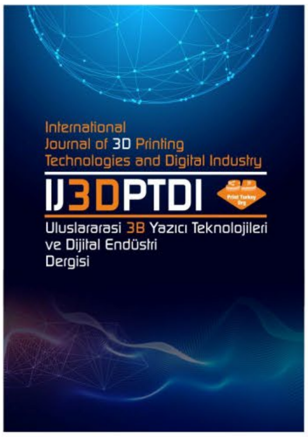

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EXAMINING THE RELATIONSHIP BETWEEN SUSTAINABLE MATERIAL AND BUILDING DESIGN IN BUILDING CONSTRUCTION WITH ADDITIVE MANUFACTURING

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ABSTRACT

Building production with additive manufacturing techniques increase. This technique accelerated building construction works. Building production with additive manufacturing techniques increase. This technique accelerated building construction works. Building construction using additive manufacturing techniques draws attention because it requires less skilled labor, can be built in a shorter time, reduces costs, and contributes to sustainability. On the other, this technique enables the on-site production of buildings and the construction of complex building designs. This study aims to investigate the effect of using sustainable materials on building energy consumption in constructing complex-designed buildings. The effect of using geopolymer, a sustainable material, on building energy performance in square and free-form buildings was investigated. Additionally, the buildings in these forms were modelled with single-layer and double-layer walls, and the impact of layers on energy consumption was examined. On the other side, the effects of building forms in different directions were also examined. In the study, the effects of different scenarios were examined using the building energy simulation program. As a result of the study, it was determined that the building form was effective in the energy consumption of the building. It was also found that in the free-form building, the exterior wall orientation affected the building energy consumption. When the exterior walls of buildings of the same form and orientation were made double-layer instead of single-layer, a 60% decrease in heating energy consumption and a 12% decrease in cooling energy consumption was observed. The study is important in terms of the relationship between free building form and energy consumption.

Keywords: Geopolymer, Additive Manufacturing, Building Energy Consumption, 3D Printed Building, Industry 4.0

1. INTRODUCTION

The world population is estimated to reach 8.5 billion in 2030 and 9.7 billion in 2050 [1]. Urbanization accelerates due to population growth. Housing demand is expected to increase by 60% with increasing urbanization. It is estimated that there will be a 75% increase in CO_2 emissions with the increase in urban areas [2]. One of the most important causes of climate change is CO_2 emissions. Reducing this emission in the construction sector is important for reducing the effects of climate change [3].

The energy consumed for heating and cooling buildings and the energy consumed in industry constitute 40% of the total energy consumed [4-5]. In addition, 65% of this energy consumed is provided by fossil resources. In Europe, 60% of the total energy is consumed by buildings in cities [6]. In addition, in the EU directive on improving the energy performance of buildings in 2018, it was stated that 50% of the energy consumed in EU countries was spent on heating and cooling buildings [7]. In Turkey, while the final energy consumption of buildings was 19.5 MTEP in 2000, this value increased by 66% in 2015 and reached 32.4 MTEP. The share of the building sector in final energy consumption reached 32.8%, surpassing the industrial sector. Therefore, it is important to reduce the energy consumption of existing and newly constructed buildings. Additionally, it is estimated in the studies that energy consumption will increase by 50% in 2050 compared to 2018 [8]. The construction industry is looking for solutions to reduce energy consumption [9]. This situation shows the importance of new construction technologies.

Industrial revolutions have changed the production methods of all sectors, as well as the construction industry. The first radical changes in the construction industry began with the settled life. The other radical change was the use of cement and steel. The radical change expected today is building construction with digital production techniques. The world is experiencing a big transformation with Industry 4.0. It is predicted that with the widespread use of industrial robots containing automation and artificial intelligence in construction, production speed will increase, and less energy will be used. Research shows that the construction industry has serious potential and there will be radical changes in the construction industry within ten years [10-12]. In addition, it is estimated that with the development of digital production technologies, there will be developments in building materials, components, and design freedom [13-15].

Digital production is a technique in which computer-aided design and production technologies are used together. This technique is important in the construction industry in terms of its suitability for on-site production and allowing the construction of complex designs. In some research, it is suggested the use of additive manufacturing, a digital production technique, in building construction [16-17]. 3D printing based on extrusion is one of the most widely used techniques in additive manufacturing. The materials used in structures constructed with extrusion technique are different from the materials used in traditional construction techniques. The concrete-like material to be used in the extrusion technique must have sufficient extrusion capacity [18]. Therefore, the mortar created for printing must be fluid, have sufficient setting time and mechanical strength [19]. Research conducted in recent years suggests the use of geopolymer in 3D printing [19-20].

