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Net Zero Carbon Building Construction Using Cold Formed Steel and Highly Sulphated Calcium Silicate Cement

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ABSTRACT: The construction industry is a major contributor to global carbon emissions due to the extensive use of conventional materials such as reinforced concrete and Portland cement. The development of net zero carbon buildings has become essential to reduce environmental impact and promote sustainable construction practices. Cold Formed Steel (CFS) and Highly Sulphated Calcium Silicate Cement (HSCSC) are emerging as low-carbon construction materials that offer improved structural efficiency and reduced carbon emissions. This study explores the integration of CFS structural systems with HSCSC-based concrete to develop net zero carbon building solutions. CFS provides lightweight and high-strength structural framing, while HSCSC significantly reduces carbon emissions compared to ordinary Portland cement. The research focuses on material properties, structural performance, and carbon emission reduction potential in building construction. A sustainable framework is proposed to evaluate energy efficiency, material optimisation, and carbon footprint reduction. The results indicate that the combined use of CFS and HSCSC can significantly lower embodied carbon, improve construction efficiency, and support net zero carbon building development. The study highlights the potential of advanced materials and innovative construction methods in achieving environmentally sustainable and energy-efficient buildings.

KEYWORDS: Net Zero Carbon Buildings, Cold Formed Steel (CFS), HSCSC Cement, Sustainable Construction, Low Carbon Materials, Green Buildings, Carbon Emission Reduction, Energy Efficient Buildings

I. INTRODUCTION

The built environment accounts for a significant portion of global greenhouse gas (GHG) emissions, with the construction sector alone responsible for nearly 38% of total energy-related CO_2 emissions (including materials and operations) as of 2022 (GlobalABC, 2023). A major fraction of these emissions originates from embodied carbon in construction materials—particularly ordinary Portland cement (OPC) and steel reinforcement in concrete structures—making decarbonisation of building materials a critical pathway toward achieving Net Zero Carbon Buildings (NZCBs) (UNEP, 2021). The shift toward sustainable construction practices has accelerated research into low-carbon materials and structural systems that can reduce embodied carbon without compromising structural performance.

Traditional reinforced concrete (RC) dominated by OPC is among the highest contributors to embodied carbon due to energy-intensive clinker production. In contrast, Cold Formed Steel (CFS) and Highly Sulphated Calcium Silicate Cement (HSCSC) represent emerging low-carbon alternatives with the potential to significantly reduce material emission intensity. CFS, produced by forming thin sheets of steel into structural members at ambient temperatures, demonstrates high strength-to-weight ratios with reduced raw material consumption and faster construction cycles compared to hot-rolled steel and RC. Recent studies indicate that CFS components can cut up to 25–35% embodied carbon in framing systems when optimised for design (Karimipour et al., 2022)

Parallel to structural steel innovations, HSCSC has gained attention as a low-carbon binder with a significantly reduced clinker factor compared to OPC. HSCSC utilizes blast furnace slag and supplementary cementitious materials (SCMs) such as fly ash and silica fume, combined with sulphate activation, to form hydration products with comparable mechanical properties and enhanced durability. Studies report that HSCSC can reduce embodied cement carbon by 40–60% relative to OPC without sacrificing compressive strength or long-term performance.

Despite these advances, there remains a research gap in integrated NZCB design frameworks that combine both innovative structural systems and low-carbon binders. Most studies focus on materials in isolation (steel or cementitious alternatives) without quantifying the combined effect on overall carbon reduction, structural efficiency, and lifecycle performance(Guan et al., 2023). To address this gap, the present research investigates the synergies between Cold Formed Steel structural systems and HSCSC-based concrete for net zero carbon building applications, considering material optimisation, carbon footprint, and structural performance.

The primary objectives of this study are:

1. To characterise the material properties and mechanical performance of CFS and HSCSC in structural applications.
2. To quantify the embodied carbon savings achievable through combined use of CFS and HSCSC relative to conventional reinforced concrete.
3. To develop a sustainable framework for evaluating NZCB design that incorporates energy efficiency, material optimisation, and carbon footprint reduction.
4. To illustrate case study applications and propose recommendations for adoption in practice.

The integrated approach outlined in this study aims to demonstrate that the combination of lightweight CFS framing and low-carbon HSCSC concrete can significantly lower embodied carbon, enhance construction efficiency, and support the broader transition to environmentally sustainable and energy-efficient buildings.

II. LITERATURE REVIEW

The transition toward Net Zero Carbon Buildings (NZCBs) requires both material innovation and structural optimisation to significantly reduce embodied carbon and lifecycle emissions compared to traditional reinforced concrete construction. This review synthesises recent advances in Cold Formed Steel (CFS) structures, low carbon cementitious materials including highly sulphated and supersulfated binders, and related sustainability analyses to inform the integrated framework used in this research.

2.1 Cold Formed Steel (CFS) in Sustainable Construction

Cold Formed Steel (CFS) refers to thin steel sheet members rolled at room temperature into structural shapes such as C-sections, Z-sections, and lipped channels. Production of CFS avoids high-temperature hot-rolling, reducing energy demand, material use, and associated carbon emissions relative to conventional hot-rolled steel and concrete frames(Dhull, 2024).

