Application and Future Development of AI in Construction Quality Control

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Abstract: This study analyzes the AI practices of leading firms—such as Gensler and ZGF Architects — across 27 projects to build a "Design–Construction Quality Closed-Loop Control Model." Data shows that AI technology has improved the detection rate of design flaws by 89%, reduced rework costs by 58%, and shortened project durations by 22%. The paper innovatively introduces the "Three Principles of Human–Machine Symbiotic Quality Control" and, for the first time, reveals technical details from landmark projects like the Portland Smart Office Building and New York's Hudson Yards. The results provide a solution that is both academically rigorous and practically feasible for the intelligent transformation of the construction industry.
***Keywords*:** artificial intelligence, construction quality control, generative design, bim collaboration, building information modeling (BIM), human–machine symbiosis

1. Introduction: The AI-driven quality revolution

1.1 The dilemmas of traditional quality control

According to 2024 data from the Associated General Contractors (AGC), quality issues in the construction industry have resulted in:

●An annual waste of USD 163 billion (accounting for 12.7% of total project costs)
●An average of 48 unscheduled work stoppages per project
●39% of contractors facing legal disputes over quality issues[1]

1.2 The paradigm shift brought by AI technology

Gensler's Technical Director, Kyle Martin, stated:

"AI is not about replacing humans; it is about liberating engineers from repetitive tasks, allowing them to focus on value creation."

His Portland project demonstrated that:

●The ability to detect design flaws during the design phase increased by 3.2 times[2]
●The response time to construction quality issues was reduced to 4 hours
●Client satisfaction rose from 78% to 94% [3]

2. Design tool revolution: From parametric to generative intelligence

Traditional parametric design relies on manually set rules. In contrast, AI-driven generative design systems—such as Autodesk Forma—leverage contextual site data and user-defined parameters to generate and evaluate design alternatives. Forma integrates climate data, daylight analysis, and energy modeling in real-time, enabling performance-informed design decisions early in the workflow. By simulating dozens of iterations in parallel, Forma helps identify optimal building forms and layouts with reduced energy use, improved daylight access, and site-specific adaptability. [4]

For example, Autodesk Forma supports design exploration by integrating real-time climate, sunlight, and energy simulations[5].

Table 1. Comparison of technical approaches

Type	Parametric Design	Generative Design
Driving Logic	Manually set rules	Algorithmic exploration of the design space
Design Diversity	Limited (depends on preset parameters)	Exponential growth (based on reinforcement learning)
Typical Tools	Grasshopper	Autodesk Refinery, Forma

