



Building Digital Twin – Digitalisation of the Thermo-accumulator Used for the Building’s Heating

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Abstract. When creating a digital twin of a building, all engineering system devices within the building must be digitised and integrated into the numerical model. This research focused on describing the processes occurring in a heat storage system, which was designed to accumulate heat during the summer period and utilise it by the building’s heating during the cold period. This is a long-term acting heat storage system with a soil-type filler. Several stages of the thermal energy storage system operation were distinguished: charging, discharging, and heat retention. During all these processes, heat exchange with the environment occurs. Typically, it is heat loss to the environment. Experimental research was performed in field conditions to analyse the mentioned processes. After each charge, the heat was dissipated in the soil volume. The output signals of the sensors were recorded and analysed. It was noticed that two temperature measurement sensors are necessary to estimate the type of work regime and charge or discharge intensity. More sensors are needed to determine the amount of stored energy more accurately.

Creating a validated numerical model and comparing measured temperatures with simulated values at the same points enables a highly accurate assessment of the stored energy in the accumulator, as well as the description and forecast of parameter changes. By integrating the numerical model of the accumulator into the building’s digital twin and combining it with building engineering systems models, it is possible to enhance the efficiency of the building’s engineering systems and reduce energy consumption.

Keywords: Thermo-accumulator · Heat Storage · Heat Transfer · Digital Twin · Soil

1 Introduction

Numerical research methods have made a breakthrough in the field of scientific research [1]. Complex systems of differential equations have become surmountable, and the possibility appeared to create mathematical models of a process, phenomenon, or device [2].

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A. Jurelionis et al. (Eds.): BDTIC 2025, LNCE 775, pp. 123–133, 2026.

https://doi.org/10.1007/978-3-032-09040-9_11

That has dramatically facilitated the conduct of experimental research. After modelling various possible scenarios, only the most optimal cases are experimentally tested, thus saving equipment and time [3]. It is also possible to test critical or dangerous cases without conducting experiments. Using statistical analysis to analyse experimental research data, predict results, and evaluate various scenarios is possible [4]. The focus is on more serious challenges, such as creating digital twins. It means making the most realistic image of an object in a virtual space [5]. For this purpose, the virtual twin must be coherent with the real object. The interface may be realised by using the sensors, whose signals determine the state of the object and the ongoing processes [6]. Since the object is in a surrounding environment, it is appropriate to measure and know at least the environment's main parameters [7]. Monitoring changes in these parameters enables the accurate determination of the impact on the object and the prediction of what will happen after a specific time interval [8].

What are the benefits of digital twins? It is the possibility of the more efficient use of the object, its more effective operation, the extension of its life, the ability to avoid undesirable situations, to experience as little loss as possible, and so on. In general, on the one hand, this is a purely economic benefit; on the other hand, it is a sustainable interaction of the object with the surrounding environment [9].

In the civil engineering sector, it is necessary to consider the object's functions when making its digital twin. It may be a dam, as an example of the object, the functions of which are to withstand loads acting from the side of the pond, to stop the motion of groundwater, to extinguish the kinetic energy of the flow being passed, etc. On the other hand, a bridge must withstand dynamic loads, possible vibrations, etc. [10].

The digital twin of a building is understood as a complex image in virtual space, covering not only the structural integrity but also the heating, ventilation, and automatic regulation of air parameters, indoor lighting, plumbing, and other engineering systems. Interaction with the environment is also essential. The atmospheric air temperature, daylight hours, solar radiation intensity, and other factors must be known. If the definition of the building's environmental parameters, depending on seasonality, can be based on the stored data of meteorological stations (Construction Climatology), the inside parameters of the buildings must be measured in real time. It is not enough to observe the collected data; numerical simulation needs to be performed, and a way must be sought to optimise the operational properties of the building [7].

Collecting data makes it possible to assess not only the possible heat losses to the environment but also the efficiency of all engineering systems in the building. After numerical simulations have determined the optimal regime of the engineering system, it is possible to compare that with the real one and change the parameters of the controllers, leading the actual system to an optimal operational regime. By analysing the parameters and operation of the systems during the day, week, month, season, and year, it is possible to find a way to optimise the long-term operation of any engineering system and reduce energy consumption [11].

