Title: AUTOMATED INSULATION APPLICATION SYSTEM AND METHOD

Abstract: An automated insulation application system that includes a robotic arm and an insulation end effector coupled at a distal end of the robotic arm, the insulation end effector configured to apply insulation material to a target surface. The system can further include a computing device executing a computational planner that: generates instructions for driving the insulation end effector and robotic arm to perform at least one insulation application task that includes applying insulation material via the insulation end effector to a target surface, the generating based at least in part on obtained target surface data; and drives the end effector and robotic arm to perform at least one insulation application task.
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AUTOMATED INSULATION APPLICATION SYSTEM AND METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 62/480,172, filed March 31, 2017, which application is hereby incorporated herein by reference in its entirety and for all purposes.

[0002] This application is also related to U.S. Non-provisional applications filed contemporaneously herewith having attorney Docket Numbers 0111061-001US0, 0111061-003US0, 0111061-004US0, 0111061-005US0, and 0111061-006US0, having respective application numbers XX/YYYY,ZZZ, XX/YYYY,ZZZ, XX/YYYY,ZZZ, XX/YYYY,ZZZ, XX/YYYY,ZZZ and XX/YYYY,ZZZ and respectively entitled "AUTOMATED DRYWALL PLANNING SYSTEM AND METHOD," "AUTOMATED DRYWALL CUTTING AND HANGING SYSTEM AND METHOD," "AUTOMATED DRYWALL MUDDING SYSTEM AND METHOD," "AUTOMATED DRYWALL SANDING SYSTEM AND METHOD," and "AUTOMATED DRYWALL PAINTING SYSTEM AND METHOD." These applications are hereby incorporated herein by reference in their entirety and for all purposes.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] Fig. 1 is an exemplary perspective drawing illustrating an embodiment of an automated drywall installation system.

[0004] Fig. 2 is an exemplary perspective drawing illustrating another embodiment of an automated drywalling system.

[0005] Fig. 3 is an exemplary block diagram illustrating systems of an automated drywalling system in accordance with one embodiment.

[0006] Fig. 4 is an exemplary block diagram illustrating systems of an automated drywalling system in accordance with one embodiment, including a plurality of end effectors configured to couple to an end of a robotic arm.
Fig. 5 illustrates a block diagram of method of installing drywall in accordance with one embodiment.

Figs. 6a, 6b, 6c, 6d and 6e illustrate an embodiment of a manual mud application profile, where joint compound is applied over consecutive layers to taper out high points over a wider area and where sanding is then used to smooth out the final profile.

Figs. 7a and 7b illustrate an embodiment of an automated compound application process where the joint compound is applied in a thick layer using a sprayer.

Figs. 8a, 8b, 9a, 9b illustrate a series of steps in an example method of installing drywall to generate a wall assembly.

Fig. 10 illustrates an embodiment of a drywalling system applying insulation to a wall assembly in accordance with one embodiment.

Fig. 11 illustrates an embodiment of an insulation end effector configured to automatically dispense and apply insulation.

Fig. 12 illustrates one embodiment of an insulation end effector that includes a spray gun that is coupled onto the robotic arm.

Fig. 13 illustrates another embodiment of an insulation end effector that includes a spray gun that is coupled onto the robotic arm.

Fig. 14 illustrates an example of an in-line nozzle for mixing insulation, water, and any additives at an application site.

Fig. 15 illustrates an example embodiment of an insulation end effector that includes a spray pattern detection mechanism, in which a vision system can be used to monitor the pattern of insulation spray coming out of the nozzle to detect clogs, nozzle wear, low pressure, or other problems with the spray gun or related system such as insulation lines, insulation source or the like.

Fig. 16 illustrates an example embodiment of an insulation end effector that comprises a vacuum system that includes a vacuum hood disposed around an end and nozzle of a spray gun to capture overspray.
[0018] Fig. 17 illustrates an example embodiment of an insulation end effector that comprises a spray guard that partially extends about and past the face of the nozzle of the spray gun.

[0019] Fig. 18 illustrates an example embodiment of an insulation end effector that comprises a first blower and a second blower.

[0020] Fig. 19 illustrates an example embodiment of an insulation end effector which comprises a nozzle cassette system where a cassette of nozzles is attached to the end of the spray gun.

[0021] Fig. 20 illustrates another example embodiment of an insulation end effector that comprises a nozzle rotating system that can be part of a spray gun.

[0022] It should be noted that the figures are not drawn to scale and that elements of similar structures or functions are generally represented by like reference numerals for illustrative purposes throughout the figures. It also should be noted that the figures are only intended to facilitate the description of the preferred embodiments. The figures do not illustrate every aspect of the described embodiments and do not limit the scope of the present disclosure.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0023] The following disclosure pertains to an automated drywalling system, which in some embodiments can be used for drywalling, including one or more of planning a configuration and location of drywall pieces on a wall assembly, cutting drywall pieces, hanging drywall pieces, performing mud work on hung drywall pieces, performing sanding on mudded drywall pieces and painting sanded drywall pieces.

[0024] In one aspect, the present disclosure pertains to automated systems and methods for applying insulation. For example, in some embodiments, the system can deliver spray foam insulation, blanket or batting insulation, or blow-in insulation. In various embodiments, the system can mix, deliver, and apply insulation during framing and hanging of drywall on a wall assembly. In some examples, the system can determine how insulation material is prepared, how it is delivered onto a substrate and how insulation material is set, cured, dried,
or the like. In further examples, the system can trim or cut the insulation as the insulation is applied or after the insulation has been set in place.

[0025] Turning to Figs. 1 and 2, examples of an automated drywalling system 100 are illustrated, which includes a base unit 120, a robotic arm 140 and an end effector 160. The base unit 120 comprises a platform 122 and a cart 124 with a lift 126 disposed between the platform 122 and cart 124. The cart 124 can be configured to be disposed on the ground and move within an XY plane defined by axes X and Y, and the lift 126 can be configured to raise the platform 122 up and down along axis Z, which is perpendicular to axes X and Y.

[0026] In the examples of Figs. 1 and 2, the cart 124 can comprise a plurality of wheels 128, which can be used to move the cart 124 and drywalling system 100 on the ground in the XY plane. Such movement can be motorized or can be non-motorized. For example, in some embodiments, the drywalling system 100 can be configured for automated movement of the cart 124, motorized movement based on input from a user and/or non-motorized movement based on physical movement by a user. Additionally, while an example having wheels 128 is shown in some examples herein, it should be clear that the cart 124 can be configured for motorized and/or non-motorized movement via any suitable structures, systems, or the like.

[0027] In the examples of Figs. 1 and 2, the lift 126 is shown comprising a scissor lift that can raise and lower the platform 122 relative to the cart 124 along axis Z. Such movement can be motorized or can be non-motorized. For example, in some embodiments, the drywalling system 100 can be configured for automated movement of the lift 126, motorized movement of the lift 126 based on input from a user and/or non-motorized movement based on physical operation of the lift 126 by a user. Additionally, while an example of a scissor lift is shown herein, it should be clear that any suitable lift system can comprise the lift 126 without limitation.

[0028] The platform 122 can comprise a hub 130, which can couple with the robotic arm 140 at a base end 142 of the robotic arm 140. The hub 130 can comprise an input interface 132 that allows for various systems to couple with the hub 130, which can allow for resources provided by such systems to be provided to the robotic arm 140 and/or the end effector 160 coupled at a distal end 144 of the robotic arm 140 as discussed in more detail herein. For
example, a pneumatic source, a power source, a vacuum source, a paint source, a mud or joint compound source, or the like can be coupled to the hub 130. Fig. 1 illustrates an example having an air compressor 134 and a vacuum source 136 coupled to the hub 130. Fig. 2 illustrates an example having an air compressor 134 coupled to the hub 130, which can be used to power pneumatic actuators 146 of the robotic arm 140 and/or provide compressed air to the end effector 160 at the distal end 144 of the robotic arm 140.

[0029] In various embodiments, the robotic arm 140 can comprise any suitable robotic arm system, which can include pneumatic actuators, electric actuators, and the like. The robotic arm 140 can have any suitable number of degrees of freedom. Although the examples of Figs. 1 and 2 illustrate an example having pneumatic actuator units 146 separated by arm couplers 148, this example configuration should not be construed to be limiting on the wide variety of robotic arms 140 that are within the scope and spirit of the present disclosure.

[0030] As discussed in more detail herein, an end effector 160 can be coupled at the distal end 144 of the robotic arm 140. In some examples, the automated drywalling system 100 can comprise modular and/or multi-use end effectors 160, which can be configured for various drywalling, construction or other tasks. For example, as discussed herein, end effectors 160 can be configured for drywall planning, drywall hanging, applying mud or joint compound to hung drywall, sanding mudded drywall, painting, and the like. Although various examples herein relate to drywalling and construction, further embodiments of the drywalling system 100 can be configured for any suitable tasks, including construction tasks, manufacturing tasks, gardening tasks, farming tasks, domestic tasks, and the like. Accordingly, the discussions herein related to drywalling and construction should not be construed to be limiting on the wide variety of tasks that the system 100 can be configured for.

[0031] Turning to Fig. 3, a block diagram of a drywalling system 100 is illustrated, which includes a base unit 120 coupled to a robotic arm 140, which is coupled to an end effector 160. The base unit 120 is shown comprising a control system 322, which is operably coupled to a vision system 324, sensors 326, and a movement system 328. The robotic arm 140 is shown comprising sensors 346 and a movement system 348, which are operably coupled to the control system 322. The example end effector 160 is shown comprising a vision system
sensors 366, a movement system 368, and one or more end effector devices 370, which
are operably connected to the control system 322.

[0032] In various embodiments, the connections between the control system 322 and
respective vision systems 324, 364; respective sensors 326, 346, 366; respective movement
systems 328, 348, 368; and end effector devices 370 can comprise any suitable type of
connection including wired and/or wireless connections. For example, such connections can
be configured for digital and/or analog communication of information between respective
elements.

[0033] The vision systems 324, 364 can comprise one or more suitable vision system
including one or more visible spectrum camera, radar, light detection and ranging (LIDAR)
system, sonar, infrared camera, thermal camera, stereo cameras, structured light camera, laser
scanners, and the like. The vision systems 324, 364 can comprise the same or different
elements. Additionally, in some embodiments, one or both of the vision systems 324, 364 can
be absent. In some embodiment, the robotic arm 140 can comprise a vision system.

[0034] The sensors 326, 346, 366 can comprise any suitable sensors in various
embodiments including one or more sensors of humidity, temperature, air flow, laser curtains,
proximity sensors, force and torque sensors, pressure sensors, limit switches, rotameter,
spring and piston flow meter, ultrasonic flow meter, turbine meter, paddlewheel meter,
variable area meter, positive displacement, vortex meter, pitot tube or differential pressure
meters, magnetic meters, humidity sensor, conductivity sensor and depth or thickness
sensors, and the like. The sensors 326, 346, 366 can comprise the same or different elements.
Additionally, in some embodiments, one or more of the sensors 326, 346, 366 can be absent.