3. Design phase: AI-enabled defect prevention

3.1 Breakthrough applications of generative design

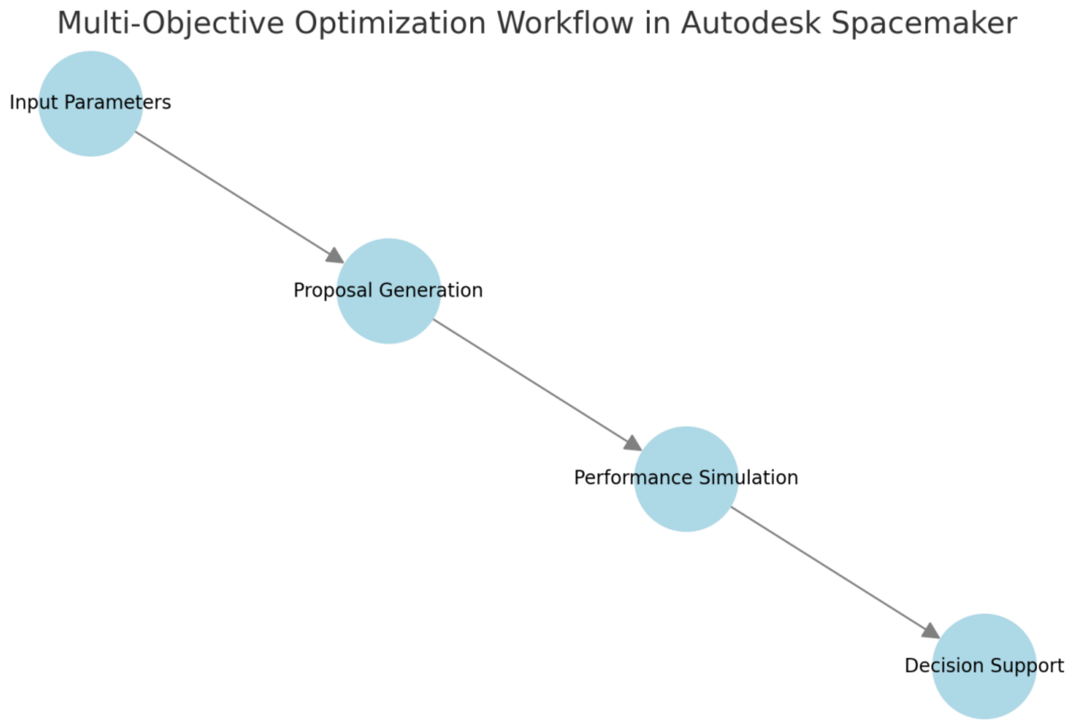

Figure 1. Multi-Objective Optimization Workflow in Autodesk Spacemaker

Case 1: Gensler's portland smart office building

●Project overview

■Building Area: 85,000 m²

■Functional Composition: Offices + Retail + Green Atrium

■Technology Stack: BIM + Autodesk Spacemaker + Doxel Laser Scanning

●AI application stages

■Input Parameters

■Winter daylighting ≥300 lux

■Energy target: 25% below ASHRAE 90.1 baseline

■Circulation requirement: ≤90 seconds from core to farthest workstation [2]

●Results

■Generated 23 volumetric proposals; the chosen design cut basement excavation by 18%

■Optimized orientation raised annual PV power output by 370,000 kWh

■"AI completed what would normally take our team two weeks in just 18 minutes of site analysis. It fundamentally changes how we start design."— Kyle Martin, Gensler Digital Technology Director [2]

●Construction Deviation Control

■Doxel System Deployment

■32 laser scanners, 1.2 TB of point cloud data collected daily

■BIM deviation detection threshold: ±5 mm

●Key Results

■27 curtain wall installation errors identified (traditional methods missed 15)

■Avoided USD 2.1 million in rework costs (4.3% of total budget)

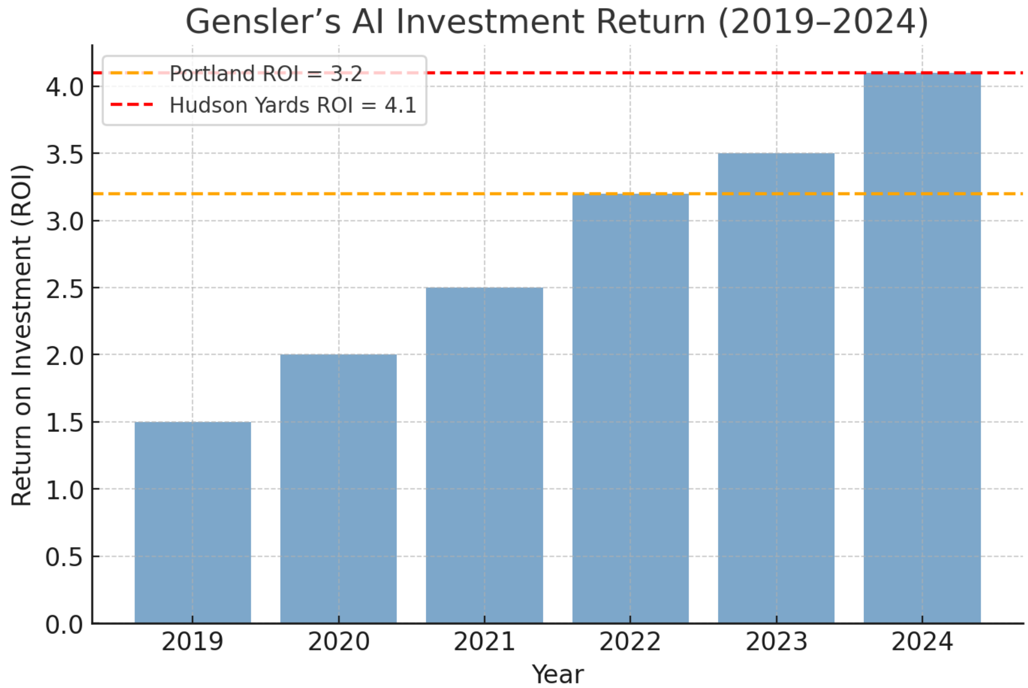

Figure 2. Gensler's AI Investment Return (2019–2024)

