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Design And Assessment Of 3D-Printed Concrete Materials For Energy-Efficient Structural Applications

[1]Kailash Dhaka, [2]Er. Raj Bala, [3]Er. Hardeep Singh
[1]M. TECH Scholar, [2,3]Assistant Professor
[1,2,3]Department of Civil Engineering, JCDMCOE, Sirsa, India

Abstract

The development of 3D-printed concrete (3DPC) is revolutionizing the construction industry by enabling innovative and energy-efficient structural designs. This study examines 3DPC materials incorporating sustainable components like recycled aggregates and supplementary cementitious materials to enhance energy efficiency and performance. Using additive manufacturing techniques, the research focuses on optimizing thermal and mechanical properties for diverse climatic conditions. The findings reveal that double-row cavity walls filled with expanded polylactic acid (E-PLA) and 3DPC mixtures with densities up to 1602 kg/m³ can achieve U-values as low as 0.20 W/m².K, significantly improving thermal insulation. Cavity-filled designs outperform void-filled ones by up to 62% in thermal performance. Fire resistance tests show that Rockwool-insulated walls effectively maintain safe surface temperatures under prolonged exposure to standard fire conditions. Furthermore, the compressive strength of 3DPC is tailored to meet structural requirements, ensuring durability. This research demonstrates the potential of 3DPC to optimize energy efficiency and sustainability in construction. By integrating advanced materials and innovative cavity configurations, it provides a cost-effective, environmentally friendly approach suitable for various climates. The findings pave the way for future advancements in 3D-printed construction, fostering sustainable and resilient built environments.

Keywords: 3DPC, Energy efficient structure, U-value, FEM

1. Introduction

Concrete material is a mixture made by mixing cementitious materials, water, coarse and fine aggregates in appropriate proportions[1][1]. It is widely used in construction, water conservancy, bridges, highways, railways and urban infrastructure construction which is one of the important civil engineering materials[2][2]. As the demand for concrete increases, the problems of high pollution and high energy consumption in production and application process have become increasingly prominent, restricting the green, healthy and sustainable development of concrete materials[3][3]. At the same time, the increasingly complex concrete structures have put forward higher requirements on the strength and durability of concrete materials due to the environment and stress characteristics[4][4].

3D printing, also known as additive manufacturing, is an automated process that produces complex shape geometries from a 3D model (computer-aided design (CAD) model) on a layer-by-layer basis, through a series of cross-sectional slices. It has the potential to reduce material waste, decrease labor cost and fast production[5][5]. For the past few years 3D-printing (3DP) technology has been widely used in architectural design, industrial manufacturing, aerospace, biological engineering, cultural relics protection and other industries with its advantages of low cost, high efficiency, strong design, and reliable quality (Figure 1)[6][6]. Concrete 3DP is an emerging digital construction technique that can realize geometrically complex designs[7][].

[1] Nagrockienė, Džigita, Giedrius Girskas, and Gintautas Skripkiūnas. "Properties of concrete modified with mineral additives." *Construction and Building Materials* 135 (2017): 37-42.
[2] Gagg, Colin R. "Cement and concrete as an engineering material: An historic appraisal and case study analysis." *Engineering Failure Analysis* 40 (2014): 114-140.
[3] Sharma, Narendra Kumar, Praveen Kumar, Sanjeev Kumar, Blessen Skariah Thomas, and Ramesh Chandra Gupta. "Properties of concrete containing polished granite waste as partial substitution of coarse aggregate." *Construction and Building Materials* 151 (2017): 158-163.
[4] Lyu, Fuyan, Dongliang Zhao, Xiaohui Hou, Li Sun, and Qiang Zhang. "Overview of the development of 3D-printing concrete: A review." *Applied Sciences* 11, no. 21 (2021): 9822.
[5] Camacho, Daniel Delgado, Patricia Clayton, William J. O'Brien, Carolyn Seepersad, Maria Juenger, Raissa Ferron, and Salvatore Salamone. "Applications of additive manufacturing in the construction industry–A forward-looking review." *Automation in construction* 89 (2018): 110-119.
[6] Meng, W. "Analysis of 3D printing technology and application trends." *Technology Innovation and Application* 339, no. 11 (2021): 146-148.
[7] Hossain, Md Aslam, Altynay Zhumabekova, Suvash Chandra Paul, and Jong Ryeol Kim. "A review of 3D printing in construction and its impact on the labor market." *Sustainability* 12, no. 20 (2020): 8492.

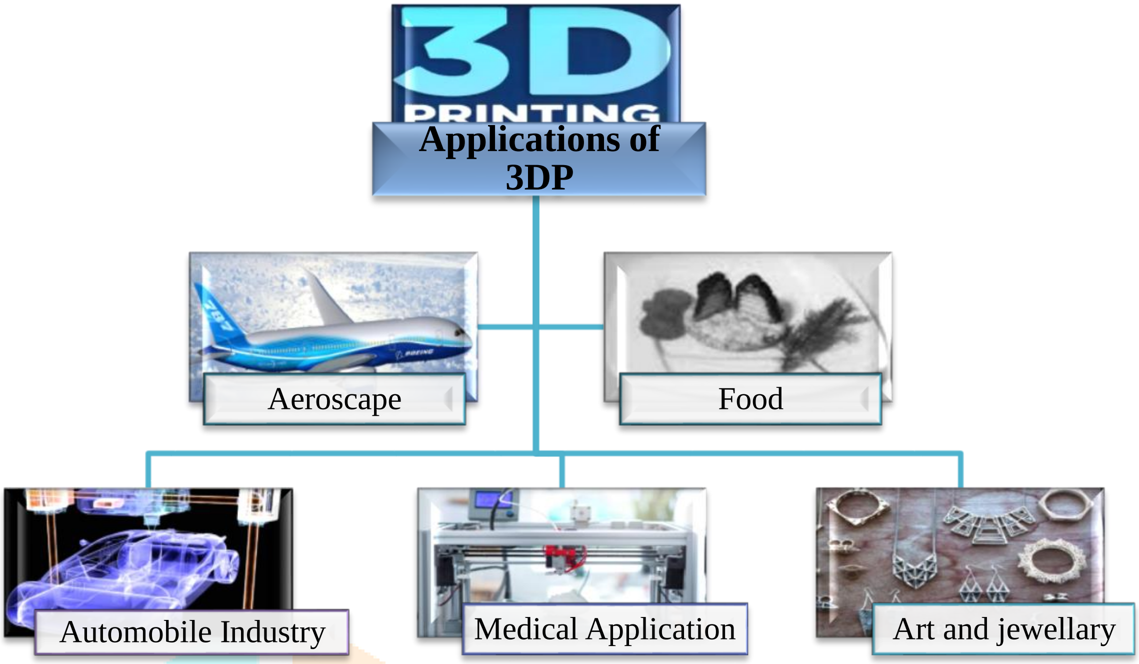


Figure 1: Applications of 3DP[8][54].

