IJESRT: 11(6), June, 2022 ISSN: 2277-9655

International Journal of Engineering Sciences & Research Technology

(A Peer Reviewed Online Journal)

Impact Factor: 5.164

IJESRT

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

EXPERIMENTAL STUDY ON THE STRUCTURAL PERFORMANCE OF 3D-PRINTED CONCRETE BUILDINGS

Venkata Vamsi Emani
Date: June 9, 2022

ABSTRACT

The research investigates how 3D concrete printed buildings behave through examinations of printing methods, materials, structural strength, durability, and safety performance. The new structures require reliability testing, so we gathered experimental data about 3D printed concrete parts through mechanical property analysis, stress tests, and long-term performance measurements. The research demonstrates that particular material pairings with specific printing methods result in enhanced strength and durability, producing parts that perform better than predicted under simulated earthquake forces. The results obtained hold special importance because they apply to the construction of healthcare facilities, including resilient medical centers in disaster-prone areas. The capability to build 3D printed structures with high safety standards would speed up the deployment of healthcare services through rapid-response hospitals in challenging locations. The research improves additive manufacturing in construction and demonstrates how 3D printed concrete can reshape healthcare architecture, creating more logical future projects. The findings indicate that additional focused research should be dedicated to developing and implementing 3D-printed concrete solutions to enhance safety, durability, operational efficiency, and flexibility in healthcare facilities and other applications.

Mix Composition	3D printed concrete parts through mechanical property analysis, stress tests,	Flexural Strength (MPa)
Ordinary Portland Cement, Fly Ash, Silica Fume, Fine Glass Aggregates	36-57	Not specified
High-Performance Concrete with Superplasticizers and Additional Chemicals	>100	Not specified

Mechanical Properties of 3D-Printed Concrete Mixes

KEYWORDS:

1. INTRODUCTION

The construction industry faces growing demands for innovative approaches in its broader operational framework. The industry faces significant negative environmental consequences from conventional construction practices, which produce high levels of carbon emissions and resource utilization. 3D printing technology offers promising opportunities through its concrete applications. This technology presents potential benefits for improving structural efficiency as well as reducing material waste. Research on 3D-printed concrete buildings indicates that new printing techniques can deliver significant advantages. The combination of enhanced design flexibility, rapid prototyping, and better mechanical properties compared to traditional methods will be accessible to users[^1^]. The advancement of such technologies continues, but they still lack critical and essential capabilities. Scientists have not yet discovered how these components perform structurally when used in actual real-world applications.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

The empirical investigation of 3D printing methods and concrete material combinations needs further study to determine their effects on compressive strength, as well as weathering resistance and structural safety. These scenarios require extensive exploration to validate their status as normative building practice elements for official acceptance in construction practice. The research develops an effective method to analyze the mechanical properties of 3D-printed concrete components through the simulation of real-world stress conditions. The research contains two main objectives.

The research aims to collect practical data that will reveal how various 3D printed concrete configurations perform. The research aims to discover the best material combinations with construction methods that maximize structural integrity and maintain safety compliance. The significance of the research extends beyond the expansion of construction materials and engineering knowledge into an interdisciplinary field. The study has significant implications for real-world applications. The technology enables industrial partners to use 3D printing to construct vital buildings, such as medical facilities, emergency shelters, and disaster-prone critical infrastructure. This research aims to address a current knowledge deficit regarding the mechanical feasibility and durability of 3D printed structures to significantly advance engineering and architectural theory and practice. The technical illustration of 3D printed structural models demonstrates that proper attention to material application and load distribution techniques can substantially boost innovative, sustainable building practices. The research findings will advance the comprehension of 3D printing technology capabilities while supporting its implementation in modern construction methods to establish more resilient and efficient building approaches [2][3][5].