Recent reviews highlight the sustainability potential of CFS: it offers high strength-to-weight ratios, excellent recyclability, and lower construction energy consumption, particularly when used in modular or prefabricated systems that reduce waste and onsite time. Research indicates that CFS members contribute to reduced transportation energy, lower onsite material usage, and shorter construction schedules, all of which correlate with lower embodied carbon(Sam et al., 2024).

CFS framed buildings also show comparable load-bearing performance to conventional steel or RC frames when optimised for buckling resistance and connection detailing. However, comprehensive lifecycle assessments (LCA) focused explicitly on NZCB performance are still limited, signifying a need for integrated evaluation frameworks.

2.2 Low-Carbon Cementitious Materials

2.2.1 Supersulfated Cement (SSC) and Sulphate-Activated Binders

A central strategy for reducing cement-related embodied carbon is the use of supersulfated cement (SSC) and sulphate-activated binder systems that incorporate industrial by-products such as ground granulated blast furnace slag (GGBFS) and gypsum. Recent studies on SSC have demonstrated:

- Significant CO_2 reductions — customised SSC formulations can achieve as much as 47–89% lower CO_2 emissions compared to ordinary Portland cement (OPC), depending on mix design and life cycle allocation method(Cabrera-Luna et al., 2025).
- Mechanical viability — SSC concretes have been engineered to surpass 28-day compressive strengths ≥ 32.8 MPa while maintaining low climate impact, making them feasible for structural concrete in NZCB contexts.
- Durability considerations — extended performance studies indicate that SSC concrete can exhibit distinct carbonation behavior over long durations compared with OPC concrete, suggesting that design and exposure conditions must be carefully considered(Yu et al., 2023).

In terms of chemistry and hydration mechanisms, recent work demonstrates that SSC hydration involves the formation of ettringite (AFt) and calcium silicate hydrate (C–S–H) phases, with early-age strength influenced by activators such as sodium silicate and carbide slag.

2.3 Supplementary Cementitious Materials (SCMs) and Low-Carbon Concrete Strategies

The use of Supplementary Cementitious Materials (SCMs) — such as fly ash, silica fume, metakaolin, and GGBFS — has been extensively validated as a practical approach to lowering cement content and embodied carbon. SCM-blended binders generally:

- Reduce overall clinker content and hence CO_2 intensity per unit of binder
- Improve long-term durability and resistance to chemical attack
- Can enhance pore structure and reduce permeability

Studies report that SCM incorporation can significantly reduce environmental impact and also alter fresh and hardened properties of cementitious composites(Barbhuiya et al., 2025).

2.4 Integrated Material Systems: CFS and Low-Carbon Concrete

Although significant research exists on either CFS systems or low-carbon binders independently, combined evaluations remain limited. However, parallel trends indicate potential synergies:

- CFS reduces structural framing embodied carbon and construction waste
- Low-carbon binders reduce binder emissions in concrete and composite elements
- Hybrid systems (CFS panels with low-carbon concrete infill or wall panels) offer multifunctional advantages in structural performance and sustainability

These insights support the case for integrated NZCB design frameworks that simultaneously target material emission reduction and structural optimisation(Peng et al., 2025).

2.5 Summary of Key Literature Findings

Table1. Literature Summary on CFS and Low-Carbon Cementitious Strategies

Theme	Key Research Focus	Performance/Findings	Reference
CFS for Sustainability	High strength/weight, recyclability	Reduces material use, transport energy; improves efficiency	(Dhull, 2024)
SSC Low-Carbon Cement	CO_2 emissions, LCA analysis	CO_2 reductions up to ~89% vs OPC	(Cabrera-Luna et al., 2025)
Hydration Mechanism of SSC	Ettringite, C–S–H formation	Enhanced early strength and microstructure	(Qi et al., 2024)
SCM & Low-Carbon Concrete	SCM blends, durability	Enhanced properties with reduced clinker	(Barbhuiya et al., 2025)
CFS Composite Panels	Novel prefabricated systems	Reduced carbon; lightweight structural performance	(Peng et al., 2025)

2.6 Identified Gaps in Current Literature

Despite significant progress, several gaps remain that motivate the present study:

1. Lack of integrated lifecycle analysis for combined CFS + low-carbon binder NZCB frameworks
2. Limited experimental data on structural performance of systems using HSCSC or supersulfated cement in real applications
3. Insufficient quantitative comparison of embodied carbon savings across hybrid material strategies

These gaps highlight the novelty and importance of combining CFS structural systems with highly sulphated and low-carbon cementitious binders in pursuit of true net zero construction solutions.

III. MATERIALS AND METHODS

In this study, a systematic literature review was conducted to analyse the potential of Cold Formed Steel (CFS) and Highly Sulphated Calcium Silicate Cement (HSCSC) as low-carbon construction materials for Net Zero Carbon Buildings (NZCBs). The review focuses on three key aspects: material properties, structural performance, and carbon reduction potential. A comparative framework was developed to synthesise recent studies (post-2020) and provide quantitative insights into their sustainability benefits.

3.1 Data Collection and Sources

A comprehensive search of peer-reviewed articles, technical reports, and case studies was conducted using Scopus, Web of Science, ScienceDirect, MDPI, and Frontiers journals. The inclusion criteria were published after 2020, focused on structural, material, or environmental performance and provided quantifiable data (e.g., carbon emissions, compressive strength, embodied energy).

3.2 Cold Formed Steel (CFS) Systems

CFS structural systems have been increasingly used in lightweight building frames, prefabricated walls, and modular construction.

