forms is not intended to be limiting.

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## Description

### BRIEF DESCRIPTION OF THE DRAWINGS

(1) Various examples and embodiments of the present invention will now be described with reference to the accompanying drawings, in which:

(2) FIG. 1A is a perspective view of an example of a clamping assembly;

(3) FIG. 1B is a further perspective view of the clamping assembly of FIG. 1A;

(4) FIG. 1C is a side view of the clamping assembly of FIG. 1A;

(5) FIG. 1D is a top view of the clamping assembly of FIG. 1A;

(6) FIG. 2 is a perspective view of a block transfer apparatus incorporating the clamping assembly of FIGS. 1A to 1D;

(7) FIG. 3A is a schematic bottom view of a clamping assembly shown in use clamping a first block type;

(8) FIG. 3B is a schematic top view of the clamping assembly of FIG. 3A;

(9) FIG. 3C is a sectional view of the clamping assembly taken through section A-A of FIG. 3A;

(10) FIG. 4A is a schematic bottom view of a clamping assembly shown in use clamping a second block type;

(11) FIG. 4B is a schematic top view of the clamping assembly of FIG. 4A;

(12) FIG. 4C is a sectional view of the clamping assembly taken through section B-B of FIG. 4A;

(13) FIG. 5A is a schematic bottom view of a clamping assembly shown in use clamping a third block type;

(14) FIG. 5B is a schematic top view of the clamping assembly of FIG. 5A;

(15) FIG. 5C is a sectional view of the clamping assembly taken through section C-C of FIG. 5A;

- (16) FIG. 6A is a schematic bottom view of a clamping assembly shown in use clamping a fourth block type;
- (17) FIG. 6B is a schematic top view of the clamping assembly of FIG. 6A;
- (18) FIG. 6C is a sectional view of the clamping assembly taken through section D-D of FIG. 6A;
- (19) FIGS. 7A to 7Q provide a detailed sequence of schematic views of a block transfer apparatus illustrating controlled movements thereof;
- (20) FIG. 8A is a perspective view of a further example of a block transfer apparatus;
- (21) FIG. 8B is a further perspective view of the block transfer apparatus of FIG. 8A;
- (22) FIG. 8C is a top view of the block transfer apparatus of FIG. 8A;
- (23) FIG. 8D is a front view of the block transfer apparatus of FIG. 8A;
- (24) FIGS. 9A to 9F provide a detailed sequence of schematic views of the block transfer apparatus of FIG. 8A illustrating controlled movements thereof;
- (25) FIG. 10A is a perspective view of a further example of a block transfer apparatus;
- (26) FIG. 10B is a front view of the block transfer apparatus of FIG. 10A;
- (27) FIG. 10C is a further perspective view of the block transfer apparatus of FIG. 10A; and,
- (28) FIGS. 11A to 11E provide a detailed sequence of schematic views of the block transfer apparatus of FIG. 10A illustrating controlled movements thereof.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

- (29) An example of a clamping assembly **10** for clamping a block will now be described with references to FIGS. **1A** to **1D**.
- (30) The term “block” used herein is a piece of material, typically in the form of a polyhedron, such as a cuboid having six quadrilateral and more typically substantially rectangular faces. The block is typically made of a hard material and may include openings or recesses, such as cavities or the like. The block is configured to be used in constructing a structure, such as a building or the like and specific example blocks include bricks, besser blocks, concrete masonry units or similar.
- (31) In this example, the clamping assembly **10** includes a pair of gripper jaws **20**, **30** including datum surfaces **21**, **31** and **22**, **32** in first and second orthogonal planes to locate the block relative thereto. The clamping assembly **10** is configured to locate an end and top or bottom face of the block in the first and second orthogonal planes and then apply a clamping force to opposing sides of the block so as to locate the block in a third plane orthogonal to both the first and second planes to thereby datum the position of the block with respect to the clamping assembly **10**.
- (32) An advantage of the above-described clamping assembly **10** is its ability to provide a reliable and repeatable mechanical datum for the block it is clamping. This is particularly useful in a robotic system in which the clamping assembly may be used to clamp a block and transfer it for pick up by a robotic arm. As the position and orientation of the block is known relative to the clamping assembly, the block may be accurately transferred to the robotic arm and the robotic arm may be programmed to pick up the block from a precise location with respect to the clamping assembly. This enables a further clamp (i.e. end effector) of the robotic arm to pick up a block in the same position every time which is important to ensure that the block is placed accurately at its target destination. The ability to mechanically datum the block in the gripper jaws removes the need for a vision system to image the block in the clamping assembly in order to determine its precise 6 DOF location. By eliminating the need for a camera-based vision system, the robotic block transfer system is made more reliable and efficient.
- (33) A number of further features will now be described.
- (34) In one example, the datum surfaces form a V-shaped wedge into which the block is located. This corresponds to the intersection of the X and Z planes in FIGS. **1C** and **1D**. As will be described in further detail below, typically the block is allowed to drop into the wedge under the force of gravity when the clamping assembly is oriented at an acute angle, typically around 45 degrees to the ground.
- (35) Typically, each gripper jaw includes at least one first datum surface extending at least partially



between top and bottom surfaces of the gripper jaw and towards the opposing gripper jaw for locating an end of the block. The at least one first datum surface is provided by one of a surface integral with each gripper jaw or a plate element mounted to a surface integral with each gripper jaw. In an example configuration, a thin wear plate/strip, for example made from Steel or the like is fixed to the surface integral with each gripper jaw. These strips or inserts can be replaced periodically when the datum surface starts to wear and this obviates the need to replace the entire gripper jaw.

(36) Further, each gripper jaw includes at least one second datum surface that is parallel to a top or bottom surface of the gripper jaw and projects towards the opposing gripper jaw for locating the top or bottom surface of the block. The at least one second datum surface is provided by one of the top or bottom surface of each gripper jaw or plate elements mounted to the top or bottom surfaces of each gripper jaw. It will be appreciated therefore that the datum surfaces could be surfaces machined into the body of each gripper jaw, whilst in other embodiments the datum surfaces may be provided by additional plate elements fixed to surfaces of the gripper jaw.

(37) In one example, the at least one second datum surface is discontinuous. In this regard, the top or bottom surface of each gripper jaw and/or plate elements fixed thereto may be segmented so as to provide gaps suitable for a gripper of a robotic arm to grip the block whilst it is held by the clamping assembly to effect transfer to the robotic arm. It is to be appreciated that in order to datum the block in the at least one second datum plane contact with one or more surface segments or plate elements may be used. In some examples, depending on the length of block being clamped, more than one surface segment or plate element providing the second datum surface will be in contact with the block whereas for shorter blocks only one surface segment or plate element may contact the block.