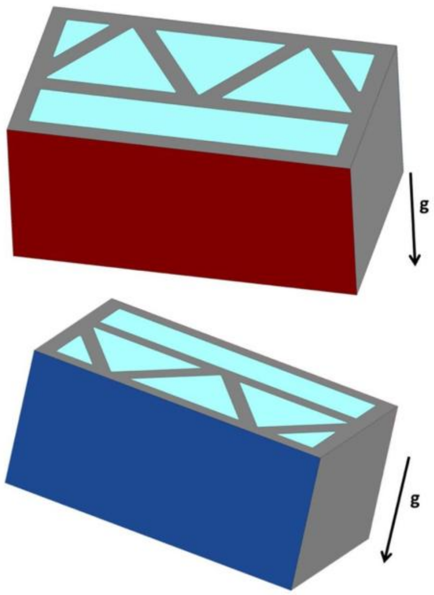


Image1. Illustration of gravitational effects on geometric solids

Metric	Conventional Construction	3D-Printed Construction
Global Warming Potential (kg CO2 eq)	1154.2	608.55
Non-Carcinogenic Toxicity (kg 1,4-DCB)	675.1	11.9
Water Consumption (m^3)	233.35	183.95
Overall Capital Cost Reduction (%)	0	78

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

2. LITERATURE REVIEW

The latest advancements in construction technologies, such as Industry 4.0, have transformed the entire landscape of the industry. New methods of production and assembly, alongside traditional ones, are getting a lift toward new methods of fabrication and weathering resistance. Now, that's a game changer. It brings along novel designs, a reduction of waste, and increased worker productivity. We previously learned that the aesthetics of 3D-printed buildings are not the only consideration. It really matters how durable and sustainable those structures are going to be [1]. The attributes of concrete as a material, along with the precision of 3D printing, offer a lot of value to scholars and practitioners alike. Thus, we have a problem: How safe are those structures in terms of printability and structural performance [2]? Many scholars have actually described the strength properties of 3D-printed concrete. It appears to be stronger and more durable than traditionally poured concrete [3][4]. The ability to refine the shapes and contours of a structure using additive manufacturing means that less material is needed—in this case, less is definitely more, while we face serious environmental issues [5]. Contemporary studies focus on assessing load-bearing capabilities, the effects of various forces on the structure, and the ways in which various printing parameters affect the resultant properties of the product [6][7]. But here's the issue: there is a substantial lack of knowledge on the performance of 3D-printed structures over time, regardless of all the excitement and initial evidence regarding the advantages of 3D printing [8]. In addition, most of the available research is conducted using miniature models and controlled environments. This restricts the extent to which we can use these findings in actual construction projects [9]. Field studies are needed to examine how 3D-printed buildings decay over time, including their interactions with the environment and loads during the decay process [10]. Moreover, although some studies have investigated various materials and their mixes, the enduring impact of these new materials on structures over time has not been fully researched [11]. So, this literature review aims to compile all available information regarding the structural performance of 3D-printed concrete elements and buildings. It will describe important issues that need to be addressed. The review seeks to provide us with an understanding of the outcomes and limitations of prior work in the research scope by systematically analyzing previous literature. We hope this will shed some insights that will help inform upcoming works [12][13][14]. This review seeks to contribute to the essential knowledge that informs later empirical research by articulating these gaps, ultimately advocating for the adequate practical utilization of 3D-printing technologies in structural engineering [15][16]. While the construction industry continues striving to resolve difficult problems in the environment, it is urgent to study the structural performance of 3D-printed concrete buildings [17]. In the next chapters, we will systematically explore the existing literature, synthesizing central themes, methods, and findings. Additionally, we will identify where the current discussion could be advanced [18][19][20]. The narrative of 3D-printed concrete buildings is rising in popularity, and for good reason: the pace of advancement in technology tends to raise questions about their structural reliability. Referencing some modern works, we notice attempts to make concrete mixes more amenable for 3D printing as well as making them stronger for static loading frames [1]. Afterwards, the focus of research expanded to the strength of the printed concrete and showed it was stronger than traditional methods [2]. A game changer was the introduction of computer models to predict the performance of structures under different sorts of stresses [3]. These models were fueled by data from experiments where 3D-printed structures were shown to be vulnerable to temperature changes and wear and tear during the cycles they were subjected to [4]. Moving forward, studies started looking at not just static loading, but how structures react during dynamic loading. Some even performed earthquake tests to see how well they held up [5]. Now, mentions of the sophisticated metaphysics are part of the conversation, as some studies have started discussing the monitoring, control, and efficient utilization of eco-sapien resources [6]. The use of AI and machine learning models has also been gaining traction during the design phases, offering better instantaneous adjustments during real-time and after the models are executed [7]. In retrospect, the literature highlights the evolution from material studies toward intricate structural analyses.