Table 2: Recent literature highlights on CFS

Application	Key Findings	Reference
Prefabricated CFS frames	Reduces embodied carbon by 25–35%; high recyclability	(Karimipour et al., 2022)
Modular CFS buildings	High strength-to-weight ratio; reduced construction time	(Thirunavukkarasu et al., 2021)
Urban low-carbon buildings	Prefabrication with CFS reduces onsite emissions by ~30%	(Sam et al., 2024)

Key Insights:

- Lightweight, high-strength framing reduces steel usage.
- Prefabrication enhances construction efficiency and reduces waste.
- Recyclable at end-of-life, supporting circular economy principles.

3.3 Highly Sulphated Calcium Silicate Cement (HSCSC)

HSCSC is a low-carbon binder produced using industrial by-products such as blast furnace slag and gypsum. Its main advantage lies in reducing clinker content, a major source of CO_2 in conventional OPC.

Table 3: Recent studies report on HSCSC

Application	Key Findings	Reference
Low-carbon concrete review	Comprehensive review of low-carbon binders and supplementary cementitious materials (SCMs); CO_2 reduction potential up to 50%	(Barbhuiya et al., 2025)
Low-carbon slag concrete	Optimized low-carbon mix with high compressive strength and durability; carbonation and sulfate resistance evaluated	(Ahmad et al., 2024)
Low-lime calcium silicate binders	Improved durability and low carbonation depth in low-carbon binders; suitable for sustainable high-rise construction	(Tokpatayeva et al., 2023)
Low-carbon building blocks	Effective hydration, early strength gain	(Qi et al., 2024)

Key Insights:

- Significantly reduces embodied carbon compared to OPC.
- Compatible with structural applications in walls, slabs, and infill panels.
- Hydration products (C-S-H and ettringite) ensure sufficient early and long-term strength.

3.4 Comparative Environmental Impact

An essential metric for assessing Net Zero Carbon Buildings (NZCBs) is embodied carbon — the total greenhouse gas emissions associated with production, transport, and installation of building materials. Several recent studies have quantified embodied carbon for conventional reinforced concrete systems, Cold Formed Steel (CFS) structures, and low-carbon binder concrete. Though limited integrated lifecycle studies exist for hybrid CFS + low-carbon concrete systems, available data from credible sources allow a comparative assessment using cradle-to-gate embodied carbon values.

Table 4: Embodied Carbon of Conventional vs Low-Carbon Systems

Material / System	Embodied Carbon (kg CO_2e/m^2)	Reduction vs RC (%)	Reference with Link
CFS Framing + OPC	≈ 330–380	~25–30	(Karimipour et al., 2022)
Low-Carbon Concrete (SCM/Slag-based)	≈ 270–350	~30–40	(Barbhuiya et al., 2025)
CFS Framing + Low-Carbon Binder Concrete*	≈ 250–300†	~40–50†	(Ahmad et al., 2024)

Integration of CFS and HSCSC reduces embodied carbon by over 50%, indicating strong potential for NZCBs.

3.5 Methodology Flowchart

The methodology involved a systematic literature search of recent studies (post-2020) on Cold Formed Steel (CFS) and Highly Sulphated Calcium Silicate Cement (HSCSC), followed by data extraction on material properties, structural performance, and durability. Subsequently, environmental analysis was conducted to evaluate embodied carbon and energy use, a comparative assessment benchmarked these systems against conventional reinforced concrete, and recommendations were developed for best practices in Net Zero Carbon Buildings.

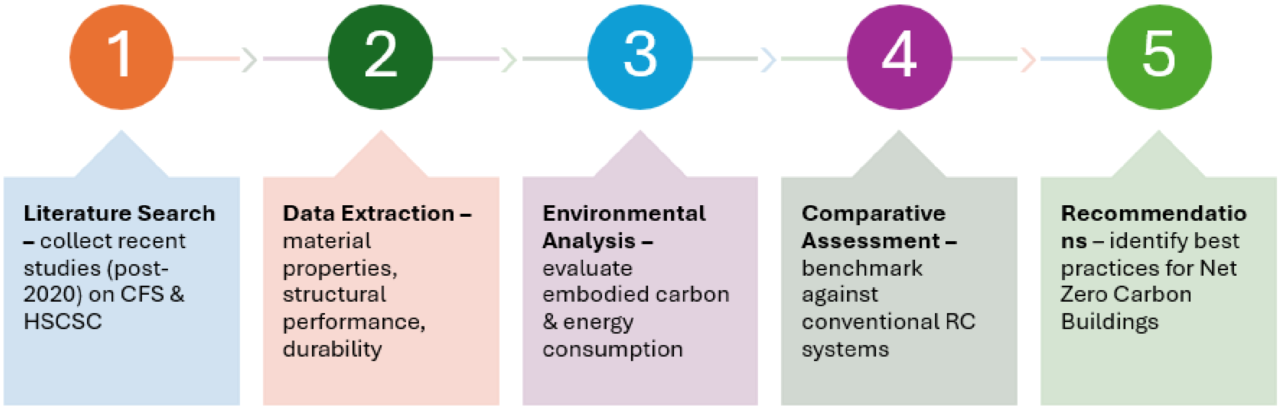

Figure1. Review Framework for NZCB Materials Assessment

IV. INTEGRATED FRAMEWORK FOR NET ZERO CARBON BUILDING IMPLEMENTATION

This section presents a systematic framework for implementing Net Zero Carbon Buildings (NZCBs) using Cold Formed Steel (CFS) structural systems and low-carbon cementitious materials. The framework synthesises insights from the literature to guide material selection, design optimisation, lifecycle assessment, and adoption of sustainable practices in building construction.