(38) The gripper jaws of the clamping assembly may therefore be configured to accommodate blocks of varying length. In one example, the jaws may accommodate one or more of a full-size block of length  $L$ , a three-quarter size block of length  $0.75 L$ , a half-size block of length  $0.5 L$  and a quarter-size block of length  $0.25 L$ .

(39) Typically, the gripper jaws are configured to clamp blocks of varying length at different pre-defined positions along the length of the gripper jaws. In this regard, each gripper jaw may include a plurality of first datum surfaces spaced apart along a lengthwise direction thereof. The plurality of spaced apart first datum surfaces are typically further stepped apart laterally with respect to each gripper jaw so as not to overlap in the lengthwise direction thereof. In this arrangement, an end of blocks of varying length are each located on one of the plurality of first datum surfaces of each gripper jaw. Accordingly, when a particular block type is held by the clamping assembly in a datumed configuration, only one of the plurality of first datum surfaces will be in contact with the block.

(40) The clamping method of the gripper jaws will now be described. Typically, a first of the pair of gripper jaws has a plurality of first gripper pads arranged to define the third plane for locating a side face of the block when clamped. The plurality of first gripper pads may be mounted onto an inner face of the first gripper jaw or into recesses formed therein such that the pads protrude slightly past the inner face. In one example, the plurality of first gripper pads comprise a pair of spaced apart rows of first gripper pads extending in a lengthwise direction of the first gripper jaw. In a preferred arrangement, at least four first gripper pads will contact a first side face of the block when clamping. Typically, this comprises two first gripper pads in the first row and two first gripper pads in the second row. This arrangement will provide four points of contact typically whereby the gripper pads in the first and second rows are equally spaced apart in the lengthwise direction.

(41) A second of the pair of gripper jaws typically has a plurality of second gripper pads arranged co-linearly in a lengthwise direction thereof such that when a clamping force is applied to the block the plurality of second gripper pads act to urge the block into planar alignment with the third plane

defined by the plurality of first gripper pads. In this regard, the second gripper pads are typically located on the second gripper jaw approximately midway between the spaced apart rows of first gripper pads. In this way, the line of action of the clamping force through the second gripper pads will be midway between the corresponding lines of action of the clamping force through the first gripper pads. This arrangement assists in providing planar alignment in the third plane (i.e. Y-plane) and prevents the block from being angularly misaligned in the jaws.

(42) The first and second gripper pads are arranged on stepped surfaces of each gripper jaw so that each different length of block clamped by the assembly is contacted by a different plurality of first and second gripper pads.

(43) In one example, any block clamped by the assembly will be in contact with at least four first gripper pads and at least two second gripper pads when a clamping force is applied. In other arrangements it may be possible for a block to be in contact with only three first gripper pads and one second gripper pad.

(44) It is to be understood that when a block is clamped by the above-described clamping assembly it may be held initially in an undatumed and unknown position. In order to datum the block in the jaws, typically the block is allowed to drop into the wedge under gravity to locate onto the datum surfaces defining the first and second orthogonal planes.

(45) In order to effect this drop, typically the clamping assembly is pivotable (either directly or indirectly) and the drop is performed when the gripper jaws have been pivoted to a relative angle to the ground of at least one of: between 30 to 60 degrees; between 35 to 55 degrees; between 40 to 50 degrees; and, approximately 45 degrees. As the jaws must be opened in order to allow the block to drop, the angle is chosen for a particular block type to ensure that the block is not inadvertently dropped out of the clamping assembly.

(46) In operation, in one example, the block is initially clamped in the gripper jaws in an approximate position. It is then rotated to a drop position whereby the gripper jaws release the block and allow it to drop into the wedge. The block is then re-clamped when it is located in the wedge so that the block is then clamped in a datumed position.

(47) In another broad form there is provided a block transfer apparatus for transferring a block between an upstream clamp of a block delivery system and a downstream clamp of the block delivery system. The block transfer apparatus includes a frame pivotally mounted to a support; and, a clamping assembly mounted to the frame and linearly extendable relative thereto, the clamping assembly including a pair of gripper jaws including datum surfaces in first and second orthogonal planes to locate the block relative thereto. The clamping assembly is configured to at least: receive a block from the upstream clamp, wherein the block is initially clamped in the gripper jaws in an approximate position; rotate to a drop position whereby the gripper jaws release the block and allow it to drop into a V-shaped wedge formed by the datum surfaces to thereby locate an end and top or bottom face of the block in the first and second orthogonal planes; re-clamp the block after the drop by applying a clamping force to opposing sides of the block so as to locate the block in a third plane orthogonal to both the first and second planes to thereby datum the position of the block with respect to the clamping assembly. Finally, the block transfer apparatus presents the block clamped in the datumed position for transfer to the downstream clamp.

(48) In one example, the support comprises a distal end of a boom used for transferring blocks therealong and the upstream clamp forms part of a shuttle for delivering a block along the boom.

(49) The downstream clamp may be an end effector of a robotic block placement arm that is programmed to place blocks during construction of a building structure.

(50) In some arrangements, the block transfer apparatus includes a distance range sensor for use in determining the proximity between the clamping assembly and the block held by the upstream clamp. Any suitable distance range sensing technology such as ultrasonic, laser etc may be used. Feedback from the distance sensor can be used to control the block transfer apparatus to pick up the block from the upstream clamp.

(51) In a further broad form, there is provided a block delivery system for delivering blocks for placement during construction of a building structure. The block delivery system includes a boom for transferring blocks therealong; an upstream clamp forming part of a shuttle that delivers blocks along the boom; a downstream clamp associated with an end effector of a robotic block placement arm that is programmed to place blocks during construction of the building structure; and, a block transfer apparatus for transferring a block between the upstream clamp and the downstream clamp, the block transfer apparatus including: a frame pivotally mounted to a distal end of the boom; and, a clamping assembly mounted to the frame and linearly extendable relative thereto, the clamping assembly including a pair of gripper jaws including datum surfaces in first and second orthogonal planes to locate the block relative thereto, wherein the clamping assembly is configured to at least: receive a block from the upstream clamp, wherein the block is initially clamped in the gripper jaws in an approximate position; rotate to a drop position whereby the gripper jaws release the block and allow it to drop into a V-shaped wedge formed by the datum surfaces to thereby locate an end and top or bottom face of the block in the first and second orthogonal planes; re-clamp the block after the drop by applying a clamping force to opposing sides of the block so as to locate the block in a third plane orthogonal to both the first and second planes to thereby datum the position of the block with respect to the clamping assembly; and, present the block clamped in the datumed position for transfer to the downstream clamp.

