CLAIMS

1. In combination, a storage unit storable within a three-dimensional storage system and a storage/retrieval vehicle navigable through said three-dimensional storage system to storage locations therein at which said storage unit is selectively storable and retrievable, wherein said storage/retrieval vehicle comprises:

a frame conveyable through said three-dimensional storage system;

a platform atop said frame for receipt of said storage unit thereon; and

a loading/unloading mechanism operable to load and unload said storage unit to and from said platform at four different sides thereof, said loading/unloading mechanism comprising:

an extendable/retractable arm selectively deployable at each of said four different sides of the platform of said storage/retrieval vehicle to define a respective one of four different working states, said extendable/retrievable arm configured to be selectively extended to any of said four different sides of said platform;

a rotatable turret installed on said platform to reside beneath the storage unit when said storage unit is loaded onto said platform, said extendable/retractable arm configured to be selectively extended from said rotatable turret into a deployed position reaching outwardly beyond a perimeter of said platform, said turret being rotatable into a plurality of different working positions in which the arm is extendable outwardly from the turret in four different directions respectively at said four different sides of the platform, said extendable/retractable arm further comprising a catch member carried thereon for engagement with an underside of the storage unit;

and wherein said storage unit comprises:

a catch channel residing in said underside of the storage unit and in which the catch member of the extendable/retractable arm is selectively

engageable, wherein said catch channel lies on a circular path formed around a center point of a floor panel of said storage unit, and wherein said catch member traverses the catch channel along said circular path during rotation of the turret, while the storage unit is seated on said platform; and

at least one secondary catch feature positioned relative to the catch channel, said at least one secondary catch feature configured to be engaged by the extendable/retractable arm in a retracted state thereof in a loading operation, in an event the extendable/retractable arm fails to engage the catch channel;

and wherein said extendable/retractable arm renders said loading/unloading mechanism adjustable between said four different working states, each of said four different working states operable to load and unload said storage unit to and from the platform of said storage/retrieval vehicle at a respective one of said four different sides of the platform, and wherein said extendable/retractable arm and said rotatable turret enable unloading of the storage unit from said platform in any one of the four different directions at said four different sides of the storage/retrieval vehicle, regardless of an original orientation in which said storage unit was previously loaded onto the platform of the storage/retrieval vehicle, and without re-orienting said storage unit from said original orientation.

2. The combination of claim 1, wherein the loading/unloading mechanism is switchable between said four different working states, each operable to load and unload said storage unit at a respective one of the four different sides of the platform, and said storage/retrieval vehicle is configured to enable static support of the storage unit on said platform in a static orientation thereon, while said loading/unloading mechanism transitions between the four different working states.

3. The combination of claim 1, wherein said catch channel is configured to span a full 360-degree of said circular path, said catch channel further configured to span at least 270-degrees of said circular path.

4. The combination of claim 1, wherein:

said extendable/retractable arm comprises a movable shuttle, and wherein said catch member of said extendable/retractable arm resides on said movable shuttle, and wherein said movable shuttle is engageable with said storage unit and displaceable back and forth along said extendable/retractable arm;

said platform comprises outer deck surfaces disposed around the rotatable turret, and wherein the rotatable turret resides in recessed elevation relative to said outer deck surfaces;

the storage unit comprises at least one redundant catch feature recessed in the underside thereof at a distance situated outwardly from the circular path of the catch channel, and wherein said at least one redundant catch feature comprises a plurality of redundant catch recesses, each of said catch recesses residing between the catch channel and a respective side of the storage unit; and

the catch channel is a primary catch feature engageable by the extendable/retractable arm in a deployed state thereof during a loading operation intended to pull said storage unit onto the platform of the storage/retrieval vehicle, and wherein said primary catch feature is a curved feature lying on said circular path, and wherein said at least one secondary catch feature positioned relative to the primary catch feature is configured to be engaged by the extendable/retractable arm in a retracted state thereof in the loading operation, in an event the extendable/retractable arm fails to engage the primary catch feature.