It was initially developed by and is continuously evolving to be a prominent technology in the construction industry[9][8]. It is proven to bring many benefits like increased customization, reduced construction time, labor, and material requirement. D-shape, contour crafting, and extrusion-based concrete printing are the common techniques in concrete 3DP[10][9]. Out of them, extrusion-based concrete printing is the most commonly used technology, and the number of research studies is increasing exponentially worldwide[11][10]. The application of 3D printing technology in the construction industry has obvious advantages, as shown in Figure 2.

[8] Shahrubudin, Nurhalida, Te Chuan Lee, and R. J. P. M. Ramlan. "An overview on 3D printing technology: Technological, materials, and applications." *Procedia manufacturing* 35 (2019): 1286-1296.

[9] Khoshnevis, Behrokh, Anders Carlson, Neil Leach, and Madhu Thangavelu. "Contour crafting simulation plan for lunar settlement infrastructure buildup." In *Earth and Space 2012: Engineering, Science, Construction, and Operations in Challenging Environments*, pp. 1458-1467. 2012

[10] Perkins, Isaac, and Martin Skitmore. "Three-dimensional printing in the construction industry: A review." *International Journal of Construction Management* 15, no. 1 (2015): 1-9.

[11] Buswell, Richard A., WR Leal De Silva, Scott Z. Jones, and Justin Dirrenberger. "3D printing using concrete extrusion: A roadmap for research." *Cement and concrete research* 112 (2018): 37-49.

Figure 1: Advantages of 3DP technology in construction[12][11].

The development and evaluation of 3D-printed concrete materials represent a significant advancement in energy-efficient structural design. This innovative approach leverages additive manufacturing techniques to produce complex geometries and optimize material usage, reducing waste and energy consumption during construction. 3D-printed concrete allows for the incorporation of sustainable materials, such as recycled aggregates and supplementary cementitious materials, further enhancing its environmental performance. Additionally, the precision of 3D printing enables the design of structures with improved thermal insulation, airtightness, and energy efficiency. Evaluating the mechanical and thermal properties of these materials is crucial to ensure their viability and compliance with structural safety standards. By integrating energy-efficient design principles with advanced manufacturing technologies, 3D-printed concrete has the potential to revolutionize the construction industry, contributing to sustainable and resilient built environments. Here are some potential researches objectives follow as:

- Investigate the material composition and additive manufacturing parameters to optimize the thermal insulation and strength properties of 3DP concrete.
- Explore the potential of integrating energy-efficient features, such as thermal insulation and reduced material usage, into the design of structural components using 3D printing techniques.
- To integrate the developed material into structural designs that optimize energy efficiency through reduced heat transfer and improved thermal comfort.

[12] Yin, Jian, Yiru Suo, Tao Lv, Kaisi Ma, Xincheng Wang, and Zhonghua Zhang. "Application of 3D printing technology in the construction industry and its development prospects." In *2021 International conference on Smart Technologies and Systems for Internet of Things (STS-IOT 2021)*, pp. 2-8. Atlantis Press, 2022.

2. Literature Review

The literature collectively highlights significant advancements in 3D-printed concrete (3DPC) technology and its applications in sustainable construction. Zhang et al. (2024)[13][58] demonstrated the economic and environmental benefits of 3DPC over Conventional Masonry Structures (CMS), showing a 16.9% cost reduction, 64.1% decrease in workforce usage, and 72.5% reduction in environmental impact. Similarly, Tari et al. (2023)[14][59] explored Magnesium Potassium Phosphate Cement (MKPC) and phase change materials (PCM), achieving a 28% reduction in environmental impact with M20 concrete, despite minimal energy savings.

Efforts to enhance thermal performance were evident in studies by Cui et al. (2022)[15][62] and Hao et al. (2022)[16][63]. Cui et al. improved thermal regulation in 3DP concrete by incorporating micro-encapsulated paraffin, though at the cost of reduced compressive and flexural strength. Hao et al. developed PCMs with recycled fine particles, achieving a significant reduction in thermal conductivity by 31.04%, showcasing 3DPC's potential for energy-efficient construction.

Material optimization was another critical focus. Shahzad et al. (2021)[17][64] addressed clogging issues by developing industrial waste-derived materials with excellent compressive strength, fluidity, and setting time. Meanwhile, Markin et al. (2019)[18][70] optimized foam concrete mixtures, producing lightweight, thermally efficient, and load-bearing materials suitable for multi-story buildings.

Structural and design aspects of 3DPC were explored by Suntharalingam et al. (2021)[19][20][65, 68] and Martínez et al. (2020)[21][69]. Suntharalingam et al. evaluated fire resistance, finding that solid and Rockwool-insulated composite walls provided superior protection, while cavity walls showed poor energy performance.

[13] Zhang, Hanghua, Xiaoyi Liu, Jianzhuang Xiao, Guangchao Ji, Shipeng Zhang, Shu-Chien Hsu, and Chi-Sun Poon. "Comparative eco-efficiency assessment of 3D-printed recycled aggregate concrete structure for mid-rise residential buildings." Journal of Building Engineering 95 (2024): 110349.

[14] Tari, Mohammadreza Khalili, Amir Reza Faraji, Alireza Aslani, and Rahim Zahedi. "Energy simulation and life cycle assessment of a 3D printable building." Cleaner Materials 7 (2023): 100168.

[15] Cui, Hongzhi, Shiheng Yu, Xiangpeng Cao, and Haibin Yang. "Evaluation of printability and thermal properties of 3D printed concrete mixed with phase change materials." Energies 15, no. 6 (2022): 1978.

[16] Hao, Lucen, Jianzhuang Xiao, Jingting Sun, Bing Xia, and Wanzhi Cao. "Thermal conductivity of 3D printed concrete with recycled fine aggregate composite phase change materials." Journal of Cleaner Production 364 (2022): 132598.