(52) Referring again to FIGS. 1A to 1D, the clamping assembly **10** will be described in further detail. The clamping assembly **10** includes a frame **11** to which the gripper jaws **20, 30** are slidably mounted onto rails **14, 16** via bearing blocks or rail guides for linear movement in a lateral direction in order to open and close the jaws. The jaws **20, 30** are belt driven by a servo motor **17** that turns a lead screw **15** connecting the jaws to thereby move the jaws along the rails **14, 16** in order to apply and release a clamping force to a block. Further bearing blocks or rail guides **12, 13** are also mounted to one side of the frame **11** and these guides are engageable onto rails of a block transfer apparatus as will be described in further detail below.

(53) As shown in FIGS. 1A and 1B, first gripper jaw **20** includes two rows of spaced apart gripper pads **41, 42** along the length of the first gripper jaw **20**, whilst second gripper jaw **30** includes a single row of spaced apart gripper pads **43** along the length of second gripper jaw **30**. These gripper pads exert a clamping force onto a block when clamped and are arranged so that the gripper pads **43** of the second gripper jaw **30** urge the block into planar alignment in a Y-plane defined by the gripper pads **41, 42** of the first gripper jaw **20** in contact with the block. In this regard, the single row of gripper pads **43** of the second gripper jaw **30** are typically located approximately midway between the height of the two rows defined respectively by gripper pads **41, 42** of the first gripper jaw **20**. This arrangement prevents angular misalignment or twisting of the block in the jaws.

(54) Each gripper jaw **20, 30** of the clamping assembly has a body extending in a lengthwise direction. In plan view, the gripper jaws **20, 30** each have a central portion **25, 35** and fore and aft portions **26, 36** and **27, 37** that are inwardly tapered from the central portion **25, 35** towards respective opposing ends of each jaw **20, 30**. Internally, the body of each gripper jaw has a central recessed portion, from which the body defines a stepped profile in opposing directions towards respective ends of each jaw. The inner face of each jaw therefore defines a number of laterally stepped apart recessed portions, each defining a recessed inner surface and corresponding lip segment as will be described in further detail below with respect to the schematic views shown in FIGS. 3A to 3C, 4A to 4C, 5A to 5C and 6A to 6C.

(55) In FIG. 1D, it is to be noted that the clamping assembly **10** includes a plurality of first datum surfaces **21, 31** that are stepped apart in a lengthwise direction of the gripper jaws **20, 30**.

Advantageously, this enables the clamping assembly **10** to be able to clamp and datum blocks of varying length which increases its utility. There may also be provided a plurality of second datum surfaces **22, 32** as shown that have gaps between them suitable for a clamp of a robot to grip the block whilst held by the clamping assembly **10** for transfer thereto.

(56) An example of a block transfer apparatus **200** is provided in FIG. 2. In this example, the block transfer apparatus **200** includes a lengthwise extending frame or bracket **210** to which the clamping assembly **10** is translatable mounted for linear extension and retraction therealong about rails **215**, **216**. The rail guides **12**, **13** mounted to the frame **11** of the clamping assembly **10** receive the rails **215**, **216** therein and the clamping assembly **10** is belt driven along the rails by servo motor **220**. In use, the block transfer apparatus **200** is pivotally mounted to a support (such as a distal end of a boom) to enable controlled rotation about pivot axis P. In the example shown, the bracket **210** has structural cross bracing support **212** attached thereto and a pivot mount **213** is provided on this support. On the opposing side, a pivot mount **214** which may be in the form of a high precision reduction gearing is provided mounted to the bracket **210**. Mounted beneath the bracket **210** is an adhesive applicator **230** for dispensing construction adhesive onto the block **1**. In use, the block is translated beneath nozzles of the adhesive applicator in order to apply adhesive along a substantial length of the block surface. Further details of operation of the block transfer apparatus **200** are described below with references to FIGS. 7A to 7Q.

(57) Referring now to FIGS. 3A to 3C, 4A to 4C, 5A to 5C and 6A to 6C, there are shown detailed schematic representations of a clamping assembly **100** for use in clamping various block types in a datumed position. In these figures, the nomenclature of first and second gripper jaws is the opposite of that used with respect to FIGS. 1A to 1D.

(58) In the below description, each gripper jaw of the clamping assembly has a body extending in a lengthwise direction. In plan view, the gripper jaws have a central portion and fore and aft portions that are inwardly tapered from the central portion towards respective opposing ends of each jaw. Internally, the body of each gripper jaw has a central recessed portion, from which the body defines a stepped profile in opposing directions towards respective ends of each jaw. The inner face of each jaw therefore defines a number of laterally stepped apart recessed portions, each defining a recessed inner surface and corresponding lip segment.

(59) It is to be understood that at least some of the lips define the plurality of first datum surfaces spaced apart along a lengthwise direction of each jaw and stepped apart laterally so as not to overlap in the lengthwise direction thereof.

(60) In FIGS. 3A to 3C, the clamping assembly **100** is shown clamping a quarter-length block **1** having a single core or cavity therethrough, although this is for purposes of illustration only.

(61) In this arrangement, the block **1** is clamped in the central recessed portion of the jaws **110**, **150** between first recessed inner surfaces **111**, **151**. The end face **3** of the block **1** is in contact with first lip segments **121**, **161** that define first datum surfaces in the X-plane. In this example, first insert wear strips **140**, **180** are fixed onto the corresponding first lip segments **121**, **161** and the block **1** is held in contact with these strips. A top or bottom face **6** of the block **1** is in contact with plate elements **144**, **184** that are fixed to the top surface of respective jaws **110**, **150** proximate the central portion thereof. These plate elements **144**, **184** project inwardly so as to at least partly extend above the central recessed portion of the jaws. The plate elements **144**, **184** define second datum surfaces in the Z-plane and accordingly in the clamped configuration shown, the block **1** is datumed in the X and Z planes.

(62) Respective sides **4** and **5** of the block **1** are clamped respectively by first gripper pads **130**, **131** and **130'**, **131'** that are fixed proximal first recessed inner surface **111** of the first gripper jaw **110** and second gripper pads **170**, **171** that are fixed proximal first recessed inner surface **151** of the second gripper jaw **150**. As shown in FIG. 3B, the first gripper pads are arranged in spaced apart rows with first gripper pads **130**, **131** being in an upper row and first gripper pads **130'**, **131'** being in a lower row so as to position first gripper pad **130** above first gripper pad **130'** and first gripper pad **131** above first gripper pad **131'**. The second gripper pads **170**, **171** are arranged co-linearly in a single row that is centrally disposed between the two rows of first gripper pads.

