INTELLIGENT STRUCTURAL CELLS TECHNOLOGY (ISCT)

INTELLIGENT SELF-MONITORING AND ADAPTIVE STRUCTURAL CELL SYSTEM FOR MODULAR BUILDINGS AND INFRASTRUCTURE

FULL PATENT SPECIFICATION DRAFT

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ABSTRACT

An intelligent structural cell system for modular buildings and infrastructure is disclosed. The system comprises a plurality of structurally load-bearing cells, each cell having a structural body, one or more interfaces for connection with neighboring cells, and one or more sensing, processing, communication, energy, material-delivery, repair, or actuation components. The cells form a distributed structural network in which condition information associated with load, strain, deformation, cracking, temperature, energy condition, environmental exposure, or other structural parameters can be collected and shared among neighboring cells or a supervisory control system. A response system may determine an adaptive action for a damaged, overloaded, degraded, or otherwise selected cell. The action may include redistribution of structural demand, activation of reinforcement or repair resources, isolation of a cell, increased monitoring, connection of an additional cell, replacement of a cell, or combinations thereof. A multi-function cell interface may simultaneously provide mechanical load transfer and one or more data, energy, or material pathways. The system provides a modular and potentially expandable architecture for structures capable of distributed self-monitoring, communication, adaptation, verification, and learning.

1. TECHNICAL FIELD

The present disclosure relates to engineered structures, modular construction, structural health monitoring and adaptive infrastructure. More particularly, the disclosure relates to a system in which a plurality of structurally load-bearing cells are interconnected to form a building or infrastructure assembly, with individual cells configured to monitor their condition, communicate structural information, and participate in adaptive responses.

2. BACKGROUND OF THE INVENTION

Conventional buildings and infrastructure are generally constructed as continuous or modular systems in which structural components may be inspected or monitored individually but are not necessarily configured as a distributed network of intelligent load-bearing cells. Damage detection systems, sensors, building automation and modular construction systems may exist independently. However, there remains a technical need for an integrated architecture combining a load-bearing cellular unit, a multi-function structural interface, local condition sensing, cell-to-cell communication, adaptive response and replaceable or expandable structural organization.

The present concept therefore treats a structure as an engineered network of cooperating structural cells. Each cell may possess local information about its structural condition and may exchange selected information with neighboring cells or a supervisory system. The network may use this information to coordinate inspection, repair, strengthening, isolation, replacement, expansion or other adaptive actions.

3. PROBLEM ADDRESSED

The invention is directed to one or more challenges including localized structural damage detection, limited visibility of load redistribution, difficulty in upgrading existing structures, replacement of damaged modular elements, integration of structural and information interfaces, distributed decision-making and scalable structural expansion.

4. SUMMARY OF THE INVENTION

In one embodiment, the invention comprises a plurality of intelligent structural cells interconnected by structural interfaces. Each cell includes a load-bearing structural body and may include one or more sensors, a processing unit, a communication module, an energy module, a repair-material compartment, a reinforcement compartment or an actuator. The cells exchange selected condition information through a distributed network. When an abnormal condition is detected, a response process determines one or more actions. The action can include load redistribution through neighboring cells or controllable connections, activation of a strengthening mechanism, delivery of repair material, isolation of a selected cell, replacement by another cell, or addition of new cells.

A particularly useful implementation includes a universal multi-function interface providing mechanical interlock, shear transfer, reinforcement connection, data communication, energy transfer and optionally material transfer through a coordinated connection assembly.

5. SYSTEM ARCHITECTURE

The system may include: (a) a structural cell layer comprising load-bearing modular cells; (b) an interface layer connecting adjacent cells; (c) a sensing layer for acquiring structural and environmental information; (d) a local processing layer; (e) a communication layer for cell-to-cell and supervisory communication; (f) an energy layer; (g) an actuation or adaptation layer; and (h) an optional repair-material delivery layer.