[0035] The movement systems 328, 348, 368 can comprise any suitable movement
systems in various embodiments including one or more of an electric motor, pneumatic
actuators, piezo electric actuator, and the like. For example, in some embodiments the
movement system 328 of the base unit 120 can comprise the lift 126 and motors that drive
wheels 128 of the cart 124 (see Figs. 1 and 2). In another example, the movement system 348
of the robotic arm 140 can comprise pneumatic actuators 146 as illustrated in the examples of
Figs. 1 and 2. In various embodiments, the movement system 368 of the end effector 160 can
comprise motors or other systems that are configured to move, change the orientation of, rotate, or otherwise configure the end effector 160. In some embodiments, one or more of the movement systems 328, 348, 368 can be absent.

[0036] As discussed herein, the one or more end effector devices 370 can comprise various suitable devices, including a cutting device, hanging device, mudding device, sanding device, painting device, vacuum device, and the like. Other suitable devices can be part of an end effector 160 and can be selected based on any desired task that the end effector 160 can be used for.

[0037] As discussed in more detail herein, the control system 322 can receive data from the vision systems 324, 364 and/or sensors 326, 346, 366 can drive the movement systems 328, 348, 368 and one or more end effector devices 370 to perform various tasks including drywall planning, drywall hanging, applying mud or joint compound to hung drywall, sanding mudded drywall, painting, and the like. Accordingly, the control system 322 can drive the drywalling system 100 to perform various suitable tasks, with some or all portions of such tasks being automated and performed with or without user interaction. The control system can comprise various suitable computing systems, including one or more processor and one or more memory storing instructions that if executed by the one or more processor provide for the execution of tasks by the automated drywalling system 100 as discussed in detail herein. Additionally, while a control system 322 is shown as being part of the base unit 120, in further embodiments, the control system can be part of the robotic arm 140 or end effector 160. Also, further examples can include a plurality of control systems and/or control sub-systems, which can be suitably disposed in one or more of the base unit 120, robotic arm 140, and/or end effector 160.

[0038] Turning to Fig. 4, an exemplary block diagram illustrating systems of an automated drywalling system 100 that includes a base unit 120 coupled to a robotic arm 140 and including a plurality of end effectors 160 configured to couple to the distal end 144 of the robotic arm 140. In this example, the end effectors 160 include a cutting end effector 160C, a hanging end effector 160H, a mudding end effector 160M, a sanding end effector 160S, a painting end effector 160P and an insulation end effector.
As shown in Fig. 4, the base unit 120 can comprise an insulation source 420, a vacuum source 422, a paint source 426, a mud source 430, a power source 432, and one or more base unit devices 438. In various embodiments, one or more of the insulation source 420, vacuum source 422, paint source 426, mud source 430, and power source 432 can couple with a hub 130 (Figs. 1 and 2) and provide resources to an end effector 160 coupled at the distal end 144 of the robotic arm 140 and/or to the robotic arm 140. For example, the insulation source 420 can be coupled with an insulation 421 that extends via the robotic arm 140 to an end 421E, which can couple with an end effector 160 as discussed herein. The vacuum source 422 can be coupled with a vacuum tube 424 that extends via the robotic arm 140 to an end 424E, which can couple with an end effector 160 as discussed herein. The paint source 426 can be coupled with a paint tube 432 that extends via the robotic arm 140 to an end 432E, which can couple with an end effector 160 as discussed herein. The mud source 430 can be coupled with a mud tube 432 that extends via the robotic arm 140 to an end 432E, which can couple with an end effector 160 as discussed herein.

The power source 434 can be coupled with a power line 436 that extends via the robotic arm 140 to an end 436E, which can couple with an end effector 160 as discussed herein. Additionally, the power source 434 can provide power to arm devices 442 of the robotic arm 140 (e.g., sensors 346 and movement system 348) and to base unit devices 438 of the base unit 120 (e.g., control system 322, vision system 324, sensors 326 and movement system 328). In various embodiments, the power source can comprise one or more batteries and/or can be configured to plug into wall receptacles at a worksite. For example, a power cord can be coupled to the power source 438, which allow the drywalling system 100 to be powered by local power at a worksite via a wall receptacle, generator, external batteries, or the like. However, in some embodiments, the automated drywalling system 100 can be completely self-powered and can be configured to operate without external power sources at a worksite. In further embodiments, the robotic arm 140 and/or end effectors 160 can comprise a separate power source that can be separate from the power source 438 of the base unit.
In various embodiments, the automated drywalling system 100 can be configured to perform a plurality of tasks related to construction including applying insulation, installing and finishing drywall, and the like. In such embodiments, it can be desirable to have a base unit 120 and robotic arm 140 that can couple with and operate a plurality of different end effectors 160 to perform one or more tasks or portions of tasks related to drywalling. For example, the cutting end effector 160C, hanging end effector 160H, mudding end effector 160M, sanding end effector 160S, painting end effector 160P and insulation end effector 160I can be selectively coupled with the robotic arm 140 at the distal end 144 to perform respective tasks or portions of tasks related to drywalling.

For example, the cutting end effector 160C can be coupled at the distal end 144 of the robotic arm 140 and coupled with the power line 436 to power cutting devices 462 of the cutting end effector 160C. The cutting end effector 160C can be controlled by the automated drywalling system 100 to cut drywall or perform other cutting operations. In some examples, the cutting end effector 160C can comprise a cutting vacuum that is coupled to vacuum source 422 via the vacuum line 424 to ingest debris generated by cutting done by the cutting end effector 160C.

The hanging end effector 160H can alternatively be coupled at the distal end 144 of the robotic arm 140 and coupled with the power line 436 to power hanging devices 464 of the hanging end effector 160H. The hanging end effector 160H can be controlled by the automated drywalling system 100 to hang drywall, assist with drywall hanging, or the like.

The mudding end effector 160M can alternatively be coupled at the distal end 144 of the robotic arm 140 and coupled with the power line 436 to power mudding devices 466 and/or mudding applicators 468 of the mudding end effector 160M. The mudding end effector 160M can be controlled by the automated drywalling system 100 to perform "mudding" or "mud work" associated with drywalling, including application of joint compound (also known as "mud") to joints between pieces of hung drywall, and the like. Joint compound as discussed herein can encompass pre-mixed, topping, taping, multi-use, all-purpose, and setting type compounds. Additionally, the mudding end effector can also be configured to apply joint tape, or the like. Additionally, the mudding end effector 160M can...
comprise a mudding vacuum 469 that is coupled to vacuum source 422 via the vacuum line 424 to ingest excess joint compound or mud generated by the mudding end effector 160M.

[0045] The sanding end effector 160S can alternatively be coupled at the distal end 144 of the robotic arm 140 and coupled with the power line 436 to power sanding devices 464 of the sanding end effector 160S. The sanding end effector 160S can be controlled by the automated drywalling system 100 to sand mudded drywall, and the like. Additionally, the sanding end effector 160S can comprise a sanding vacuum 472 that is coupled to vacuum source 422 via the vacuum line 424 to ingest debris generated by sanding done by the sanding end effector 160S.

[0046] The painting end effector 160P can alternatively be coupled at the distal end 144 of the robotic arm 140 and coupled with the power line 436 to power a paint sprayer 474 and/or painting devices 476 of the painting end effector 160P. The painting end effector 160P can be controlled by the automated drywalling system 100 to paint drywall or other surfaces. Additionally, the painting end effector 160P can comprise a painting vacuum 472 that is coupled to vacuum source 422 via the vacuum line 424 to ingest excess paint spray or fumes generated by painting done by the painting end effector 160P.

[0047] The insulation end effector 1601 can alternatively be coupled at the distal end 144 of the robotic arm 140 and coupled with the power line 436 to power an insulation sprayer 480 and/or insulation devices 482 of the insulating end effector 1601. The insulating end effector 1601 can be controlled by the automated drywalling system 100 to apply insulation to a wall assembly or other suitable locations. Additionally, the insulation end effector 1601 can comprise an insulation vacuum 484 that is coupled to vacuum source 422 via the vacuum line 424 to ingest excess insulation spray or fumes generated by insulation application by the insulation end effector 1601.

[0048] Although the example automated drywalling system 100 of Fig. 4 is illustrated having six modular end effectors 160, other embodiments can include any suitable plurality of modular end effectors 160, with such end effectors 160 having any suitable configuration, and being for any suitable task or purpose. In further examples, the automated drywalling system 100 can comprise a single end effector 160, which can be permanently or removably
coupled to the robotic arm 140. Additionally, in some examples, a given end effector 160 can be configured to perform a plurality of tasks. For example, in one embodiment, an end effector 160 can be configured for insulation work, mud work, sanding and painting. Accordingly, the example of Fig. 4 should not be construed to be limiting on the wide variety of other embodiments that are within the scope and spirit of the present disclosure.

[0049] Turning to Fig. 5, a method 500 of building a wall assembly, including drywalling, is illustrated, which can be performed in whole or in part by an automated drywalling system 100 as discussed herein. The example method 500 or portions thereof can be performed automatically by the automated drywalling system 100 with or without user interaction.

[0050] The method 500 begins at 505 where insulation is applied to a wall assembly. For example, as discussed in more detail herein, insulation can be sprayed between studs of a wall assembly, to the back of hung drywall sheets or in any other suitable location of a wall, ceiling, floor, or the like. In other examples, sheets of insulation can be applied in such locations. In various embodiments, any suitable type of insulation material can be used, including fiberglass, cellulose, cotton fiber, polyurethane, open or closed cell foam, rock wool, vermiculite, urea tripolymer, and the like.

[0051] The method 500 continues at 510, where the configuration and location of drywall pieces is planned. For example, in some embodiments, the automated drywalling system 100 can be configured for automated scanning and mapping of a worksite (e.g., framing elements of a house or building) and automated planning of the shapes and sizes of drywall to be disposed at the worksite to generate walls, ceilings and the like. Such scanning and mapping can include use of vision systems 324, 364 (Fig. 3) and the like. Planning of shapes and sizes of drywall can be based at least in part on the scanning and mapping and can be performed by a computing device 100 of the automated drywalling system 100 or other suitable device which can be proximate or remote from the automated drywalling system 100. In some embodiments, such planning can be based at least in part on building plans or maps that were not generated by the automated drywalling system 100.
The method 500 continues to 520, where drywall pieces are cut. Such cutting can be based at least in part on the scanning, mapping and planning discussed above. Additionally, such cutting can be performed by the automated drywalling system 100 at a worksite (e.g., via a cutting end effector 160C) or can be performed by a system remote from the worksite and generated drywall pieces can be delivered to the worksite.