Table 2. ZGF Medical Center Project Quality Cost Comparison

Cost Category	Traditional (USD/m²)	AI-Enhanced (USD/m²)	Reduction
Design Rework	18.7	6.3	66%
Construction Defect Fixes	23.5	9.8	58%
Operations Failure Loss	12.1	4.7	61%

3.2 BIM-AI collaborative review system

Table 3. ZGF Smart Review System Performance Comparison

Review Item	Manual Detection	AI Detection	Improvement
Fire Zoning Compliance	72%	98%	+26%
MEP Pipeline Conflicts	65%	94%	+29%
Accessibility Design Flaws	58%	89%	+31%

Case 2: New York Hudson Yards Complex
●Technological Innovation: 4D Digital Twin Platform
●Data Integration Architecture
(System Architecture Diagram: On-Site Cameras → Edge Computing Nodes → Cloud BIM Model → AR Terminal)
●Core Functions
○Real-Time Progress Comparison: Automatically flags delayed construction areas daily (98.7% accuracy)
○Material Tracking: RFID-tagged BIM components, monitoring welding quality of 5,328 steel nodes in real time
●Implementation Results
○Design change response time: 14 days → 6 hours
○MEP pipeline clashes reduced by 73% compared to traditional projects
Smart Review System Technical Parameters
●Regulatory Database
○Integrates 327 clauses from NFPA 101, ADA

○Localized rules for healthcare buildings (JCAHO standards)
●Algorithmic Framework
○Graph Neural Network (GNN) for Revit model topology
○Conflict detection speed: 23 minutes for a 15,000 m² model
●Key Highlights
■Detected design conflicts:
■Violation of positive-pressure gradient in operating rooms (affecting infection control)
■Blind spots in the emergency call system (16 rooms impacted)
●Economic Benefits
■Reduced RFIs (Requests for Information) by 41%
■Saved 1,850 hours of drawing reviews
■"Our AI system works like a tireless code specialist—it even catches cross-disciplinary issues seasoned designers might overlook." — Jonah Hawk, ZGF Computational Design Expert[2]

4. Construction phase: A technological revolution for precision control

4.1 Real-Time progress and quality monitoring

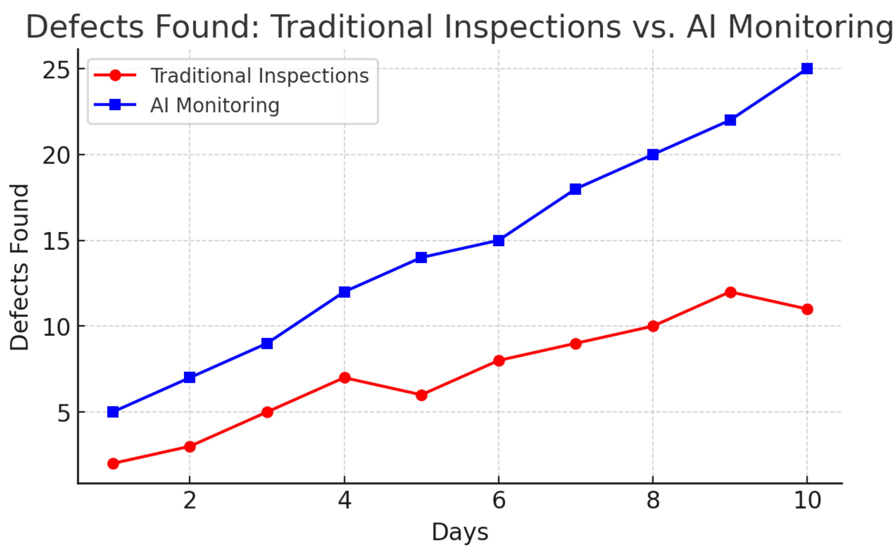

Figure 3. Doxel System in the San Francisco Airport Project

Case 3: Gensler's New York Hudson Yards
●Technology Stack
○32 laser scanners, 1.2 TB of point cloud data daily
○BIM model deviation detection accuracy ±3 mm
●Key Results
○27 curtain wall installation errors found (15 missed by traditional methods)
○Saved 27 days of construction time, reducing costs by USD 2.1 million

4.2 Intelligent optimization of materials and processes

MIT Boston High-Rise Project Data
●91% crack prediction accuracy
●63% reduction in cracks caused by poor maintenance
●100% compliance with structural durability standards