The network may be centralized, decentralized or hybrid. In a decentralized embodiment, a cell can exchange information with one or more immediate neighbors and participate in a distributed decision. In a hybrid embodiment, local decisions are supplemented by a building-level digital twin or supervisory controller.

6. INTELLIGENT STRUCTURAL CELL

Each intelligent structural cell may have a cube, rectangular, hexagonal, triangular or other geometry suitable for the intended structural assembly. The cell may be formed from reinforced concrete, steel, composite materials, engineered timber, geopolymer materials or hybrid materials.

The cell may include an outer load-bearing shell, internal reinforcement, sensor locations, a processing compartment, an energy compartment, communication hardware, a repair-material compartment and one or more actuation elements. Not every embodiment requires every component. Some embodiments may be passive except for sensing and communication, while others may include active adjustment or repair functions.

7. UNIVERSAL INTELLIGENT CELL INTERFACE

Adjacent cells may be connected through a multi-function interface. The interface may provide mechanical interlocking, shear transfer and alignment. It may also include reinforcement connectors, electrical contacts, optical or wireless data links, power contacts and material ports.

An exemplary interface includes complementary male and female mechanical geometry, sealing surfaces, alignment guides, connector bars or couplers, protected data contacts and optional energy or material passages. The combination of multiple connection functions in a coordinated structural interface may simplify assembly, replacement, expansion and monitoring.

8. DISTRIBUTED CELL NETWORK

Cells may communicate with neighboring cells in a mesh, chain, ring, hierarchical or other network topology. Information shared may include load, stress, strain, deformation, crack indicators, temperature, energy level, environmental data, cell identity, connection status and adaptation status.

A network may establish a local structural condition map. A damaged cell can therefore be evaluated not only according to its own sensors but also according to changes measured in adjacent cells. This may improve localization of structural events and support coordinated response.

9. ADAPTIVE DAMAGE RESPONSE

When a cell detects an abnormal condition, the system may execute a response sequence. First, the condition is identified and classified. Second, neighboring cells and/or a supervisory controller are informed. Third, the system evaluates possible actions. Fourth, one or more actions are selected and implemented. Possible actions include increased monitoring, temporary support, connection tightening, activation of reinforcement, delivery of repair material, redistribution of load through an alternate path, isolation of a noncritical cell, replacement of a cell or addition of a new cell.

The system may verify the resulting condition and store information describing the event and response. The stored information may be used to refine future inspection or adaptation rules.

10. MATERIAL DELIVERY AND REPAIR SYSTEM

In selected embodiments, a cell contains a repair-material compartment or is connected to a material-delivery network. A repair material may be delivered to an interface, crack, damaged region or neighboring cell. The material may comprise cementitious repair material, polymeric material, mineralizing material, sealant, grout or another compatible treatment.

A central reservoir, distributed reservoirs or replaceable cartridges may supply the material. Pumps, valves and controlled ports may selectively direct material to a target location.

11. ADAPTIVE STRUCTURAL ORGANIZATION

The cellular architecture may support structural expansion. Additional cells may be attached to exposed interfaces. Cells may also be replaced, upgraded or reconfigured. A structure may therefore be designed with a planned expansion path rather than a fixed final geometry.

In some embodiments, the system uses structural analysis to determine where additional cells would provide the greatest improvement in capacity, redundancy or usable volume.

12. OPERATION METHODOLOGY

Step 1: Assemble or provide a network of structural cells.
Step 2: Establish baseline structural and connection information.
Step 3: Collect sensor information during operation.
Step 4: Analyze local and network-level condition information.
Step 5: Communicate relevant information among cells or to a supervisory system.
Step 6: Determine an adaptive action.
Step 7: Implement strengthening, repair, isolation, replacement, connection adjustment or another action.
Step 8: Verify the resulting structural condition.
Step 9: Store the event and response information for future analysis.