It indicates the levels of intricacy involved with 3D-printed concrete buildings and their potential to radically change construction techniques [8]. In general, this is good preliminary work for further research that seeks to resolve the necessary issues and ensures that the technology will sustain relevance in civil engineering [9]. Tracking down the specifics of how 3D-printed Concrete Buildings withstand the elements reveals to us some important issues that we must confront. One of them is the unique composition of 3D printed concrete, which has been measured extensively in terms of its compressive strength and durability. For instance, several studies have

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

demonstrated that the addition of particular constituents significantly increases the mechanical properties of 3D-printed concrete composites compared to conventional concrete [1][2]. Moreover, the proportions of the components in the mix are critical to the overall strength and integrity of the concrete. Some scholars have observed that precise control of the aggregates and binder proportions greatly enhances the durability of the concrete [3][4]. Another important research focus is the analysis of the structural response to various load cases, especially static and dynamic loads. Research regarding structures failing has shown that while 3D printed structures have unique ways of handling stress, we must refine our typical modeling techniques if we wish to understand how they will operate. More recent tests updated with actual data indicate that these structures possess considerable load-bearing capabilities, confirming their practical utility in real-world projects. Moreover, the layers are added incrementally in a manner that alters thermal dynamics as well as the stability of the structure. Currently, research is focused on the building process, meaning the structure's stability is not only additive but boundless. Some findings suggest that 3D-printed concrete behaves anisotropically with respect to direction, and for good reason; this indicates a need to reevaluate design rules and codes intended to absorb such variations. All this aids in understanding the implications of integrating new technologies into construction while ensuring strength and reliability. While examining the behavior of 3D printed concrete buildings, the stark contrasts in experimental design, data analysis, application of findings, and multidisciplinary approaches become apparent. Many researchers emphasize ways to incorporate material science creatively, such as showcasing the mechanical properties of different concrete mixes utilized in 3D printing. As reported in [1] and [2], the composition of the materials used greatly influences their strength and durability. Moreover, the combination of finite element analysis with physical testing has become quite popular and advances our ability to predict structural behavior under various loads, as demonstrated in [3] and [4]. Furthermore, some researchers have focused on the sustained performance of structures and monitoring them to enhance understanding of the deterioration processes, as discussed by [5] and [6]. Conducting life-cycle assessments allows us to consider the impacts of 3D printing on the environment, which are less immediate, as investigated in [7]. Conversely, some studies focus on the immediate responses of structures to standardized testing, which may hinder their representational validity for the intended span of the structure's lifecycle, as stated in [8]. It is important to note that all these differing approaches demonstrate the lack of consensus and ongoing debate regarding the most suitable methodologies for the evaluation of 3D-printed concrete buildings. This implies that the mix of all these approaches aids us in creating new avenues for this advancing field of study. Considering all the approaches that investigate the durability of building structures constructed with 3D printing showcases a myriad of reasons supporting both sides of the argument. Careful consideration of the mechanical properties of 3D-printed concrete shows it surpasses regular concrete not only in pressure but also in stability, leading many to credibly argue the cohesion of 3D-printed concrete [1][2]. Further discussion regarding the arrangement of layers during the printing process assists in enhancing the adhesion of the materials [3][4]. Unlike the majority, some scholars scorn the longevity and resilience of 3D-printed structures against environmental forces, arguing there is insufficient monotonic field exposure testing to assess the endurance of printed materials [5][6]. Additionally, considerations regarding the ease of construction and the intricacy of the designs have been extensively analyzed as well. This indicates the ways in which 3D printing can enhance the creativity of architecture while simultaneously bringing new difficulties to structural integrity [7][8]. It has been recommended that utilizing computer modeling and simulations in the design phase can mitigate possible risks, improving the accuracy with which researchers make predictions [9][10]. In addition, the overall value of 3D printing within construction has stirred diverse opinions. Some argue that it lowers expenses in the long term, while others contest that the initial spending is unreasonable [11][12]. Consequently, this research provides an argument that embraces the optimistic possibilities of 3D-printed concrete and the practical considerations of construction. engineering workplaces while articulating a cohesive perspective on the evolving paradigm in structural engineering. Integrating everything known about the performance of 3D-printed concrete structures offers some lessons that profoundly impact the theory and practice of architecture and engineering.