Geopolymer materials are formed by activating aluminosilicate materials such as fly ash, ceramic waste, metakaolin, and silica fume [21-24]. Geopolymer has high application potential due to its high chemical and thermal resistance, ability to be obtained from industrial and waste products, contribution to the economy, and prevention of environmental pollution [20]. Research shows that approximately 820 million tons of construction waste is generated in Europe every year [25-26]. The use of geopolymer, developed from waste materials as an alternative to Portland cement used in construction, stands out with its contribution to the environment [27-28] (Figure 1).

Since the 1980s, geopolymer materials have been viewed as alternatives to Portland cement because of their low CO_2 emissions and performance advantages. Researchers have suggested the use of geopolymers in structures due to their properties such as high strength, temperature resistance and durability [29-30]. Geopolymer has potential for use due to its chemical and thermal resistance, rapid mechanical strength development, and economic and environmental benefits such as being a waste product [31]. These materials are resistant to acid attack, fire and high temperatures [32-34]. Since its discovery, geopolymer materials have also attracted attention as a promising material for building restoration. It is also used for concrete repair at airports, railways and military bases in Australia [34].

There are studies in the literature examining the use of geopolymers in building production. In a study, the static strength of fly ash-based geopolymer mortar after 3D printing was investigated. At the end of the study, it was concluded that the static strength of the geopolymer mortar was high. The study also stated that it is possible to use traditional construction methods and 3D printing techniques together [35]. In another study on mortars, the technical properties and application methods of mortars produced from cement, fly ash, silica fume, blast furnace slag, fine aggregate, superplasticizer, viscosity modifier, and fiber materials used in the extrusion technique were investigated. The effects of the properties such as tensile, stress, viscosity, etc. of these mortars with different properties on 3D printing were investigated. As a result of the study, they concluded that geopolymers were promising for extrusion mortar in 3D printing from technical, environmental, and economic perspectives [36].

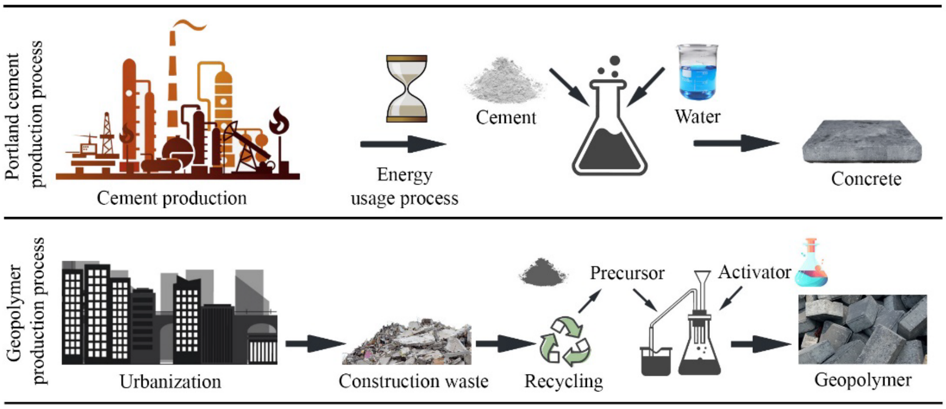


Figure 1. Portland cement and geopolymer production process

In another study, a slag-based geopolymer material was developed for use in the construction of buildings with 3D printing. The pressure strength of the geopolymer material developed in the study was increased. In the study, it was shown that the production of large structural elements was possible [37].

In 1997, the additive manufacturing technique was used for the first time in building construction [38]. Studies were conducted examining the potential use of this technique in buildings. In a study examining the contribution of the technique to environmental sustainability, it was stated that it would also contribute to the freedom of designs [11]. The additive manufacturing method allows building facades to be designed in free forms [39]. Building construction process are long in traditional construction methods. This situation causes an increase in the need for housing. The potential of this technology, enables building production with additive manufacturing techniques, has accelerated studies on this subject. In this study, it was examined that the potential of using sustainable materials in the construction of buildings produced with additive manufacturing techniques. For the study, the square and free form building plans, thought to be printed with 3D printing, were created. The geopolymer material was used in the production of these buildings. In the study, the changes in energy consumption according to different building plans were examined.

2. MATERIAL AND METHODS

In this study, the relationship between the use of sustainable materials in building production and building design was examined. Four different scenarios were created: Two of the scenarios were for a building have a square plan, with single and double-layer walls, and the other scenarios were for a building have a free-form plan, with single and double-layer walls. These scenarios were modelled through the building energy simulation program. Then, the effects of changes in the building surface and wall properties on the energy performance of the building were examined.