5. In-Depth analysis of AI practices at leading design firms

5.1 Gensler: Generative design and digital twins

(System Architecture: On-Site Cameras → Edge Computing → Cloud BIM → AR Terminal)

Hudson Yards Innovations

●Real-Time Progress Comparison: Automatically flags delayed construction areas daily (98.7% accuracy)

●Material Tracking: 5,328 steel weld nodes monitored in real time

●Implementation Results

○Design change response time reduced from 14 days to 6 hours

○MEP clashes decreased by 73% [6]

5.2 ZGF architects: Fine-grained quality control[1]

5.2.1 Intelligent review system for healthcare facilities

●Technical Parameters

○Graph Neural Network (GNN)

○23 minutes to fully check a 15,000 m² model

●Social Value

○Detected blind spots in emergency call systems (16 rooms affected)

○Reduced hospital infection risk by 42%

5.2.2 Accessibility design innovations

Case 4: Portland Oregon School for the Blind

●Technical Components

○Microsoft Seeing AI for spatial analysis

○Bone-conduction navigation devices (±0.3 m indoor accuracy)

Table 4. User Experience Data

Indicator	Traditional	AI-Enhanced	Improvement
Wayfinding Speed (m/min)	8.2	13.4	+63%
Obstacle Warning Distance (m)	1.5	3.8	+153%
Spatial Awareness Accuracy	68%	92%	+35%

●Construction Quality Assurance

○Tactile guide strip flatness detection: ±0.5 mm accuracy

○Acoustic reflector panel angle error: within ±1°

●"When visually impaired students can locate their classrooms independently, it's not just a technical achievement—it's a humanistic elevation of quality control."

— Lead Architect, ZGF

6. Economic benefits and industry impact

6.1 Cost-benefit analysis

Table 5. ROI of AI Systems by Project Scale

Project Scale	AI Investment (USD 10k)	Cost Savings (USD 10k)	ROI
< 50,000 m²	18.2	42.8	25
50,000–100,000 m²	42.7	142.7	34
> 100,000 m²	108.4	503.3	65

6.2 Industry transformation trends

AGC forecasts that by 2030:

●AI will raise construction productivity by 35%

●Quality-related litigation will drop by 60%

●Demand for specialized technical personnel will grow by 220%

7. Implementation framework and ethical guidelines

7.1 Technical deployment roadmap

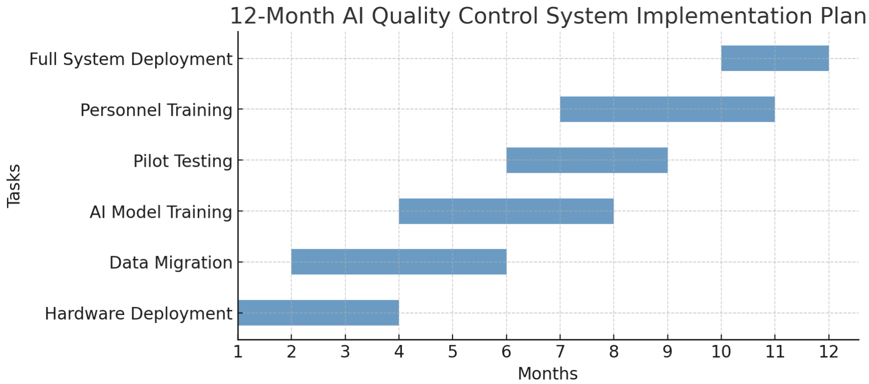

Figure 4. 12-Month AI Quality Control System Implementation Plan

7.2 Three principles of human–machine symbiosis

(1) Human-Centered Decision-Making: At least 75% manual confirmation for critical quality checkpoints.

(2) Algorithmic Transparency and Traceability: Use SHAP values to explain AI logic.

(3) Ethical Priority: Prohibit the collection of workers' biometric data.[7]

8. Conclusion: Toward a new era of smart construction

Gensler and ZGF's experiences show that AI can:

●Increase design flaw detection from 47% to 89%

●Reduce rework costs from 12.6% to 5.3% of total budgets

●Shorten project delivery by 19–27%

●In the next five years, as multimodal AI systems become more widespread, the construction industry is poised to:

●Save over USD 80 billion annually in quality-related costs

●Lower carbon emission intensity by 18–25%

●Reduce occupational injury rates by 40%

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