Managing the building's heating and cooling systems ensures the highest energy efficiency, thus reducing operating costs. Digital twins allow the simulation and optimisation of heat or coolness flows, heat accumulation, and dissipation while selecting the best methods and scenarios for the ventilation of the accommodations [11].

The investigation discussed in this article concerns an individual building with a living area of $100 \div 200 \text{ m}^2$. Solar collectors produce heat for the building's heating. A water tank-type heat accumulator can be installed inside the building to distribute better heat for heating the building for one or a few days. The phase change materials should be used as the fillers for the thermal accumulator to extend the heat storage period to a week. A soil-type heat accumulator was installed below the building to extend the time to the interseasonal period.

This research aimed to digitise the processes in the heat accumulator and create a digital twin of a soil-type thermo-accumulator. The questions to be answered are: What needs to be known, and where and how are the parameters required to be measured to estimate the amount of stored energy? On the other hand, the thermo-accumulator must be integrated into the building's engineering systems and the digital twin of the entire building.

By supplementing the building digital twin with a digitalised thermo-accumulator operating on real-time data, modelling, optimising, and predicting the operation of the heating and cooling systems, it is possible to increase the efficiency of building heating systems and contribute to the broader goal of sustainable energy use. In a later step, going to the larger scale's heat storage could significantly contribute to the creation of smart cities.

2 Digitalisation of the Thermal Energy Storage System

The thermal energy of a constant-volume body is directly related to its internal energy, which in turn depends on its temperature. The temperature is often measured relative to a reference temperature, thereby defining the amount of energy in relation to the reference. In the case of a thermal storage system, the reference could be a value set by the energy consumer based on what the heat will be used for. In the case of building heating, the indoor air temperature that needs to be maintained is determined. It can be a fixed value of this temperature taken as a reference. On the other hand, it would be the value of the task signal for the temperature maintenance system controller, e.g., $T_{set} = 20 \text{ }^\circ\text{C}$. Then, if the average temperature of the heat accumulator's ground filler T_{av_ac} is higher than the aforementioned task temperature T_{set} ($T_{av_ac} > T_{set}$), the heat storage is charged with heat. In the case of the heat pump use, the temperature of the freezing point of water can be set as a reference ($T_{set} = 0 \text{ }^\circ\text{C}$). Using the soil temperature surrounding the heat storage system below the ground surface ($h > 1 \text{ m}$) is complicated as a reference temperature. This temperature depends on the season, and heat losses from the storage system can also affect it.

The amount of energy charged into the heat storage system E_{st} can be found by Eq. (1):

$$E_{st} = \rho V c_p (T_{av_ac} - T_{set}). \quad (1)$$

where:

ρ – Density of the soil, kg/m^3 .

V – Accumulator's volume, m^3 .

c_p – Specific heat of the soil, $\text{J}/(\text{kg} \cdot \text{K})$.

t – Time, s.

The process of the charge or discharge can be described by Eq. (2) (Fig. 1):

$$E_{st} = \rho V c_p \Delta T_{av_ac} = k \rho V c_p (T_{t(j+1)} - T_{t(j)}). \quad (2)$$

where:

k – Empirical coefficient, dimensionless.

T_t – Temperature measured at the point of the accumulator, °C.

j – Time moment, s.

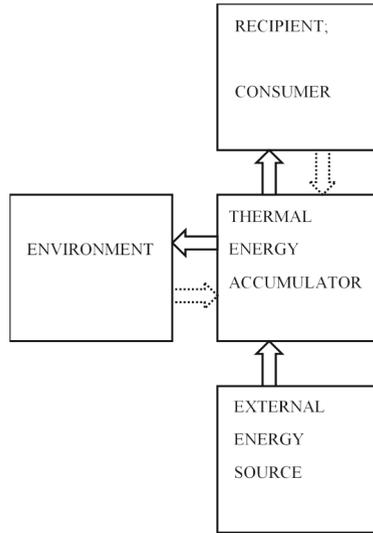


Fig. 1. Operating scheme of the heat storage system.