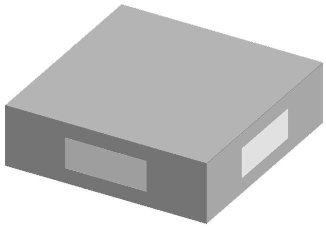
2.1. Reference Building

Two plans were created in the study to examine the relationship between the use of sustainable materials and building design. The first of these plans is square, the other is free form. The square planned building is the reference building. These buildings are open-plan, detached residences. It is assumed that the buildings were created using a 3D printer extrusion technique. Geopolymer, the most used material in 3D printing of buildings, was used in building production [27-40]. The reference building in the study is in Istanbul where is in the II. Degree day zone according to the TS 825 Standard for Thermal Insulation Rules in Buildings [41]. Building technical specifications were created by considering climatic conditions (Table 1).

2.2. Sustainable Mortar Properties Used in 3D Printing

In the study, geopolymer material was used in 3D printed buildings. Geopolymer materials are obtained by activating materials such as fly ash, ceramic waste, metakaolin, and silica fume [21-24]. A study was conducted with slag-based, fly ash-based, metakaolin-based, and lime alkali-activated slag-property geopolymer materials.

Table 1. Reference building properties

	**Meteorological data**	Meteonorm İstanbul 2024 IPCC AR4 A1B Scenario	**Occupancy**	4 persons
			Indoor temperature	21 °C
	Building Materials Properties			
	$U_{external\ wall}$	0.57 W/m^{2}K	U_{floor}	0.57 W/m^{2}K
	$U_{ceiling\ (Unused\ Attic)}$	0.38 W/m^{2}K	U_{window}	1.8 W/m^{2}K
	Infiltration	0.8 (n/h)		

It was concluded that fly ash-based geopolymers are more advantageous in terms of carbon emission and cost compared to geopolymers with other properties [27-40]. Therefore, fly ash-based geopolymer was used in this study (Table 2).

Table 2. Geopolymer technical properties

Properties	k (W/m K)	C_p (J/Kg K)	ρ (Kg/m^3)
Geopolymer (fly-ash)	1,35	891	2199

2.3. Numerical Simulation

There are passive and active measures that can be taken during the building design phase to increase the energy efficiency of buildings. Passive measures aim to reduce the building's energy needs through maximum use of renewable energy sources. Active measures are related to the mechanical systems of buildings [9]. Design support systems have been developed to examine the effects of these measures on the energy efficiency of the building [42]. One of these systems is the creation of building energy simulations. Some programs have been developed to create building energy simulations. The most widely used program in recent years and the one that produces the most realistic results is the DesignBuilder building energy simulation program [43-45]. This program can analyse issues such as the building's energy efficiency, CO_2 emissions, and comfort conditions [46]. In the study, passive measures were examined using the DesignBuilder building energy simulation program. Building forms, orientations, and wall layer scenarios were created for the study. The base areas and volumes of the scenarios created in the study are the same. The scenario plans were given in Figure 2.

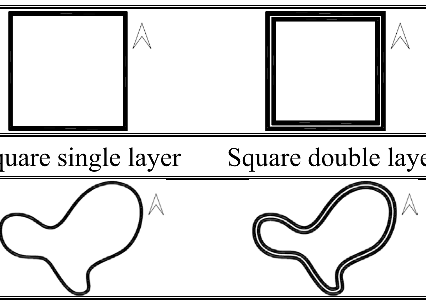


Figure 2. The scenario plans

3. RESULTS and DISCUSSION

3.1. Effect of Building Plan Design

For the study, square and free form building plans were created to examine the effect of building form on energy consumption. The effect of building form on heating and cooling energy consumption was investigated. Annual energy consumed for heating and cooling was calculated. The study also examined the relationship between form and direction. The obtained results are given in Figure 3.