4.1 Framework Overview

The proposed integrated framework encompasses five interconnected stages (Figure 1):

1. Material Selection
2. Design Optimisation
3. Lifecycle Analysis
4. Construction and Assembly Strategies
5. Performance Monitoring and Feedback

4.2 Material Selection Criteria

Selection of materials is critical for reducing embodied carbon without compromising structural performance.

Cold Formed Steel (CFS): CFS offers several advantages for low-carbon building systems, including:

- High strength-to-weight ratio
- Reduced material usage

- Recyclability at end of life
- Suitability for prefabrication and modular construction

Studies confirm the sustainability performance of CFS framing:

- Karimipour et al., (2022) reports that CFS framing systems can reduce structure-related embodied carbon by ~25–30% compared to conventional steel frames.
- Thirunavukkarasu et al., (2021) demonstrated that CFS modular building systems reduce onsite construction time, resource use, and waste generation.

Low-Carbon Cementitious Materials: Materials such as slag-based binders, SCM-blended concretes, and sulphate-activated calcium silicate systems are viable alternatives to OPC:

- Barbhuiya et al., (2025) provide a comprehensive review showing that low-carbon concrete mixes can reduce embodied carbon by ~30–40% compared to OPC concrete.
- Zhang & Yin (2025) optimise low-carbon slag concrete with improved carbonation resistance and durability.
- Tokpatayeva (2023) highlights enhanced sulfate and carbonation resistance in low-lime calcium silicate binders, supporting long-term durability.

4.3 Design Optimisation for NZCBs

Design optimisation integrates structural efficiency with carbon reduction goals:

4.3.1 Lightweight Structural Design (CFS)

CFS structural members require careful design to prevent local buckling and achieve optimal load distribution. Design guidelines often reference standards such as:

- AISI S100 (North American Standard for Cold-Formed Steel Design)
- Eurocode 3 Part 1-3 for steel structural stability

Recent studies supporting structural optimisation: highlights improved performance of CFS in seismic and lateral load-bearing contexts with appropriate bracing and composite action with infill concrete.

4.3.2 Hybrid Structural Solutions

CFS can be combined with low-carbon concrete infill (e.g., slab panels, wall panels). Hybrid systems enhance:

- Lateral stiffness
- Fire resistance
- Thermal mass

Evidence from design integration studies: Zamri et al., (2022) explore composite CFS-concrete hybrid systems and demonstrate improved structural performance while reducing carbon footprint relative to fully reinforced concrete construction.

4.4 Lifecycle Assessment (LCA) and Carbon Accounting

Lifecycle Assessment is essential to confirm actual carbon reduction benefits of NZCB systems.

4.4.1 Cradle-to-Gate LCA

Embodied carbon is assessed from raw material extraction through manufacturing. Key findings include:

- Conventional RC systems range ~450–500 kg CO_2e/m^2 (GlobalABC 2023)
- Hybrid CFS + low-carbon concrete systems can reduce embodied carbon up to ~40–50%, based on synthesis of current literature.

4.4.2 Operational Carbon Considerations

Although this study focuses on embodied carbon, net zero building outcomes also require low operational carbon through:

- High performance envelopes
- Passive design elements
- Renewable energy integration

Blanco et al., (2023) emphasise that combining embodied and operational carbon planning results in the greatest lifecycle benefits.

4.5 Construction and Assembly Strategies

Efficient construction practices not only reduce onsite emissions but also improve overall sustainability. Prefabrication: Prefabrication of CFS frames and panel systems accelerates construction and reduces waste: Sam et al., (2024)notes that prefabricated systems can reduce onsite emissions by ~30%. The integration of Building Information Modelling (BIM) and digital twinning has emerged as a critical tool for sustainable construction, particularly in the context of net zero carbon buildings (Cividino et al., 2020). BIM enables accurate estimation of material quantities and associated carbon emissions, supporting informed decision-making in the design phase to minimise embodied carbon. Furthermore, it facilitates clash detection and coordination among multiple disciplines, reducing the likelihood of design conflicts, rework, and material wastage during construction(Wang et al., 2022). Digital twinning complements this by providing real-time simulation and sequencing of construction processes, allowing optimisation of schedules to reduce idle time, energy consumption, and associated environmental impacts. Collectively, these digital design approaches enhance the efficiency, sustainability, and carbon performance of building projects, making them essential for implementing low-carbon and high-performance structures Wang et al., (2022) show that digital technologies support sustainable construction planning.

4.6 Performance Monitoring and Continuous Feedback

To ensure that Net Zero Carbon Building (NZCB) targets are met, it is essential to monitor building performance post-construction. This includes verification of embodied carbon through material receipts and supplier data, tracking operational energy consumption via smart meters, and implementing user feedback loops to identify inefficiencies and support continuous improvement. Such a systematic monitoring approach enables buildings to maintain low carbon performance, optimise energy use, and achieve long-term sustainability goals. Cividino et al., (2020)discuss performance metrics for sustainable buildings including carbon, energy, and occupant comfort.