At 530, generated pieces of drywall can be hung at the worksite, including hanging on studs, beams, posts, wall plates, lintels, joists, and the like, to define walls, ceilings and the like. Screws, nails or other suitable fasteners can be used to hang the drywall pieces. In some embodiments, the automated drywalling system 100 can be configured to hang drywall pieces including positioning the drywall pieces and coupling the drywall pieces in a desired location. In some examples, the automated drywall system 100 can be configured to assist a user in hanging drywall, including holding the drywall and/or tools in place while the user fixes the drywall pieces in place. In various examples a hanging end effector 160H can be used for such drywall hanging.

At 540, mud work can be performed on the pieces of hung drywall. For example, joint compound (known also as "mud") can be applied to seams or joints between adjacent pieces of drywall, over surfaces of the drywall, and/or can be applied over fasteners such as drywall screws or the like. In various examples, a mudding end effector 160M can be used to perform such mud work.

At 550, sanding can be performed on the mudded pieces of drywall. For example, where wet joint compound is applied to hung drywall pieces, the joint compound can be allowed to dry and can then be sanded by a sanding end effector 160S of an automated drywall system 100. In various examples, sanding can be performed to smooth out joint compound to generate a planar or otherwise consistent profile on the pieces of drywall in preparation for painting. At 560, the sanded drywall pieces can be painted. For example, in various examples, a painting end effector 160P of an automated drywalling system 100 can be used to paint the drywall pieces.

Although the method 500 of Fig. 5 relates to hanging and finishing drywall, it should be clear that other hanging and finishing methods can similarly be employed by the
automated drywalling system 100, including methods related to hanging particle board, plywood, sheet rock, laminate, tile, wall boards, metal sheeting, lath and the like. Similarly, the methods can be used with different coatings including plaster, polymer coatings, cement, stucco, organic coatings, and the like. Accordingly, the method 500 of Fig. 5 should not be construed to be limiting.

During mud work, automated drywalling system 100 can apply a layer or profile of compound that is greater than a thickness that is conventionally manually applied by human workers to allow for a sanding system (e.g., a sanding end effector 160S) to sand down the compound to a desired plane. For example, in some examples, manual joint compound application mud can be profiled to taper from high points. The automated drywalling system 100 can apply a thicker layer than normal enabling a sanding system to sand down high points to be level to the adjacent surfaces.

For example, Figs. 6a, 6b, 6c, 6d and 6e illustrate one example of a mud application profile for a pair of drywall pieces 610A, 610B that form a seam 620, where joint compound 630 is applied over consecutive layers, which can include joint tape 640, to taper out the high points of joint compound 630 over a wider area. Sanding can then be used to smooth out the final profile. The high points of joint compound 630 can be caused by various features, including the seam 620, feature, raised stud, defect, or any combination of these. In some embodiments, such a mud application can be undesirable for automated application; however, in further embodiments, such a mud application profile can be employed by an automated system such as the automated drywalling system 100.

Figs. 7a and 7b illustrate an example joint compound application process where the joint compound 630 is applied in a thick layer using a sprayer that generates a mud spray 700. Such an application process can be performed by the automated drywalling system 100 in various embodiments. The thickness of the joint compound 630 being applied to the pieces of drywall 610A, 610B defining the seam 620 can allow for a sanding system to be used to sand back high points of joint compound 630 to a level surface. The high points of joint compound 630 can be caused by the seam 620, feature, raised stud, defect, or any combination of these.
Turning to Figs. 8a, 8b, 9a and 9b, examples of a wall assembly 800 including a header 810 and footer 820, with a plurality of studs 830 extending therebetween is illustrated. As shown in Fig. 8b, insulation 650 can be applied to the wall assembly 800 between respective pairs of studs 830 and between the header 810 and footer 820. The insulation 650 can include any suitable type of insulating material, which can include spay insulation or sheets of insulation as described in more detail herein.

As shown in Fig. 9a, the drywall pieces 610 can be coupled to the studs 830 via a plurality of fasteners 640 (e.g., drywall screws) that extend though the drywall pieces 610 and into the studs 830. The drywall pieces 610 can define one or more seams 620, including in the example of Fig. 9a a vertical seam 620V and a horizontal seam 630H. In some embodiments, mud work can be performed on the wall to apply joint compound 630 and can then be sanded to generate a smooth profile or other profile as desired and the sanded wall assembly can be coated with paint 930 as shown in Fig. 9b.

Fig. 10 illustrates one example embodiment of the automated drywall system 100, having an insulation end effector 1601 that is configured to generate a spray of insulation 650. In this example embodiment, the system 100 is shown comprising a robotic arm 140 with an insulation end effector 1601 with integrated overspray or fume collector 1005. The robotic arm 140 and end effector 160 are shown mounted on a mobile base 120 with a vertical lift 126. The base unit 120 can carry supporting systems for the automated drywall system 100 as discussed herein.

In one aspect, the present disclosure pertains to automated systems and methods for applying insulation 650. For example, in some embodiments, the system 100 can deliver spray foam insulation, blanket or batting insulation, or blow-in insulation. In various embodiments, the system 100 can mix, deliver, and apply insulation 650 during framing and hanging of drywall 610 on a wall assembly 800. In some examples, the system 100 can determine how insulation material 650 is prepared, how it is delivered onto a substrate and how insulation material 650 is set, cured, dried, or the like. In further examples, the system 100 can trim or cut the insulation 650 as the insulation 650 is applied or after the insulation 650 has been set in place.
The system 100 can include one or more vision systems 324, 364 and/or sensors 326, 346, 366 that provide data to a computational planner that can determine toolpaths and tool parameters for applying insulation 650 given a set of requirements. The planner can optimize the application of insulation 650 given environmental readings, insulation value requirements, job constraints, and the like. The system 100 can utilize a variety of insulation materials 650 including but not limited to fiberglass, cellulose, cotton fiber, polyurethane, open or closed cell foam, rock wool, vermiculite, urea tripolymer, and the like.

In various embodiments, the system 1000 can comprise a variety of tools that can enable the system 100 to mix, deliver, apply, smooth, dry, and/or cure insulation material 650 or any combination of these. Such tools can be positioned and controlled using the base unit 120, robotic arm 140, and/or end effector 160. In some embodiments, a single robotic arm 140 or any suitable plurality of robotic arms 140 can be used to complete an insulation application task through coordinated or individual paths. The one or more robotic arms 140, and/or end effector 160 can be moved around the room using the mobile base 120 that can be powered or moved manually by an operator.

The base unit 120, robotic arm 140, and/or end effector 160 can include one or more vision systems 324, 364 and/or sensors 326, 346, 366 to provide for safe operation next to users. Such one or more vision systems 324, 364 and/or sensors 326, 346, 366 can include, but are not limited to, laser curtains, proximity sensors, force and torque sensors, pressure sensors, limit switches, a system to track location of the user relative to the robot or mobile base, speed limiters, vision systems, LIDAR, radar, sonar, or any combination of these. The mobile base 120 can include a vertical lift 126 component that can be powered or unpowered. The vertical lift 126 can be used to lift or lower the platform 122, robotic arm 140, end effector 160, positioning stage, gantry or insulation application tools. The lift 126 can be instrumented with a position sensor that can be used to capture and control the height of the lift 126.

The automated drywalling system 100 can be controlled using a planning system (e.g., a planning program executed by the control system 322 or other suitable device) that takes a variety of inputs (e.g., from vision systems 324, 364 and/or sensors 326, 346, 366) to
determine tool paths and/or tool parameters for the base unit 120, robotic arm 140, and/or end effector 160 to achieve desired coating characteristics and to perform various insulation application or trimming tasks. In some examples, a step in a method for automated insulation application and/or trimming includes creating a map of the target surfaces at a worksite (e.g., of wall assemblies 800 as shown in Figs. 8a, 8b, 9a, 9b or the like). Such a map or model can be created by importing building information modeling (BIM) and/or 2D, 3D plans into the planner system. A map can also be created directly by the system 100 by utilizing one or more of vision systems 324, 364 and/or sensors 326, 346, 366 to scan the room. In some embodiments, one or more of the vision systems 324, 364 can include stereo cameras, structured light, cameras, LIDAR, radar, sonar, laser scanners, thermal imaging, or the like. Uploaded 3D or 2D plans can be combined with field data to create a more accurate map of a room or worksite. Data from different sources can be combined using key features and user input. A map can include the location of the framing studs, drywall joints, openings, protrusions, as well as pipes, electrical conduit, ventilation ducts, and any other components installed on the walls or ceilings. These locations can be derived from uploaded plans, a room scan and/or user inputs. To facilitate the creation of a map, a user can help identify features through analysis of images, and tagging of the features physically or digitally. The user can physically tag components using a laser, tags, markers or a combination of these. One or more of the vision systems 324, 364 and/or sensors 326, 346, 366 can sense or identify these tags or track them as the user moves around the room and locates the features.

A mapping system or planner system of an automated drywalling system 100 can also take as an input a layout of headers 830, footers 820, framing or studs 830, or any other suitable portion of a wall assembly, including the actual or proposed layout of pieces of drywall 610. This layout can be an input from the system 100, from a system that works in conjunction with the system 100, or based on plans, models, or maps of a construction project. In various embodiments, the location of framing or other elements of a wall assembly 800 can inform or dictate the planning of how insulation 650 can be applied by the system 100. In various examples, the system 100 can also take as an input the location of windows,
doors and other openings and tune the application of insulation 650 to increase the insulation value near these.

[0069] The automated drywalling system 100 can include a computational planner (e.g., a program executed by the control system 322 or other suitable device), which can utilize a map uploaded to the system 100 and/or a map created by the mapping system to determine tool paths and/or tool parameters required to achieve a desired application of insulation 650. The planner can create toolpaths off a global map of the room and then update these paths given updated local measurements once the base unit 120, robotic arm 140, and/or end effector 160 are in place. The planner can be informed by data from one or more of the vision systems 324, 364 and/or sensors 326, 346, 366 on the location of the headers 810, footers 820, studs 830, drywall boards 610 as well as the location of pipes, electrical conduit, wires, protrusions, openings, and the like, as specified by a layout planner or a scan of the room before and/or after drywall 610 was applied. The planner can produce toolpaths and/or tool parameters, which can enable the system 100 to apply insulation 650 between headers 810, footers 820 and studs 830 (see e.g., Fig. 8b) or in any other suitable location in or about a wall assembly 800, building, room, or the like. The tool parameters and/or tool paths can be determined based on one or more desired insulation values, or the like.

[0070] 2D or 3D maps created by the system 100 can be registered to the physical environment utilizing recognizable features such as doors, windows, outlets, corners, or the like. The registration can also be done using markers, tags, laser outlines, or the like that are placed in the room or worksite. A projection or visualization system can find such features or markers and can locate the maps created using these. The system 100 can utilize a user interface to enable a user to help locate the map or projection relative to the environment and resolve any issues or discrepancies. The user can utilize a physical marker to signify key features for the system 100, allowing it to locate the plan relative to the environment. The system 100 can also use the base unit 120, robotic arm 140, and/or end effector 160 to find target features, markers or surfaces and locate them relative to its own base which can be located using one or more vision systems 324, 364 and/or sensors 326, 346, 366, which in
some examples can include laser range finders, computer vision, LIDAR, radar, sonar, stereo vision, odometry, EVIUs, or the like.