In the free-form structures, wall surface areas vary depending on the direction. This situation affected the energy consumption of buildings at different rates. When the square plan building was accepted as the reference building, the energy consumed for heating purposes increased by 5.29%, 5.42%, 6.18%, 6.22%, 5.72%, 5.30%, 5.25% and 5.07% at FF 0°, FF 45°, FF 90°, FF 135°, FF 180°, FF 225°, FF 270°, FF 315° values, respectively. The square form was more compact than other forms. Therefore, the energy required to heat this form was less than other forms. When the surface area of the building in relation to the outside environment increased, the amount of energy required for heating increased. According to the different direction analysis results, the lowest heating energy consumption was in the square-shaped building, while the highest energy consumption was in FF 135°. This was related

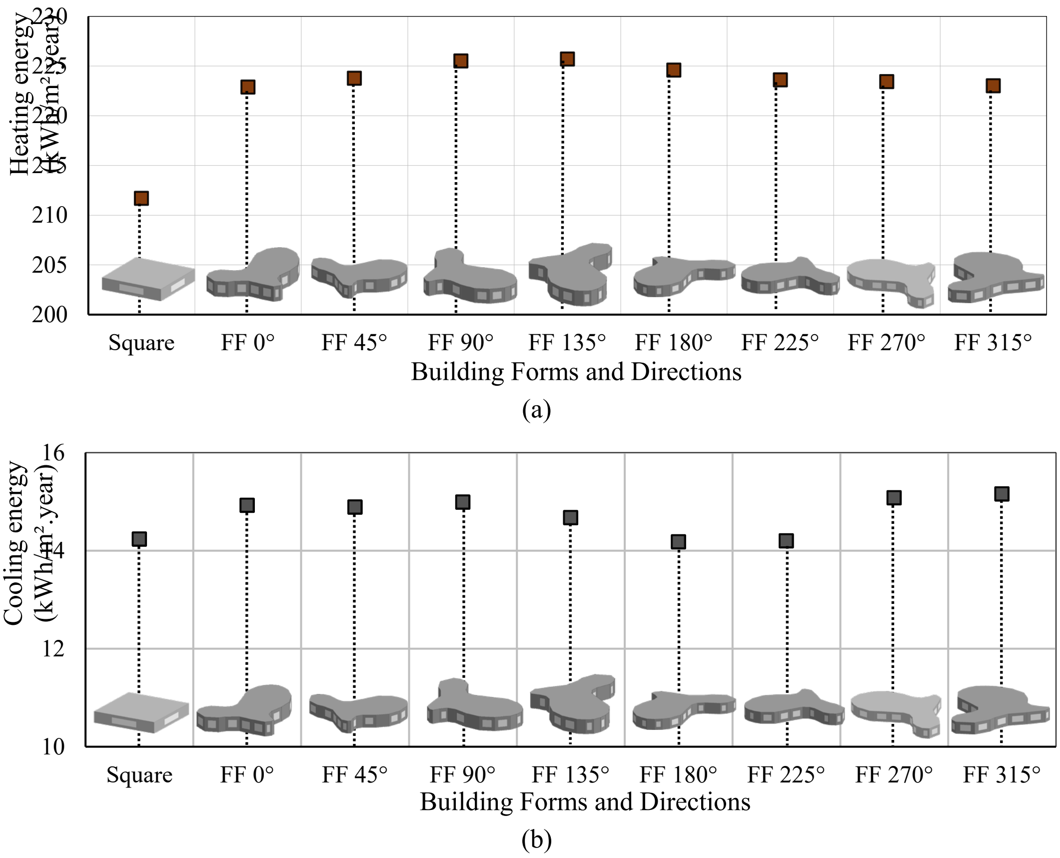


Figure 3 (a). Effect of building form on energy consumption for heating **(b).** Effect of building form on energy consumption for cooling

to the fact that the largest surface of the free form building in this direction was in the north. Increasing the surface width in the direction where the least sunlight comes increased the heating load. The results obtained showed that the heating energy requirement varied according to the building form. Studies on building form in the literature confirm this situation. Rashdi and Embi [47] studied the changes in the electrical energy required for cooling buildings in hot climates when the building form is T, L, U, I, ellipse and round. At the end of the study, it was stated that I-shaped buildings consume less energy for cooling than L-shaped buildings. They emphasized that this situation is related to the expansion of the building surface area.

When the square-formed building was accepted as the reference building in the study, the energy consumed for free-form buildings in different directions varied. When the square form was accepted as the reference, there was an increase of 4.85%, 4.38%, 5.06%, 2.92%, 5.92%, 6.11% compared to FF 0°, FF 45°, FF 90°, FF 135°, FF 270°, FF 315°, respectively. Compared to the reference, there was a decrease of 0.39% and 0.27% at FF 180° and FF 225. It is expected that the amount of energy required for cooling will be less in buildings with compact structures. The cooling load was calculated to be less in the FF 180° direction, where the surface area received less sunlight. This shows that increasing the surface area of the building relative to the outside environment reduces the amount of energy required for cooling. In the literature, Kocagil and Oral [48] examined the effect of building form on the heating and cooling loads of buildings in hot-dry climate regions. Six different forms and four different architectural plans were used in the study. Among the studied forms, the lowest heating and cooling load was in the inner courtyard plan and the highest was in the L-type plan. This situation is related to surface areas.