13. EXAMPLE EMBODIMENTS

Example 1 — Intelligent Building: A multi-storey building is assembled from reinforced structural cells. Each cell monitors strain and connection condition and communicates with adjacent cells.

Example 2 — Adaptive Bridge: A bridge deck or supporting system is composed of interconnected cells that identify localized overload and increase monitoring or activate additional support.

Example 3 — Intelligent Foundation Grid: Foundation cells monitor settlement. A cell experiencing abnormal differential movement communicates with neighboring cells and a control system to identify a strengthening or replacement operation.

Example 4 — Tunnel System: Ring-shaped or polygonal cells monitor deformation and pressure. A localized damaged cell can be strengthened or replaced.

Example 5 — Emergency Shelter: Cells are rapidly connected through universal interfaces and expanded by adding additional units.

Example 6 — Remote or Space Construction: Robotic equipment assembles structural cells into a base habitat and subsequently adds cells to enlarge or repair the structure.

14. ADVANTAGES AND INDUSTRIAL APPLICABILITY

Potential advantages include distributed monitoring, modular replacement, improved structural awareness, expandable construction, reduced maintenance disruption, targeted repair and scalable infrastructure. Applications may include buildings, bridges, tunnels, foundations, marine structures, industrial facilities, emergency shelters, remote habitats and other engineered systems.

15. ALTERNATIVE EMBODIMENTS

The invention is not limited to any single cell geometry, structural material, communication protocol or sensing technology. The cell may communicate through wired, wireless, optical, inductive or other pathways. The interface may be detachable or permanent. Local processing may be omitted in simple embodiments or expanded in advanced embodiments. The adaptive action may be automated, semi-automated or initiated by an operator based on the distributed condition information.

16. TECHNICAL DRAWINGS

The following technical drawing sheet illustrates the proposed intelligent structural cell architecture, exemplary cell geometries, universal interface, distributed communication network, adaptive damage response, internal layout, material delivery system, applications and system workflow.

