Integrating Artificial Neural Networks for Learning from Physically Collected Performance Data

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This project investigates potentials of integrating artificial intelligence in the digital fabrication process to approximate climatic performance digitally for design evaluation before fabrication. As an evaporative experiment cooling of robotically printed clay pots is studied. Instead of building a simulation model, the project proposes to use artificial neural networks (ANNs) to learn from geometric features and their relation to physically recorded data. The trained ANN is then used to approximate the performance of the newly generated digital models. After testing the feasibility of such an approximation method, it is aimed to scale the experiment in a larger, architectural scale.

In a workshop at IaaC, students were asked to design 'Zheer Pots' which is a double-layered system containing two clay pots, that is activated through the deposition of water into the sand layer in-between. When the water starts to evaporate, the surface temperature of both pots decreases, this influences the temperature decrease in the inner pot. The indicators that influence this decrease are the morphologic properties of the clay pot such as the noise and the thickness as well as the properties of the physical environment, namely humidity, wind velocity and the high temperature which accelerate the evaporation process. In the experiment, the environmental properties were monitored to test the relationship between morphology and cooling performance. Students were asked to develop a design strategy that influences the cooling, making assumptions about the design related indicators. These designs were then robotically printed to track their performance.

By deposition of the water in the system, robotically-printed samples were activated, and their reactions were recorded. These reactions were tracked by thermal imaging and temperature sensors to generate a training set for ANN. One of the limitations in working with physical samples and ANNs is the generation of a training set. If a single print would be taken as one training sample, a very large set of prints had to be generated, which would require a long printing process. Therefore, a machine learning model was developed by subdividing a pot in a set of samples by representing it to ANN as a collection of mesh vertices. Each mesh vertex was analyzed according to its geometric feature, i.e. the amount convexity or concavity of the certain point regarding to its neighboring vertices (Wilkinson,2014), the thickness of the print at that location and its corresponding temperature performance recorded by thermal imaging. This information for each mesh-vertex was represented to the ANN as one training sample. Such training model enabled to generate a set of 2000 samples from one single print, which ended up in a good performance in approximation.

In a further step, an evolutionary learning method (CPPN) was used to generate new digital samples. Compositional Pattern Producing Networks-CPPN (Stanley,2007) was implemented as a parametrization method to learn from the good performing local morphological features and generate new local features that generate noise patterns on the surface of the pot. Without having information on the global geometry, the CPPN was generating features by only displacing the mesh points of an initially represented shape without any surface noise. The trained ANN was approximating the performance of the generated local features to incrementally train the CPPN to generate good patterns. A set of different samples were inherited at the end of this process, that differ in the surface feature, however, share similar behavior of increasing the surface area. One of the best performing results according to approximation were printed and tested in the physical environment to validate the feasibility of the developed process and the possibility of integrating such process in larger scale experiments.

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[Journal Article] Stanley, Kenneth O.2007. “Compositional Pattern Producing Networks: A Novel Abstraction of Development.” *IGenetic Programming and Evolvable Machines 8(2), 131-162*

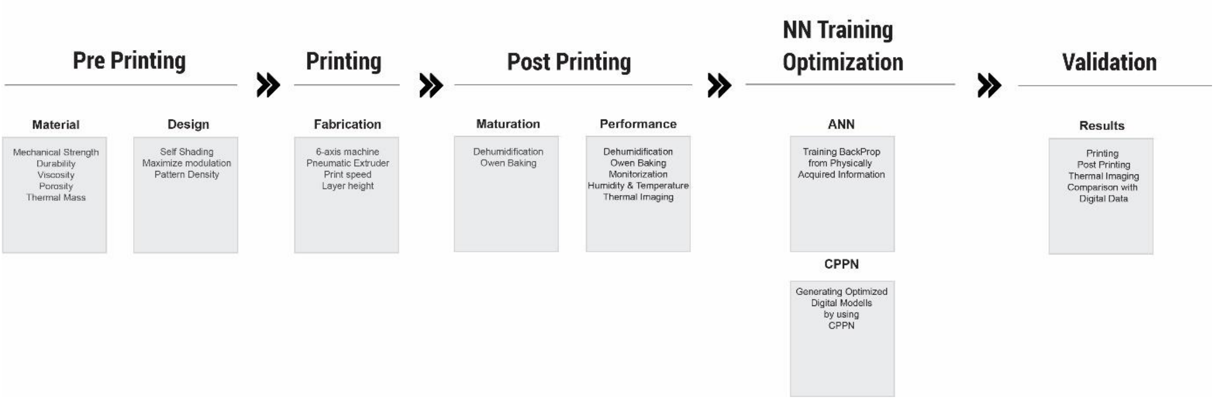

Figure 11 Acquiring climatic information using thermal imaging from robotically printed clay pot (Kunaljit Chadha, 07/2018, ©IaaC).