5. The combination of claim 4, wherein said combination comprises a plurality of secondary catch features, each of said secondary features residing adjacent a respective outer perimeter side of the storage unit, and wherein the primary catch feature and the at least one secondary catch feature are located at an underside of the storage unit, and wherein the primary catch feature and the at least one secondary catch feature are recessed into the storage unit.

6. The combination of claim 4, wherein the curved feature is configured to span a full 360-degree of said circular path, said curved feature further configured to span at

least 270-degress of said circular path.

7. A storage/retrieval vehicle for use in a three-dimensional storage system delimiting storage locations at which respective storage units are selectively storable and retrievable, wherein said storage/retrieval vehicle comprises:

a frame conveyable through said three-dimensional storage system;

a platform located atop said frame for receipt of said storage unit thereon; and

a loading/unloading mechanism operable to load and unload said storage unit to and from said platform, said loading/unloading mechanism comprising:

an extendable/retractable arm selectively deployable at each of four different sides of the platform of said storage/retrieval vehicle to define a respective one of four different working states, said extendable/retrievable arm configured to be selectively extended to each of said four different sides of said platform;

a rotatable turret installed on said platform to reside beneath the storage unit when said storage unit is loaded onto said platform, said extendable/retractable arm configured to be selectively extended from said rotatable turret into a deployed position reaching outwardly beyond a perimeter of said platform, said turret being rotatable into a plurality of different working positions in which the arm is extendable outwardly from the turret in four different directions respectively at said four different sides of the platform, said extendable/retractable arm further comprising a catch member carried thereon for engagement with an underside of the storage unit;

and wherein said storage unit comprises:

a catch channel residing in said underside of the storage unit and in which the catch member of said extendable/retractable arm is selectively engageable, wherein said catch channel lies on a circular path formed around a center point of a floor panel of said storage unit, and wherein said

catch member traverses the catch channel along said circular path during a rotation of the turret, while the storage unit is seated on said platform; and

at least one secondary catch feature positioned relative to the catch channel, said at least one secondary catch feature configured to be engaged by the extendable/retractable arm in a retracted state thereof in a loading operation, in an event the extendable/retractable arm fails to engage the catch channel;

and wherein said extendable/retractable arm renders said loading/unloading mechanism adjustable between four different working states, each of said four different working states operable to load and unload said storage unit to and from the platform of said storage/retrieval vehicle at a respective one of said four different sides of the platform of the storage/retrieval vehicle, and wherein said extendable/retractable arm facilitates unloading of the storage unit from said platform in any one of the four different directions at said four different sides of the platform of the storage/retrieval vehicle, regardless of an original orientation in which said storage unit was previously loaded onto the platform of the storage/retrieval vehicle, and without re-orienting said storage unit from said original orientation.

8. The storage/retrieval vehicle of claim 7, in combination with at least one storage unit selected from amongst said storage units, wherein said extendable/retractable arm further comprises a movable shuttle engageable with the storage unit and displaceable back and forth along said extendable/retractable arm, and wherein a distance by which the extendable arm extends outward beyond the perimeter of the platform in the deployed position is less than half of a width of the storage unit, and wherein:

said catch channel is a primary catch feature engageable by the movable shuttle, said primary catch feature situated intermediately between a center of the storage unit and an outer side thereof;

said secondary catch feature is disposed outwardly from said primary catch

feature and towards an outer side thereof; and

wherein said storage/retrieval vehicle further comprises:

a set of load status sensors distributed at different locations over a landing area of the platform, each of said load status sensors operable to detect presence of the storage unit in overlying relation to said load status sensors when said storage unit is seated on said landing area, and wherein the loading/unloading mechanism is configured to retract a predetermined distance sufficient to pull the storage unit fully into the landing area of the platform if the primary catch feature was engaged, and wherein said predetermined distance is sufficient to pull the storage unit partially onto the platform if the secondary catch feature was engaged;

a processor configured to query the set of load status sensors after retraction of the loading/unloading mechanism by said predetermined distance and identify one of a successful loading of the storage unit onto the landing area based on a positive detection signal from all of said load status sensors and a partial loading of the storage unit onto the landing area based on lack of a positive detection signal from at least one of said load status sensors.