[17] Shahzad, Qamar, Junyi Shen, Rabia Naseem, Yonggang Yao, Saad Waqar, and Wenqiang Liu. "Influence of phase change material on concrete behavior for construction 3D printing." Construction and Building Materials 309 (2021): 125121.

[18] Markin, Viacheslav, Venkatesh Naidu Nerella, Christof Schröfl, Gyunay Guseynova, and Viktor Mechtcherine. "Material design and performance evaluation of foam concrete for digital fabrication." Materials 12, no. 15 (2019): 2433.

[19] Suntharalingam, Thadshajini, Perampalam Gatheeshgar, Irindu Upasiri, Keerthan Poologanathan, Brabha Nagaratnam, Marco Corradi, and Dilini Nuwanthika. "Fire performance of innovative 3D printed concrete composite wall panels–A Numerical Study." Case Studies in Construction Materials 15 (2021): e00586.

[20] Suntharalingam, Thadshajini, Irindu Upasiri, Perampalam Gatheeshgar, Keerthan Poologanathan, Brabha Nagaratnam, Paulo Santos, and Heshachanaa Rajanayagam. "Energy performance of 3d-printed concrete walls: A numerical study." Buildings 11, no. 10 (2021): 432.

[21] Martínez-Rocamora, Alejandro, Rodrigo García-Alvarado, Euro Casanova-Medina, Luis Felipe González-Böhme, and Fernando Auat-Cheein. "Parametric programming of 3D printed curved walls for cost-efficient building design." Journal of Construction Engineering and Management 146, no. 5 (2020): 04020039.

Martínez et al. demonstrated cost and material savings of up to 61% and 53%, respectively, through optimized curved wall designs using BIM parametric programming.

Together, these studies highlight 3DPC's potential to revolutionize construction through cost savings, energy efficiency, improved material properties, and sustainability.

3. Problem Statement

The construction industry is continuously evolving to meet the demands of sustainability, energy efficiency, and cost-effectiveness. Traditional construction materials and methods often fall short in achieving these goals due to limitations in material customization, energy performance, and adaptability to complex structural designs. Recent advancements in 3D printing technology present an opportunity to revolutionize the construction industry by enabling the development of innovative materials tailored to energy-efficient and structurally optimized designs. However, the integration of 3D-printed concrete materials into mainstream construction practices faces significant challenges. These include achieving the required mechanical properties, thermal efficiency, and structural reliability of the material, as well as evaluating its performance under various design scenarios. This study aims to address these challenges by developing and evaluating 3D-printed concrete materials that enhance energy efficiency while maintaining structural integrity. The findings will contribute to sustainable construction practices and pave the way for widespread adoption of advanced manufacturing technologies in the building industry.

4. Material and Methods

Energy efficiency of 3DP structure in various climates throughout the world is going to be the focus of the study. A structure's thermal comfort is determined by the element's thermal transmittance value (U-value), which is determined by the climatic condition of the area. To achieve a certain U-value that is appropriate for its climate, it is helpful to insert air gaps or insulation layers between the building's components. 3D concrete printing allows for more design freedom, allowing for the fabrication of structures with air voids that fulfill structural and thermal requirements [72].

4.1 Research Methodology

The proposal research methodology was to design an energy efficient 3DPC structure with minimized U-values of painted walls as per climatic zone norms. The research employed five unique 3DPC wall configurations of three dissimilar materials with ideal thermal performances [73]. The densities of Mix 1, Mix 2, and Mix 3 equal to 1304.24 kg/m^3, 992 kg/m^3 and 1602 kg/m^3 respectively. The recommended configurations have been arrived at due to the existing implemented 3DP walls within the industry. They were fabricated using a range of cavity cross-sectional areas and geometries the same as hollow bricks with the nozzle having a 50 mm square cross-section. The wall designs that were considered have a length of 1 meter and height of 0.5 meters. The width of the cavities was between 15 cm and 20 cm. To achieve a lower

U-value, voids were filled with easily obtainable cheap local dry sand and Expanded Polylactic Acid (E PLA). The investigation included all three heat transmission mechanisms: thermal conduction or transfer, thermal convection, thermal radiation etc. This is depicted by the configurations of 3D PC walls shown in figure 3.1 below.

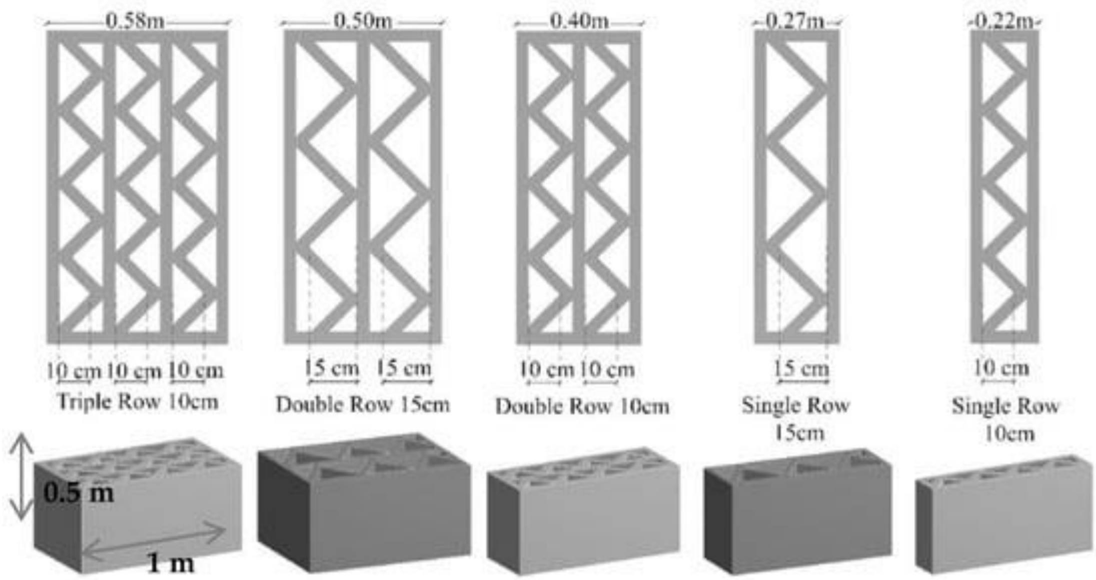


Figure 3.1: Different 3DPC cavity wall configurations

4.2 Model Development

The U-value of the 3DPC walls was calculated using a 3D heat transfer simulation that included steady-state and laminar airflow. A variety of cavity configurations of hollow concrete bricks were used to test the models developed using ANSYS software, which was used to construct the wall designs [74]. Neumann-Dirichlet boundary condition was used because two parallel faces were considered diabatic at the different temperature; it was possible to have heat flow, perpendicular to the two faces. The radiative heat transport inside the air cavities was calculated by using the Discrete Ordinate Radiation Model (DORM). The mesh was constructed from cubic beads with a size of 3mm edge length.