The change in the temperature of the soil filler over time can show what process is taking place: the temperature increase $\Delta T_{av_ac}/t > 0$ means that the heat storage system is charging; $\Delta T_{av_ac}/t \leq 0$ means discharge or heat loss E_{loss} to the environment. Heat loss to the environment occurs continuously. The soil surrounding the heat storage system acts as a secondary heat storage. It would be appropriate to measure its temperature T_{s_gr} . This would allow us to understand the state of the soil outside the heat storage system. A slow change in the temperature T_{s_gr} (when the depth $h \geq 1$ m) indicates seasonality, and a more intense change in T_{s_gr} indicates that the heat storage system has probably been charged or is charging. Then, the temperature of the soil filler increases, and the temperature difference $\Delta T_{loss} = T_{av_ac} - T_{s_gr}$ also increases. This means a possible increase in heat loss to the environment. When the heat storage system is discharged, the temperature difference ΔT_{loss} decreases. If the temperature of the accumulator's filler becomes lower than that of the ground outside, a change in the direction of heat spread is possible.

For the minimum requirement, the heat storage system's temperature should be measured at least at one point. However, a very pronounced inertia will be observed.

Therefore, measuring the temperatures of the system's filling at least at two points is recommended. One temperature sensor could be installed next to or at least closer in the distance of $l = 0.1 \div 0.2$ m to the energy source, and the other sensor could be installed in the centre of the heat storage system's volume, limited by its walls and the heating circuit.

What parameters need to be known to describe the soil-type accumulator itself? First, the parameters of the soil, which was used as the filler, are needed: type, density, and moisture. Afterwards, the heat capacity of the soil (the ability to store heat) and thermal conductivity (a parameter required to calculate charge or discharge intensity, also related to heat loss). Next are the heat storage system's capacity dimensions: height, length, and width. Based on that, the volume may be found, and based on the volume, it is possible to compute the amount of energy that could be charged. The depth at which the heat accumulator is located is needed as well. There should be no interaction with the groundwater. Therefore, the level of the water table can be indicated. Depending on the depth, the type and moisture of the surrounding soil should also be defined. Structural features of the heat storage system: thickness, material, and properties of each layer of the thermo-accumulator's walls, if the walls were constructed.

In the case of high accuracy heat storage system's model preparation, the accumulator's thermal charging device must be described: the external energy source itself, the power of the energy source and its variation over time, the type of thermal charging device (electrical, heated fluid flow, etc.), the position of the charging device in the filler (bottom, inner part, center, top), the shape and dimensions of the charging device (tubes, tube loop, tube coil, flat surface - single-sided, double-sided, etc.). The energy extraction, i.e., thermal discharge device, must be described similarly.

3 Methodology

The experiments were conducted in field conditions. The heat storage system was placed underground at a depth of 0.2 m below the ground surface. The accumulator had the shape of a parallelepiped, whose internal volume was equal to $V = 0.25 \text{ m}^3$ (Fig. 2). The horizontal cross-section was square, and the area (A) was equal to $A = 0.5 \times 0.5 = 0.25 \text{ m}^2$. The height was equal to 1 m. The accumulator's volume was filled with sand of 10% moisture. Sand parameters were such: $\rho = 1845 \text{ kg/m}^3$, $\lambda = 1.7 \div 2.0 \text{ W/(m}\cdot\text{K)}$, $c_p = 1200 \div 1300 \text{ J/(kg}\cdot\text{K)}$ [12].

Two heating devices were constructed; however, the first, located at the top of the heat storage system, was not utilised in this experimental research. Therefore, it is not described. The second heating device was made from heating tubes and covered by a flat steel surface. This device was placed at the bottom of the heat storage system. The electric resistance of the heating tubes was equal to $R = 71.4 \Omega$. The electric current I was measured during the experiments by a special multimeter of the ESCORT 3136A type. Five temperature sensors, TJ1-Pt1000/A, were used for the temperature measurement and placed at a vertical distance equal to $h = 0, 0.1, 0.5, 0.9,$ and 1.0 m from the heated surface centre. Data Logger PT-104, connected to the computer, was used to read the sensors' signals.