(63) In this way, when a clamping force is applied to the block **1**, the plurality of second gripper pads **170**, **171** act to urge the block into planar alignment with a third plane (the Y-plane) defined

by the surfaces of the plurality of first gripper pads **130, 131, 130', 131'**. This arrangement of gripper pads prevents angular misalignment when the block is clamped as side face **4** of the block **1** has four points of contact and side face **5** has two points of contact disposed midway between the opposing points of contact on the other side. As such, in this configuration the position of the block **1** is datumed in the X, Y and Z planes relative to the clamping assembly **100**.

(64) In FIGS. **4A** to **4C**, the clamping assembly **100** is shown clamping a half-length block **1** having a two cores or cavities therethrough, although this is for purposes of illustration only.

(65) In this arrangement, the block **1** is clamped by respective fore and aft portions of each gripper jaw **110, 150**, between second recessed inner surfaces **112, 152** in the aft portion and second recessed inner surfaces **113, 153** in the fore portion. The end face **3** of the block **1** is in contact with second lip segments **123, 163** that define first datum surfaces in the X-plane. In this example, second insert wear strips **141, 181** are fixed onto the corresponding second lip segments **123, 163** and the block **1** is held in contact with these strips. A top or bottom face **6** of the block **1** is in contact with plate elements **145, 185** that are fixed to the top surface of respective fore portions of the gripper jaws **110, 150** so as to project inwardly past the second recessed inner surfaces **113, 153**. In addition, the top or bottom face **6** of the block **1** is also in contact with plate elements **146, 186** that are fixed to the top surface of respective aft portions of the gripper jaws **110, 150** so as to project inwardly past the second recessed inner surfaces **112, 152**. The plate elements **145, 146, 184, 186** define second datum surfaces in the Z-plane and accordingly in the clamped configuration shown, the block **1** is datumed in the X and Z planes.

(66) Side **4** of the block **1** is clamped respectively by first gripper pads **132, 132'** that are fixed proximal second recessed inner surface **112** of the first gripper jaw **110** and first gripper pads **133, 133'** that are fixed proximal second recessed inner surface **113** of the first gripper jaw **110**. Side **5** of the block **1** is clamped respectively by second gripper pad **172** that is fixed proximal second recessed inner surface **152** of the second gripper jaw **150**, and second gripper pad **173**, that is fixed proximal second recessed inner surface **153** of the second gripper jaw **150**. The respective first and second gripper pads are arranged substantially as previous described, except spaced apart further in a lengthwise direction of the gripper jaws. As the block **1** is clamped, the plurality of second gripper pads **172, 173** act to urge the block into planar alignment with a third plane (the Y-plane) defined by the surfaces of the plurality of first gripper pads **132, 133, 132', 133'**. As such, in this configuration the position of the block **1** is datumed in the X, Y and Z planes relative to the clamping assembly **100**.

(67) In FIGS. **5A** to **5C**, the clamping assembly **100** is shown clamping a three quarter-length block **1** having a three cores or cavities therethrough, although this is for purposes of illustration only.

(68) In this arrangement, the block **1** is clamped by respective fore and aft portions of each gripper jaw **110, 150**, between third recessed inner surfaces **114, 154** in the aft portion and third recessed inner surfaces **115, 155** in the fore portion. The end face **3** of the block **1** is in contact with third lip segments **125, 165** that define first datum surfaces in the X-plane. In this example, third insert wear strips **142, 182** are fixed onto the corresponding third lip segments **125, 165** and the block **1** is held in contact with these strips. A top or bottom face **6** of the block **1** is in contact with plate elements **145, 185** that are fixed to the top surface of respective fore portions of the gripper jaws **110, 150** so as to project inwardly past the third recessed inner surfaces **115, 155**. In addition, the top or bottom face **6** of the block **1** is also in contact with plate elements **146, 186** that are fixed to the top surface of respective aft portions of the gripper jaws **110, 150** so as to project inwardly past the third recessed inner surfaces **114, 154**. The plate elements **145, 146, 184, 186** define second datum surfaces in the Z-plane and accordingly in the clamped configuration shown, the block **1** is datumed in the X and Z planes.

(69) Side **4** of the block **1** is clamped respectively by first gripper pads **134, 134'** that are fixed proximal third recessed inner surface **114** of the first gripper jaw **110** and first gripper pads **135, 135'** that are fixed proximal third recessed inner surface **115** of the first gripper jaw **110**. Side **5** of

the block **1** is clamped respectively by second gripper pad **174** that is fixed proximal third recessed inner surface **154** of the second gripper jaw **150**, and second gripper pad **175** that is fixed proximal third recessed inner surface **155** of the second gripper jaw **150**. The respective first and second gripper pads are arranged substantially as previous described, except spaced apart further in a lengthwise direction of the gripper jaws than the previous examples. As the block **1** is clamped, the plurality of second gripper pads **174**, **175** act to urge the block into planar alignment with a third plane (the Y-plane) defined by the surfaces of the plurality of first gripper pads **134**, **135**, **134'**, **135'**. As such, in this configuration the position of the block **1** is datumed in the X, Y and Z planes relative to the clamping assembly **100**.

(70) In FIGS. **6A** to **6C**, the clamping assembly **100** is shown clamping a full-length block **1** having a four cores or cavities therethrough, although this is for purposes of illustration only.

(71) In this arrangement, the block **1** is clamped by respective fore and aft portions of each gripper jaw **110**, **150**, between fourth recessed inner surfaces **116**, **156** in the aft portion and fourth recessed inner surfaces **117**, **157** in the fore portion. The end face **3** of the block **1** is in contact with fourth lip segments **127**, **167** that define first datum surfaces in the X-plane. In this example, fourth insert wear strips **143**, **183** are fixed onto the corresponding fourth lip segments **127**, **167** and the block **1** is held in contact with these strips. A top or bottom face **6** of the block **1** is in contact with plate elements **145**, **185** that are fixed to the top surface of respective fore portions of the gripper jaws **110**, **150** so as to project inwardly past the fourth recessed inner surfaces **117**, **157**. In addition, the top or bottom face **6** of the block **1** is also in contact with plate elements **146**, **186** that are fixed to the top surface of respective aft portions of the gripper jaws **110**, **150** so as to project inwardly past the fourth recessed inner surfaces **116**, **156**. The plate elements **145**, **146**, **184**, **186** define second datum surfaces in the Z-plane and accordingly in the clamped configuration shown, the block **1** is datumed in the X and Z planes.