The U-value is determined by first calculating the heat flow through the planned walls in ANSYS and then using Equation (1).

$$U = \frac{q}{\Delta T} \quad (1)$$

The user-defined temperature differential between the inside and outside temperatures is denoted by ΔT, and q is the surface average weighted heat flow. By keeping the ambient temperature constant at 28°C, the specified temperature difference (ΔT) of 25 K, 35 K, and 45 K were ascertained. This research aimed for two U-values, 0.2 and 0.5 W/m2.K, in accordance with the rules and regulations. At the temperature variations described above, these U-values were generated using simulation.

4.3 Outcomes of the Corresponding Study

Several designs that incorporate 3D printed material with cavities were also examined, and the multi-row wall had the best balance of 3D printed material and cavities needed to reach the desired U-value and structural performance of 0.20 W/m2.K at most. Additionally, the results show that the incorporation of parallel cavity rows has a far more pronounced effect of reducing the U-value compared to simply increasing the size of the cavity itself. Table 3.1 above shows the % reduction in U-value of each one of the designs against the single row 15 cm cavity wall structure for Mix 3. With the raise in density, the U-value reduced progressively and reached the minimum with a triple row cavity height of 15 cm for all the three mixtures. When moving to a single row beyond the double row 20 cm cavity layout the effect of these changes with temperature differential is negligible in the U-value. Therefore, the triple row 15 cm cavity layout was omitted, although this design was identified as suitable for many temperature zones.

Table 3.1: % of U-value decrease for various configurations at 45 K ΔT

Wall Configuration	U-value ($W/m^2.K$)	Reduction % Compared to Single Row 15cm
Single Row 15 cm	1.25	0
Single Row 20 cm	1.22	2
Double Row 15 cm	0.73	44
Double Row 20 cm	0.72	45
Triple Row 15 cm	0.49	62

At a temperature of 45 K, Figure 3.2 shows the variance in U-value for 3DPC walls produced using Mix 3, which includes walls with air cavities, sand-filled walls, and E-PLA filled cavities. Mix 1, Mix 2, and Mix 3 were all used in this investigation, and the variance is consistent with all three. Clearly, the U-values have decreased with cavity filling, and the lowest U-value was attained after E-PLA filling.

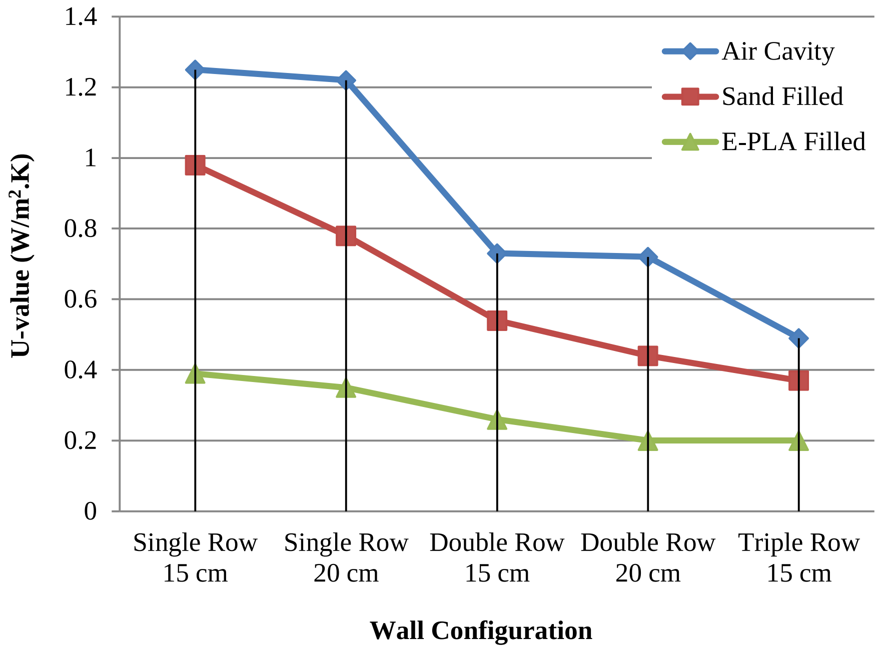


Figure 3.2: Effect of cavity fills on U-values at ΔT 40 K in Mix 3 printing

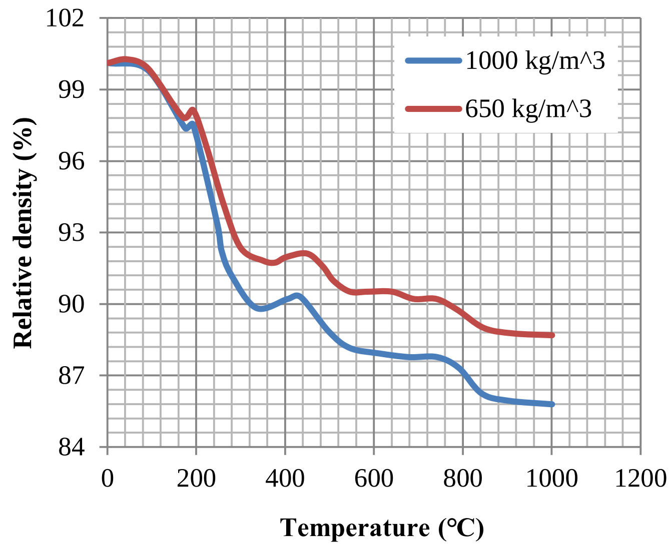
Last but not the least; the findings of this research work have unveiled the ideal material, wall disposition and type of printing that would be suitable for each of the Koppen-Geiger climate classification of the world. The choice was made depending on two factors: the minimum possible count of cavity rows as well as the amount of material used. The work designates the specified U-values for each of the zone provided by national legislation of the climatic zones of the world. A binder jet and an E-PLA filled double row 20 cm configuration with Mix 3 was used to achieve a U-value of 0.20 W/m2.K. This configuration was therefore suggested for walls in the London area in UK in order to achieve the intended U-value of 0.23W/m2.K.