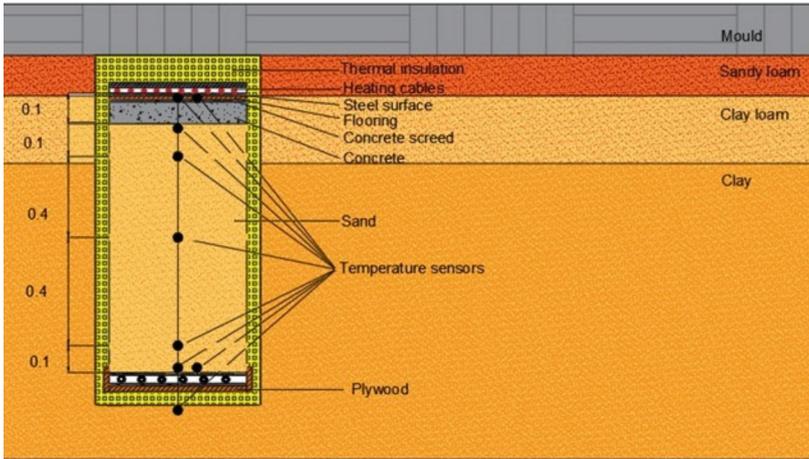


Fig. 2. Experimental setup.

The heat storage system's operation was simulated numerically using COMSOL software, version 6.1. A numerical simulation of a thermal accumulator constructed below the building (Fig. 3) was planned in the next step.

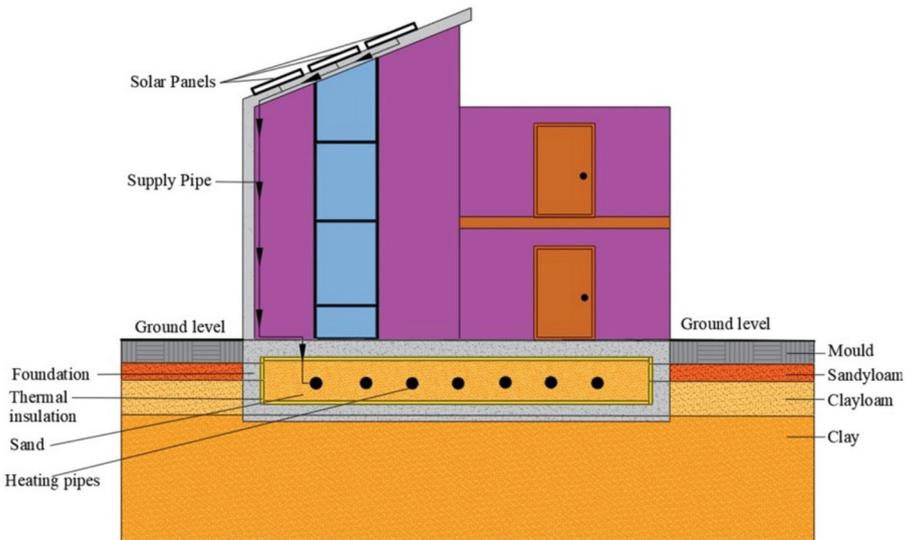


Fig. 3. Heat storage system constructed below the building.

4 Results

The results of experimental research on the heat storage system's charge are presented in Fig. 4. During this two-hour charge, the heating device consumed 1.39 kWh of electricity. When the heating device was turned on, the energy was used to heat the heating elements and the surface. Hence, the temperature sensor installed at the centre of the heated surface from the ground side began to respond after 72 s. The moment of connecting the heating device can be used as a reference point, but the ground filler begins to charge when the sensor responds. That can also serve as a reference point. When the heating device was disconnected, its temperature was higher than the ground. This meant that the thermal charge continued until the temperatures equalised. Therefore, temperature sensors are of priority.