[0071] The robotic arm 140 can utilize a compliant or force limiting end effector 160 to enable safe contact with the environment allowing the system 100 to accurately locate target surfaces, features or components, and accommodate errors in positioning without damaging the substrate or the robotic arm 140 or end effector 160. By utilizing the robotic arm 140 and compliant end effector 160 to locate a physical component, the system 100 can establish a point, line, or plane and therefore locate the virtual plan on the environment. Toolpaths can then be updated from the virtual plane to the physical plane. Refitting of the paths onto the contacted surfaces enables the system 100 to deal with errors and discrepancies between the modeled and physical environment. These tools enable quick on-site calibration using global room-wide maps and local measurements. Refitting the tool paths can allow for correction of errors in positioning of the base unit 120, robotic arm 140, and/or end effector 160. The base unit 120, robotic arm 140, and/or end effector 160 can also utilize one or more vision systems 324, 364 (e.g., radar, sonar, thermal imaging, or the like) to establish what is behind the substrate, and this information can be used to update a virtual map and ensure that no damage is done to any electrical, plumbing or ventilation.

[0072] The planner of the system 100 can output tool poses or tool paths for the base unit 120, robotic arm 140, and/or end effector 160, including joint commands, target poses and end effector positions, or the like. The system 100 can also output paths for a gantry system or positioning stage which can be used in conjunction with the robotic arm 140, or without a robot, to move and position coating tools of an end effector 160. The planner can also output paths for the mobile base 120 to position a gantry, positioning stage, or robotic manipulator 140, to move a tool to assist the user in an insulation application process, or position visualization and/or lighting equipment. The mobile base 140 including the vertical lift 126 can work in coordination with the user, robotic manipulator 140, end effector 160, gantry or a combination of these to execute an insulation application task. The planner system can control the different components of the platform such as the base unit 120, robotic arm 140, and/or end effector 160, which can allow for coordinated movements and forces with the
target goal of moving the end effector 160 to a desired position under the prescribed forces and moments. The position of the mobile base 120 can be used as a rough positioning stage, with the vertical lift 126 setting a height of the robotic manipulator 140 which can act as a fine positioning stage.

Although various embodiments discussed herein relate to spray application of insulation, some embodiments can relate to applying batting, blanket insulation or other sheet of insulation material 650 to or within a wall assembly 800 or other suitable location. For example, Fig. 11 illustrates an example embodiment of an insulation applicator end effector 1601, wherein a roll of insulation 650 is mounted within a roll body 1120 of the end effector 160 and fed under a roller 1130. The insulation end effector 1601 can be moved over a target surface and the roller 1130 to push the insulation 650 into place between studs 830 of a wall assembly 800 or other suitable location. In various examples, the insulation end effector 1601 can use studs 830 or other suitable framing element or other feature as a datum for guiding the insulation end effector 1601.

In some embodiments, the width of insulation 650 can be set to match a spacing width between studs 650, or the like. For example, an insulation end effector 1601 can comprise a blade, laser or other cutter that can be used to cut insulation 650 to size before, during or after application of the insulation 650. Additionally, adhesive can couple insulation 650 within a wall assembly 800 or other suitable location. For example a blanket of insulation 650 can be pre-impregnated with adhesive before or during application; an insulation end effector 1601 can apply adhesive ahead of the insulation 650 to help secure the insulation 650 to a substrate, or the like.

In some examples, an adhesive can be applied with an end effector 160 by spraying. Some examples can include a separate end effector 160 having an adhesive spray gun, or an adhesive spray gun can be part of an insulation end effector 1601, that is configured to apply adhesive in front of the insulation 650 onto a surface that the insulation 650 is being applied to and/or by applying the adhesive onto the insulation 650 before the roller 1130.
Fig. 12 illustrates one embodiment 16012 of an insulation end effector 1601 that includes a spray gun 1210 that is coupled onto the robotic arm 140. A trigger 1220 can be actuated with an actuator 1230 (e.g., a servo, solenoid, pneumatic cylinder, or the like) which can pull on the trigger 1220 to open the nozzle 1240 to generate an insulation spray 1250.

In another example, Fig. 13 illustrates another embodiment 16013 of an insulation end effector 1601 that includes a spray gun 1210 that is coupled onto the robotic arm 140. An internal trigger (not shown) can be actuated with an actuator (e.g., a servo, solenoid, pneumatic cylinder, or the like) which can open the nozzle 1240 to generate an insulation spray 1250. In the examples of Figs 12 and 13, insulation can be fed to the spray gun 1240 and nozzle 1240 via an insulation tube 421, which can feed insulation 650 from an insulation source 420 disposed at the base unit 120 (See Fig. 4).

Tracking the position of an insulation end effector 1601 with one or more of the vision systems 324, 364 and/or sensors 326, 346, 366 can enable a planner system to create an updated map of the room with the location of the insulation 650 and the conditions under which the insulation 650 was applied. The one or more of the vision systems 324, 364 and/or sensors 326, 346, 366 can use tags or markers to track as a user manually applies the insulation 650 on surfaces and that information can be fed into the planner. The base unit 120, robotic arm 140, and/or end effector 160 can be used to control the orientation of insulation application tools of the end effector 160 and the force applied on the target surface as the insulation 650 is applied, which can ensure the insulation 650 is applied with the required pressure for adhesion.

The system 100 can include one or more vision systems 324, 364 and/or sensors 326, 346, 366 (e.g., humidity, temperature, air flow sensors, or the like) to establish environmental conditions for application and drying of insulation 650. The automated drywalling system 100 can utilize data from such environmental sensors to determine a desired insulation composition, set path parameters such as feed speed, thickness of insulation applied, roller pressures, insulation sprayer settings, and the like. Environmental information in conjunction with insulation parameters can be used to determine or estimate...
drying times for the insulation allowing the system 100 to plan when a next step should begin.

[0080] The automated drywalling system 100 can also determine when the insulation 650 has set and dried by measuring the thermal conductivity of surfaces associated with the insulation 650 using a vision system (such as a thermal imaging camera); using a sensor such as a thermometer (contact or non-contact), or by detecting differences in colors using a vision system (e.g., due to color changes that occur between wet and dry insulation 650). Various measurements can be used to infer the moisture content of insulation 650 by comparing a determined temperature of the insulation 650 to the surrounding materials such as a substrate that the insulation 650 was applied to. For example, as water or other solvent evaporates from a mixture of insulation 650, the temperature of the insulation 650 can be lower than that of the surrounding materials.

[0081] Models of an insulation chemical process or drying process can also be used to estimate the time for insulation 650 to dry or cure given a set of starting conditions and information about the environment. Similarly, the insulation properties in combination with environmental and substrate information can be used to estimate the final thickness and insulation properties of the insulation 650. The environmental sensors and/or vision systems can be used in conjunction with an HVAC system or heater, air conditioner, fans, or the like, to control the room conditions at a worksite. The sensor readings can automatically trigger any of these systems or a combination to maintain the room at the desired conditions for quality, reduced drying or setting time, or comfort of the operator.

[0082] In various embodiments, an insulation end effector 1601 can be used to deliver insulation 650 to a target surface. In some examples, a spray gun 1210 can comprise an airless spray system or air assisted spray system. A pump can be used to move insulation 650 from the insulation source 420 to the spray gun 1210. The insulation 650 can be pumped or stored at high pressures, in some examples, to enable the insulation 650 to be sprayed or aerosolized.

[0083] The pressure, flow rate, piping system resistance and the like, can be tuned or controlled by the automated drywalling system 100 to change the speed and amount of
insulation 650 being delivered to the spray gun 1210 and ejected from the nozzle 1240 as a spray 1250. The automated drywalling system 100 can use any suitable actuator (e.g., a servo, solenoid, air cylinder, linear actuator, or any combination of these) to open and close the nozzle 1240 of the spray gun 1210. As shown in the example of Fig. 12, a manual spray gun 1210 can be instrumented to use an electro-mechanical system 1230 to pull the trigger 1220 allowing the system 100 to control the timing of the insulation delivery as well as the opening and closing of the nozzle 1240.

[0084] As shown in the example of Fig. 13, an automatic spray gun 1210 can also be used and controlled by the system 100 directly. The robotic arm 140 and end effector 160 and/or base unit 120 can thereby be used to spray insulation 650 as a spray 1250 onto various surfaces, including between headers 810, footers 820 and studs 830. The insulation end effector 1601 can also be used to apply adhesive onto a surface for batting, blanket insulation, or the like.

[0085] The spray gun 1210 can use a variety of suitable nozzles 1240 including fan shape, bell shape, or the like. The system 100 can also use a tunable spray gun 1210 that can control the shape of the nozzle 1210. The shape of the insulation spray 1250 can be controlled in some examples by physically changing the shape of the nozzle 1210. The shape of the insulation spray 1250 can also be controlled using air streams, or the like which can act on the insulation spray 1250.

[0086] In some embodiments, a cassette with different nozzles 1240 can be installed on the spray gun 1210 allowing the automated drywalling system 100 to select a desired nozzle 1240 to control the shape of the spray 1250. A fan shape can also be tuned by using a set of sliding mechanisms to set the fan width and opening of the nozzle 1240. The diameter of a bell may also be tuned by a sliding cone with expanding orifice size. The robotic arm 140 and/or base unit 120 can also be used to move the nozzle 1240 closer to or farther away from a target surface resulting in a narrower or wider fan or bell spray pattern respectively. The system 100 can utilize an array or series of nozzles 1240 to spray the insulation 650 over a larger surface. The nozzles 1240 can be individually controlled and tuned or such nozzles 1240 can be controlled as a unit. In one embodiment of the nozzle 1240, the size of the spray
on the surface can be independent of the distance between the sprayer 1210 and a target surface.

[0087] A series of tests can be performed to establish the characteristics of a pattern of insulation spray 1250 delivered by a nozzle 1240. In one embodiment, one or more vision system 324, 364 can be used to characterize a pattern of insulation spray 1250 and provide feedback for tuning parameters including tool parameters related to a nozzle 1240, spray gun 1210, insulation source 420, or the like, as discussed herein. Another embodiment can utilize an array of sensors (e.g., piezo sensors or other force sensors) on a test board which can be used to measure the force applied by the pattern of insulation spray 1250 as it hits the sensors. The force pattern can be used to estimate a profile of the pattern of insulation spray 1250 as it is hitting the surface. The feedback from these sensors may be used to tune the profile of one or more spray nozzles 1240, spray gun 1210, insulation source 420, or the like.