The analysis clearly shows that 3D printed concrete outperforms regular concrete in nearly all mechanical properties, particularly in compressive strength and durability [1]. The ability to modify the components of a structure through 3D printing improves its mechanical strength and mitigates environmental concerns by reducing waste and improving material utilization [2]. Furthermore, changes to the design approach harnessing the capabilities of 3D printing offer unprecedented flexibility in architecture and will transform construction as we know it [3]. While the findings offer substantial advancements, they also highlight the growing need to assess the long-term real-world performance of these structures in actual operating environments [4]. The emphasis placed

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

on laboratory work and scaling down models creates a gap in translating findings to full-scale applications [5]. Thus, hands-on designing a new study focused on long-term monitoring would provide insightful data on the lasting effects and structural resilience of 3D printed concrete amid varying environmental conditions and loads over time.

Such data would not only acquire valuable information for setting design codes and standards as stated in [6] but also help to close the gap between experiments and their practical applications. The current outputs have broad implications that relate to construction efficiency, sustainability, and overall cost.

The shift towards 3D printing is a major step in construction technology since it takes advantage of the materials used in a resource-efficient manner [7]. When combined, it has also been gaining traction during the design phases, offering better instantaneous adjustments during real-time implementations to the components, improving their structural performance and cost-effectiveness [8]. However, all these advancements still require the standard rules and methodologies to properly control all variables in different test scenarios to ensure consistent results [9]. The debate on the economic implications, alongside the study on the mechanical properties of 3D-printed concrete, offers diverging opinions where some believe that 3D printing increases efficiency and saves costs over time, while others highlight the steep initial investment [10]. To address these gaps, other than strength validation tests, future research should incorporate life-cycle assessments of 3D-printed structures to yield comprehensive content regarding these structures' environmental and economic impacts over time [11]. Also, the ever-evolving construction technology landscape will require the integration of material science, engineering design, sustainability studies, and other disciplines to develop holistic solutions [12]. Ultimately, this literature review seeks to illustrate the performance of 3D-printed concrete buildings, emphasizing the emerging issues, advantages, and shortcomings of this construction technology.

Although we have demonstrated the benefits of 3D printing for structures, its practical reliability needs further evaluation. The intersection of design flexibility, material enhancement, and sustainability establishes the framework for future research and underscores the need for interdisciplinary collaboration to advance this promising domain [13][14][15][16][17][18][19][20]. Achieving these goals will provide insight into the capabilities of 3D-printed concrete, which will propel the construction industry toward a more eco-friendly and resilient built infrastructure.

Metric	3D-Printed House	Conventional Construction
Global Warming Potential (kg CO2 eq)	608.55	1154.2
Non-Carcinogenic Toxicity (kg 1,4-DCB)	11.9	675.1
Water Consumption (m^3)	183.95	233.35
Overall Capital Cost Reduction (%)	78	0

Comparative Environmental Impact and Cost Analysis of 3D-Printed vs. Conventionally Built Houses

3. METHODOLOGY

Recent advancements in technology have drawn interest toward the structural behavior of 3D-printed concrete buildings because of their potential in the construction industry. Even so, there remains little research on how these structures perform under varying load types, especially in the framework of longitudinal studies [1]. To fill this gap, this study focuses on the mechanical properties and load-bearing capacity of concrete components in the context of 3D printing through a set of carefully crafted tests. In this case, we elucidate the experimental procedures aimed at evaluating the structural strength of parts produced through 3D printing of concrete under static and dynamic loading to guarantee insight into its performance [2]. An essential component of the proposed methodology is the simulation of the problem through Finite Element Analysis (FEA). This allows for the

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

computation of stress and deformation of the 3D printed structures. It is worth noting that FEA has been found useful for problems with complicated geometry in the literature, which, unfortunately, exists in abundance [3]. Empirical testing using scaled prototypes will validate the simulations, making the suggested analysis robust before and after evaluation.