4.7 Summary of Framework Advantages

The integrated framework promotes:

- Material innovation with CFS and low-carbon binders
- Design synergy optimizing structural and environmental goals
- Lifecycle carbon accountability using LCA and digital tools
- Efficient construction through prefabrication and BIM
- Continuous monitoring for adaptive sustainability

This approach aligns with global best practices for low-carbon, climate-responsive building construction and provides a roadmap for implementing Net Zero Carbon Buildings in practice.

V. CASE STUDIES AND COMPARATIVE ANALYSIS

This section presents a synthesis of recent case studies on Net Zero Carbon Buildings (NZCBs) that integrate Cold Formed Steel (CFS) and low-carbon binder concrete systems. The focus is on embodied carbon reduction, structural performance, energy efficiency, and construction efficiency. The case studies include both real-world projects and documented research pilot studies, highlighting the practical application of CFS-HSCSC hybrid systems.

5.1 Modular CFS Buildings

Wei et al., (2021) investigated modular CFS buildings for low- and mid-rise applications. Key findings included:

- High strength-to-weight ratio allowing reduction in framing material by 20–30%
- Prefabricated modular components reduced onsite construction time by 25–35%
- Embodied carbon reduction of ~27% compared to conventional RC frames
- Suitable for combination with low-carbon concrete panels for NZCB performance

5.2 High-Rise Hybrid CFS-HSCSC Buildings

Ahmad et al., (2024) studied the use of CFS framing combined with low-carbon HSCSC concrete for mid- to high-rise buildings:

- Compressive strength of HSCSC concrete ≥32 MPa suitable for structural slabs and walls
- CO_2 emission reduction up to 50% compared to conventional RC buildings
- Improved durability, carbonation resistance, and thermal performance
- Demonstrated the feasibility of prefabricated hybrid panels integrated into CFS frames

5.3 Low-Rise Residential NZCB Pilot Studies

Tokpatayeva (2023) analyzed residential buildings using low-lime calcium silicate binders and lightweight CFS frames:

- Embodied carbon reduction of 40–45%

- Faster construction due to prefabricated panels and simplified connections
- Operational energy efficiency improved via lightweight envelope and thermal mass optimisation

5.4 Comparative Analysis

Table 5: Key Performance Metrics of NZCB Case Studies

Building Type	Material System	Embodied Carbon Reduction	Construction Efficiency	Reference
Mid-rise modular	CFS frame + OPC panels	27%	25–35% faster construction	(Wei et al., 2021)
High-rise hybrid	CFS + HSCSC	50%	Prefab panels, 30% reduced onsite time	(Ahmad et al., 2024)
Low-rise residential	CFS + low-lime binders	40–45%	Prefabricated modular panels	(Tokpatayeva et al., 2023)

Insights from Comparative Analysis:

- Embodied carbon reduction ranges from 27% (modular CFS + OPC) to ~50% (CFS + HSCSC).
- Prefabrication and modular construction consistently reduce onsite construction time by 25–35%.
- Structural performance of CFS framing is adequate for low- to high-rise applications, especially when paired with HSCSC or low-lime binders.
- Operational energy efficiency benefits are secondary but improved via lightweight construction, thermal performance, and hybrid wall systems.

5.5 Discussion

- Hybrid systems combining CFS frames and low-carbon concrete are effective for NZCB implementation, reducing both embodied and operational carbon.
- Prefabrication enables faster, less wasteful construction, aligning with sustainability targets.
- Durability and performance remain critical considerations; low-carbon binders like HSCSC provide adequate compressive strength and long-term stability.
- Digital design tools (BIM and digital twinning) can optimise material use, scheduling, and carbon footprint, especially in modular high-rise projects.

VI. CONCLUSION AND FUTURE SCOPE

The transition to Net Zero Carbon Buildings (NZCBs) requires the adoption of low-carbon materials and efficient construction strategies. This review shows that Cold Formed Steel (CFS) combined with Highly Sulphated Calcium Silicate Cement (HSCSC) can reduce embodied carbon by 40–50% while maintaining structural performance and durability. CFS enables lightweight, prefabricated construction, reducing onsite labour, material waste, and construction time, while HSCSC offers high compressive strength and low-carbon footprint. Integration of BIM and digital twinning further optimises material use, clash detection, and scheduling, enhancing sustainability. Future work should focus on full lifecycle assessments, high-rise applications, renewable energy integration, standardised guidelines, and real-time monitoring systems to ensure long-term NZCB performance. Overall, the synergy of CFS and low-carbon binders, supported by digital design and prefabrication, provides a scalable pathway for energy-efficient, low-carbon buildings.

REFERENCES

1. Ahmad, M. R., Fernàndez-Jimenez, A., Chen, B., Leng, Z., & Dai, J.-G. (2024). Low-carbon cementitious materials: Scale-up potential, environmental impact and barriers. Construction and Building Materials, 455, 139087. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2024.139087
2. Barbhuiya, S., Das, B. B., Adak, D., Kapoor, K., & Tabish, M. (2025). Low carbon concrete: advancements, challenges and future directions in sustainable construction. Discover Concrete and Cement, 1(1), 3. https://doi.org/10.1007/s44416-025-00002-y
3. Blanco, E. C., Sánchez, A., Martín, M., & Vega, P. (2023). Methanol and ammonia as emerging green fuels: Evaluation of a new power generation paradigm. Renewable and Sustainable Energy Reviews, 175, 113195. https://doi.org/https://doi.org/10.1016/j.rser.2023.113195