However, the variability of the glass ratios on the surfaces also affects the cooling load. Neves and Marques [49] studied the effect of changing the wall-to-glass ratio on building energy consumption in Sao Paulo, which has a hot climate. In the study, the cooling load was reduced by 40% by changing the window/wall ratio. According to the analysis of this studies results, the lowest cooling energy consumption was in FF 180°, while the highest energy consumption was in FF 315°. The results showed that building form and orientation have an impact on the amount of energy required to cool the building.

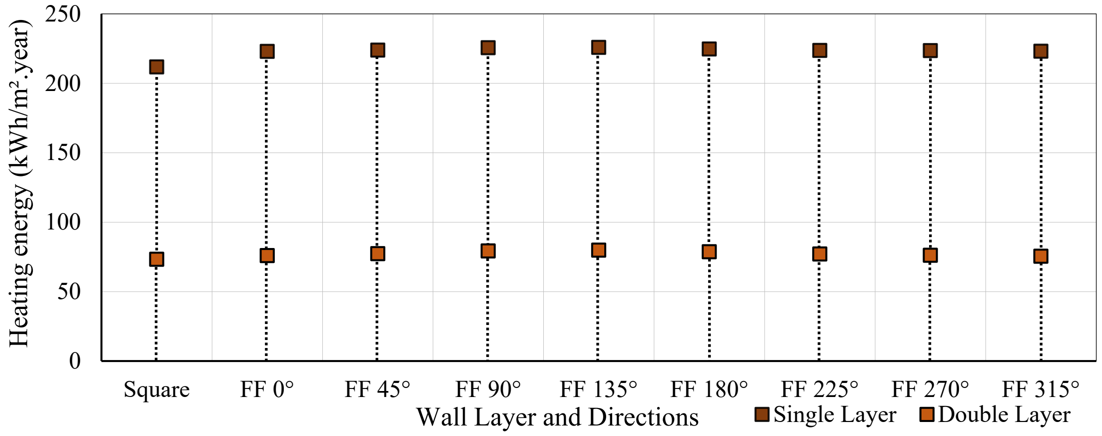
3.2. Effect of Building Exterior Wall Layer

In the study, the effect of using single or double layers in building walls on energy consumption was investigated. Annual heating and cooling energy consumption was calculated for different forms of buildings in case of single or double-layer wall use. Additionally, the situation where the buildings were in different directions was also examined (Figure 4 (a), (b). The study showed that the energy consumed for heating was reduced if the walls were double layered in all models. This was related to the fact that the heat transfer through the double-layered wall was less than the single-layered wall [50]. In the case of double-layer walls, heating energy consumption decreased by 3.52%, 5.49%, 8.18%, 8.88%, 7.38%, 5.19%, 3.84%, 2.96% at FF 0°,FF 45°, FF 90°, FF 135°, FF 180°, FF 225°, FF 270° and FF 315°, respectively, compared to the reference building. In a compact square-plan building spent less energy for heating. In addition, the differentiation of the building form in different directions changed the distribution of the heating load according to the directions. The study showed that cooling energy consumption was reduced when the walls were double-layered instead of single-layered in all models. In the case of double-layer walls, cooling energy increased by 9.20%, 6.44%, 4.55%, 2.24%, 2.00%, 11.21%, 11.50% at FF 0°, FF 45°, FF 90°, FF 135°, FF 225°, FF 270°, FF 315° respectively, compared to the reference building. There was a 0.12% decrease at FF 180°. When the heating and cooling loads of single-layer and double-layer walls at the same directions were compared; the double-layer wall heating loads of FF 0°, FF 45°, FF 90°, FF 135°, FF 180°, FF 225°, FF 270° and FF 315 are 65.41%, 65.99%, 65.48%, 64.87%, 64.68%, 64.99%, 65.55%, 65.97%, 66.20% less than the single-layer heating load, respectively. When the cooling load was examined, a reduction of 11.39%, 7.71%, 9.83%, 12.02%, 12.11%, 11.14%, 9.38%, 6.96%, and 7.21% was observed in the double-skinned wall, respectively. It was observed that the amount of energy spent on heating and cooling decreases at all angles in the double-layered wall.