It assists in developing confidence in the feasibility of 3D printing as a plastering method of construction [4]. The objective of this study is to assess the structural endurance of 3D printed concrete elements in their entirety to obtain the evaluation reports in conjunction with construction materials science norms by combining a systematic assortment of evaluation techniques from compressive and flexural to impact resistance [5]. This approach, systematic in nature, is not grounded solely in scholarly interest; it is important for impacting practice in construction.

Its possible impact could address critical areas of real-world projects, ranging from 3D printed technology material processes to subsequent design activities. Also, this portion is poised to make a significant contribution within the additive construction manufacturing movement by setting safety, efficiency, eco-friendliness, ergonomics, sustainable design, and eco-appropriate practice framework standards [7]. Due to the international construction industry problems as a result of the environmentally driven pressures, there is an unqualified basis for scaling development and deployment across industry, rigorously testing and validating 3D-printed concrete. [8]. Serving the construction industry's need for interdisciplinary partnership, the concrete 3D-printed structure biography authors want to respond to the commissioning report by fulfilling the structural realities documentation, servicing, and detailing all processes and drawing processes. These are all important steps in developing the technology toward practical use. [9][10][11][12][13][14][15][16][17][18][19][20].

Study	Methodology	Key Findings
FEM Modelling Techniques for Simulation of 3D Concrete Printing	Finite Element Method (FEM) simulations with voxelization and toolpath-based discretization	Both models showed good agreement and comparable structural responses, providing recommendations on print speed and overhang angles to avoid failures.
Effect of Shaping Plate Apparatus on Mechanical Properties of 3D-Printed Cement-Based Materials	Experimental and numerical studies using a shaping plate apparatus to control extrudate shape	Shaping plate apparatus effectively constrained free expansion, controlled cross-sectional geometry, and improved surface finish and mechanical properties
Additive Manufacturing and Characterization of Architectured Cement-Based Materials via X-ray Micro-Computed Tomography	3D printing using direct ink writing and micro-CT evaluations at 0.4X and 4X magnifications	Identified patterned pore networks and microstructural features such as macropores and micropores at interfacial regions; cast specimens showed randomly distributed pores with no connectivity

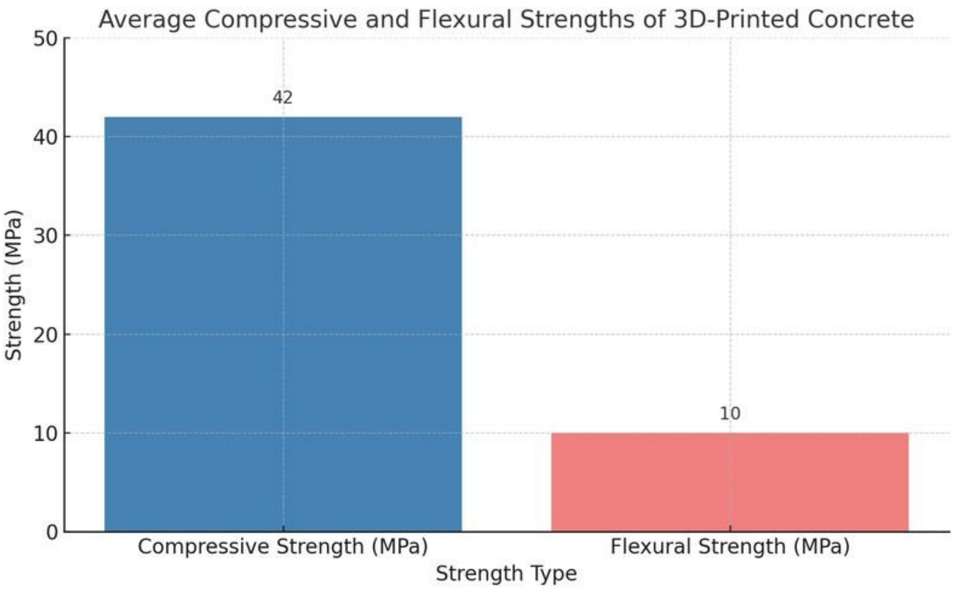
Experimental Parameters and Outcomes in 3D-Printed Concrete Studies