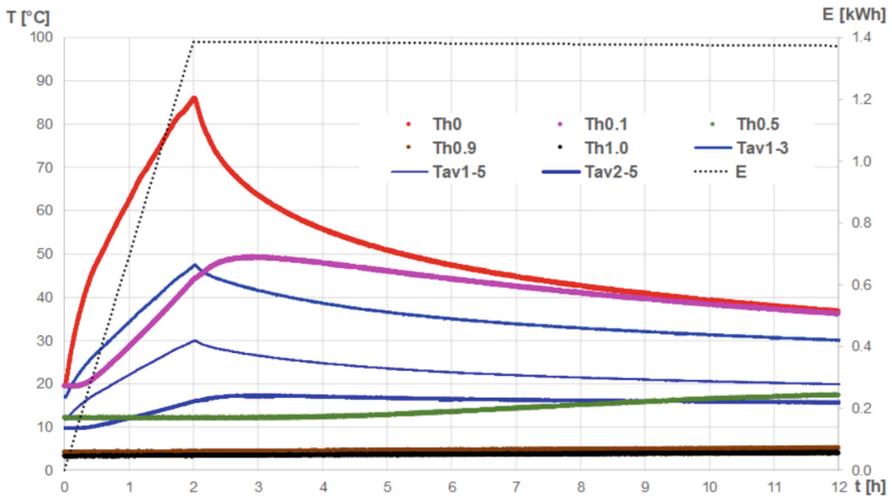


Fig. 4. Change in temperature at different points of the thermo-accumulator, an average temperature change depending on time, and the amount of energy charged to the accumulator.

As the heat spread to other soil layers, sensors at varying distances from the heating device measured the first temperature change at later times. During the experiment, the sensor installed at a distance of $h = 0.1$ m began to record the temperature increase after $t = 11$ min 24 s, and at a distance of $h = 0.5$ m, after two and a half hours.

Analysing the character of the temperature change of the heat storage system's soil filler, the temperature T_{h0} measured at the heating device quite accurately defines the time of thermal charging. At a distance of $h = 0.1$ m ($T_{h0.1}$), a delay in time was observed, and at a distance of $h = 0.5$ m, no change in temperature $T_{h0.5}$ was observed in the first two hours, corresponding to the accumulator's charging.

After the thermal charge was completed, temperature T_{h0} decreased. However, the heat from the more heated soil layer spread to cooler soil layers (Fig. 2). Almost an hour later, temperature $T_{h0.1}$ also began to decrease. However, temperature $T_{h0.5}$ increased because heat was dissipated throughout the filler and reached its centre.

Five temperature sensors were placed in the heat storage system's filler. Two average temperatures were calculated: $T_{av1-3} = (T_{h0} + T_{h0.1} + T_{h0.5})/3$ and $T_{av1-5} = (T_{h0} + T_{h0.1} + T_{h0.5} + T_{h0.9} + T_{h1.0})/5$. Significantly higher values of temperatures T_{h0} and $T_{h0.1}$ affected the nature of the variation of T_{av1-3} and T_{av1-5} and inaccurately described the processes occurring in the accumulator. According to the readings and T_{av1-3} and T_{av1-5} calculations, an erroneous conclusion may be drawn about the energy use in the accumulator, that is, discharge or heat loss to the environment.

By eliminating the readings of the first sensor and calculating the average filler temperature as follows: $T_{av2-5} = (T_{h0.1} + T_{h0.5} + T_{h0.9} + T_{h1.0})/4$, a more accurate description of the process may be obtained. However, the slight decrease in temperature T_{av2-5} after the end of the charge introduces uncertainties.

It can be stated that the first sensor, which measures the temperature T_{h0} , is needed to determine the start of the charge, heat exchange conditions, and charge duration. For a detailed determination of the processes occurring in the heat storage system, at least two sensors are required in the soil filler itself.