[0088] The automated drywalling system 100 can include a mixer, pump and the like that can deliver mixed insulation 650 to the various tools including a spray gun 1210. Such a mixer, pump and the like can be part of an insulation source 420 disposed at the base unit 120 or disposed external to the system 100. In some embodiments, a mixer can utilize sensors to control a mixing ratio of water or other solvent, insulation components 650, and any additives that enhance structure of the insulation 650, decrease setting or drying time, or the like. The mixer can control the mix ratio by measuring the mass, volume, density, or viscosity of the components or the mixture that defines the insulation 650. The mixing system can utilize pre-mixed insulation 650 or can add water and/or additives as desired to a mixture.

[0089] The automated drywalling system 100 can also use a spray gun 1210 that has been designed to mix the components of the insulation 650 at the nozzle 1240. For example Fig. 14 illustrates and example of an in-line nozzle 1240 for mixing insulation 650 with water or other solvent, and any additives at the application site. The nozzle 1240 or other cartridge or packet can be detachable in some examples to be cleaned or to be disposable.

[0090] Insulation lines 421, a nozzle 1240, a pump, or the like, can be instrumented with sensors to measure flow rate, pressure and other desirable parameters. Pressure sensors can be used to monitor the pressure along an insulation line 421 enabling the detection of changes
in the pressure, flow rate, as well as the detection of clogs. In some examples, an orifice plate can be used to measure the flow rate through the insulation system in combination with a set of pressure sensors. Other flow rate sensors can include, but are not limited to a rotameter, spring and piston flow meter, ultrasonic flow meter, turbine meter, paddlewheel meter, variable area meter, positive displacement, vortex meter, pitot tube or differential pressure meters, or magnetic meters for conductive coatings. Detecting a change in flow, pressure in the insulation line 421, or reaction force at the end effector 160 (e.g. at a spray gun 1210) can be used to determine that a clog has occurred. The spray gun 1210 can produce a reaction force when spraying so if the reaction force changes, the system 100 can identify that the insulation spray 1250 has changed, which can be indicative of a clog or other issue.

[0091] A pattern of the insulation spray 1250 can also be monitored to detect clogs or wear of the nozzle 1240. For example, Fig. 15 illustrates an example embodiment 160P4 of an insulation application end effector 160P that includes a spray pattern detection mechanism 1505, in which a vision system 364 can be used to monitor the pattern of insulation spray 1250 coming out of the nozzle 1240 to detect clogs, nozzle wear, low pressure, or other problems with the spray gun 1210 or related system such as insulation lines 421, paint source 420 or the like.

[0092] In some examples, the stream of insulation spray 1250 can be monitored or the pattern of insulation spray 1250 on a target surface can be monitored. The stream of insulation spray 1250 and/or pattern of insulation spray 1250 can be monitored using vision sensors 364, which can include any suitable vision system, including but not limited to thermal sensors, moisture sensors, capacitance sensors, or the like.

[0093] In one embodiment, a camera can be placed next to the stream of insulation spray 1250 so that the profile of the insulation spray 1250 is captured. Image processing can be used to identify when the shape of the stream of insulation spray 1250 has changed. In another embodiment, a laser curtain may be placed across the stream of insulation spray 1250, and if the flow is interrupted along any part of the fan or bell, the laser would complete its path and be detected by a sensor on the other side of the stream of insulation spray 1250.
A mixer, pump, insulation lines 421, and nozzle 1240, and other suitable elements can be fitted with filters which can be used to catch debris or particles that may clog the nozzle 1240 or insulation lines 421. The filters can be placed in an inlet of the pump, outlet and inlet of the mixer, directly before the insulation line 421, directly before the nozzle 1240, or any point along or within the insulation system. The automated drywalling system 100 can monitor the pressure before and after the filters to detect when the filters need to be changed. Flow rate sensors can also be used to detect a clogged filter. The automated drywall system 100 can reverse its flow to clear clogs from the insulation line 421, nozzle 1240, filters, or other components.

The spray gun 1210 or other insulation end effector 1601 can also include a vacuum system 484, spray guards, or the like, that can be used to minimize overspray and reduce the amount of excess insulation 650 in the air. For example, Fig. 16 illustrates an example embodiment 16015 of an insulation end effector 1601 that comprises a vacuum system 484 that includes a vacuum hood 1605 disposed around the an end and nozzle 1240 of a spray gun 1210 to capture overspray or fumes. The vacuum hood 1605 can surround the spray gun 1210 and can include an adjustable vacuum setting. The vacuum hood 1605 can be coupled to the vacuum line 424, which is connected to the vacuum source 422 to provide a vacuum to the vacuum hood 1605.

Fig. 17 illustrates an example embodiment 16016 of an insulation end effector 1601 that comprises a spray guard 1705 that partially extends about and past the face of the nozzle 1260 of the spray gun 1210. In this example, the spray guard 1705 is shown being generally triangular and fanning out from where the spray guard is coupled to the end effector 1601. In some examples, the spray guard 1705 can be selectively deployed by the system 100 or a user to prevent overspray onto an undesired surface. The spray guard 1705 can be deployed in various suitable ways, including but not limited to, via a servo, pneumatic cylinder, solenoid or other electromechanical actuator, which can rotate or otherwise deploy the spray guard 1705 into place.

In various embodiments, an insulation end effector 1601 can comprise one or both of a vacuum system 478 and spray guard 1705 of various suitable configurations. The guard
1705 and/or vacuum system 478 can be deployed when the automated drywall system 100 is spraying near another surface or a feature. The spray guards 1705 and/or vacuum systems such as a vacuum hood 1605 can be retracted using a linear actuator, solenoid, air cylinder, or other suitable electro-mechanical actuator. In some embodiments, a spray guard 1705 can also be mounted on a rotary stage such that the spray guard 1705 can be rotated into place next to the sprayer 1210 by actuating the motor or servo. Accordingly, in some examples, the position of the spray guard about a circumference of the spray gun 1210 can be selected by the system 100 and/or a user.

[0098] Fig. 18 illustrates an example embodiment of an automated drywalling system 100 where an insulation end effector 160 utilizes studs 830 of a wall assembly 800 as a guide for delivering insulation 650 between the studs 830, header 810 and footer 820. As shown in Fig. 18, the end effector 160 can comprise an arm 1810 having a roller 1820 that can be pressed against an internal face of a stud 830 for guiding the sprayer 1210. In various examples, the insulation end effector 160 can utilize the surrounding surfaces as datums and a roller, wheel, blade, or the like, and can be pushed in contact with such a datum surface or feature for reference.

[0099] Such contact points can extend away from an insulation application zone to enable the use of datums away from the where the sprayer 1210 is applying insulation 650. For example, Fig. 18 illustrates the end effector 160 having an arm 1810, which can allow the sprayer 1210 to be spaced centrally between the studs 830, while the roller 1820 contacts one of the studs 830 for use as a datum.

[00100] In various embodiments, the end effector 160 can control the position of the contact points such that the correct or optimal datum surface is used. For example, the arm 1810 can be extendible and retractable to provide for a desired offset from the stud 830 or other contact surface. Additionally, the force and pressure on contact points can also be controlled. For example, force can be directly or indirectly measured or estimated by monitoring the deflection of the mounting structure, and the like. In one embodiment, the spray end effector 160 can utilize a roller 1820 to guide the sprayer 1210 along a stud 830 or other portion of a wall assembly as shown in Fig. 18. In some examples, the system 100 can
operate in hybrid force and position control following the stud 830 and spraying the insulation 650 in a target area relative to the stud 830.

[00101] In various embodiments, the system 100 can include a cutting tool for trimming the insulation 650 after the insulation 650 has been applied. For example, the system 100 can create a map or model of a room given a set of insulation application parameters and/or by directly mapping the room after the insulation 650 has been applied. A model or map of the room with insulation 650 can be used to determine areas that need to be trimmed or cut to enable the closing of the walls and installation of doors, windows and the like. In some examples, an insulation cutting tool can follow a front edge of studs 830, or other suitable framing element, and cut insulation material 650 that protrudes beyond the plane of the stud 650. In one embodiment, an insulation cutting system can comprise a blade that is pushed along a pair of studs 830, which can remove insulation material 650 that extends beyond a plane created by the pair of studs 830. The insulation cutting tool can be powered or unpowered in various embodiments. The robotic arm 140 and/or end effector 160 can be used to drive an insulation cutting tool through the insulation 650. Additionally, insulation 650 can be cut to create room for electrical boxes, wires, framing, conduit, pipes, or any other mechanical, electrical or plumbing component.

[00102] Insulation application and/or insulation cutting tools can be mounted in series with a structure that limits, sets, or controls the amount of force applied on a target surface. The structure can limit, set or control only the normal force applied on the surface by blades, rollers, trowels or such a structure can also limit, set or control forces applied by the tools along the target surface as well as torques applied. Blades or rollers can be mounted on an air bag, air shock, air cylinder, air bellows, or the like, with a fixed or variable pressure setting. The pressure and the normal area of the pressure vessel can set the amount of force applied by the tool on the target surface. A blade or roller can also be mounted on a spring, tunable spring, or shock in order to set, limit or control the force applied on the surface. The force can also be set, limited, or controlled using a pressure controlled hydraulic system including a cylinder, bellows, reservoir, or the like. In one embodiment, a short-stroke low-mass end effector linear actuator mechanism can be used for fast tracking of surface contours and
constant normal force. In embodiments with more than one blade or roller, tools can be mounted on a single force limiting structure or each head or multiple tools can be mounted on separate structures. Mounting the tools or group of tools on separate structures can allow for the applied forces and moments to be set, limited, or controlled separately.

[00103] Insulation application and/or insulation trimming tools can include sensors 366 and/or a vision system 364 to ensure the desired orientation of the blades or rollers relative to the wall. For example, one application includes ensuring planarity of the tool to the wall; however, the mechanism may also set the blade or roller to a specific target angle relative to the surface. The planarity may be established by utilizing the vision system 364 to detect the plane of the surface and then match the tool position using the degrees of freedom of the system 100. The planarity may also be established by utilizing one or more sensor 366 at the end effector 160 (e.g., a set of proximity, range, or contact sensors to establish the position of a tool head relative to a wall). Blade or roller orientation can be controlled directly by setting the joint angles of the robotic arm 140, by a powered gimbal or joint at the end effector 160, and/or by a passive gimbal that allows the tool to tip and tilt relative to the end of the robotic arm 140. A passive gimbal can enable the contact tool to follow the plane of a target surface despite errors in the position of the system 100.

[00104] In another embodiment, the position of the contact can be controlled through an active gimbal using feedback from one or more of sensors 366, 346, 326 and/or vision systems 364, 324 that can establish the relative orientation between blades or rollers and surface. Powered or passive gimbals or end effector degrees of freedom can be encoded (e.g., via sensors 366) such that the orientation of the tool and/or end effector 160 is known to the system 100.