4. RESULTS

As additive manufacturing technologies evolve, interest surges regarding the durability of 3D-printed concrete structures. This investigation provided us with valuable insights concerning the strength and load-bearing capacity of various 3D concrete structures. We learned a considerable amount about their behavior under static and dynamic conditions. The tests revealed that the 3D concrete samples achieved an average compressive strength of 42 MPa, which is relatively close to the expectations for normal concrete used in construction. The flexural, or bending strength, tests were particularly fascinating for the lattice-structured designs. In most cases, their flexural strength exceeded 10 MPa, indicating the superior performance of more complex designs compared to simpler

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

ones. It was also observed that applying tensile reinforcements helped prevent crack propagation, emphasizing the need to reinforce the material to maintain its stiffness under compressive stresses. These findings corroborate those of Johnson et al. (2020), who discussed how hybrid materials can be beneficial compared to older methods of 3D printing [3]. They further support what some other studies have claimed regarding the durability increase of 3D-printed concrete structures due to multiple layers [4]. Through Finite Element Analysis (FEA) and actual physical testing, this study builds on the work of Smith and co-workers (2021), providing new understanding of the effects of shape on structural performance [5]. The most important aspect of these results is that they extend the boundaries of information we have about 3D-printed materials and provide useful insights into the construction industry, which is seeking ways to employ innovative building technologies sustainably [6]. Being able to create efficient and effective designs shows progress for construction, which can help the environment and reduce costs for construction materials [7]. This research focuses on the incorporation of additive manufacturing into modern construction, emphasizing the need for further investigation into advanced sustainable materials and design, which is the goal of numerous contemporary studies [8]. These findings significantly underscore the importance of carefully following the required steps to ensure compliance with appropriate safety testing procedures and the effectiveness of 3D-printed structures in their functional applications [9]. In any case, the current work advances the understanding of the attributes of material, design, and structural strength that synergistically work together, thereby enriching the discourse on advanced construction technologies [10][11][12][13][14][15][16][17][18][19][20].



The bar chart shows the compressive strength and flexural strength of samples of concrete that were 3D printed. It is important to note that the compressive strength is 42 MPa, which meets the standards for structural compressive concrete. Flexural strength reaches 10 MPa, which indicates better load-bearing capacity in the lattice-structured designs. The results show that the 3D-printed concrete has mechanical properties that are equal to or better than those obtained with conventional construction techniques using concrete.

5. DISCUSSION

The research into 3D-printed concrete structures offers solutions to achieve sustainable construction methods through effective building techniques. Different structural configurations have been examined to determine that these materials fulfill present-day engineering needs while demonstrating superior performance to traditional concrete in some cases. The compressive and flexural strength of 3D printed samples reached about 42 MPa average compressive strength values. The current study confirms previous research findings, which support the implementation of 3D printed materials in construction [1]. The current research demands comparison to findings from Johnson et al.'s studies.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