4.4 Development of Finite Element Model (FEM)

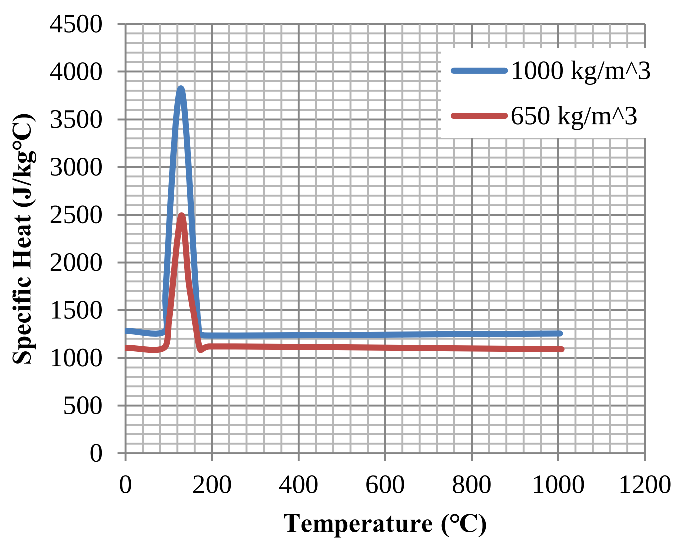
This section describes the process of creating the 3D FEM for analyzing the thermal behavior of heat transport in 3DP polycarbonate wall panels with various cross-sectional configurations. This research makes use of the ABAQUS program, which enables the examination of structures' thermal behavior via both coupled and uncoupled thermal analysis. The three main factors that must be considered when evaluating a building's fire performance are its insulation, integrity, and structural load bearing capability [75,76]. The process of studying the combined mechanical and thermal behavior in this way is called coupled analysis. Uncoupled heat transfer analysis was conducted because the walls that are not carrying any load were the only focus of this investigation. In order to analyze insulation failure, the chosen wall panels were subjected to a conventional fire scenario according to ISO 834 [77]. The researchers then measured any unusual change in surface temperature. The fire insulation material used in this investigation is rockwool.

Concrete and Rockwool insulation must have exact temperature-dependent thermal properties like thermal conductivity, specific heat, and relative density for in-depth heat transfer studies of 3DPC non-load-bearing wall configurations with and without cavity insulation. Experimental and analytical results were used to determine the thermal characteristics of LFC at high temperatures and densities of 650 kg/m3 and 1000 kg/m3, respectively [78].

Figures 3.3 (a–c) display the foamed concrete's thermal characteristics at high temperatures, whereas Figure 3.4 shows the fluctuation in Rockwool's thermal conductivity. At high temperatures, Rockwool has a density of 100 kg/m3 and a specific heat of 840 J/kg.°C [79].



(a)



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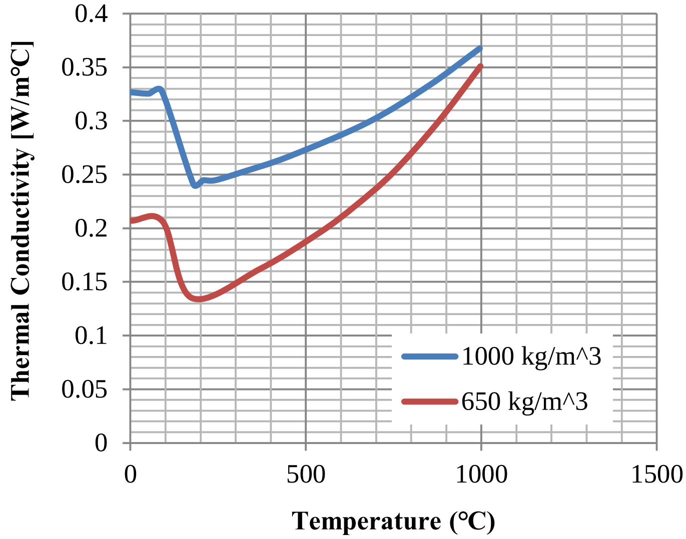


(c)

Figure 3.3: Thermal properties of Foamed concrete: (a) Relative density; (b) Specific heat; (c) Thermal conductivity

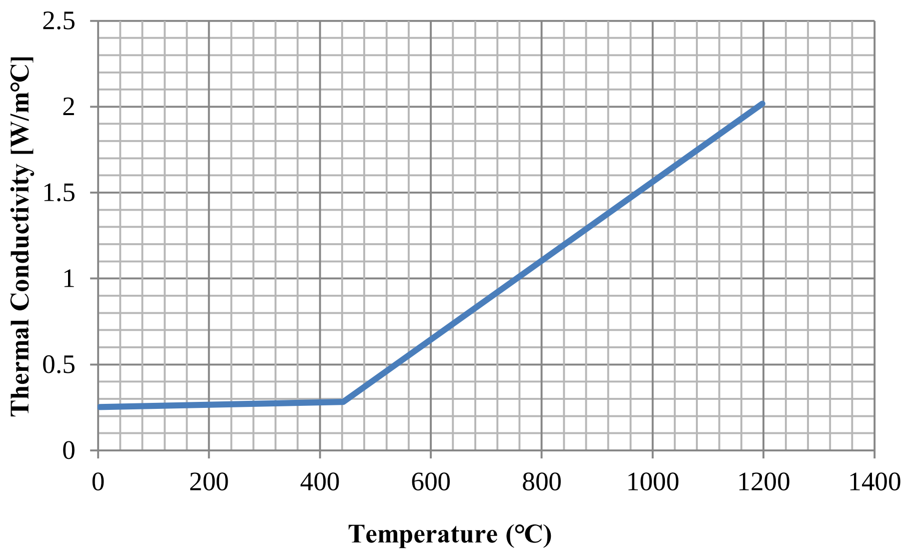


Figure 3.4: Thermal conductivity of Rockwool

4.5 Parametric Analysis of 3DP on Wall Panels in Various Layouts

The thermal behavior of five distinct wall designs was examined using an expanded version of the previously established FE heat transfer model. These wall panels were tested and shown to increase fire performance when used with Rockwool cavity insulation. The average unexposed surface temperature increase cannot exceed 140 °C and 200 °C at any location to meet the fire resistance in insulation requirement, according to Eurocode standards (EN 1992-1-2, 2017) [80]. A structural member's insulation fire rating (IFR) is determined by the amount of time it takes for the unexposed surface to reach temperature increments of 140 and beyond degrees Celsius. The developed wall panels' IFR was therefore calculated using the model.