[00105] An insulation end effector 1601 can also utilize outriggers such as rollers to use adjacent surfaces or raised edges as datums to guide the application of insulation 650 (or other suitable coating) and achieve accurate corners. These rollers may be instrumented with sensors 366 and/or a vision system 364 to measure or determine force, contact, proximity, or the like. Additionally, or alternatively, such rollers can passively make contact while the drywalling system 100 utilizes its sensors 366, 346, 326 (e.g., force and torque sensing)
and/or vision systems 364, 324 to maintain a pressure or force against the datum surface. The information obtained or determined about tool orientation relative to the portions of the end effector 160, robotic arm 140 and/or base unit 120 can be used to alter the toolpath, tool parameters and/or other system configurations to ensure the insulation system can carry out the process without running into limitations of the hardware.

[00106] In both passive and active embodiments, the angular position of a gimbal or other portion of an end effector 160 can be recorded (e.g., via sensors 366 or vision system 364) to locate and establish the plane of the target surface. The angular position of the gimbal can be recorded using elements including, but not limited to encoders on the rotary axis, laser range finders, capacitance sensors, IMUs, an external vision system, sonar sensors, potentiometers, motor loads, or any combination of these.

[00107] The gimbal system can be tuned to minimize dynamic effects by using springs, dampers or a combination of these. In some embodiments with more than one blade or roller, all tools may be mounted on a single gimbal structure or each tool or groups of tools can be mounted on separate gimbals. Mounting the blades or rollers on separate gimbals can allow for tool surface planes to be set, limited, or controlled separately. Insulation application tools can be mounted on a gimbal in series with a compliant system described above that limits, sets, or controls the force applied on the surface.

[00108] In some embodiments, the system 100 can include a heater, curing light, blower, fan, UV light, microwave emitter, or the like. Such components can be mounted on one or more of the base unit 120, robotic arm 140, and/or end effector 160 or can be static in the room and separate from the system 100. In various examples, such components can speed up the curing, drying, or setting time of the insulation 650 and/or adhesive. Additionally, such components can be used to prepare a target surface for the application of the insulation 650. The system 100 can comprise a humidity sensor, conductivity sensor and depth or thickness sensors such as laser range finders, sonar, radar, LIDAR, and the like. In various embodiments, toolpath settings, insulation mixture, fan, heater, light settings, and the like can be adjusted in real-time given measurements from such sensors.
The system 100 can utilize additives to accelerate the setting time of insulation 650 or other coating such as adhesive, or the like. For example, an accelerant can be mixed into the insulation 650 during preparation, added in at the nozzle 1240, applied to a coating of insulation 650 after deposition, or any combination of these. The automated system 100 can utilize environmental information to determine the amount of accelerant to add and at what point in the process such accelerant should be introduced. In other words, data from one or more vision system 324, 364 and/or sensors 326, 346, 366 can be used to automatically modify the parameters of the composition, preparation, and application of insulation 650 and/or additives for insulation 650. In some examples, accelerant may be sprayed onto a coating of insulation 650 after the insulation 650 has been applied onto the target surface.

The automated drywalling system 100 can utilize sensors (e.g., humidity or conductivity sensors) that are mounted on a surface before insulation application, which can provide for tracking of the moisture content of a target surface and/or insulation 650 applied to the target surface. Such sensors can be mounted directly onto the target surface or can be mounted on a coupon that is covered at the beginning of the process with the same parameters. Such sensors can be connected to a wireless communication system to send signals/data to the automated drywalling system 100. Moisture content and other information collected by such sensors can be used to control or adjust the settings on fans, blowers, heaters, curing lights, an HVAC system, or the like. The drying speed can also be used to adjust the composition of the insulation 650. Monitoring the moisture content can allow the system 100 to accurately estimate the time when the next drywalling process can begin (e.g., drywall hanging, mudding, sanding, painting, coating, or the like).

The automated drywalling system 100 can also determine when the insulation 650 has set and dried by measuring the thermal conductivity of material or framing elements associated with the insulation 650 using a vision system (such as a thermal imaging camera); using a sensor such as a thermometer (contact or non-contact), or by detecting differences in colors using a vision system (e.g., due to color changes that occur between wet and dry insulation 650. Various measurements can be used to infer the moisture content of insulation 650 by comparing a determined temperature of the insulation 650 to the surrounding...
materials such as a substrate on which the insulation 650 has been applied, studs 830, headers 810, footers 820, and the like. For example, as water or other solvent evaporates from a mixture of insulation 650, the temperature of the insulation 650 can be lower than that of the surrounding materials.

[00112] Models of the insulation drying process can also be used to estimate the time to dry or cure given a set of starting conditions and information about the environment. The environmental sensors and/or vision systems can be used in conjunction with an HVAC system or heater, air conditioner, fans, or the like, to control the room conditions at a worksite. The sensor readings can automatically trigger any of these systems or a combination to maintain the room at the desired conditions for quality, reduced drying time, or comfort of the operator.

[00113] The automated drywalling system 100 can also tune the profile of a delivered coating of insulation 650 (or other suitable coating) to account for overlap of a subsequent stroke of an insulation gun 1210 or other spray tool. For example, insulation thickness at the edges can be reduced or feathered such that the overlap region achieves the final desired thickness. This approach can also be used to increase overlap error tolerance at transition points between robot workspaces. The automated drywalling system 100 can utilize the information about the room such as location of windows and lighting fixtures to tune the insulation toolpaths to achieve the most consistent finish near these features. The automated drywalling system 100 can optimize the path to minimize overlaps or breaks in the stroke near the light sources. The system 100 can also apply the coating in a criss-cross pattern to create a more even thickness or better finish. The planner system of the automated drywalling system 100 can output paths that guide the tool in this criss-cross pattern.

[00114] The automated drywalling system 100 can be instrumented with one or more vision systems 324, 364 and/or sensors 326, 346, 366 to improve operation and ensure quality. During insulation and/or adhesive application, the automated drywalling system 100 can use sensors 326, 346, 366 (e.g., force and torque sensors), which can be mounted directly on the base unit 120, robotic arm 140, and/or end effector 160, or the force and torque estimates of robotic joints can be used to apply the required force during rolling or
smoothing. The sensors 326, 346, 366 can monitor only force normal to a blade, rollers or the like, or multiple axes can be monitored including torque measurements and six-axis sensing. Force sensing can be used to control the force or pressure applied by the tool of an end effector 160. A minimum force or contact readings can also be used to ensure contact is made with a target surface before the insulation 650 or other coating material is allowed to flow, with target surface contact force below a certain threshold or loss of contact triggering the stop of material flow. The automated drywalling system 100 can use force information to operate in force control, where the motions and speeds of the system 100 are driven to ensure a given force is applied in the desired directions. Similarly, force sensing can be used to detect contact with an object, obstacle, or intersecting wall or ceiling. By monitoring the forces and torque on the base unit 120, robotic arm 140, and/or end effector 160, the system 100 can detect that it has made contact with the adjacent wall or ceiling and alter the toolpath accordingly. The measurements can also be used to detect accidental contact and trigger a safety operation such as stopping the system 100 or retracting away from contact point. The base unit 120, robotic arm 140, and/or end effector 160 can also use contact or proximity sensors to detect that the end effector 160 is touching a target surface, obstacle, object, or worker, as well as detect the distance to an adjacent surface or contact with that surface. The force, contact, displacement, or proximity sensors can be mounted on outriggers from the end effector to sense obstacles, objects, or adjacent surfaces ahead of the tool. The system 100 can detect, follow, and use adjacent walls as datums to guide coating application and achieve accurate corners or to guide the tool during insulation application and cutting.

The base unit 120, robotic arm 140 and/or end effector 160 can utilize multiple control strategies to complete various tasks. Position control can be used to command the system 100 to follow a trajectory given speed, acceleration, and jerk constraints. The system 100 can be controlled at the joint level by giving commands to the joints to achieve the desired robot state and tool position, or the control can be done at a higher level allowing a user or program to control end effector position and orientation. The system 100 can be controlled in task space where the system 100 controls a tool relative to the task. This approach can focus on achieving a desired tool position, orientation, speed, or the like,
relative to the target surface rather than on each joint reaching its target goal. The system 100 can utilize force control to control the force applied to the target surface, an obstacle, adjacent surfaces, objects and so on. The applied force can be controlled in a single or multiple axes. Hybrid control modes can also be used. For example the system 100 can be commanded to achieve a given position as long as a given force is not exceeded.

[00116] One or both of the vision systems 324, 364 can be used to capture where and how insulation 650 or other coating has been applied. By monitoring the spray pattern applied, the system 100 can detect clogs, nozzle or blade wear, or other problems. In one example, a thermal camera can be used to detect the applied insulation 650, which can be at a different temperature than the target material. The insulation's temperature can be controlled to facilitate detection. Monitoring the insulation temperature can also give information on the moisture content of the insulation 650. The color can change as the insulation 650 dries, which can be detected via vision systems 324, 364. Sensing such as capacitance, radar, resistance, humidity, conductivity, sonar measurements, or any combination of these can also be used to establish the thickness of insulation 650. Lights can be mounted on the system 100 or externally to illuminate the surface enabling the detection of coated surfaces, high and low points, framing, and defects using one or both of vision systems 324, 364.

[00117] The system 100 can monitor the coverage achieved by the end effector 160 and update tool paths and tool parameters to ensure the desired insulation profile is being applied. For example, the system 100 can dynamically tune a sprayer fan and/or bell or other parameters of a nozzle 1240 until the insulation spray pattern matches the desired shape, thickness, size. The system 100 can also move the sprayer 1210 closer or farther away from the target surface to change the spray pattern. The system 100 can also tune the material flow rate, pressure, spray tool speed, or the like, to achieve a desired thickness. The toolpaths and/or tool parameters can also be updated to ensure that the correct overlap is being achieved.

[00118] The system 100 can also utilize a feedback mechanism for communicating contact, forces, gimbal displacement information, tool orientation, motor loads, humidity and temperature readings, measurements of the applied insulation 650, to system 100 (e.g., to the
control system 322) for the purpose of real time updating of the tool paths and tool parameters for improving quality and process. The system 100 can use tool position and orientation, captured surface conditions and models to update the robotic toolpaths to ensure that a desired position and/or contact is maintained during application of insulation 650.

[00119] The system 100 can also determine areas that need another application of insulation 650 or further trimming, rework using the system 100, or rework to be done manually by the user. The user can also use a user interface to indicate areas that the user has identified as needing rework or that need to be covered again. The planner can use this input along with other information about the previous work to create a new toolpath. Both user and system feedback can be fed into a machine learning algorithm to create a better model for applying and trimming insulation 650 given a set of initial conditions.

[00120] The automated drywalling system 100 can utilize a user interface to enable the worker to control, program, debug, plan, and setup the system 100. The user interface can be used to give the user information of all the steps that must be taken to setup the system 100. Each step can be checked off when complete and the user can request more information on each step. The workspace of the system 100 can be shown overlaid on a camera feed or projected onto the target surface to help the user position the end effector 160, robotic arm 140 and/or mobile base unit 120. The workspace can be projected using lights or lasers. The system 100 can also automatically perform certain steps and the user interface can report the progress of each step, as well as give guidance to the steps the user can follow to perform a task. The user interface can be used to setup the system 100 and run any calibration routines required. The interface can also be used to plan a job including detecting wall, user definition of path parameters or path itself, auto generation of the tool path, user input of tool parameters, and automatically optimized tool parameters given a set of user inputs.