(72) Side **4** of the block **1** is clamped respectively by first gripper pads **136**, **136'** that are fixed proximal fourth recessed inner surface **116** of the first gripper jaw **110** and first gripper pads **137**, **137'** that are fixed proximal fourth recessed inner surface **117** of the first gripper jaw **110**. Side **5** of the block **1** is clamped respectively by second gripper pad **176** that is fixed proximal fourth recessed inner surface **156** of the second gripper jaw **150**, and second gripper pad **177** that is fixed proximal fourth recessed inner surface **157** of the second gripper jaw **150**. The respective first and second gripper pads are arranged substantially as previous described, except spaced apart further in a lengthwise direction of the gripper jaws than the previous examples. As the block **1** is clamped, the plurality of second gripper pads **176**, **177** act to urge the block into planar alignment with a third plane (the Y-plane) defined by the surfaces of the plurality of first gripper pads **136**, **137**, **136'**, **137'**. As such, in this configuration the position of the block **1** is datumed in the X, Y and Z planes relative to the clamping assembly **100**.

(73) Referring now to FIGS. **7A** to **7Q**, the controlled operation of the block transfer apparatus **200** shall be described in the context of a block delivery system **300** for delivering blocks for placement during construction of a building structure.

(74) In this example, operation of the block transfer between the downstream and upstream clamps **55**, **80** of the block delivery system **300** via the block transfer apparatus **200** shall be described. In FIG. **7A**, a block **1** is being transferred to the downstream clamp **80** which is a robotic gripper of a robotic block placement arm (not shown). As soon as the downstream clamp **80** has gripped the block **1**, the clamping assembly **10** of the block transfer apparatus **200** may release the block. In this block handover position, the block transfer apparatus **200** is in a horizontal orientation with the clamping assembly **10** fully extended in the longitudinal direction.

(75) In FIG. **7B**, the block transfer apparatus **200** releases the block and begins to rotate away from the downstream clamp **80** about support **52** which is a mount at the distal end of boom **50**, the support **52** defining a rotation or pivot axis about which the block transfer apparatus **200** is able to pivot. In this initial phase of rotation, the clamping assembly **10** remains at full extension.

(76) In FIG. 7C, as rotation of the block transfer apparatus **200** continues, the clamping assembly **10** begins to retract and move linearly along rails of the frame or bracket **210** of the block transfer apparatus **200**. In FIG. 7D, retraction of the clamping assembly **10** continues whilst the block transfer apparatus **200** is rotating and in this state the clamping assembly **10** is now retracted sufficiently to be within the envelope of the frame or bracket **210**.

(77) In FIG. 7E, the clamping assembly **10** is shown fully retracted with respect to frame **210** as the block transfer apparatus **200** approaches a nearly vertical orientation. In FIG. 7F, the block transfer apparatus **200** has rotated past vertical and the clamping assembly **10** has begun to extend away from its fully retracted position. In this state, the orientation of the clamping assembly **10** has “flipped” over from the initial orientation shown in FIG. 7A.

(78) The block transfer apparatus **200** continues rotation until the longitudinal axis of the frame **210** is aligned with the lengthwise direction of the boom **50** as shown in FIG. 7F. In this state, the clamping assembly **10** is nearly fully extended so as to reach into the opening **51** of the distal end of the boom **50**. Typically, there is a recess or cut-out in the underside portion of the distal end of the boom so that the block transfer apparatus **200** can enter the envelope of the boom without any physical clash. Depending on the size of the cut-out, the clamping assembly **10** may be able to reach full extension during rotation. Otherwise, the block transfer apparatus **200** rotates into alignment with the boom **50** first and then extends the clamping assembly **10** into the boom **50**.

(79) As shown in FIG. 7H, the clamping assembly **10** is then fully extended into a position whereby it clamps a block held by the downstream clamp **55** disposed inside the boom **50**. The downstream clamp **55** typically forms part of a shuttle mechanism that delivers blocks internally through the boom **50**. Once the clamping assembly **10** has clamped the block, the downstream clamp **55** may release its grip of the block. It is to be understood that the position of the block with respect to the gripper jaws of the clamping assembly **10** is not precisely known at this stage.

(80) In FIGS. 7I and 7J, the clamping assembly **10** is shown beginning to retract away from its fully extended position whilst the frame **210** remains in alignment with the boom **50**. In FIG. 7J, the clamping assembly **10** has retracted sufficiently so that it is within the cut-out portion of the underside of the distal end of the boom in a safe position for rotation of the block transfer apparatus **200** to begin.

(81) In FIG. 7K, the block transfer apparatus **200** is rotated to a horizontal orientation whilst the clamping assembly **10** remains in an extended state (retracted only a sufficient amount to clear the distal end of the boom upon exit thereof). An adhesive applicator (see FIG. 2A) mounted to the block transfer apparatus **200** then begins dispensing adhesive onto an upper face of the block whilst the clamping assembly **10** retracts the block and thereby translates it linearly beneath nozzles of the adhesive applicator. Once the adhesive dispensing is complete and when the clamping assembly **10** is nearly fully retracted as shown in FIG. 7L the block transfer apparatus **200** rotates to a drop position in which the block is datumed.

(82) The drop position is shown in FIG. 7M. In this example, the block transfer apparatus **200** and clamping assembly **10** are oriented at an angle to the ground of approximately 45 degrees. In this position, the clamping assembly **10** releases its clamp of the block and allows it to drop under gravity into the wedge **70** defined by the first and second datum surfaces as previously described which thereby datums the block in the clamping assembly **10** with respect to the X and Z planes as shown. Once the drop has been performed and the block is datumed in these planes, the gripper jaws of the clamping assembly **10** re-clamp the block to thereby locate the block in a third plane orthogonal to both the first and second planes to thereby fully datum the position of the block with respect to the clamping assembly **10**.

(83) After the drop is complete and the block is re-clamped in the gripper jaws, the block transfer apparatus **200** commences further rotation at a safe speed as shown in FIG. 7N. The block transfer apparatus **200** continues to rotate whilst the clamping assembly **10** is extended to the edge of the frame **210** as shown in FIG. 7O. Rotation speed is then decreased whilst the clamping assembly **10**

continues to extend beyond the frame **210** as shown in FIG. 7P.

(84) In FIG. 7Q, the final stage of rotation of the block transfer apparatus **200** and extension of the clamping assembly **10** is completed resulting in the block being held out in a substantially horizontal position for transfer to the upstream clamp **80** as shown in FIG. 7A. The cycle then repeats as further blocks are transferred by the block delivery system for laying by the robotic placement arm on a construction site in order to construct a building. It is to be noted that in the transfer position shown in FIG. 7A, the clamping assembly **10** has been flipped 180 degrees from its orientation when adhesive was applied to the block in FIG. 7L. As such the block is now oriented in the clamping assembly **100** such that the face with adhesive applied is now facing downward ready for laying.