20 wall specimens with five distinct cross-sectional configurations, 2 material densities (650 kg/m3 and 1000 kg/m3), and without or with cavity insulation are part of the parametric analysis. The chosen layouts and density of materials are stemming from the 3DP walls that were really built with 15 cm and 20 cm cavities. The various wall panel cross-sectional configurations examined in the research are shown in Figure 3.1. Data from the parametric analysis are shown in Table 3.2.

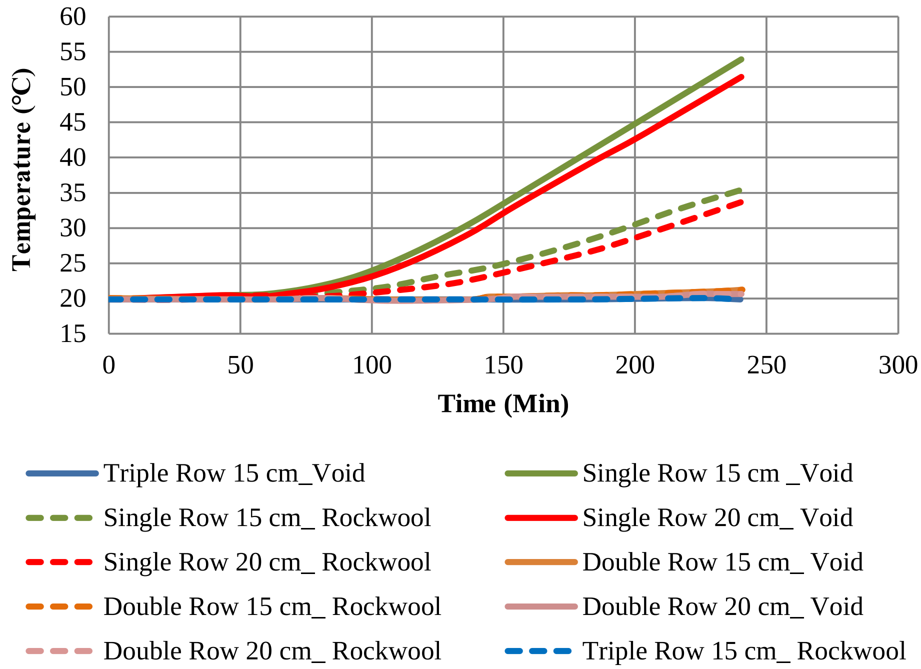
Table 3.2: Parametric Study Outline

Wall Configuration	Density (kg/m^3)	Insulation Type	Number of Models
Single Row 15 cm	650,1000	Cavity, Rockwool insulation	4
Single Row 20 cm			4
Double Row 15 cm			4
Double Row 20 cm			4
Triple Row 15 cm			4
Total			20

5. Test Result and Discussion

A time-dependent fire Unexposed Structure Temperature (UST) was monitored using ABAQUS CAE tools, and the heat transfer FE model's firesides were subjected to the standard fire curve, ISO 834. The work goes into extensive discussion on the fire behavior of various wall designs and densities as it pertains to the insulation fire rating.

All five wall layouts with densities of 650 kg/m3 and 1000 kg/m3 are shown in Figure 4.1 (a,b), which show the fluctuation of the UST. It is easy to see that the IFR increases with increasing panel density for every single wall panel. In terms of fire resistance, both the cavities and Rockwool in-filled walls performed very well. According to the wall design, the IFR remained below the limitation temperature of 160°C (140°C + 20°C) after 4h. In addition, the double-row and triple-row wall layouts clearly have a minimal temperature gain.