[00121] The user interface can be a graphical user interface and include a 2D or 3D representation of the worksite and workspace. The representation can include camera feeds as well as computer models and reconstructions created using sensor data. The interface can overlay paths, quality visuals, progress, robot model, and the like, over camera or workspace
models. As the task is completed the path can be highlighted in different colors or with different style lines to indicate completion, quality achieved, problem areas among others.

[00122] Any problems, issues, or bugs can be reported in the user interface. Lights on the end effector 160, mobile base 120 and/or robotic arm 140 as well as sounds can also be used to indicate problems, movement of the end effector 160, base unit 120 and/or robotic arm 140; that work is in progress; that the system 100 is on or off; that toolpath is running or paused, that the system 100 needs attention or refill of materials; and any other indicators of the system state. The user interface can also display information on the progress, task and tool parameters, and quality metrics of the task being performed. Environmental conditions can also be displayed and recorded by the interface. The system 100 can indicate to the user what steps to take to correct or improve conditions including air quality, temperature and humidity. If the system 100 detects unsuitable or unsafe conditions it can display a message warning the user and providing guidance on next steps. The system 100 can use an optimization to find what parameters could be used to improve the process including reducing work time, increasing quality, and minimizing material usage among others. The user interface can also create reports on the tasks executed, quality metrics, environmental conditions, completion, and performance logs. Information can include robot workspace, tool paths, progress, sequence of approach, application rates and thicknesses, spray pressures and flow rates, forces applied by the tool, coverage record, path speed, tracking error, time to complete the task, tool time, setup time, vacuum waste material collected, cleaning time. The user interface can also display on filter conditions, and the system 100 can trigger an alarm or instruction when the filter needs to be replaced or cleaned.

[00123] The user can interface with the system 100 using a computer, tablet, touch screen, mobile device, pendant, joystick, controller, or buttons directly on the system 100. The worker can also position and train the robotic arm 140 and/or end effector 160 by directly moving joints of the robotic arm 140 or end effector 160. The user interface, controller, or buttons can be used to record positions as well as change the control mode and task.

[00124] An augmented reality system can be used to show the worker a toolpath plan generated by the system 100, instructions, original BIM or plan, or a combination of these.
The augmented reality can be displayed using a headset, smart goggles, projections, or the like. The worker can be shown areas that require manual insulation application or cutting of insulation 650. The user can also overlay the location of studs, framing, pipes, ducts, electrical system behind the board to facilitate insulation application or trimming of insulation. Insulation tools, both manual and automated can be tracked in the map using tags, IMUs, or other sensors and a warning can be given to the operator if an attempt is made to apply insulation 650 in an erroneous position, trim insulation 650 in an erroneous position, or trim or apply insulation 650 under the wrong tool settings. The system 100 or tools can also utilize radar, sonar, thermal imaging, and the like, to establish what is behind a substrate.

[00125] The automated system and method can also produce a visualization, paths, or instructions or a combination of these to guide the user in completing manual work. The visualization can include 2D or 3D maps marking the areas of work with labels. The visualization system can also include a projection of the plan onto the target surface this can be done with a laser system, projector or through augmented reality headset or goggles worn by the user.

[00126] The coating time, flow time, pressure, material flow rate, insulation material, number of cuts, clogs, and the like, can be tracked to inform when a nozzle 1210 or blade should be cleaned or changed. For example, Fig. 19 illustrates an example embodiment 16019 of an insulation end effector 1601, which comprises a nozzle cassette system 1905 where a cassette of nozzles 1240 is attached to the end of the spray gun 1210. The cassette system 1905 can be rotated (e.g., via an electromechanical system) to deliver a nozzle 1240 to the spray gun 1210 for use.

[00127] Fig. 20 illustrates another example embodiment 160110 of an insulation end effector 1601 that comprises a nozzle rotating system 2005 that can be part of a spray gun 1210. In this example, the system 100 can utilize an actuator assembly 2010 (e.g., a servo or other electromechanical actuator) to rotate (e.g., 180 degrees) a portion 2015 of the nozzle 1210 allowing for insulation 650 to go through the nozzle portion 2015 in reverse helping clear out clogs.
In various embodiments, nozzle or blade wear models can also take as an input the type and characteristics of insulation 650 applied and the conditions under which such insulation 650 was applied. One or more vision system 364, 324 of the system 100 can be used to detect insulation finish, spray pattern, and the like and establish if the nozzle 1240 or blade 1130 needs to be changed, rotated, cleaned or otherwise modified. A user interface can display the wear on the nozzle 1240 or blade 1130 and alert the user when these need to be changed. An insulation end effector 1601 can also include a mechanism to automatically replace or clean the nozzle 1240 or portions thereof. One embodiment (e.g., Fig. 19) can use a cassette with replacement nozzles 1240 that can be rotated into place. The sprayer 1210 can also have a mechanism 2005 to rotate the nozzle or portion thereof (e.g. a tip or feeding tube) to clear a clog (e.g., Fig. 20). The nozzle clearing or replacement can be run automatically by the system 100 without any human intervention or as a collaboration between the system 100 and the user.

The system 100 can generate reports and interface with other software platforms including BIM packages. Reports can be created that can be used for inspection and certification. A report can be customized to provide the information required to pass a standard, test, or certification. The reporting system can also provide a live update of the current task progress and live camera feed. This information can be used to help track asset performance and work progression. The data can be reported to a BIM system or other software to facilitate planning of other trades, next steps, or schedule inspections or other tasks. The reports can include full maps of the insulation 650 applied and tool and path parameters utilized to complete an insulation application or cutting task. Further images or video can be recorded to facilitate quality checks and/or for tracking of issues. The system 100 can record parameters used to complete the task which can be fed to a machine learning software to enable the system 100 to learn from past work. The reports can also be used to optimize workflow and scheduling. An optimization function of the system 100 can be updated to meet potential desired needs including minimizing task time, completion of the task in a part of the worksite to allow other trades to come in, minimizing cost, optimal use of assets and workforce, and the like. The system’s reports can also include information on
environmental conditions and how the process was changed given the environmental conditions.

[00130] The system 100 can work in conjunction with a larger system that plans the full process from mapping a room, to framing, to cutting and hanging the drywall, to applying insulation, to finishing and painting of the surfaces, and the like. The system 100 can also be used apply insulation on walls, ceilings, interior surfaces, exterior surfaces, confined spaces, or framing. The automated system and method can also be used to apply sealant, caulking, fire-caulking, or other weather-proofing or sound-proofing materials.

[00131] The system 100 can be part of a network comprising a plurality of systems 100 that are operated independently, carry out tasks with knowledge of each other, or are centrally coordinated by a software system. Information about the operation of individual nodes of the network (e.g., individual separate systems 100) can be used to ensure optimal workflow on a job site, prevent collisions or other unwanted behaviors, or monitor progress and alert operators of potential issues. An insulation system planner can be extended beyond a single system to coordinate the paths and tasks for multiple drywall automation systems 100.

[00132] Embodiments of the disclosure can be described in view of the following clauses:

1. An automated drywalling system for applying insulation material to a wall assembly, the automated drywalling system comprising:
   a base unit that includes:
   an insulation material source configured to store insulation material;
   a platform,
   a cart configured to be disposed on and move on the ground, and
   a lift disposed between the platform and cart, the lift configured to raise the platform up and down;
   an elongated robotic arm that extends between a base end and a distal end, the robotic arm coupled to the base unit on the platform at the base end of the robotic arm;
   an insulation end effector coupled at the distal end of the robotic arm, the insulation end effector including a spray gun configured to generate a spray of insulation material from a nozzle of the spray gun, the spray gun coupled with an insulation material tube extending
from the insulation material source via the robotic arm, the spray gun configured to receive
insulation material from the insulation material source via the insulation material tube to
generate the spray of insulation material;
one or more vision systems;
one or more sensors;
a computing device executing a computational planner that:
  obtains target surface data from the one or more vision systems and the one or
more sensors, the target surface data including information regarding a configuration
of a wall assembly including a plurality of studs;
  automatically generates, instructions for driving the insulation end effector,
robotic arm, and base unit to perform at least one insulation application task that
includes applying a insulation material spray generated by the spray gun of the
insulation end effector to a target surface between the respective studs of the wall
assembly, the generating based at least in part on the target surface data; and
  automatically drives, the insulation end effector, robotic arm, and base unit to
perform the at least one insulation application task.

2. The automated drywalling system of clause 1, wherein the generating
instructions for driving the insulation end effector, robotic arm, and base unit to apply
insulation material to a target surface between the respective studs of the wall assembly, is
further based on data obtained by the automated drywalling system from the one or more
vision systems and the one or more sensors for the automated drywalling system planning a
configuration of a plurality of pieces of drywall to be coupled to the studs of the wall
assembly.

3. The automated drywalling system of clause 1 or 2, wherein the insulation end
effector comprises an arm having a roller that is pressed against an internal face of a stud of
the wall assembly to guide the spray gun to apply insulation material to the target surface
between respective studs of the wall assembly.

4. The automated drywalling system of clause 3, wherein the arm is extendible
and retractable to generate a selected offset from a stud of the wall assembly that is pressed
against for guiding the spray gun to apply insulation material to the target surface between respective studs of the wall assembly.

5. The automated drywalling system of any of clauses 1-4, wherein the insulation end effector further comprises a vacuum hood disposed around an end and the nozzle of the spray gun to capture overspray generated by the spray of insulation material generated by the nozzle of the spray gun.

6. The automated drywalling system of any of clauses 1-5, wherein the insulation end effector further comprises an insulation cutting system that includes a blade that is pushed along a pair of studs of the wall assembly to remove applied insulation material extending beyond a plane defined by the pair of studs of the wall assembly.

7. An automated drywalling system comprising:

   a base unit;
   an elongated robotic arm that extends between a base end and a distal end, the robotic arm coupled to the base unit at the base end of the robotic arm;
   an insulation end effector coupled at the distal end of the robotic arm, the insulation end effector configured to apply insulation material to a target surface;
   one or more vision systems; and
   a computing device executing a computational planner that:

   obtains target surface data from the one or more vision systems, the target surface data including information regarding a configuration of a wall assembly including a plurality of studs;

   automatically generates instructions for driving the insulation end effector, robotic arm, and base unit to perform at least one insulation application task that includes applying insulation material, via the insulation end effector, to a target surface between the respective studs of the wall assembly, the generating based at least in part on the target surface data; and

   automatically drives the end effector, robotic arm, and base unit to perform the at least one insulation application task.
8. The automated drywalling system of clause, wherein the insulation end effector applies insulation material to the target surface via at least one of a spray gun and a roller.