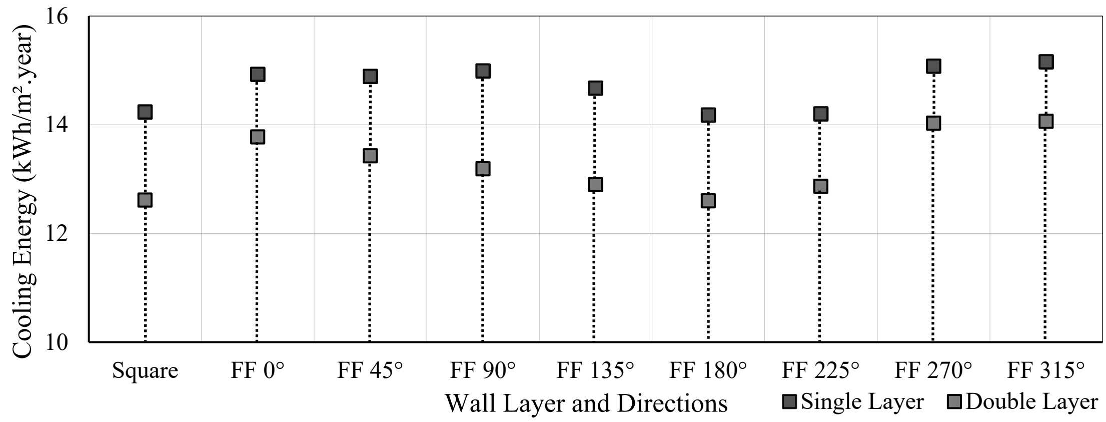
4. CONCLUSIONS

In the construction industry, building construction times are insufficient for shelter. The reason for this is that the construction period of the structure is long with traditional construction methods. In addition, the construction sector accounts for 40% of total energy consumed. Additive manufacturing technologies have high potential for reducing energy consumption. Developments in building production technology with additive manufacturing have accelerated the work in this field. Building production with additive manufacturing is important in terms of fast and on-site production, reduced labor force, cost reduction potential and contribution to sustainability. Additionally, this technology enables designers to implement flexible designs. Flexible designs that overcome application difficulties can both increase the comfort conditions of users and provide aesthetic solutions. In this study, the relationship between the use of sustainable materials in building production and building design was examined. The results obtained in the study are summarized below.

- The results showed that the building form is effective on the heating energy consumption of buildings.
- Compact building forms provide advantages in reducing the energy needs for heating and cooling.
- In climates where heating energy is high, large surfaces of free building forms should be oriented south, and in cold climates, north.
- Positioning large surfaces is important to reduce energy consumption in free-form structures. Whether the building walls are single-layer or two-layer affects the energy consumption of the building.
- Heat transfer is reduced in the double-layered wall, which reduces the energy consumption of the building.



(a)



(b)

Figure 4 (a). Effect of building form and number of layers on energy consumption for heating **(b).** Effect of building form and number of layers on energy consumption for cooling

The study results are important in terms of the relationship between additive manufacturing technologies and sustainable material use. It also provides guidance on the importance of building orientation in the freeform design of buildings. However, since traditional construction methods have been used for many years, buildings can be constructed with readily available equipment and less cost. Digital fabrication techniques require high research and development. Although the application is easy in digital production, the initial investment cost is high. Therefore, there are still challenges in additive manufacturing techniques.

REFERENCES

1. United Nations Department of Economic and Social Affairs (UN DESA), "World Population Prospects 2022: Summary of Results", https://population.un.org/wpp/Publications, 5 May 2024.

2. Glavic, P., "Evolution and current challenges of sustainable consumption and production", Sustainability, Vol.13, Issue 16, Pages 9379, 2021.

3. Sümer-Haydaraslan, K., Yaşar, Y., "Evaluation of building design strategies according to the effects of climate change by simulation-based optimisation: a case study for housing in different climate regions", International Journal of Global Warming, Vol.30, Issue 1, Pages 33-59, 2023.

4. Zhan, J., Liu, W., Wu, F., Li, Z., Wang, C., "Life cycle energy consumption and greenhouse gas emissions of urban residential buildings in Guangzhou City", Journal of Cleaner Production, Vol.194, Pages 318-326, 2018.

5. International Energy Agency, "Global Energy & CO_2 Status Report", https://www.iea.org/reports/global-energy-co2-status-report-2019, 15 January 2024.

6. www.iea.org/ International Energy Agency, Energy Technology Perspectives. 20 Temmuz 2023.

7. EPBD 2018, Directive 2010/31/EU of the European Parliament and of Council of 30 May 2018 on the energy performance of buildings (recast), EU Commission, Official Journal of the European Union, 2018.

8. Energy Information Administration, "International Energy Outlook 2021", https://www.eia.gov/todayinenergy/detail.php?id=49876, 10 January 2024.