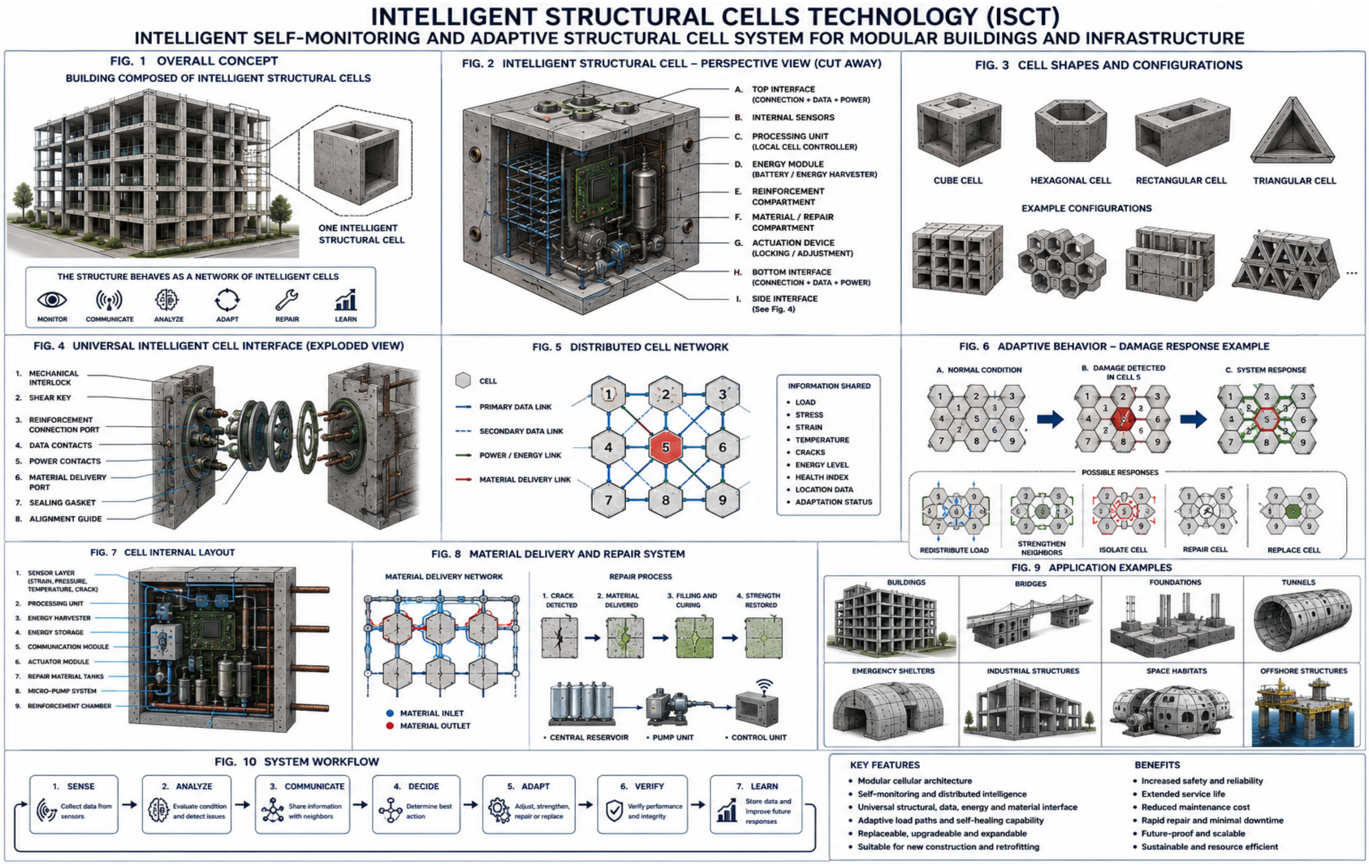

Figure Descriptions

FIG. 1 illustrates an overall building formed from intelligent structural cells. FIG. 2 illustrates an internal cutaway of an exemplary cell. FIG. 3 illustrates possible cell geometries and configurations. FIG. 4 illustrates a multi-function intelligent cell interface. FIG. 5 illustrates a distributed cell communication network. FIG. 6 illustrates an adaptive response to a damaged cell. FIG. 7 illustrates an internal cell layout. FIG. 8 illustrates a material delivery and repair system. FIG. 9 illustrates example applications. FIG. 10 illustrates the system workflow of sensing, analysis, communication, decision, adaptation, verification and learning.

17. CLAIMS

1. An intelligent structural system comprising a plurality of structurally load-bearing cells interconnected to form an engineered structure, each cell comprising a structural body and at least one connection interface, wherein at least a subset of the cells further comprises one or more condition-sensing elements and is configured to communicate condition information associated with the structural body or the connection interface.

2. The system of claim 1, wherein the condition information comprises load, stress, strain, deformation, cracking, temperature, vibration, environmental exposure, energy condition, connection status, or combinations thereof.

3. The system of claim 1, wherein the cells form a distributed communication network.

4. The system of claim 3, wherein a cell communicates directly with at least one neighboring cell.

5. The system of claim 1, wherein each cell comprises a local processing unit.

6. The system of claim 5, wherein the local processing unit determines a local structural condition from signals generated by the sensing elements.

7. The system of claim 1, further comprising a supervisory control system configured to receive information from a plurality of cells.

8. The system of claim 1, wherein the connection interface provides mechanical load transfer between adjacent cells.

9. The system of claim 8, wherein the connection interface further provides a data communication pathway.

10. The system of claim 9, wherein the connection interface further provides an electrical energy pathway.

11. The system of claim 10, wherein the connection interface further provides a material transfer pathway.

12. The system of claim 1, wherein the connection interface comprises complementary mechanical interlocking geometry.

13. The system of claim 12, wherein the mechanical interlocking geometry includes a shear-transfer feature.

14. The system of claim 1, wherein the connection interface comprises reinforcement connectors.

15. The system of claim 14, wherein the reinforcement connectors comprise mechanical couplers, threaded couplers, embedded plates, headed connectors, or combinations thereof.