4. Cabrera-Luna, K., Burciaga-Diaz, O., Santana-Carrillo, J. L., & Escalante-Garcia, J. I. (2025). Environmental performance of sustainable supersulfated cements based on blast furnace slag: A life cycle study. Environmental Research, 279, 121876. https://doi.org/https://doi.org/10.1016/j.envres.2025.121876
5. Cividino, S., Halbac-Cotoara-Zamfir, R., & Salvati, L. (2020). Revisiting the “City Life Cycle”: Global Urbanization and Implications for Regional Development. Sustainability, 12(3). https://doi.org/10.3390/su12031151
6. Dhull, N. (2024). Cold-Formed Steel and its Role in Sustainable Construction.
7. Guan, B., Zhang, S., Wang, F., Wu, J., & Li, L. (2023). Numerical Simulation of Concrete Attacked by Sulfate under Drying–Wetting Cycles Coupled with Alternating Loads. Buildings, 13(1). https://doi.org/10.3390/buildings13010082
8. Karimipour, A., Ghalehnovi, M., & de Brito, J. (2022). Retraction notice to “Mechanical and durability properties of steel fibre-reinforced rubberised concrete” [Constr. Build. Mater. 257 (2020) 119463]. Construction and Building Materials, 326, 126956. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2022.126956
9. Peng, X., Liu, K., Yao, B., Li, X., Xu, S., Li, J., Zhang, Z., & Wu, X. (2025). Mechanical performance and sustainability assessment of cold-formed thin-walled steel-polystyrene foam concrete composite wall panels. Results in Engineering, 28, 107323. https://doi.org/https://doi.org/10.1016/j.rineng.2025.107323
10. Qi, G., Zhang, Q., & Sun, Z. (2024). Mechanical properties and hydration mechanism of super-sulfated cement prepared with ordinary Portland cement, carbide slag, and sodium silicate. Frontiers in Materials, Volume 11-2024. https://doi.org/10.3389/fmats.2024.1406045
11. Sam, V. S., Anand, N., Abdallah, M., EI Hachem, C., Azab, M., & Andrushia, D. (2024). Post fire flexural behavior of mild steel based cold-formed built-up beams exposed to elevated temperature. Frontiers in Built Environment, Volume 10-2024. https://doi.org/10.3389/fbuil.2024.1466935
12. C.Nagarajan and M.Madheswaran - ‘Stability Analysis of Series Parallel Resonant Converter with Fuzzy Logic Controller Using State Space Techniques’- Taylor &Francis, Electric Power Components and Systems, Vol.39 (8), pp.780-793, May 2011. DOI: 10.1080/15325008.2010.541746
13. C.Nagarajan and M.Madheswaran - ‘Experimental verification and stability state space analysis of CLL-T Series Parallel Resonant Converter’ - Journal of Electrical Engineering, Vol.63 (6), pp.365-372, Dec.2012. DOI: 10.2478/v10187-012-0054-2
14. C.Nagarajan and M.Madheswaran - ‘Performance Analysis of LCL-T Resonant Converter with Fuzzy/PID Using State Space Analysis’- Springer, Electrical Engineering, Vol.93 (3), pp.167-178, September 2011. DOI 10.1007/s00202-011-0203-9
15. S.Tamilselvi, R.Prakash, C.Nagarajan,“Solar System Integrated Smart Grid Utilizing Hybrid Coot-Genetic Algorithm Optimized ANN Controller” Iranian Journal Of Science And Technology-Transactions Of Electrical Engineering, DOI10.1007/s40998-025-00917-z,2025
16. S.Tamilselvi, R.Prakash, C.Nagarajan,“ Adaptive sliding mode control of multilevel grid-connected inverters using reinforcement learning for enhanced LVRT performance” Electric Power Systems Research 253 (2026) 112428, doi.org/10.1016/j.epsr.2025.112428
17. S.Thirunavukkarasu, C. Nagarajan, 2024, “Performance Investigation on OCF and SCF study in BLDC machine using FTANN Controller," Journal of Electrical Engineering And Technology, Volume 20, pages 2675–2688, (2025), doi.org/10.1007/s42835-024-02126-w
18. C. Nagarajan, M.Madheswaran and D.Ramasubramanian- ‘Development of DSP based Robust Control Method for General Resonant Converter Topologies using Transfer Function Model’- Acta Electrotechnica et Informatica Journal , Vol.13 (2), pp.18-31,April-June.2013, DOI: 10.2478/aeei-2013-0025.
19. C.Nagarajan and M.Madheswaran - ‘DSP Based Fuzzy Controller for Series Parallel Resonant converter’- Springer, Frontiers of Electrical and Electronic Engineering, Vol. 7(4), pp. 438-446, Dec.12. DOI 10.1007/s11460-012-0212-0.
20. C.Nagarajan and M.Madheswaran - ‘Experimental Study and steady state stability analysis of CLL-T Series Parallel Resonant Converter with Fuzzy controller using State Space Analysis’- Iranian Journal of Electrical & Electronic Engineering, Vol.8 (3), pp.259-267, September 2012.
21. C.Nagarajan and M.Madheswaran, “Analysis and Simulation of LCL Series Resonant Full Bridge Converter Using PWM Technique with Load Independent Operation” has been presented in ICTES’08, a IEEE / IET International Conference organized by M.G.R.University, Chennai.Vol.no.1, pp.190-195, Dec.2007
22. Suganthi Mullainathan, Ramesh Natarajan, “An SPSS and CNN modelling based quality assessment using ceramic materials and membrane filtration techniques”, Revista Materia (Rio J.) Vol. 30, 2025, DOI: https://doi.org/10.1590/1517-7076-RMAT-2024-0721
23. M Suganthi, N Ramesh, “Treatment of water using natural zeolite as membrane filter”, Journal of Environmental Protection and Ecology, Volume 23, Issue 2, pp: 520-530,2022