(85) A second example of a block transfer apparatus **500** shall now be described with reference to FIGS. 8A to 8D and 9A to 9F.

(86) In this example, the block transfer apparatus **500** is for transferring a block **1** between an upstream clamp (not shown) of a block delivery system and a downstream clamp **80** of the block delivery system. The block transfer apparatus **500** includes a frame **510** pivotally mounted to a support and a clamping assembly **400** mounted to the frame **510** and linearly extendable relative thereto, the clamping assembly **400** including a pair of gripper jaws **420**, **430** for clamping opposing sides of the block.

(87) The block transfer apparatus **500** is configured to receive a block **1** from the upstream clamp, wherein the block **1** is initially clamped in the gripper jaws **420**, **430** in an approximate position; rotate to a drop position whereby the gripper jaws **420**, **430** release the block **1** and allow it to self-datum onto first and second orthogonal datum surfaces **424**, **434** and **518** to thereby register an end and top or bottom face of the block in corresponding first and second orthogonal planes; re-clamp the block **1** after the drop by applying a clamping force to opposing sides of the block so as to register the block **1** against a third datum surface **422**, **423** defining a third plane orthogonal to both the first and second planes to thereby datum the position of the block **1** with respect to the clamping assembly **400**; and, present the block **1** clamped in the datumed position for transfer to the downstream clamp **80**.

(88) In this example, the clamping assembly **400** includes a frame **411** to which the gripper jaws **420**, **430** are slidably mounted onto rails **441**, **442** via bearing blocks or rail guides for linear movement in a lateral direction in order to open and close the jaws. The jaws **420**, **430** may be belt driven by a servo motor that turns a lead screw **443** connecting the jaws to thereby move the jaws along the rails **441**, **442** in order to apply and release a clamping force to a block.

(89) The first gripper jaw **420** includes two rows of spaced apart gripper pads **422**, **423** rigidly mounted to an inner face **421** along the length of the first gripper jaw **420**, whilst the second gripper jaw **430** includes a single row of spaced apart gripper pads **431**, **431'** mounted to a distal end of flexible fingers or battens **432**, **432'** along the length of second gripper jaw **430**. The gripper pads exert a clamping force onto a block when clamped and are arranged so that the gripper pads **431**, **431'** of the second gripper jaw **430** urge the block into planar alignment in a Y-plane defined by the gripper pads **422**, **423** of the first gripper jaw **420** in contact with the block. In this regard, the single row of gripper pads **431**, **431'** of the second gripper jaw **430** are typically located approximately midway between the height of the two rows defined respectively by gripper pads **422**, **423** of the first gripper jaw **420**. This arrangement prevents angular misalignment or twisting of the block in the jaws.

(90) The flexible finger members or battens **432**, **432'** spaced apart along the length of the second gripper jaw **430**, allow the pads **431**, **431'** to flex laterally and compensate for variations in flatness of the side of the block along its length (which may for instance be slightly bowed) as well as any lateral flex in the gripper jaws themselves. This ensures an equal clamping force is applied along the length of the block as each finger will flex to a different degree depending on the variation in flatness. Some of the flexible fingers **432'** are partially restrained by retaining clips **433** that act to



pretension the finger members. Each flexible finger is located at its base into a recessed portion **436** of the second gripper jaw **430**.

(91) The block transfer apparatus **500** further includes a lengthwise extending frame **510** to which the clamping assembly **400** is translatably mounted for linear extension and retraction therealong about rails **515**, **516**. Rail guides or bearing blocks mounted to the frame **411** of the clamping assembly **400** receive the rails **515**, **516** therein and the clamping assembly **400** is belt driven along the rails by servo motor **520**. In use, the block transfer apparatus **500** is pivotally mounted to a support (such as a distal end of a boom) to enable controlled rotation about pivot axis P. In the example shown, the frame **510** has structural cross bracing support **512** attached thereto and a pivot mount **513** is provided on this support. On the opposing side, a pivot mount **514** which may be in the form of a high precision reduction gearing is provided mounted to the frame **510**. Additionally, a datum bar or plate **517** is mounted to the structural support **512** so that it extends in a direction parallel to the lengthwise direction of the gripper jaws **420**, **430**. This datum bar **517** is used to datum the top or bottom face of the block as will be described in further detail below. In this example, the distal ends **424**, **434** of the gripper jaws provide datum surfaces which register an end face of the block.

(92) Referring now to FIGS. **9A** to **9F**, the controlled operation of the block transfer apparatus **500** shall be described in the context of a block delivery system for delivering blocks for placement during construction of a building structure.

(93) In this example, operation of the block transfer between the downstream and upstream clamps of the block delivery system via the block transfer apparatus **500** shall be described.

(94) In FIG. **9A**, the block transfer apparatus **500** is shown with its clamping assembly **400** extended out and reaching into a boom **50** to receive a block **1** from a downstream clamp (not shown) such as a shuttle clamp that runs along the boom element **50**. In this example, the clamping assembly **400** has been rotated about axis **52** in a counter-clockwise direction through a recess or cut-out in the underside portion of the distal end of the boom so that the block transfer apparatus **500** can enter the envelope of the boom without any physical clash. Depending on the size of the cut-out, the clamping assembly **400** may be able to reach full extension during rotation. Otherwise, the block transfer apparatus **500** rotates into alignment with the boom **50** first and then extends the clamping assembly **400** into the boom **50**. Once the clamping assembly **400** has clamped the block, the downstream clamp may release its grip of the block. It is to be understood that the position of the block with respect to the gripper jaws of the clamping assembly **400** is not precisely known at this stage.

(95) In FIGS. **9B** and **9C**, the clamping assembly **400** is shown rotating out of the boom in a clockwise direction and starting to retract away from its fully extended position in preparation for the block datuming operation. In FIG. **9D**, when the block transfer apparatus **500** is in the drop position (oriented at an angle to the ground of approximately 45 degrees), the clamping assembly **400** releases its clamp of the block and allows it to drop under gravity so that the block self-datums onto first and second orthogonal datum surfaces (**424**, **434**) and **518** to thereby register an end and top or bottom face of the block in corresponding first and second orthogonal planes. This datums the blocks with respect to the X and Z planes as depicted in FIGS. **8C** and **8D**. Once the drop has been performed and the block is datumed in these planes, the gripper jaws of the clamping assembly **400** re-clamp the block by applying a clamping force to opposing sides of the block so as to register the block against a third datum surface defining a third plane (Y plane) orthogonal to both the first and second planes to thereby datum the position of the block with respect to the clamping assembly **400**.