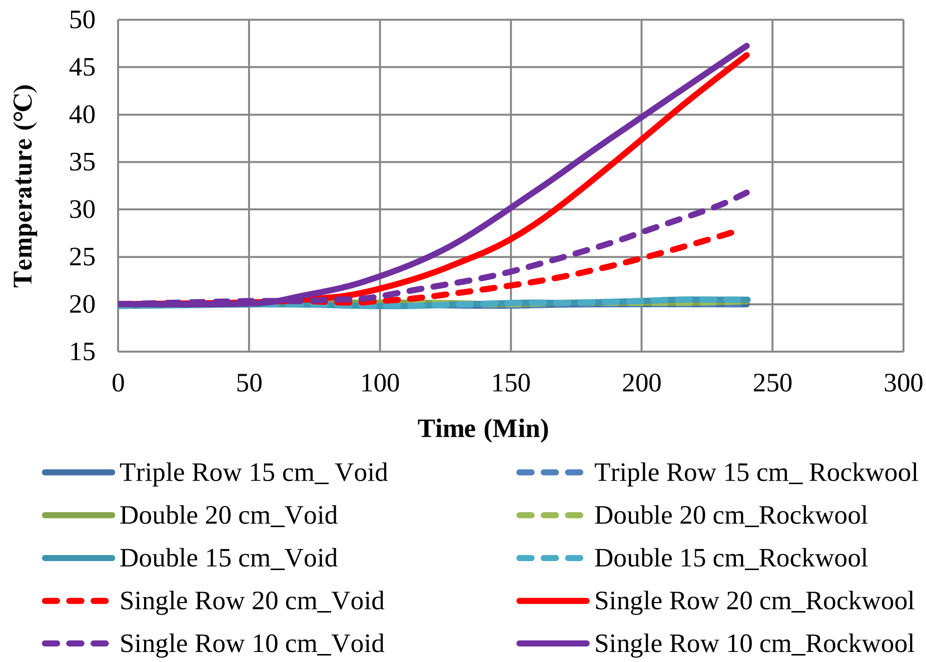
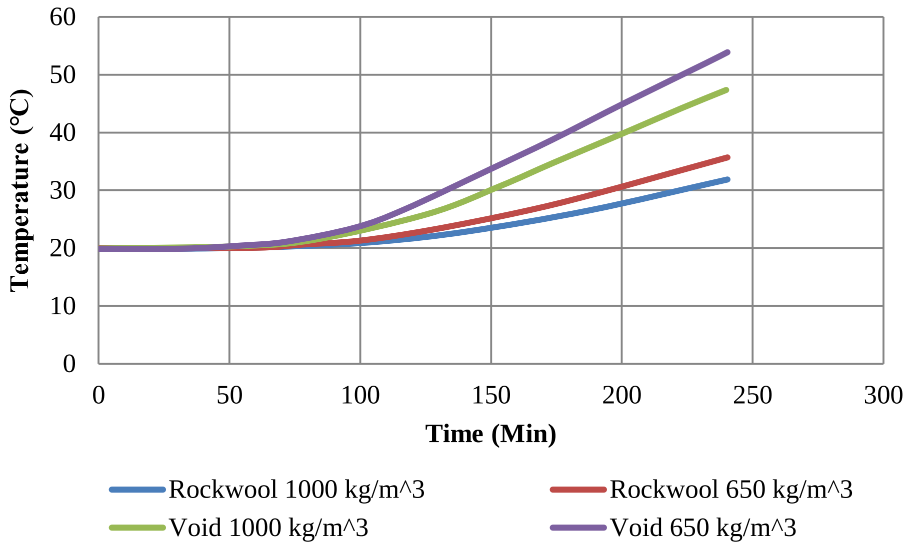
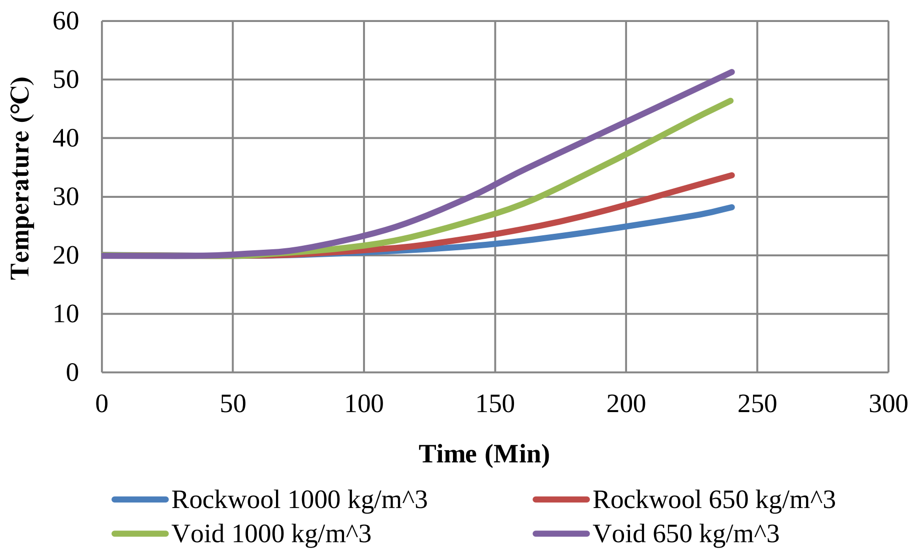


Figure 4.1: UST change with density for various wall designs (a) 650 kg/m3; (b) 1000 kg/m3

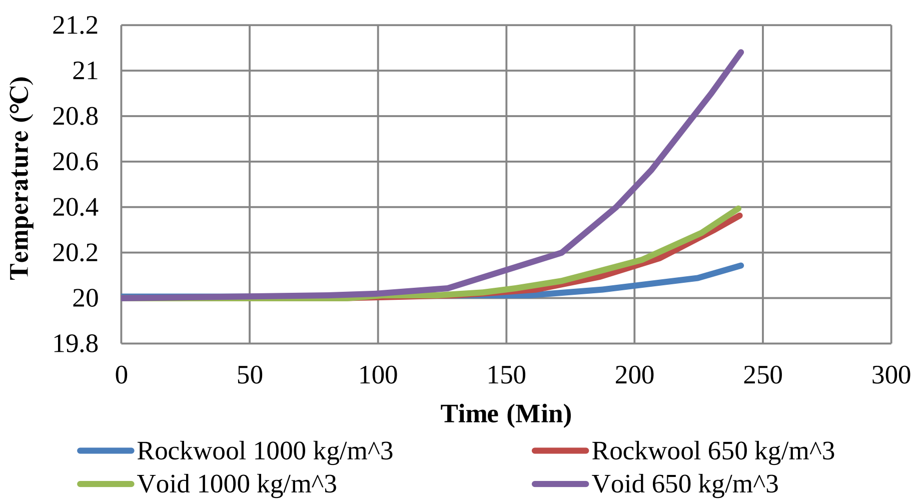
Figure 4.2 (a–e) presents a comparison of the UST change for all of the wall designs under normal fire conditions for varied material densities. The period of time covered by the comparison is up to four hours. In Table 4.1, it can see the temperature increase that occurred in each of the various wall designs over the course of 4h.


Temperature (°C)
Time (Min)
Rockwool 1000 kg/m^3
Rockwool 650 kg/m^3
Void 1000 kg/m^3
Void 650 kg/m^3

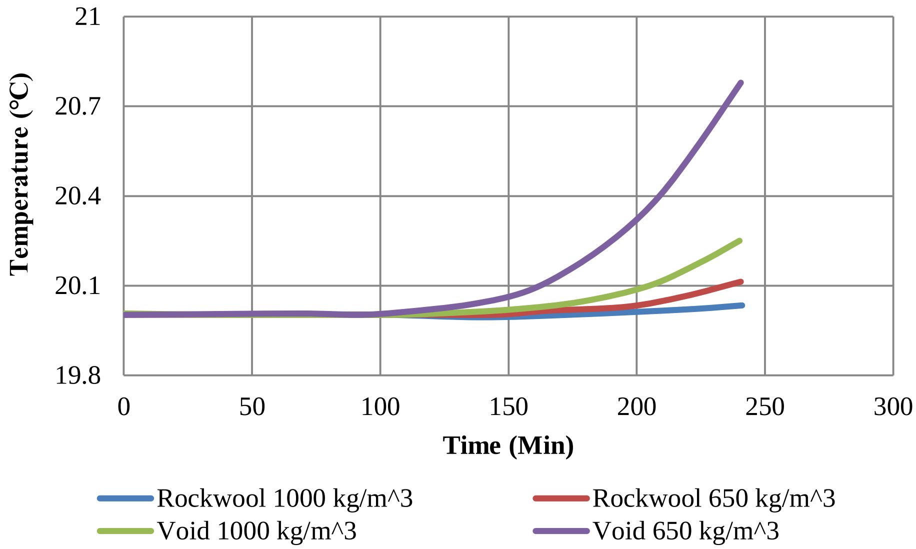
(a)