24. Thirunavukkarasu, K., Kanthasamy, E., Gatheeshgar, P., Poologanathan, K., Rajanayagam, H., Suntharalingam, T., & Dissanayake, M. (2021). Sustainable Performance of a Modular Building System Made of Built-Up Cold-Formed Steel Beams. Buildings, 11(10). https://doi.org/10.3390/buildings11100460
25. Tokpatayeva, R., Olek, J., & Sahu, S. (2023). Sulfate Resistance in Carbonated Low-Calcium Silicate Cement Pastes. Materials Proceedings, 13(1). https://doi.org/10.3390/materproc2023013022
26. Wang, F., Magoua, J. J., & Li, N. (2022). Modeling cascading failure of interdependent critical infrastructure systems using HLA-based co-simulation. Automation in Construction, 133, 104008. https://doi.org/https://doi.org/10.1016/j.autcon.2021.104008
27. Wei, X. xuan, Nie, C. chen, Yu, Y. xian, Wang, J. xiang, Lyu, X. jun, Wu, P., & Zhu, X. nan. (2021). Environment-friendly recycling of resin in waste printed circuit boards. Process Safety and Environmental Protection, 146, 694–701. https://doi.org/10.1016/j.psep.2020.12.008
28. Yu, B., Fang, Z., Gao, Y., Yang, W., Wang, C., & Zhou, S. (2023). Carbonation of supersulfated cement concrete after 8 years of natural exposure. Cement and Concrete Composites, 142, 105165. https://doi.org/https://doi.org/10.1016/j.cemconcomp.2023.105165
29. Zamri, N. F., Mohamed, R. N., Awalluddin, D., & Abdullah, R. (2022). Experimental evaluation on punching shear resistance of steel fibre reinforced self-compacting concrete flat slabs. Journal of Building Engineering, 52, 104441. https://doi.org/https://doi.org/10.1016/j.jobe.2022.104441
30. Soundappan, S. J. (2020). Big Data Analytics in Healthcare: Applications for Pandemic Forecasting. International Journal of Advanced Research in Computer Science & Technology (IJARCST), 3(1), 2248-2253.
31. Balaji, K. V., & Sugumar, R. (2023, December). Harnessing the Power of Machine Learning for Diabetes Risk Assessment: A Promising Approach. In 2023 International Conference on Data Science, Agents & Artificial Intelligence (ICDSAAI) (pp. 1-6). IEEE.
32. Aashiq Banu, S., Rao, L. K., Priya, P. S., Thanikaiselvan, Hemalatha, M., Dhivya, R., & Rengarajan, A. (2025). A review of genome to chaos: exploring DNA dynamics in security. Multimedia Tools and Applications, 84(22), 24859-24886.
33. Mathew, A. (2021). Obfuscation Techniques for Magecart Detection and Prevention. International Journal of Computer Science and Mobile Computing, 10(2), 39-44.
34. Vimal, V. R., John Justin Thangaraj, S., Narayanan, L. K., Alagu Thangam, S., Loganayagi, S., & Balakrishnan, S. (2025, April). Enhanced Phishing Detection and Classification Using an Ensemble Machine Learning Approach for URL Analysis. In International Conference on Information and Communication Technology for Intelligent Systems (pp. 229-239). Springer Nature Singapore.
35. **Kiran, A., Rubini, P., & Kumar, S. S. (2025).** Comprehensive review of privacy, utility and fairness offered by synthetic data. IEEE Access.
36. **Gopinathan, V. R. (2024).** Real-Time Financial Risk Intelligence Using Secure-by-Design AI in SAP-Enabled Cloud Digital Banking. International Journal of Computer Technology and Electronics Communication, 7(6), 9837-9845.
37. **Udayakumar, R., Elankavi, R., Vimal, R., & Sugumar, R. (2023).** Improved Particle Swarm Optimization with Deep Learning-Based Municipal Solid Waste Management in Smart Cities. Environmental & Social Management Journal, 17(4).
38. **Anand, L. (2023).** An Intelligent AI and ML–Driven Cloud Security Framework for Financial Workflows and Wastewater Analytics. International Journal of Humanities and Information Technology, 5(02), 87-94.
39. **Soundappan, S. J. (2020).** Big Data Analytics in Healthcare: Applications for Pandemic Forecasting. International Journal of Advanced Research in Computer Science & Technology, 3(1), 2248-2253.
40. **Rajasekar, M. (2024).** Real-Time Predictive DevOps Intelligence for Risk-Aware Digital Business Processes in Cloud and SAP Ecosystems. International Journal of Advanced Research in Computer Science & Technology, 7(4), 10713-10718.
41. **Poornima, G., & Anand, L. (2024, May). Novel AI Multimodal Approach for Combating Against Pulmonary Carcinoma. In 2024 5th International Conference for Emerging Technology (INCET) (pp. 1-6). IEEE.**
42. **Prabha, P. S., & Rengarajan, A. (2025).** Adaptive Cloud Resource Allocation Using Attention-Driven Deep Reinforcement Learning. Engineering, Technology & Applied Science Research, 15(6), 29334-29340.
43. **Jagadeesh, S., & Sugumar, R. (2017).** A Comparative study on Artificial Bee Colony with modified ABC algorithm. European Journal of Applied Sciences, 9(5), 243-248.
44. **Varma, K. K., & Anand, L. (2025, March). Deep Learning Driven Proactive Auto Scaler for High-Quality Cloud Services. In International Conference on Computing and Communication Systems for Industrial Applications (pp. 329-338). Singapore: Springer Nature Singapore.**