(96) After the drop is complete and the block is re-clamped in the gripper jaws, the block transfer apparatus **500** commences further rotation in a clockwise direction whilst concurrently extending the clamping assembly **400** out in a horizontal disposition as shown in FIG. **9E**. In this example, during extension, the block may be translated over a transfer adhesive applicator to apply adhesive

to the bottom surface of the block. In this position, the block is held out for transfer to the upstream clamp **80** (e.g. end effector of robotic block placement arm) as shown in FIG. **9F** from which it is subsequently laid in position.

(97) A third example of a block transfer apparatus **700** shall now be described with reference to FIGS. **10A** to **10C** and **11A** to **11E**.

(98) In this example, the block transfer apparatus **700** is for transferring a block **1** between an upstream clamp of a block delivery system and a downstream clamp of the block delivery system as previously described. The block transfer apparatus **700** includes a frame **710** pivotally mounted to a support and a clamping assembly **600** mounted to the frame **710** and linearly extendable relative thereto, the clamping assembly **600** including a pair of gripper jaws **620**, **630** for clamping opposing sides of the block.

(99) The block transfer apparatus **700** is configured to receive a block **1** from the upstream clamp, wherein the block **1** is initially clamped in the gripper jaws **620**, **630** in an approximate position; rotate to a drop position whereby the gripper jaws **620**, **630** release the block **1** and allow it to self-datum onto first and second orthogonal datum surfaces **626**, **718** to thereby register an end and top or bottom face of the block in corresponding first and second orthogonal planes; re-clamp the block **1** after the drop by applying a clamping force to opposing sides of the block so as to register the block **1** against a third datum surface **622**, **623** defining a third plane orthogonal to both the first and second planes to thereby datum the position of the block **1** with respect to the clamping assembly **600**; and, present the block **1** clamped in the datumed position for transfer to the downstream clamp.

(100) In this example, the clamping assembly **600** includes a frame **611** to which the gripper jaws **620**, **630** are slidably mounted onto rails **641**, **642** via bearing blocks or rail guides for linear movement in a lateral direction in order to open and close the jaws. The jaws **620**, **630** may be belt driven by a servo motor that turns a lead screw **643** connecting the jaws to thereby move the jaws along the rails **641**, **642** in order to apply and release a clamping force to a block.

(101) The first gripper jaw **620** includes two rows of spaced apart gripper pads **622**, **623** rigidly mounted to an inner face **621** along the length of the first gripper jaw **620**, whilst the second gripper jaw **630** includes two rows of spaced apart gripper pads **632**, **634** mounted to a distal end of flexible fingers or battens **633**, **635** along the length of second gripper jaw **630**. The gripper pads exert a clamping force onto a block when clamped and are arranged so that the gripper pads **632**, **634** of the second gripper jaw **630** urge the block into planar alignment in the third datum plane defined by the gripper pads **622**, **623** of the first gripper jaw **620** in contact with the block. In this regard, the two rows of gripper pads **632**, **634** of the second gripper jaw **630** are close together and are typically located approximately midway between the height of the two rows defined respectively by gripper pads **622**, **623** of the first gripper jaw **420**. This arrangement prevents angular misalignment or twisting of the block in the jaws.

(102) The flexible finger members or battens **633**, **635** spaced apart along the length of the second gripper jaw **430**, allow the pads **634**, **636** to flex laterally and compensate for variations in flatness of the side of the block along its length (which may for instance be slightly bowed). This ensures an equal clamping force is applied along the length of the block as each finger will flex to a different degree depending on the variation in flatness. Each flexible finger is located at its base into a respective upper and lower cap **636**, **637** mounted along respective top and bottom edges of the second gripper jaw **430** so as to pretension the gripper pads. In this arrangement, the gripper pads **432**, **434** alternate in position between the first and second rows.

(103) The block transfer apparatus **700** further includes a lengthwise extending frame **710** to which the clamping assembly **600** is translatably mounted for linear extension and retraction therealong about rails **715**, **716**. Rail guides or bearing blocks mounted to the frame **611** of the clamping assembly **600** receive the rails **715**, **716** therein and the clamping assembly **600** is belt driven along the rails by a servo motor. In use, the block transfer apparatus **700** is pivotally mounted to a support

(such as a distal end of a boom) to enable controlled rotation about pivot axis P. In the example shown, the frame **710** has U-shaped support **712** mounted to the frame **710** to which a datum bar or plate **717** is mounted so that it extends in a direction parallel to the lengthwise direction of the gripper jaws **620**, **630**. This datum bar **717** is used to datum the top or bottom face of the block as will be described in further detail below. In this example, a datum bracket **626** is mounted to a proximate end of the support structure of gripper jaw **620** and this bracket provides a datum surface which registers an end face of the block. In other examples, another datum bracket **626** could be installed in a similar manner in association with gripper jaw **630**.

(104) Referring now to FIGS. **11A** to **11E**, the controlled operation of the block transfer apparatus **700** shall be described in the context of a block delivery system for delivering blocks for placement during construction of a building structure.

(105) In this example, operation of the block transfer between the downstream and upstream clamps of the block delivery system via the block transfer apparatus **700** shall be described.

(106) In FIG. **11A**, the block transfer apparatus **700** is shown with its clamping assembly **600** extended out and reaching into a boom **50'** to receive a block **1** from a downstream clamp **55'** such as a shuttle clamp that runs along the boom element **55'**. In this example, the clamping assembly **600** has been rotated about axis **52'** in a clockwise direction through a recess or cut-out in the topside portion of the distal end of the boom so that the block transfer apparatus **700** can enter the envelope of the boom without any physical clash. Depending on the size of the cut-out, the clamping assembly **600** may be able to reach full extension during rotation. Otherwise, the block transfer apparatus **700** rotates into alignment with the boom **50'** first and then extends the clamping assembly **600** into the boom **50'**. Once the clamping assembly **600** has clamped the block, the downstream clamp **55'** may release its grip of the block. It is to be understood that the position of the block with respect to the gripper jaws of the clamping assembly **600** is not precisely known at this stage.

(107) In FIG. **11B**, the clamping assembly **600** is shown rotating out of the boom in a counter-clockwise direction and starting to retract away from its fully extended position in preparation for the block datuming operation. In FIG. **11C**, when the block transfer apparatus **700** is in the drop position (oriented at an angle to the ground of approximately 45 degrees), the clamping assembly **600** releases its clamp of the block and allows it to drop under gravity so that the block self-datums onto first and second orthogonal datum surfaces **626** and **718** to thereby register an end and top or bottom face of the block in corresponding first and second orthogonal planes. Once the drop has been performed and the block is datumed in these planes, the gripper jaws of the clamping assembly **600** re-clamp the block by applying a clamping force to opposing sides of the block so as to register the block against a third datum surface defining a third plane orthogonal to both the first and second planes to thereby datum the position of the block with respect to the clamping assembly **600**.