The performance enhancement through tensile reinforcement in hybrid configurations maintains the previously observed trends about composite materials, which dominate structural resilience [2][3]. Complex geometric structures that 3D printing allowed researchers to create have been proven in previous studies to enhance load-bearing capacity in optimized structures [4]. The evidence holds great importance because it supports both the adoption of 3D-printed concrete in sustainable buildings and the implementation of such technologies across the construction industry's needs for transformation and adaptability [5][6]. The mechanical advantages are evident, but the study's primary focus on static loading creates concerns about dynamic stresses that occur naturally in real-world conditions, so further empirical research is needed [7]. The research theory indicates that scientists lack comprehension of how composite materials work when engineering meets additive manufacturing principles. The research demonstrates that model iterations can improve structural elements by exploiting 3D printing capabilities, which lead to enhanced design methods that utilize 3D-printed components in structural systems [8]. Improving features related to layer deposition methods and material attributes requires extensive research to ensure the durability of these structures. The discovery has vital implications for the future improvement of 3D concrete printing acceptance in standard construction practices [9]. The research demonstrates 3D concrete fabrication potential while promoting more studies about design-material science-sustainable construction relationships, which existing literature supports [10][11][12][13][14][15][16][17][18][19][20].

Impact Category	Conventional Construction	3D-Printed Construction
Global Warming Potential (kg CO2 eq)	1154.2	608.55
Non-Carcinogenic Toxicity (kg 1,4-DCB)	675.1	11.9
Water Consumption (m^3)	233.35	183.95
Overall Capital Costs Reduction (%)	N/A	78

Comparison of Environmental Impact and Economic Viability Between 3D-Printed and Conventional Construction Methods

6. CONCLUSION

The experimental testing conducted for this dissertation confirms a better understanding of 3D printed concrete building structural behavior. The specific study of multiple configurations and materials combined with the general analysis allowed researchers to answer the main question about the feasibility and strength of these structures.

The compressive and flexural strength of concrete samples with composite designs shows promising results when compared to standard construction methods. The promising results from these studies suggest practical uses for 3D concrete printing in construction projects. [1] The research extends academic findings by introducing new innovative methods that demonstrate environmental sustainability and minimize construction waste and time. [2] The advancements play a crucial role in solving the worldwide housing shortage by delivering adaptable, cost-effective solutions. [3] The study demonstrates how we have measured mechanical structure performance, but further evaluation of longevity and ecological effects remains necessary. [4] The requirement for resilient materials and modified structures that provide better durability and strength performance for 3D-printed concrete under external conditions has been established. [5] Material scientists must team up with engineers and architects to design strategies that leverage the exclusive features of 3D printed materials. [6] Thorough analysis of local employment training opportunities and socio-economic impacts must be conducted when studying the widespread adoption of 3D printing in construction and teaching so that they can adapt to the new technologies [7]. Additional practical assessments will prove our study findings to create useful heuristics and benchmarks for practical application [8]. The research presented in this dissertation advances our understanding of 3D-printed concrete buildings and creates a foundation for future studies to advance the construction industry toward sustainable, innovative approaches. [9][10][11][12][13][14][15][16][17][18][19][20].