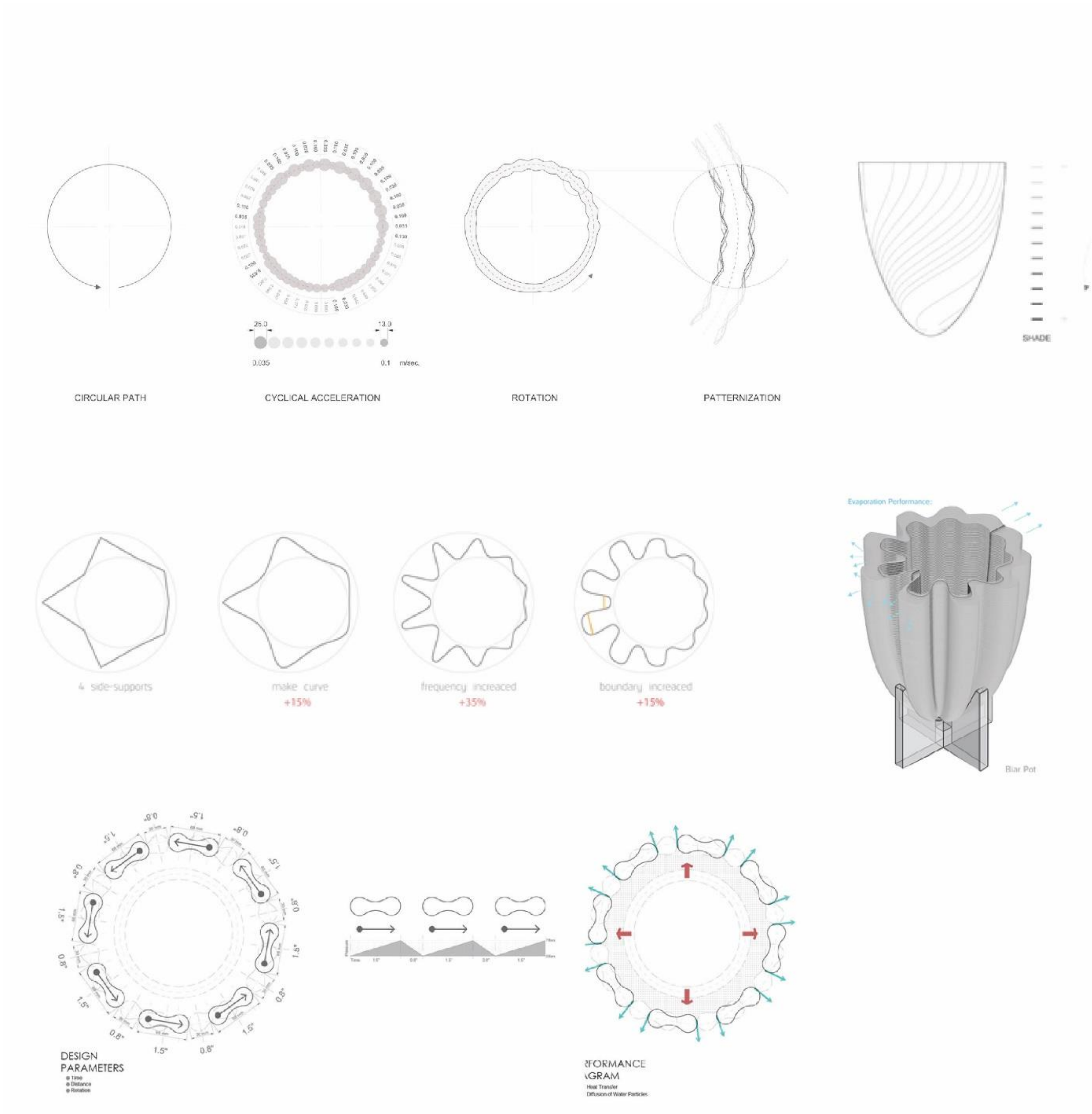

Figure 2 Some of the strategies developed by the students during the workshop to increase the cooling performance (©IaaC)

Figure 3 Some of the strategies developed by the students during the workshop to increase the cooling performance(©IaaC)

