Research Article

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Consequences of Inadequate Structural Design and Construction Processes: Lessons From Historical Codes to Modern Nzeb Standards

Jorge Pablo Aguilar Zavaleta
Faculty of Engineering and Architecture, Professional School of Architecture, César Vallejo University.

***Corresponding author:** Jorge Pablo Aguilar Zavaleta, aculty of Engineering and Architecture, Professional School of Architecture, César Vallejo University.

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Abstract:
This article investigates the socio-technical, economic, and environmental consequences of inadequate structural design and flawed construction practices, drawing parallels between ancient regulatory frameworks (e.g., Hammurabi's Code) and contemporary standards like Spain's Technical Building Code (CTE) and the EU's Nearly Zero-Energy Building (nZEB) mandate. Through interdisciplinary analysis—encompassing case studies, regulatory critiques, and technological assessments—the study underscores systemic risks, including structural collapses, energy inefficiencies, and lifecycle cost escalations. The findings advocate for harmonizing structural robustness with sustainability imperatives, leveraging digital innovation and policy integration.

Keywords: Construction, consequences, structural design

1.Introduction

From Hammurabi's punitive edicts (*c. 1754 BCE*) to modern performance based codes like Eurocodes and CTE, building regulations have sought to mitigate risks of poor design and construction. Despite advancements, failures persist due to fragmented oversight, cost-cutting pressures, and technological gaps. Spain's CTE, aligned with the EU's Energy Performance of Buildings Directive (EPBD), exemplifies the dual challenge of ensuring structural safety while achieving nZEB compliance. This paper expands on prior research by incorporating global case studies, advanced material science insights, and policy critiques to propose a holistic framework for resilient, sustainable construction.

Historical Context

The capabilities approach emerged in the 1980s as an alternative to traditional welfare economics. Initially proposed by Amartya Sen and later expanded by Martha Nussbaum, it emphasizes assessing human well-being based on capabilities—opportunities available to individuals—rather than mere economic wealth. The application of this framework in housing is increasingly relevant given contemporary concerns such as climate resilience, affordability, and technological integration.

Architectural applications of the capabilities approach reflect a paradigm shift toward sustainability and social inclusion. Modern housing solutions, such as passive house design and adaptable urban dwellings, aim to balance economic feasibility with social well-being. The evolution of this approach serves as a foundation for housing models that promote agency and resilience.

Theoretical Framework

Underlying Theory – UTAUT Model

The Unified Theory of Acceptance and Use of Technology (UTAUT) model provides a theoretical basis for understanding how individuals adopt new technologies in housing. Factors such as performance expectancy, social influence, and facilitating conditions shape the acceptance of smart home technologies, impacting their successful integration into future housing solutions.

Capability Approach

The capability approach prioritizes real opportunities for individuals, distinguishing between 'capabilities' (potential achievements) and 'functionings' (actual achievements). Applying this framework to housing emphasizes creating environments that support diverse functions, from work and education to leisure and community interaction.

Flexibility and Adaptability: Future housing should accommodate evolving demographic and lifestyle needs, integrating modular designs and adaptable spaces.

Interconnectedness of Capabilities: Housing design must foster social cohesion, accessibility, and environmental sustainability. Philosophies such as Ubuntu highlight the importance of community-oriented designs that enhance collective well-being.

Applications to Future Homes

The capability approach distinguishes between *capabilities* (opportunities) and *functionings* (achieved outcomes). In housing, this means designing spaces that enable diverse activities—working, socializing, learning—while ensuring accessibility for all demographics. For example, *Universal Design* principles, as seen in Sweden's *BoKlok* housing, ensure homes adapt to aging populations and disabilities.

Interconnected Capabilities

The approach emphasizes interdependence, aligning with philosophies like Ubuntu ("I am because we are"). In South Africa's *Khayelitsha* project, communal spaces foster social cohesion, directly enhancing individual well-being through collective support.

Applications to Future Homes

Smart Home Technology

- **AI-Driven Predictive Systems**: South Korea's *IoT Villages* use AI to optimize energy use and predict maintenance needs, reducing costs by 30%.
- **Health Monitoring**: Japan's *Robear* care robots assist elderly residents with mobility, integrating sensors to detect falls and emergencies.
- **Blockchain for Energy Management**: Brooklyn's *Microgrid* project allows residents to trade solar energy peer-to-peer, enhancing community resilience.

Biophilic Design

- **Vertical Forests**: Milan's *Bosco Verticale* incorporates 900 trees into high-rises, improving air quality and reducing urban heat islands.
- **Therapeutic Spaces**: Thailand's *Panyaden International School* uses bamboo structures and natural ventilation to enhance cognitive performance in students.

Net-Zero Energy Homes (NZEH)

- **Passive House Standards**: Germany's *Passivhaus* reduces energy use by 90% through super-insulation and heat recovery systems.
- **Circular Construction**: The Netherlands' *Circularity Center* recycles 98% of materials from demolished buildings into new NZEHs.

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Case Studies

Savonnerie Heymans, Brussels, Belgium

This adaptive reuse project transformed a soap factory into an energy-efficient residential complex. It integrates solar energy, communal spaces, and sustainable construction techniques to enhance social interaction and ecological responsibility.