If the parameters of the thermal charge or discharge device were measured, it would be possible to compute the amount of energy put into the heat storage system. In our case, these were the electrical parameters of the heating device: resistance and electric current. In the case of heat carrier fluid usage, the flow rate and the inlet and outlet fluid temperatures should be measured. Combining this data with measurements of filler temperatures would allow for a much better assessment of the processes occurring in the accumulator. The heat loss should also be determined.

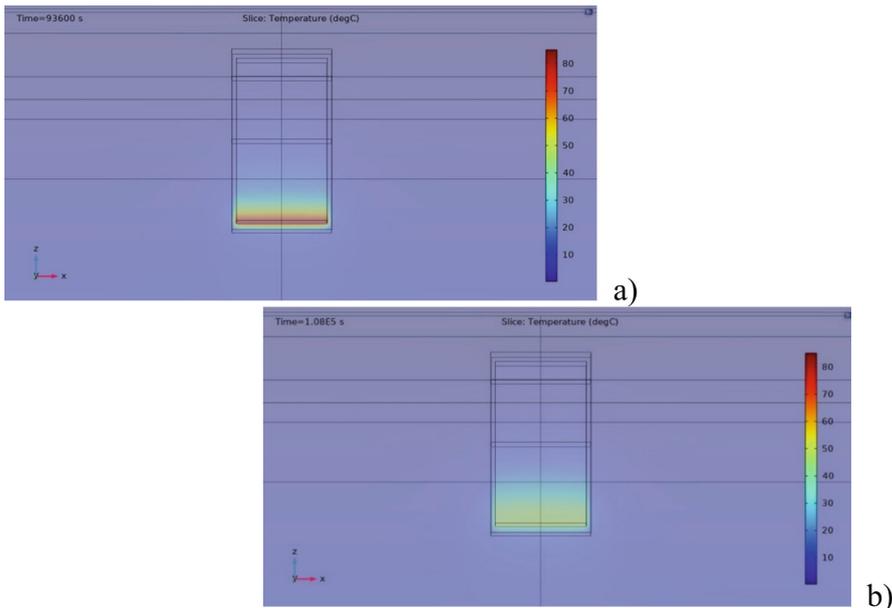


Fig. 5. The temperature profiles of the soil accumulator and surrounding ground in the case of the accumulator's model after $t = 2$ h (a) and 6 h (b).

It is possible to operate with the average soil-type heat accumulator temperature T_{av2-5} , using data from sensors located further from the charging and discharging devices. Then, evaluating the change in T_{av2-5} over time makes it possible to assess the processes in the filler. However, the assessment will be approximate without the first-mentioned sensor in contact with the heating or cooling device.

At least one, preferably several, temperature sensors, which can be placed on the outside of the heat storage system, above, below, and at its walls, are needed to assess heat losses to the environment.

Having a heat storage system model (Fig. 5) would make it possible to reduce the number of sensors, and the assessment of the processes would be much more accurate.

Temperature sensors placed in the filler of the accumulator should be connected to the data logger to enable the signal to be read and transmitted remotely. The temperature and the other sensors can be connected to a cloud-based database using communication protocols such as Modbus, MQTT, or BACnet. The collected data can be transmitted and processed using AWS IoT. The digital twin of the heat accumulator needs to be created and integrated into the digital twin of the building using BIM. We recommend using COMSOL Multiphysics, but ANSYS is also very helpful in simulating the heat storage system's thermal processes: the charge and discharge of the heat storage system and heat loss to the environment. After the model of the thermo-accumulator is created, it is possible to use AI, train machine learning models for specific tasks or write a program for the unique algorithms. The tasks may be different, such as optimising thermal storage based on weather forecasts and building occupancy. The predicted results can be checked with actual results after a certain time, ensuring the accuracy of the predictions. It is necessary to display heat accumulator performance in real-time. Mobile apps would be used to monitor and control the accumulator's operation remotely.

5 Conclusions

When developing a digital twin of a building that includes a thermal energy storage device, it is necessary to understand the principles of the heat storage system's operation. Mathematical models and numerical simulations enable us to determine the optimal number of temperature-measuring devices and place them most effectively.