9. The combination of said storage/retrieval vehicle and said storage unit as claimed in claim 8, wherein said distance is sufficient to pull the storage unit partially onto the platform if the secondary catch feature was engaged, and receipt of the positive detection signal from a subset of said load status sensors after retraction of the loading/unloading mechanism by said distance causes said processor to identify a failed engagement of the primary catch feature and successful engagement of the secondary catch feature, and said partial loading of the storage unit onto the platform.

10. The storage/retrieval vehicle of claim 9, wherein the processor is configured to, after detection of said failed engagement of the primary catch feature and said partial loading of the storage unit, re-deploy the loading/unloading mechanism and push a partially loaded storage unit off the platform.

11. The storage/retrieval vehicle of claim 10, wherein the processor is configured to, after re-deployment of the loading/unloading mechanism and pushing of the partially loaded storage unit off the platform, re-attempt loading of pushed-off storage unit onto the platform via an engagement of the primary catch feature by the loading/unloading mechanism.

12. A storage unit for use in a three-dimensional storage system navigable by a fleet of storage/retrieval vehicles, each storage/retrieve vehicle amongst said fleet of storage/retrieval vehicles having a loading/unloading mechanism mounted thereon, by which the storage unit is engaged and unloaded from a platform of the storage/retrieval vehicle into a storage location in said three-dimensional storage system and loaded onto said platform of said storage/retrieval vehicle from said storage location, and wherein said loading/unloading mechanism comprises:

an extendable/retractable arm selectively deployable at each of four different sides of said platform of the storage/retrieval vehicle to define a respective one of four different working states, said extendable/retrievable arm configured to be selectively extended to each of said four different sides of said platform;

a rotatable turret installed on said platform to reside beneath the storage unit when said storage unit is loaded onto said platform, said extendable/retractable arm configured to be selectively extended from said rotatable turret into a deployed position reaching outwardly beyond a perimeter of said platform, said turret being rotatable into a plurality of different working positions in which the arm is extendable outwardly from the turret in four different directions respectively at said four different sides of the platform, said extendable/retractable arm further comprising a catch member carried thereon for engagement with an underside of the storage unit;

and wherein said extendable/retractable arm renders said loading/unloading mechanism adjustable between said four different working states, each of said four

different working states operable to load and unload said storage unit to and from the platform of said storage/retrieval vehicle at a respective one of said four different sides of the platform, and wherein said extendable/retractable arm and said rotatable turret unloading of the storage unit from said platform in any one of the four different directions respectively at said four different sides of the platform, regardless of an original orientation in which said storage unit was previously loaded onto the platform of the storage/retrieval vehicle, and without re-orienting said storage unit from said original orientation;

and wherein said storage unit comprises:

a primary catch feature residing at said underside of said storage unit, said primary catch feature engageable by said catch member of the extendable/retractable arm, and wherein said primary catch feature is a curved feature lying on a circular path formed around a center point of a floor panel of said storage unit, and wherein said catch member traverses said primary catch feature along said circular path during a rotation of the rotatable turret, while the storage unit is seated on said platform; and

at least one secondary catch feature positioned relative to the primary catch feature, said at least one secondary catch feature configured to be engaged by the extendable/retractable arm in a retracted state thereof in a loading operation, in an event the extendable/retractable arm fails to engage the primary catch feature.

13. The storage unit of claim 12, wherein the primary catch feature is a recessed catch channel, said primary catch feature configured to span a full 360-degree of said circular path, said primary catch feature configured to span at least 270-degrees of said circular path.