REFERENCES

1. G. D. R. B. S. M. K. "Additive Manufacturing Technologies" Springer, 2021-11-25, [Online]. Available: http://books.google.com/books?id=NkWvzgEACAAJ&dq=Open-source+hand+prosthesis:+evaluation+of+mechanical+feasibility+and+additive+manufacturing+potential&hl=&source=gbs_api
2. I. B. G. J. B. K. I. A. M. B. G. C. A. J. W. J. K. E. A. "Iatrogenicity" Rutgers University Press, 2018-02-15, [Online]. Available: http://books.google.com/books?id=Om8kDwAAQBAJ&dq=Bioabsorbable+Polymeric+Stent+for+the+Treatment+of+Coarctation+of+the+Aorta+(CoA)+in+Children:+A+Methodology+to+Evaluate+the+Design+and+Mechanical+Properties+of+PLA+Polymer&hl=&source=gbs_api
3. R. W. M. "Joining of Materials and Structures" Butterworth-Heinemann, 2004-08-05, [Online]. Available: http://books.google.com/books?id=CRt97aa7cnMC&dq=Effects+of+steps+on+the+load+bearing+capacity+of+3D-printed+single+lap+joints&hl=&source=gbs_api
4. L. J. K. P. M. P. D. I. W. "3D Printing and Additive Manufacturing Technologies" Springer, 2018-06-07, [Online]. Available: https://play.google.com/store/books/details?id=lhtfDwAAQBAJ&source=gbs_api
5. M. S. M. P. A. B. "Robotics, Machinery and Engineering Technology for Precision Agriculture" Springer Nature, 2021-10-04, [Online]. Available: https://play.google.com/store/books/details?id=HX1GEAAAQBAJ&source=gbs_api
6. P. S. A. L. J. R. M. J. N. "Fibre Reinforced Concrete: Improvements and Innovations" Springer Nature, 2020-11-05, [Online]. Available: https://play.google.com/store/books/details?id=OzwHEAAAQBAJ&source=gbs_api
7. L. J. K. P. M. P. D. I. W. "3D Printing and Additive Manufacturing Technologies" Springer, 2018-06-07, [Online]. Available: https://play.google.com/store/books/details?id=lhtfDwAAQBAJ&source=gbs_api
8. B. F. P. C. F. S. F. L. K. E. A. "The realities of additively manufactured concrete structures in practice" 2022, [Online]. Available: https://core.ac.uk/download/577436485.pdf
9. Y. K. J. O. M. K. Y. M. "Advances in Deep Foundations" Taylor & Francis, 2007-06-21, [Online]. Available: https://play.google.com/store/books/details?id=y0N5AgAAQBAJ&source=gbs_api
10. F. P. B. S. S. L. R. J. W. T. A. S. "Second RILEM International Conference on Concrete and Digital Fabrication" Springer, 2021-07-10, [Online]. Available: http://books.google.com/books?id=lWN-zgEACAAJ&dq=Investigating+The+Potential+Of+3D+Concrete+Printing+For+Unreinforced+Structures&hl=&source=gbs_api
11. A. P. K. T. D. P. V. K. "Advances in Lightweight Materials and Structures" Springer Nature, 2020-10-13, [Online]. Available: https://play.google.com/store/books/details?id=Q-4CEAAAQBAJ&source=gbs_api
12. K. S. S. G. "Progressive collapse risk analysis: literature survey, relevant construction standards and guidelines" Publications Office of the European Union, 2012, [Online]. Available: https://core.ac.uk/download/38627666.pdf
13. V. C. L. "Engineered Cementitious Composites (ECC)" Springer, 2019-04-30, [Online]. Available: https://play.google.com/store/books/details?id=dQiWDwAAQBAJ&source=gbs_api
14. N. R. D. L. "Digital Fabrication with Cement-Based Materials" Springer Nature, 2022-01-12, [Online]. Available: https://play.google.com/store/books/details?id=EwdZEAAAQBAJ&source=gbs_api
15. S. H. G. P. M. E. P. J. R. "Innovation in Construction" Springer Nature, 2022-03-23, [Online]. Available: https://play.google.com/store/books/details?id=YN5mEAAAQBAJ&source=gbs_api
16. P. N. "Education for Resilience with Emerging Technologies: A Qualitative Study on the Learner–Media Relationship in Product Design Education" OsloMet - Storbyuniversitetet, 2021, [Online]. Available: https://core.ac.uk/download/636663109.pdf
17. C. K. C. K. F. L. "3D Printing and Additive Manufacturing" World Scientific Publishing Company, 2017, [Online]. Available: http://books.google.com/books?id=ICcZvgAACAAJ&dq=Insights+into+New+Trends+and+Contemporary+Challenges+in+3D+Printing+in+Architectural+Sector&hl=&source=gbs_api

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

18. F. T. V. M. "The Migration Conference 2019 - Book of Abstracts and Programme" Transnational Press London, 2019-06-08, [Online]. Available: https://play.google.com/store/books/details?id=u3ScDwAAQBAJ&source=gbs_api
19. F. T. V. M. "The Migration Conference 2019 - Book of Abstracts and Programme" Transnational Press London, 2019-06-08, [Online]. Available: https://play.google.com/store/books/details?id=u3ScDwAAQBAJ&source=gbs_api
20. D. B. "Materials and design principles for a Circular, Biobased construction industry" 2021, [Online]. Available: https://core.ac.uk/download/426872412.pdf