9. Sümer-Haydaraslan, K., Dikmen, N., "Investigation of the effects of curtain wall angle on energy consumption in buildings", Journal of the Faculty of Engineering and Architecture of Gazi University, Vol.39, Issue 1, Pages 315-326, 2024.

10. Linner, T., Pan, W., Hu, R., Zhao, C., Iturralde, K., Taghavi, M., Trummer, J., Schlandt, M., Bock, T., "A technology management system for the development of single-task construction robots", Construction Innovation, Vol.20, Pages 96-111, 2020.

11. Ghaffar, S.H., Corker, J., Fan, M., "Additive manufacturing technology and its implementation in construction as an eco-innovative solution", Automation in Construction, Vol.93, Pages 1-11, 2018.

12. Brischetto, S., Maggiore, P., Ferro, C.G., "Special Issue on Additive Manufacturing Technologies and Applications", Technologies, Vol.5, Issue 3, Page 58, 2017.

13. Dong S., Yu Y., "Numerical and experimental studies on capturing behaviors of the inflatable manipulator inspired by fluidic origami structures", Engineering Structures, Vol.245, 112840, 2021.

14. Zhu A., Pauwels P., De Vries B., "Smart component-oriented method of construction robot coordination for prefabricated housing", Automation in Construction, Vol.129, 103778, 2021.

15. Gebhard L., Mata-Falc´on J., Anton A., Dillenburger B., Kaufmann W., "Structural behaviour of 3D printed concrete beams with various reinforcement strategies", Engineering Structures, Vol.240, 112380, 2021.

16. Ma, G., Wang, L., Ju, Y., "State-of-the-art of 3D printing technology of cementitious material an emerging technique for construction", Science China Technological Sciences, Vol.61, Pages 475-495, 2018.

17. Weng, Y., Li, M., Ruan, S., Wong, T.N., Tan, M.J., Yeong, K.L.O., Qian, S., "Comparative economic, environmental and productivity assessment of a concrete bathroom unit fabricated through 3D printing and a precast approach", Journal of Cleaner Production, Vol.261, 121245, 2020.

18. Sümer-Haydaraslan K., "Examining the effect of digital manufacturing and traditional building construction techniques on the building production process", Journal of Science and Technology, Vol.3, Issue 3, Pages 1-13, 2024.

19. Robayo-Salazar, R., Mejía de Gutiérrez, R., Villaquirán-Caicedo, M. A., Arjona, S.D., "3D printing with cementitious materials: Challenges and opportunities for the construction sector", Automation in Construction, Vol.146, 104693, 2023.

20. Youssef, N., Rabenantoandro, A.Z., Lafhaj, Z., Dakhli, Z., Chehade, F.H., Ducoulombier, L., "A novel approach of geopolymer formulation based on clay for additive manufacturing", Construction Robotics, Vol.5, Pages 175-190, 2021.

21. Davidovits, J., "Properties of Geopolymer Cements", International Conference on Alkaline Cements and Concretes, Pages 120-128, Kiev, 1994.

22. Khale D., Chaudhary, R., "Mechanism of geopolymerization and factors influencing its development: a review", Journal of Materials Science, Vol.42, Pages 729-746, 2007.

21. Brooks, J.J., Megat Johari, M.A., Mazloom, M., "Effect of admixtures on the setting times of high-strength concrete", Cement and Concrete Composites, Vol.22, Issue 4, Pages 293-301, 2000.

24. Bouzoubaâ, N., Lachemi, M., "Self-compacting concrete incorporating high volumes of class F fly ash", Cement and Concrete Research, Vol.31, Issue 3, Pages 413-420, 2001.

25. Ciampa, D., Cioffi, R., Colangelo, F., Diomedi, M., Farina, I., Olita, S., "Use of unbound materials for sustainable road infrastructures" Applied Sciences, Vol.10, Issue 10, 3465, 2020.

26. Galvez-Martos, J.L., Styles, D., Schoenberger, H., Zeschmar-Lahl, B., "Construction and demolition waste best management practice in Europe", Resources, Conservation and Recycling, Vol. 136, Pages 166-178, 2018.

27. Poblocki, K., Pawlak, M., Drzezdzon, J., Gawdzik, B., Jacewicz, D., "Clean production of geopolymers as an opportunity for sustainable development of the construction industry", Science of The Total Environment, Vol.928, 172579, 2024.

28. Singh, N.B., Middendorf, B., Geopolymers as an alternative to Portland cement: an Overview, Construction and Building Materials, Vol.237, 117455, 2020.