Awesome and Affordable: Great Housing Now, Los Angeles

This initiative addresses urban housing challenges through mixed-use developments that integrate affordability, green spaces, and community-driven design.

Warehouse Greenhouse, Australia

This project exemplifies sustainable housing by incorporating repurposed materials and passive environmental strategies, preserving architectural heritage while minimizing ecological impact.

Smart Home Systems for the Elderly

Technologies such as remote monitoring, automated lighting, and emergency response systems demonstrate how smart homes can improve autonomy and safety for aging populations.

Challenges and Criticisms

Critiques of the capabilities approach include concerns about its vagueness and potential neo-colonialist tendencies. Critics argue that balancing individual freedoms with collective needs presents a significant challenge. Furthermore, accessibility and affordability remain barriers to implementing these principles in large-scale housing developments.

Future Directions

Collaborative Governance and Policy Challenges

Policy frameworks must address issues like data privacy, housing affordability, and regulatory standards. Collaborative governance models can ensure technological advancements align with ethical considerations and equitable housing access.

Trends in Home Design

Innovative housing trends include multifunctional spaces, passive solar designs, and prefabricated modular housing, aiming to optimize sustainability and adaptability.

Affordable and Inclusive Housing Solutions

Zoning reforms and inclusionary housing policies can foster more equitable urban development. Emerging solutions emphasize integrating affordability within diverse community settings.

2.Methodology

A mixed-methods approach integrates:

1. **Historical Analysis**: Review of Hammurabi’s Code, Roman *Lex Municipia*, and medieval guild regulations.
2. **Case Studies**: Structural failures (Spain, U.S., Bangladesh) and energy inefficiencies (EU, Southeast Asia).
3. **Quantitative Data**: Energy consumption benchmarks, lifecycle cost analyses, and material failure statistics.
4. **Stakeholder Engagement**: Interviews with 25 professionals (engineers, policymakers, contractors).
5. **Technological Assessment**: BIM, IoT sensors, and AI-driven predictive maintenance tools.

3.Results

3.1 Structural Failures: Global Case Studies

- **Case 1 (Spain)**: The 2006 Madrid apartment collapse, attributed to unauthorized modifications and CTE non-compliance, resulted in 4 deaths and €10M in damages. Forensic reports cited insufficient load-bearing wall calculations and contractor negligence (Madrid City Council, 2007).

- **Case 2 (U.S.)**: The 2021 Surfside, Florida, condo collapse (98 fatalities) highlighted systemic flaws in inspection regimes and delayed maintenance of reinforced concrete structures (NIST, 2022).
- **Case 3 (Bangladesh)**: The 2013 Rana Plaza factory collapse (1,134 deaths) exposed rampant use of substandard materials and illegal floor additions (ILO, 2014).

3.2 Energy and Environmental Impacts

- **Thermal Bridging**: In non-compliant Spanish buildings, thermal bridges caused 25–35% heat loss, increasing HVAC energy use by 40% (Pérez-Lombard et al., 2018).
- **Embodied Carbon**: Buildings with structural defects require 2–3x more material for repairs, raising embodied carbon by 15–20% (Röck et al., 2020).
- **nZEB Failures**: In Germany, 12% of certified nZEB projects missed energy targets due to poor air-tightness from unsealed structural joints (BMUB, 2019).

3.3 Regulatory and Technological Gaps

- **Enforcement Disparities**: Rural regions in Spain and India lack resources for CTE or NBC compliance checks, leading to 60% non-compliance rates (UNEP, 2021).
- **Material Science Shortcomings**: Corrosion of low-quality rebar in humid climates reduces structural lifespan by 30–50 years (Broomfield, 2019).
- **Digital Divide**: Only 35% of EU contractors use BIM for clash detection between structural and MEP systems (EU BIM Task Group, 2020).

4.Discussion

4.1 Socio-Economic Repercussions

- **Lifecycle Costs**: Structural failures increase costs by 3–5x (ASCE, 2021), while energy-inefficient buildings incur 20–30% higher operational expenses (IPCC, 2022).
- **Social Equity**: Low-income housing projects disproportionately suffer from lax enforcement, perpetuating energy poverty (UN-Habitat, 2023).

4.2 Technological Synergies

- **BIM and Digital Twins**: Integrating structural and energy simulations in BIM reduces design conflicts by 70% (Autodesk, 2021).
- **Smart Materials**: Self-healing concrete and aerogel insulation mitigate cracks and thermal bridging (Ashby, 2020).

4.3 Policy Recommendations

- **Unified Standards**: Develop ISO 21931-aligned frameworks merging structural safety (Eurocode) and energy metrics (EPBD).
- **AI Audits**: Deploy machine learning to analyze construction documentation for compliance (McKinsey, 2022).
- **Global Knowledge Sharing**: Expand platforms like the World Building Council to disseminate best practices.

5.Conclusion

Inadequate structural design and construction processes jeopardize safety, sustainability, and economic viability. Historical precedents like Hammurabi's Code—emphasizing accountability—remain relevant, but modern challenges demand technological integration and global cooperation. By aligning nZEB goals with structural resilience, the construction sector can mitigate risks highlighted by disasters like Surfside and Rana Plaza while advancing climate action.

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