14. The storage unit of claim 12, wherein said at least one secondary catch feature resides at said underside of said storage unit, and at a location situated outwardly from the circular path of said primary catch feature.

15. The storage unit of claim 14, said storage unit comprising a plurality of secondary

catch features, each of said secondary catch features residing outwardly of the circular path of the primary catch feature.

16. A method of handling a storage unit using a storage/retrieval vehicle in a storage system having storage locations disposed on multiple sides of travel paths through said storage system, said storage/retrieval vehicle having a loading/unloading mechanism adjustable between four different working states, each of said four different working states operable to load and unload said storage unit at a respective one of four different sides of the storage/retrieval vehicle, said loading/unloading mechanism comprising an extendable/retractable arm mounted on a rotatable turret, said method comprising:

    with said storage unit carried on said storage/retrieval vehicle, and while maintaining said storage unit in a static orientation and position on said storage/retrieval vehicle, switching the loading/unloading mechanism between two of the four different working states, by selectively rotating said rotatable turret to any one of two different sides of the storage/retrieval vehicle corresponding to said two of the four different working states, and by selectively extending said extendable/retractable arm into a deployed position reaching outwardly beyond a perimeter of a platform of said storage/retrieval vehicle and in said any one of the two different sides corresponding to said two of the four different working states, thereby changing a side of the storage/retrieval vehicle from which said storage unit is off-loadable, without re-positioning said storage unit on said platform of said storage/retrieval vehicle and without re-orienting said storage unit on said platform of said storage/retrieval vehicle;

and wherein said method further includes:

    triggering a catch member carried on said extendable/retractable arm to engage with a primary catch feature residing in an underside of said storage unit and lying on a circular path formed around a center point of a floor panel of said storage unit, when said extendable/retractable arm is extended in said any one of the two different sides corresponding to said two of said four different working

states;

triggering said catch member to traverse said primary catch feature along said circular path during rotation of the rotatable turret, while the storage unit is seated on said platform;

triggering said catch member to engage at least one secondary catch feature positioned relative to the primary catch feature, in an event the extendable/retractable arm fails to engage the primary catch feature, and further triggering said catch member to engage said secondary catch feature when said extendable/retractable arm is in a retracted state in a loading operation;

enabling said storage/retrieval vehicle, by said extendable/retracted arm and said rotatable turret mounted thereon, to unload said storage unit into any available storage location disposed on said multiple sides of said travel paths, regardless of an original orientation in which said storage unit was previously loaded onto said storage/retrieval vehicle, and without re-orienting said storage unit from said original orientation.

17. The method of claim 16, wherein switching said loading/unloading mechanism between said two of the four different working states, further includes switching said loading mechanism between a first working state and a second working state, and wherein selectively rotating said rotatable turret of said loading/unloading mechanism further includes rotating said rotatable turret into a plurality of different working positions and extending said extendable/retractable arm outwardly from the rotatable turret in four different directions respectively at said four different sides of the storage/retrieval vehicle, and wherein switching said loading mechanism between said first working state and said second working state comprises rotating said rotatable turret and said extendable/retractable arm of said loading/unloading mechanism between said first working state and said second working state, and during rotation of the rotatable turret and the extendable/retractable arm, accommodating relative movement between the statically maintained storage unit and a catch member of said extendable/retractable arm using said primary catch

feature of the storage unit that follows a circular path around a rotational axis of said rotatable turret.