29. Abdel-Ghani, N.T., Elsayed, H.A., Abdel Moied, S., Geopolymer synthesis by the alkali-activation of blastfurnace steel slag and its fire-resistance. HBRC Journal, Vol.14, Issue 2, Pages 159-164, 2019.

30. Lv, X., Wang, K., He, Y., Cui, X., A green drying powder inorganic coating based on geopolymer technology, Construction and Building Materials, Vol. 214, Pages 441-448, 2019.

31. Youssef, N., Rabenantoandro, A.Z., Lafhaj, Z., Dakhli, Z., Chehade, F. H., Ducoulombier, L., A novel approach of geopolymer formulation based on clay for additive manufacturing, Construction Robotics, Vol 5, Pages 175-190, 2021.

32. Pacheco-Torgal, F., Alkali-activated binders: a review. Part 2. About materials and binders manufacture. Construction and Building Materials, Vol. 22, Pages 1315-1322, 2008.

33. Liu, Y., Su, P., Li, M., You, Z., Zhao, M., Review on evolution and evaluation of asphalt pavement structures and materials, Journal of Traffic and Transportation Engineering, Vol. 7, Issue 5, Pages 573-599, 2020.

34. Shill, S.K., Al-Deen, S., Ashraf, M., Hutchison, W., Resistance of fly ash based geopolymer mortar to both chemicals and high thermal cycles simultaneously, Construction and Building Materials, Vol. 239, 117886, 2020.

35. Panda, B., Singh, G.B., Unluer, C., Tan, M.J., “Synthesis and characterization of onepart geopolymers for extrusion-based 3D concrete printing”, Journal of Cleaner Production, Vol. 220, Pages 610-619, 2019.

36. Saruhan, V., Keskinateş, M., Felekoğlu, B., “A comprehensive review on fresh state rheological properties of extrusion mortars designed for 3D printing applications”, Construction and Building Materials, Vol. 337, 127629, 2022.

37. Xia, M., Sanjayan, J., “Method of formulating geopolymer for 3D printing for construction applications”, Materials & Design, Vol. 110, Pages 382-390, 2016.

38. Pegna, J., “Exploratory investigation of solid freeform construction”, Automation in Construction, Vol.5, Issue 5, Pages 427-437, 1997.

39. Mohsen, A., “Design to manufacture of complex building envelopes”, Pages 42-100, Springer, Berlin, 2020.

40. Nguyen, L., Moseson, A.J., Farnam, Y., Spatari, S., “Effects of composition and transportation logistics on environmental, energy and cost metrics for the production of alternative cementitious binders”, Journal of Cleaner Production, Vol.185, Pages 628-645, 2018.

41. Turkish Standardization Institute, ‘TS825: thermal insulation requirements for buildings’, TSE, 2018.

42. Al-Sallal, K.A., Solar access/shading and building form: Geometrical study of the traditional housing cluster in Sana'a, Renewable Energy, Vol.8, Issues 1-4, Pages 331-334, 1996.

43. Chan, A.L.S., “Developing future hourly weather files for studying the impact of climate change on building energy performance in Hong Kong”, Energy and Buildings, Vol. 43, Issue 10, Pages 2860-2868, 2011.

44. Alam, M., Jamil, H., Sanjayan, J., Wilson, “Energy saving potential of phase change materials in major Australian cities”, Energy and Buildings, Vol.78, Pages 192-201, 2014.

45. Kuznik, F., Virgone, J., “Experimental assessment of a phase change material for wall building use”, Applied Energy, Vol.86, Issue 10, Pages 2038-2046, 2009.

46. DesignBuilder Software, “Tutorials”, www.designbuilder.co.uk, June 3, 2024.

47. Rashdi, W., and Embi. M., Analysing Optimum Building Form in Relation to Lower Cooling Load, Procedia-Social and Behavioral Sciences, Vol.222 Pages 782-790, 2016.

48. Kocagil, I. E., and Oral, G. K., The Effect of Building Form and Settlement Texture on Energy Efficiency for Hot Dry Climate Zone in Turkey. Energy Procedia, Vol. 78, Issue 2315, Pages 1835-40, 2015.

49. de Oliveira Neves, L. and Marques, T. H. T., Building Envelope Energy Performance of High-rise Office buildings in Sao Paulo City, Brazil, Procedia Environmental Sciences, Vol. 38, Pages 821-29, 2017.

50. Haydaraslan, E., Çuhadaroğlu, B., “Analysis of the Effect of Hollow Geometry of Wall Blocks on Heat Transfer”, Düzce University Journal of Science and Technology, Vol.10, Issue 4, Pages 2028-2038, 2022.