Heat dissipation in the ground is a relatively slow process. Therefore, at least several temperature sensors are required to monitor, evaluate, and describe the processes in the soil-type heat storage system in real time. At least one sensor should be in contact with or near the thermal charging and discharging systems. An additional temperature sensor, which is 0.1–0.5 m away from the walls and devices placed in the ground, is required to assess the amount of energy stored in the ground. At least one temperature sensor is needed outside the heat accumulator to determine heat losses.

Creating a numerical model of the heat storage system enables the simulation of actual heat transfer within the accumulator. Additionally, measuring temperatures in real time improves the validation and calibration of the model. Then, it is possible to calculate the amount of energy accumulated in the heat storage system with great accuracy, predict the course of processes in the future and forecast the results. That allows the digitised heat storage system to be integrated into the digital twin of the building, which in turn can increase the efficiency of the building's engineering systems and save energy.

References

1. Iordache D.A., Sterian P.E.: Study of some complex systems by using numerical methods. Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 10961 (2018). LNCS: 539–559. https://doi.org/10.1007/978-3-319-95165-2_38
2. Foundations of Modelling and Simulation of Complex Systems. In: Proceedings of the Conference. 220054321 Foundations_of_Modelling_and_Simulation_of_Complex_Systems. <https://www.researchgate.net/publication/>. Last accessed 22 March 2025
3. Witkowski, K., Kudra, G., Wasilewski, G., Awrejcewicz, J.: Mathematical modelling, numerical and experimental analysis of one-degree-of-freedom oscillator with Duffing-type stiffness. *Int. J. Non Linear Mech.* **138**, 103859 (2022). <https://doi.org/10.1016/J.IJNONLINMEC.2021.103859>
4. The Beginner's Guide to Statistical Analysis|5 Steps&Examples. https://www.scribbr.com/category/statistics/?utm_source=chatgpt.com. (Accepted: 22 March 2025)
5. Fuller, A., Fan, Z., Day, C., Barlow, C.: Digital twin: enabling technologies, challenges and open research. *IEEE Access* **8**, 108952–108971 (2020). <https://doi.org/10.1109/ACCESS.2020.2998358>
6. IoT and Digital Twin Technology: Shaping the Future of Industry and Innovation - IoT Business News. <https://iotbusinessnews.com/2023/11/14/08950-iot-and-digital-twin-technology-shaping-the-future-of-industry-and-innovation/>. Last accessed 22 March 2025
7. Yan, J., Lu, Q., Li, N., Chen, L., Pitt, M.: Common data environment for digital twins from building to city levels. *Autom. Constr.* **174**, 106131 (2025). <https://doi.org/10.1016/J.AUTCON.2025.106131>
8. Van Dinter, R., Tekinerdogan, B., Catal, C.: Predictive maintenance using digital twins: a systematic literature review. *Inf. Softw. Technol.* **151**, 107008 (2022). <https://doi.org/10.1016/J.INFSOF.2022.107008>
9. Grieves, M., Vickers, J.: Digital twin: mitigating unpredictable, undesirable emergent behavior in complex systems. In: *Transdisciplinary Perspectives on Complex Systems: New Findings and Approaches*, pp. 85–113. Springer, Heidelberg (2017). https://doi.org/10.1007/978-3-319-38756-7_4
10. Liu, Z., et al.: Near-real-time carbon emission accounting technology toward carbon neutrality. *Engineering* **14**, 44–51 (2022). <https://doi.org/10.1016/J.ENG.2021.12.019>
11. Bortolini, R., Rodrigues, R., Alavi, H., Vecchia, L.F.D., Forcada, N.: Digital twins' applications for building energy efficiency: a review. *Energies (Basel)* **15**(19) (2022). <https://doi.org/10.3390/EN15197002>
12. Campanale, M., Moro, L., Siligardi, C.: Thermal properties of sands and their dependence on physical and environmental factors. *Sci. Rep.* **15**(1), 8352 (2025). <https://doi.org/10.1038/S41598-025-93054-W>

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