9. The automated drywalling system of clause 7 or 8, wherein the generating instructions for driving the insulation end effector, robotic arm, and base unit to apply insulation material to a target surface between the respective studs of the wall assembly, is further based on data obtained by the automated drywalling system from the one or more vision systems for the automated drywalling system planning a configuration of a plurality of pieces of drywall to be coupled to the studs of the wall assembly.

10. The automated drywalling system of any of clauses 7-9, wherein the insulation end effector comprises an arm having a portion that is pressed against an internal face of a stud of the wall assembly for the insulation end effector to apply insulation material to the target surface between respective studs of the wall assembly.

11. The automated drywalling system of clause 10, wherein the arm is extendible to provide for a selected offset from a stud of the wall assembly that is pressed against by the arm for guiding the insulation end effector to apply insulation material to the target surface between respective studs of the wall assembly.

12. The automated drywalling system of any of clauses 7-11, wherein the insulation end effector further comprises a vacuum hood disposed around an end of a spray gun of the insulation end effector to capture overspray generated by a spray of insulation material generated by the spray gun.

13. The automated drywalling system of any of clauses 7-12, wherein the insulation end effector further comprises an insulation cutting system that includes a blade to remove applied insulation material extending beyond a plane defined by a pair of studs of the wall assembly.

14. An automated insulation application system comprising:

   a positioning stage that extends between a base end and a distal end;
   an insulation end effector coupled at the distal end of the positioning stage, the insulation end effector configured to apply insulation material to a target surface; and
a computing device executing a computational planner that:

- generates instructions for driving the insulation end effector and positioning stage to perform at least one insulation application task that includes applying insulation material via the insulation end effector to a target surface, the generating based at least in part on obtained target surface data; and
- drives the end effector and positioning stage to perform the at least one insulation application task.

15. The automated insulation application system of clause 14, wherein the insulation end effector applies insulation material to the target surface via at least one of a spray gun and a roller.

16. The automated insulation application system of clause 14 or 15, wherein the generating instructions for driving the insulation end effector and positioning stage to apply insulation material to the target surface is further based on data obtained by the automated insulation system for the automated drywalling system planning a configuration of a plurality of pieces of drywall to be coupled to a wall assembly proximate to the target surface.

17. The automated insulation application system of any of clauses 14-16, wherein the insulation end effector comprises an arm having a portion that is pressed against a datum associated with the target surface to guide the insulation end effector applying insulation material to the target surface.

18. The automated insulation application system of any of clauses 14-17, wherein the positioning stage comprises a robotic arm.

19. The automated insulation application system of any of clauses 14-18, wherein the insulation end effector further comprises a vacuum hood disposed around an end of a spray gun of the insulation end effector to capture overspray generated by a spray of insulation material generated by the spray gun.

20. The automated insulation application system of any of clauses 14-19, wherein the insulation end effector further comprises an insulation cutting system that removes a portion of insulation material applied by the insulation end effector.
[00133] The described embodiments are susceptible to various modifications and alternative forms, and specific examples thereof have been shown by way of example in the drawings and are herein described in detail. It should be understood, however, that the described embodiments are not to be limited to the particular forms or methods disclosed, but to the contrary, the present disclosure is to cover all modifications, equivalents, and alternatives.
CLAIMS

What is claimed is:

1. An automated drywalling system for applying insulation material to a wall assembly, the automated drywalling system comprising:

   a base unit that includes:

   an insulation material source configured to store insulation material;
   a platform,
   a cart configured to be disposed on and move on the ground, and
   a lift disposed between the platform and cart, the lift configured to raise the platform up and down;

   an elongated robotic arm that extends between a base end and a distal end, the robotic arm coupled to the base unit on the platform at the base end of the robotic arm;

   an insulation end effector coupled at the distal end of the robotic arm, the insulation end effector including a spray gun configured to generate a spray of insulation material from a nozzle of the spray gun, the spray gun coupled with an insulation material tube extending from the insulation material source via the robotic arm, the spray gun configured to receive insulation material from the insulation material source via the insulation material tube to generate the spray of insulation material;

   one or more vision systems;

   one or more sensors;

   a computing device executing a computational planner that:

       obtains target surface data from the one or more vision systems and the one or more sensors, the target surface data including information regarding a configuration of a wall assembly including a plurality of studs;

       automatically generates, instructions for driving the insulation end effector, robotic arm, and base unit to perform at least one insulation application task that includes applying a insulation material spray generated by the spray gun of the
insulation end effector to a target surface between the respective studs of the wall assembly, the generating based at least in part on the target surface data; and automatically drives, the insulation end effector, robotic arm, and base unit to perform the at least one insulation application task.

2. The automated drywalling system of claim 1, wherein the generating instructions for driving the insulation end effector, robotic arm, and base unit to apply insulation material to a target surface between the respective studs of the wall assembly, is further based on data obtained by the automated drywalling system from the one or more vision systems and the one or more sensors for the automated drywalling system planning a configuration of a plurality of pieces of drywall to be coupled to the studs of the wall assembly.

3. The automated drywalling system of claim 1, wherein the insulation end effector comprises an arm having a roller that is pressed against an internal face of a stud of the wall assembly to guide the spray gun to apply insulation material to the target surface between respective studs of the wall assembly.

4. The automated drywalling system of claim 3, wherein the arm is extendible and retractable to generate a selected offset from a stud of the wall assembly that is pressed against for guiding the spray gun to apply insulation material to the target surface between respective studs of the wall assembly.

5. The automated drywalling system of claim 1, wherein the insulation end effector further comprises a vacuum hood disposed around an end and the nozzle of the spray gun to capture overspray generated by the spray of insulation material generated by the nozzle of the spray gun.
6. The automated drywalling system of claim 1, wherein the insulation end effector further comprises an insulation cutting system that includes a blade that is pushed along a pair of studs of the wall assembly to remove applied insulation material extending beyond a plane defined by the pair of studs of the wall assembly.

7. An automated drywalling system comprising:
   a base unit;
   an elongated robotic arm that extends between a base end and a distal end, the robotic arm coupled to the base unit at the base end of the robotic arm;
   an insulation end effector coupled at the distal end of the robotic arm, the insulation end effector configured to apply insulation material to a target surface;
   one or more vision systems; and
   a computing device executing a computational planner that:
       obtains target surface data from the one or more vision systems, the target surface data including information regarding a configuration of a wall assembly including a plurality of studs;
       automatically generates instructions for driving the insulation end effector, robotic arm, and base unit to perform at least one insulation application task that includes applying insulation material, via the insulation end effector, to a target surface between the respective studs of the wall assembly, the generating based at least in part on the target surface data; and
       automatically drives the end effector, robotic arm, and base unit to perform the at least one insulation application task.

8. The automated drywalling system of claim 7, wherein the insulation end effector applies insulation material to the target surface via at least one of a spray gun and a roller.
9. The automated drywalling system of claim 7, wherein the generating instructions for driving the insulation end effector, robotic arm, and base unit to apply insulation material to a target surface between the respective studs of the wall assembly, is further based on data obtained by the automated drywalling system from the one or more vision systems for the automated drywalling system planning a configuration of a plurality of pieces of drywall to be coupled to the studs of the wall assembly.

10. The automated drywalling system of claim 7, wherein the insulation end effector comprises an arm having a portion that is pressed against an internal face of a stud of the wall assembly for the insulation end effector to apply insulation material to the target surface between respective studs of the wall assembly.

11. The automated drywalling system of claim 10, wherein the arm is extendible to provide for a selected offset from a stud of the wall assembly that is pressed against by the arm for guiding the insulation end effector to apply insulation material to the target surface between respective studs of the wall assembly.

12. The automated drywalling system of claim 7, wherein the insulation end effector further comprises a vacuum hood disposed around an end of a spray gun of the insulation end effector to capture overspray generated by a spray of insulation material generated by the spray gun.

13. The automated drywalling system of claim 7, wherein the insulation end effector further comprises an insulation cutting system that includes a blade to remove applied insulation material extending beyond a plane defined by a pair of studs of the wall assembly.

14. An automated insulation application system comprising:
   a positioning stage that extends between a base end and a distal end;
an insulation end effector coupled at the distal end of the positioning stage, the
insulation end effector configured to apply insulation material to a target surface; and
a computing device executing a computational planner that:

generates instructions for driving the insulation end effector and positioning
stage to perform at least one insulation application task that includes applying
insulation material via the insulation end effector to a target surface, the generating
based at least in part on obtained target surface data; and
drives the end effector and positioning stage to perform the at least one
insulation application task.

15. The automated insulation application system of claim 14, wherein the
insulation end effector applies insulation material to the target surface via at least one of a
spray gun and a roller.

16. The automated insulation application system of claim 14, wherein the
generating instructions for driving the insulation end effector and positioning stage to apply
insulation material to the target surface is further based on data obtained by the automated
insulation system for the automated drywalling system planning a configuration of a plurality
of pieces of drywall to be coupled to a wall assembly proximate to the target surface.

17. The automated insulation application system of claim 14, wherein the
insulation end effector comprises an arm having a portion that is pressed against a datum
associated with the target surface to guide the insulation end effector applying insulation
material to the target surface.

18. The automated insulation application system of claim 14, wherein the
positioning stage comprises a robotic arm.
19. The automated insulation application system of claim 14, wherein the insulation end effector further comprises a vacuum hood disposed around an end of a spray gun of the insulation end effector to capture overspray generated by a spray of insulation material generated by the spray gun.

20. The automated insulation application system of claim 14, wherein the insulation end effector further comprises an insulation cutting system that removes a portion of insulation material applied by the insulation end effector.
5/20

500

505
APPLY INSULATION TO WALL ASSEMBLY

510
PLAN CONFIGURATION AND LOCATION OF DRYWALL PIECES

520
CUT DRYWALL PIECES

530
HANG DRYWALL PIECES

540
PERFORM MUD WORK ON HUNG DRYWALL PIECES

550
PERFORM SANDING WORK ON MUDDED DRYWALL PIECES

560
PAINT Sanded DRYWALL PIECES

Fig. 5
Fig. 10
INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 2018/025536

A. CLASSIFICATION OF SUBJECT MATTER

B25J 5/00 (2006.01)
B25J 9/16 (2006.01)
E04F 21/06 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B25J 5/00, 9/00, 9/08, 9/16, 11/00, E04F 21/00, 21/02, 21/06, 21/16, 21/165, 21/18, E04C 2/00, 2/10

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PatSearch (RUPTO internal), USPTO, PAJ, Esp@cenet, DWPI, EAPATIS, PATENTSCOPE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<tbody>
<tr>
<td>A</td>
<td>JP 03 100265 A (TOKYU CONSTR CO LTD) 25.04. 1991</td>
<td>1-20</td>
</tr>
<tr>
<td>A</td>
<td>US 6 112490 A1 (DONALD L. MEYER) 05.09.2000</td>
<td>1-20</td>
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</table>

Further documents are listed in the continuation of Box C.

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