(108) After the drop is complete and the block is re-clamped in the gripper jaws, the block transfer apparatus **700** commences further rotation in a counter clockwise direction whilst concurrently extending the clamping assembly **600** out in a horizontal disposition as shown in FIGS. **11D** and **11E**. In this example, during extension, the block may be translated over a transfer adhesive applicator to apply adhesive to the bottom surface of the block. In this position, the block is held out for transfer to the upstream clamp (not shown).

(109) In at least one example, the above-described clamping assembly provides a reliable and repeatable means to datum a position of a block being clamped relative thereto. In a robotic system, this enables the clamping assembly or block transfer apparatus to which it may be mounted to present a block for transfer to a robotic arm in a known position and orientation. This mechanical system for self-datuming a block enables confidence in the geometric block position and orientation without requiring a camera-based vision system to image the block in the clamping assembly and determine the pose thereof which has inherent limitations in outdoor operating

environments in which vibration, light and inconsistent block geometry can cause issues.

(110) Throughout this specification and claims which follow, unless the context requires otherwise, the word “comprise”, and variations such as “comprises” or “comprising”, will be understood to imply the inclusion of a stated integer or group of integers or steps but not the exclusion of any other integer or group of integers. As used herein and unless otherwise stated, the term “approximately” means  $\pm 20\%$ .

(111) Persons skilled in the art will appreciate that numerous variations and modifications will become apparent. All such variations and modifications which become apparent to persons skilled in the art, should be considered to fall within the spirit and scope that the invention broadly appearing before described.

## Claims

1. A block transfer apparatus for transferring a block between an upstream clamp of a block delivery system and a downstream clamp of the block delivery system, the block transfer apparatus including: a frame pivotally mounted to a support; and, a clamping assembly mounted to the frame and linearly extendable relative thereto, the clamping assembly including a pair of gripper jaws that clamp opposing lateral sides of the block; wherein, the block transfer apparatus is configured to: receive a block from the upstream clamp, wherein the opposing lateral sides of the block are initially clamped in the gripper jaws in an approximate position; rotate to a drop position whereby the gripper jaws release the block and allow it to self-datum onto first and second orthogonal datum surfaces to thereby register an end and top or bottom face of the block in corresponding first and second orthogonal planes; re-clamp the block after the drop by applying a clamping force to the opposing lateral sides of the block so as to register the block against a third datum surface defining a third plane orthogonal to both the first and second planes to thereby datum the position of the block with respect to the clamping assembly; and, present the block clamped in the datumed position for transfer to the downstream clamp.
2. The block transfer apparatus according to claim 1, wherein the first datum surface that registers an end of the block is provided as part of the clamping assembly at one of: a distal end of the gripper jaws; and, a proximal end of the gripper jaws to either the jaw or a jaw support structure.
3. The block transfer apparatus according to claim 1, wherein the second datum surface that registers a top or bottom surface of the block is at least one of: provided as part of the clamping assembly along an upper lengthwise extending edge of the gripper jaws; and, provided as part of the frame in the form of a lengthwise extending bar or plate mounted to the support that is parallel to the gripper jaws.
4. The block transfer apparatus according to claim 3, wherein the third datum surface is provided by a first of the two gripper jaws.
5. The block transfer apparatus according to claim 4, wherein the first gripper jaw has a pair of spaced apart first gripper pads rigidly attached to an inner surface of the jaw.
6. The block transfer apparatus according to claim 5, wherein the first gripper pads extend lengthwise along the first gripper jaw.
7. The block transfer apparatus according to claim 4, wherein a second of the two gripper jaws includes a plurality of second gripper pads attached to flexible finger members spaced apart along the length of the jaw that allow the pads to flex laterally and compensate for variations in flatness of the side of the block along its length.
8. The block transfer apparatus according to claim 7, wherein an at least one row of second gripper pads of the second gripper jaw is located approximately midway between the pair of spaced apart first gripper pads such that when a clamping force is applied to the block it is urged into planar alignment with the third datum surface.
9. The block transfer apparatus according to claim 1, wherein the gripper jaws are configured to

accommodate blocks of varying length.

10. The block transfer apparatus according to claim 9, wherein the gripper jaws are configured to one of: clamp blocks of varying length at different pre-defined positions along the length of the gripper jaws; and, clamp blocks of varying length at the same position along the length of the gripper jaws.

11. The block transfer apparatus according to claim 1 wherein the drop position coincides with the clamping assembly being rotated to a relative angle to the ground of at least one of: between 30 to 60 degrees; between 35 to 55 degrees; between 40 to 50 degrees; and, approximately 45 degrees.

12. The block transfer apparatus according to claim 1, wherein the support comprises a distal end of a boom used for transferring blocks therealong.

13. The block transfer apparatus according to claim 1, wherein the upstream clamp forms part of a shuttle for delivering a block along the boom.

14. The block transfer apparatus according to claim 1, wherein the downstream clamp is an end effector of a robotic block placement arm that is programmed to place blocks during construction of a building structure.

15. The block transfer apparatus according to claim 1, wherein the block transfer apparatus includes a distance range sensor for use in determining the proximity between the clamping assembly and the block held by the upstream clamp.

16. A block delivery system for delivering blocks for placement during construction of a building structure, the block delivery system including: a boom for transferring blocks therealong; an upstream clamp forming part of a shuttle that delivers blocks along the boom; a downstream clamp associated with an end effector of a robotic block placement arm that is programmed to place blocks during construction of the building structure; and, a block transfer apparatus for transferring a block between the upstream clamp and the downstream clamp, the block transfer apparatus including: a frame pivotally mounted to a distal end of the boom; and, a clamping assembly mounted to the frame and linearly extendable relative thereto, the clamping assembly including a pair of gripper jaws that clamp opposing lateral sides of the block; wherein, the block transfer apparatus is configured to: receive a block from the upstream clamp, wherein the opposing lateral sides of the block are initially clamped in the gripper jaws in an approximate position; rotate to a drop position whereby the gripper jaws release the block and allow it to self-datum onto first and second orthogonal datum surfaces to thereby register an end and top or bottom face of the block in corresponding first and second orthogonal planes; re-clamp the block after the drop by applying a clamping force to the opposing lateral sides of the block so as to register the block against a third datum surface defining a third plane orthogonal to both the first and second planes to thereby datum the position of the block with respect to the clamping assembly; and, present the block clamped in the datumed position for transfer to the downstream clamp.

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