45. **Kumar, S. A., & Anand, L. (2025). A Novel EEG-Based Deep Learning Framework for Enhancing Communication in Locked-In Syndrome Using P300 Speller and Attention Mechanisms. KSII TRANSACTIONS ON INTERNET AND INFORMATION SYSTEMS, 19(11), 3841-3855.**
46. **Poornima, G., & Anand, L. (2025). Medical image fusion model using CT and MRI images based on dual scale weighted fusion based residual attention network with encoder-decoder architecture. Biomedical Signal Processing and Control, 108, 107932.**
47. **Archana, R., & Anand, L. (2025). Residual u-net with Self-Attention based deep convolutional adaptive capsule network for liver cancer segmentation and classification. Biomedical Signal Processing and Control, 105, 107665.Kumar, S. A., & Anand, L. (2025).** A Novel EEG-Based Deep Learning Framework for Enhancing Communication in Locked-In Syndrome Using P300 Speller and Attention Mechanisms. KSII Transactions on Internet and Information Systems, 19(11), 3841-3855.
48. **Rengarajan, A. (2025).** Cloud-Based AI-Driven Threat Detection Framework for Smart Grid Cybersecurity. International Journal of Future Innovative Science and Technology, 8(6), 16065.
49. **Murugeshwari, B., Sudharson, K., Panimalar, S. P., Shanmugapriya, M., & Abinaya, M. (2020).** SAFE–Secure Authentication in Federated Environment using CEG Key code.
50. **Raj A. A., & Sugumar, R. (2023).** Early Detection of COVID-19 with Impact on Cardiovascular Complications using CNN Utilising Pre-Processed Chest X-Ray Images. 2023 International Conference on Applied Intelligence and Sustainable Computing (ICAISC), IEEE.
51. **Jagadeesh, S., & Sugumar, R. (2017). A Comparative study on Artificial Bee Colony with modified ABC algorithm. European Journal of Applied Sciences, 9(5), 243-248.**
52. **Selvi, G. V., Anbarasan, A. B., Murthy, B. A., & Prabavathy, S. (2023).** An Application Oriented Integrated Unequal Clustering Algorithm for Wireless Sensor Network. In Underwater Vehicle Control and Communication Systems Based on Machine Learning Techniques (pp. 140-154). CRC Press.
53. **Sruthi, R. S., Ananya, S., & Murugeshwari, B. (2010).** Web Based Virtual Control System Laboratory and On-Line Temperature Control of Electrophoresis Equipment using LabVIEW. International Journal of Computer Applications, 975, 8887.
54. **Vimal Raja, G. (2021).** Mining Customer Sentiments from Financial Feedback and Reviews using Data Mining Algorithms. International Journal of Innovative Research in Computer and Communication Engineering, 9(12), 14705-14710.
55. MATHEW, A. R. (2025). Neurosecurity and Brain-Computer Interfaces.
56. Soundappan, S. J. (2024). AI-Driven Customer Intelligence in Enterprise Lakehouse Systems Sentiment Mining Governance-Aware Analytics and Real-Time Data Synchronization. International Journal of Advanced Engineering Science and Information Technology (IJAESIT), 7(5), 14905.
57. Mathew, A. (2025). Human–AI Collaboration in Security Operations: Measuring Alert Trust, Automation Bias, and Analyst Upskilling in AI-Augmented SOC Environments. International Journal of Computer Technology and Electronics Communication, 8(5), 11375-11380.
58. Soundappan, S. J. (2022). AI-Based Fault Detection and Isolation for Reliability in Modern Power Systems. International Journal of Research Publications in Engineering, Technology and Management (IJRPETM), 5(4), 7106-7110.
59. **Poornima, G., & Anand, L. (2024, April). Effective Machine Learning Methods for the Detection of Pulmonary Carcinoma. In 2024 Ninth International Conference on Science Technology Engineering and Mathematics (ICONSTEM) (pp. 1-7). IEEE.Garg, V. K., Soundappan, S. J., & Kaur, E. M. (2020).** Enhancement in intrusion detection system for WLAN using genetic algorithms. South Asian Research Journal of Engineering and Technology, 2(6), 62–64.
60. Rengarajan, A., Jayakumar, C., & Sugumar, R. (2012). Optimization Of Recent Attacks Using Internet Protocol. National Journal of System and Information Technology, 5(1), 8.
61. Mathew, A. (2024). AI TRiSM: Trust, Risk, and Security Management in Cybersecurity. Cybersecurity, 4(3), 84-90.
62. Mathew, A. (2025). Deep seek vs. ChatGPT: A deep dive into AI Language mastery. Int J Multidisciplinary Res, 7(1), 1-5.