16. The system of claim 1, further comprising an adaptive response module configured to determine an action in response to an abnormal condition associated with a selected cell.

17. The system of claim 16, wherein the action comprises increased monitoring.

18. The system of claim 16, wherein the action comprises strengthening of the selected cell or an adjacent cell.

19. The system of claim 16, wherein the action comprises delivery of repair material.

20. The system of claim 16, wherein the action comprises isolation of the selected cell.

21. The system of claim 16, wherein the action comprises replacement of the selected cell.

22. The system of claim 16, wherein the action comprises connection of an additional structural cell.

23. The system of claim 1, wherein at least one cell comprises a repair-material compartment.

24. The system of claim 23, wherein the repair-material compartment is connected to a controllable material-delivery port.

25. The system of claim 1, wherein at least one cell comprises an energy module.

26. The system of claim 25, wherein the energy module comprises an energy storage device or an energy harvesting device.

27. The system of claim 1, wherein the plurality of cells are configured for sequential expansion of the engineered structure.

28. The system of claim 27, wherein an additional cell is connected to an exposed interface of an existing cell.

29. The system of claim 1, wherein the structural body of a cell comprises reinforced concrete, steel, composite material, engineered timber, geopolymer material, or a hybrid combination thereof.

30. A method of operating an intelligent structural cell network comprising collecting condition information from a plurality of structurally connected cells, communicating selected information between cells or to a supervisory system, identifying an abnormal condition, determining an adaptive response, implementing the adaptive response, and verifying a resulting structural condition.

31. The method of claim 30, wherein identifying the abnormal condition comprises comparing information from a selected cell with information from at least one neighboring cell.

32. The method of claim 30, wherein determining the adaptive response includes evaluating alternative structural load paths.

33. The method of claim 30, wherein implementing the adaptive response includes strengthening, repairing, isolating, replacing, or expanding at least one cell.

34. The method of claim 30, further comprising storing an event record associated with the abnormal condition and the adaptive response.

35. A multi-function structural interface for connecting two load-bearing structural cells, comprising a mechanical load-transfer mechanism, an alignment mechanism, and at least one of a data communication connection, energy connection, or material transfer port.

36. The interface of claim 35, wherein the mechanical load-transfer mechanism comprises an interlocking shear-transfer geometry.

37. A building comprising the intelligent structural system of claim 1.

38. A bridge, tunnel, foundation, marine structure, industrial facility, emergency shelter, or remote habitat comprising the intelligent structural system of claim 1.

39. A replaceable intelligent structural cell comprising a load-bearing structural body, a multi-function connection interface, one or more sensors and a communication module, wherein the cell is configured to be disconnected from an existing structural network and replaced by another structurally compatible cell.

40. A computer-implemented structural coordination method comprising generating a network representation of a plurality of intelligent structural cells, receiving condition information from the cells, identifying a selected structural condition, determining a candidate adaptive action, communicating an action instruction, and recording verification information.

18. CONCLUDING DISCLOSURE

The Intelligent Structural Cells Technology provides a technology platform in which a building or infrastructure system can be organized as a network of load-bearing, condition-aware and communicatively connected structural units. The disclosed architecture supports multiple embodiments ranging from simple monitored modular structures to advanced systems capable of distributed analysis, adaptive response, repair, replacement and expansion.

19. PATENT DEVELOPMENT NOTICE

Before filing, the next recommended steps are a focused prior-art search, novelty mapping of each major subsystem, refinement of the independent claims around the most distinctive technical implementation, preparation of formal patent drawings suitable for the selected patent office, and professional legal review.