18. A method of handling storage units using a storage/retrieval vehicle in a storage system having storage locations in storage columns surrounding open vertical shafts, said storage locations used for storing storage units, said method comprising:

(a) attempting loading of a storage unit from a storage location onto a platform of said storage/retrieval vehicle using a loading/unloading mechanism of said storage/retrieval vehicle, said loading/unloading mechanism switchable between four different working states, each of said four different working states operable to at least load said storage unit from said storage location to said platform at a respective one of four different sides of the storage/retrieval vehicle, and wherein attempting loading of said storage unit from said storage location onto said platform of said storage/retrieval vehicle further includes:

switching the loading/unloading mechanism between said four different working states, by selectively rotating a rotatable turret of said loading/unloading mechanism to one of the four different sides of the storage/retrieval vehicle facing said storage location, and by selectively extending an extendable/retractable arm mounted on said rotatable turret, from said rotatable turret, into a deployed position reaching outwardly beyond a perimeter of said platform, in said one of the four different sides facing said storage location; and

triggering a catch member carried on said extendable/retractable arm to engage with a primary catch feature located on an underside of said storage unit and lying on a circular path formed around a center point of a floor panel of said storage unit, when said extendable/retractable arm is extended in said one of the four different sides facing said storage location;

triggering said catch member to traverse said primary catch feature along said circular path during rotation of the rotatable turret, while the storage

unit is seated on said platform;

triggering said catch member to engage at least one secondary catch feature positioned relative to the primary catch feature, in an event the extendable/retractable arm fails to engage the primary catch feature, and further triggering said catch member to engage said secondary catch feature when said extendable/retractable arm is in a retracted state in a loading operation;

(b) performing a load status check using a load status sensing device to determine whether the storage unit has been completely loaded onto said platform of said storage/retrieval vehicle;

(c) in response to detection by said load status sensing device of a failure to completely load said storage unit onto said platform of said storage/retrieval vehicle, triggering an automatic repositioning of the storage unit within the storage location; and

(d) re-attempting loading of the storage unit onto the platform of said storage/retrieval vehicle using said loading/unloading mechanism;

and wherein the method further comprises enabling said storage/retrieval vehicle, by a combination of said rotatable turret and said extendable/retractable arm embodied thereon, to re-stock said storage unit at any storage location selected from said storage locations, said storage location located on any side of an open vertical shaft selected from said open vertical shafts, without removing said storage unit from said platform and without re-orienting said storage unit on said platform.

19. The method of claim 18, wherein repositioning of the storage unit is performed by said storage/retrieval vehicle, and by said combination of said rotatable turret and said extendable/retractable arm embodied in said storage/retrieval vehicle.

20. The method as claimed in claim 18, wherein the method further comprises:

engaging, by the loading/unloading mechanism, said at least one secondary catch feature of the storage unit;

pulling, by the loading/unloading mechanism, the storage unit from said storage location and into a partially loaded position on the platform of the storage/retrieval vehicle via said secondary catch feature, in an event the loading/unloading mechanism fails to engage a primary catch feature of the storage unit;

pushing the storage unit off the platform and fully into the storage location via said secondary catch feature, and thereby triggering said automatic repositioning of the storage unit within the storage location, using said secondary catch feature; and

disengaging the loading/unloading mechanism from the secondary catch feature, and re-attempting engagement of the loading/unloading mechanism with the primary catch feature.

21. The method as claimed in claim 18, wherein selectively extending said extendable/retractable arm, further includes selectively extending said extendable/retractable arm to each of said four different sides of said storage/retrieval vehicle, and selectively deploying said extendable/retractable arm at each of said four different sides of the storage/retrieval vehicle, and thereby defining said respective one of the four different working states.

22. The method as claimed in claim 18, wherein selectively rotating said rotatable turret of said loading/unloading mechanism further includes rotating said rotatable turret into a plurality of different working positions and extending said extendable/retractable arm outwardly from the rotatable turret in four different directions respectively at said four different sides of the storage/retrieval vehicle.

23. The method as claimed in claim 18, wherein the load status sensing device comprises a set of load status sensors on the storage/retrieval vehicle, including one or more front sensors adjacent a front side of the platform from which the loading/unloading mechanism attempts to load the storage unit, and one or more rear sensors adjacent an opposing rear side of the platform, and wherein said failure to completely load said storage unit onto said platform is detected by coverage of the

one or more front sensors, but not the one or more rear sensors, by the storage unit.