Temperature (°C)
Time (Min)
Rockwool 1000 kg/m^3
Rockwool 650 kg/m^3
Void 1000 kg/m^3
Void 650 kg/m^3

(b)


Temperature (°C)
Time (Min)
Rockwool 1000 kg/m^3
Rockwool 650 kg/m^3
Void 1000 kg/m^3
Void 650 kg/m^3

(c)



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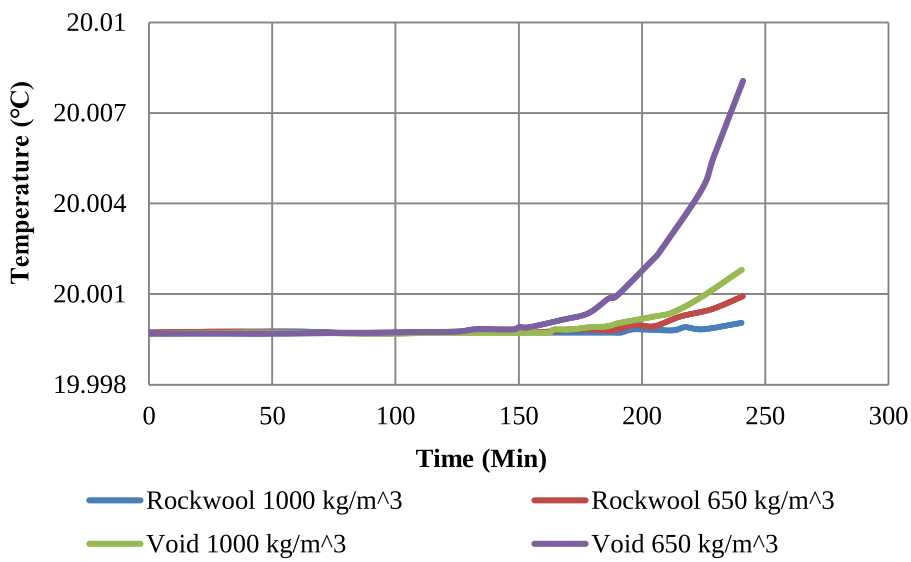

(e)

Figure 4.2: UST variation on wall design (a) Single Row 10 cm; (b) Single Row 15 cm; (c) Double Row 10 cm; (d) Double Row 15 cm; (e) Triple Row 10 cm

Data on the temperature rise of different wall constructions with and without insulation over 4 hours is compiled in Table 4.1. Walls are built single, double, and triples with thicknesses of 15 cm and 20 cm consisting of void and rockwool insulation. For single-row walls, the temperatures in the wall are higher, void configurations reached temperatures of 54.65 ℃ and 52.47 ℃ for 0.15 m and 0.2 m walls, correspondingly. These values are greatly reduced by Rockwool insulation, sustaining temperatures of 36.21℃ and 34.57℃ respectively for these thicknesses. Comparable temperature changes reveal that double-row walls have the lowest levels of temperature increase; voids range between 22.43℃ to 21.83℃ and rockwool record temperatures between 21.11℃ to 21.08℃. In general, there is little difference in the behavior of triple-row walls whether they are insulated or not, with all the arrangements stabilizing at roughly 21.00℃. The results analyzed in the paper clearly show that the rockwool insulation and additional wall layering are proper strategies for reducing heat transfer in time.

Table 4.1: Temperature increase in 4 hours by wall configuration

Wall Configurations		**Temperature** (℃)	
Single Row 15 cm	Void	54.65	48.35
	Rockwool	36.21	32.06
Single Row 20 cm	Void	52.47	47.32
	Rockwool	34.57	30.08
Double Row 15 cm	Void	22.43	21.38
	Rockwool	21.63	21.11
Double Row 20 cm	Void	21.83	21.36
	Rockwool	21.14	21.08
Triple Row 15 cm	Void	21.11	21.00
	Rockwool	21.00	21.00

In terms of insulation failure criterion during the first four hours, the findings show that both the cavity and Rockwool in-filled wall layouts offer greater fire safety. In addition, it is clear that for all wall layouts, increasing density is associated with increased fire behavior. However, the combined mechanical-thermal behavior is not considered in this heat transfer study; it only checks for insulation failure. So, to achieve superior fire performance with less material demand, a layout with 1000 kg/m3 density and Rockwool insulation in a single row of 10 cm walls could be suggested. On the other hand, for improved energy efficiency, they recommend a wall structure of 1602 kg/m3 E-PLA filled double row 20 cm. It is possible to suggest a double-row, 20-centimeter-thick wall design with a density of 1602 kg/m3 in order to create a 3DP structure that is both thermally pleasant and energy efficient, and which has improved fire performance.

6. Conclusion

This research work aimed at assessing the performance of 3DPC wall systems through computational analysis. Based on the simulation results, the following conclusions were drawn:

- Non-load bearing 3DPC cavity walls have fairly good fire resistance under the standard fire load for a 4h exposure period.
- In single row wall the increase in temperature is more and for the void configuration the temperature is around 54.65℃ for the wall thickness 15cm and 52.47℃ for 20cm thickness of the wall. The heat transmission values of Rockwool insulation is much lower compared to these values, which retains temperatures as low as 36.21℃ and 34.57℃ for the same thicknesses.
- Performance of thermal energy and fire of 3DPC walls can be boosted by raising the thickness of the wall in parallel row manner and by inserting Rock wool insulation as cavity fillers.
- The temperature rise is significantly lower in case of double-row walls: voids range between 22.43 and 21.83, rockwool stays between 21.11 and 21.08.
- Concerning the comparison of different configurations to insulation, triple-row walls demonstrate low temperature fluctuations; all the tested configurations approach 21.00°C. The results analyzed in the paper clearly show that the rockwool insulation and additional wall layering are proper strategies for reducing heat transfer in time.