24. A storage/retrieval vehicle for use in a storage system having storage locations in which storage units are stored, said storage/retrieval vehicle comprising:

a platform sized and shaped to accommodate said storage units;

a loading/unloading mechanism operable to load and unload a storage unit to and from said platform of said storage/retrieval vehicle, said loading/unloading mechanism comprising:

an extendable/retractable arm selectively deployable at each of four different sides of the platform of the storage/retrieval vehicle to define a respective one of four different working states, said extendable/retrievable arm configured to be selectively extended to any of said four different sides of said platform;

a rotatable turret installed on said platform to reside beneath the storage unit when said storage unit is loaded onto said platform, said extendable/retractable arm configured to be selectively extended from said rotatable turret into a deployed position reaching outwardly beyond a perimeter of said platform, said turret being rotatable into a plurality of different working positions in which the arm is extendable outwardly from the turret in four different directions respectively at said four different sides of the platform, said extendable/retractable arm further comprising a catch member carried thereon for engagement with an underside of the storage unit;

and wherein said storage unit comprises:

a primary catch feature residing in said underside of the storage unit and in which the catch member of the extendable/retractable arm is selectively engageable, wherein said primary catch feature lies on a circular path formed around a center point of a floor panel of said storage unit, and wherein said catch member traverses the primary catch feature along said

circular path during rotation of the rotatable turret, while the storage unit is seated on said platform;

at least one secondary catch feature positioned relative to the primary catch feature, said at least one secondary catch feature configured to be engaged by the extendable/retractable arm in a retracted state thereof in a loading operation, in an event the extendable/retractable arm fails to engage the primary catch feature;

and wherein said extendable/retractable arm renders said loading/unloading mechanism adjustable between said four different working states, each of said four different working states operable to load and unload said storage unit to and from the platform of said storage/retrieval vehicle at a respective one of said four different sides of the platform, and wherein said extendable/retractable arm and said rotatable turret enable unloading of the storage unit from said platform in any one of the four different directions at said four different sides of the platform, regardless of an original orientation in which said storage unit was previously loaded onto the platform of the storage/retrieval vehicle, and without re-orienting said storage unit from said original orientation;

a load status sensing device configured to detect whether the storage unit has been completely loaded onto said platform of said storage/retrieval vehicle; and

a local processor onboard said storage/retrieval vehicle, said local processor configured to:

(a) actuate the loading/unloading mechanism to attempt loading of the storage unit from a storage location onto the platform of the storage/retrieval vehicle;

(b) perform a load status check using the load status sensing device to detect whether the storage unit has been completely loaded onto said platform of said storage/retrieval vehicle;

(c) in response to detection by said load status sensing device of a failure to fully load said storage unit onto said platform of said storage/retrieval vehicle, trigger an automatic repositioning of the storage unit in the storage location; and

(d) re-attempt loading of the storage unit onto the platform of said storage/retrieval vehicle using said loading/unloading mechanism.

25. The storage/retrieval vehicle as claimed in claim 24, wherein said load status sensing device includes a set of load status sensors distributed at different locations over said platform of said storage/retrieval vehicle, each of said load status sensors operable to detect presence of the storage unit in overlying relation to said load status sensors when said storage unit is seated on said platform, and wherein the local processor triggers said loading/unloading mechanism to retract a predetermined distance sufficient to pull the storage unit fully into the platform of the platform, in an event the load status sensing device detects that the storage unit has been completely loaded onto said platform.

26. The storage/retrieval vehicle as claimed in claim 25, wherein said local processor cooperates with said load status sensing device and queries the set of load status sensors after retraction of the loading/unloading mechanism by said predetermined distance and identifies one of a successful loading of the storage unit onto the platform based on a positive detection signal from all of said load status sensors and a partial loading of the storage unit onto the platform based on lack of a positive detection signal from at least one of said load status sensors.