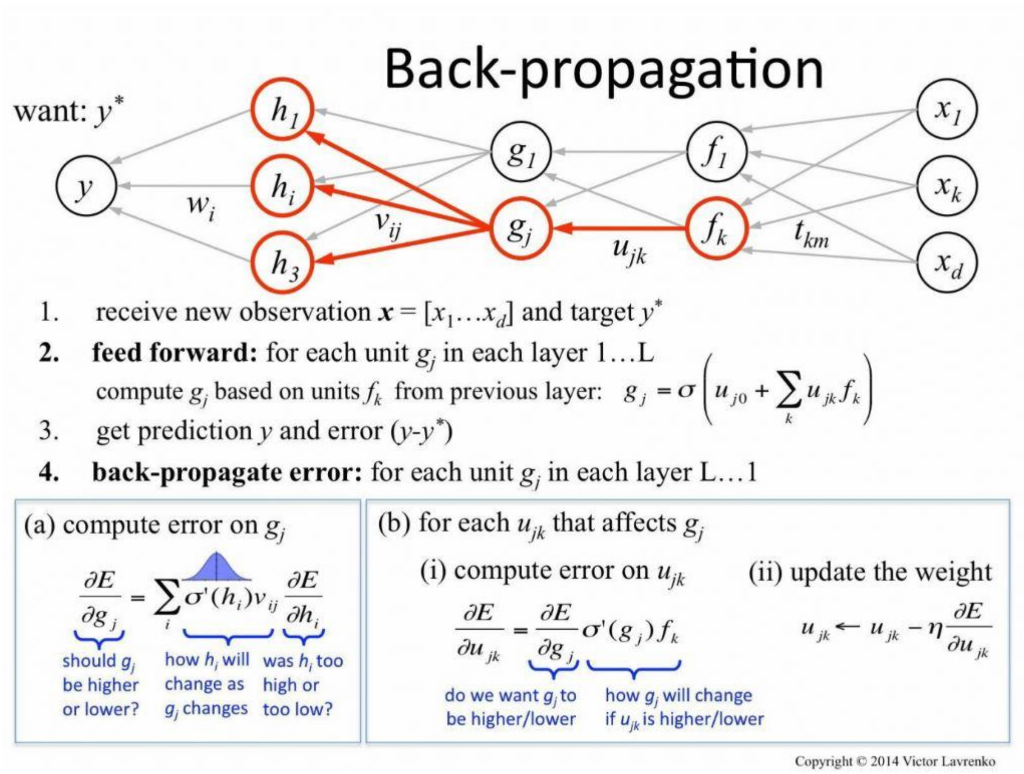

Figure 4 Backpropagation is a type of artificial neural network in machine learning that during the learning process calculates the amount of error in the approximation by comparing the approximated solution and the inputs represented to the system. (©Viktor Levrenko)[1]

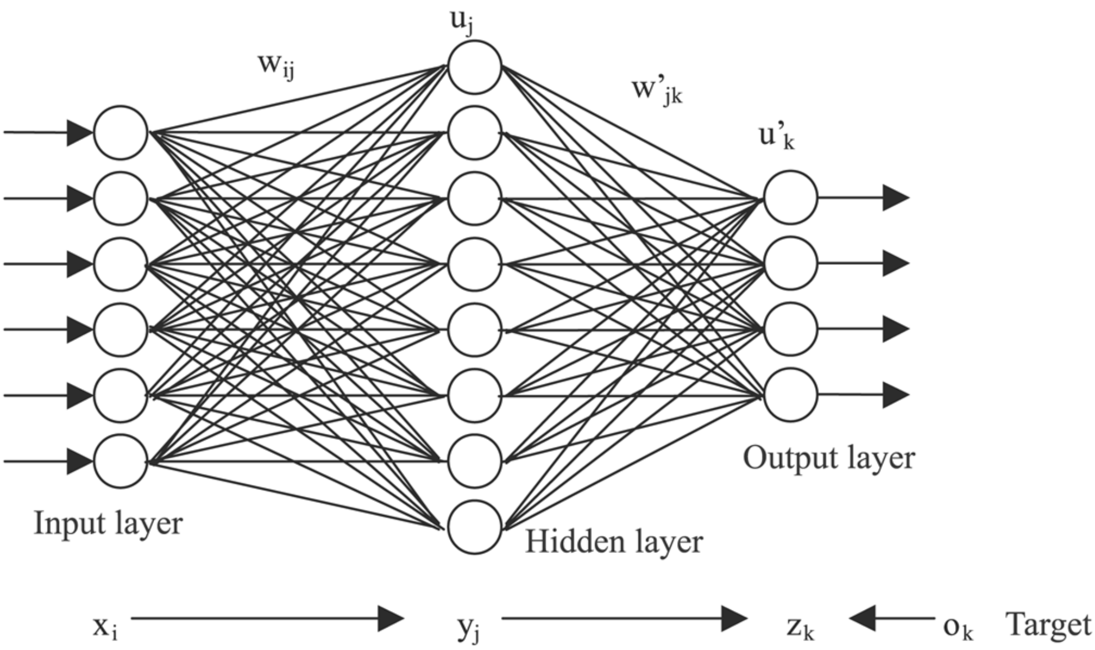

Figure 5 Supervised learning with Artificial Neural Networks is a type of artificial intelligence algorithms, that approximate a function using mathematical formula regarding represented input and output values. This method takes their inspiration from biology. Each input and output is represented as a neuron, a node that contains a bit of information. The hidden layers in between contain neurons that inherit a mathematical function. These neurons are connected to other layers by so-called weights, which are numeric values that pass through the function inherited in the neurons. By iteratively updating the weights the neural network tries to achieve an accurate approximation.[2]

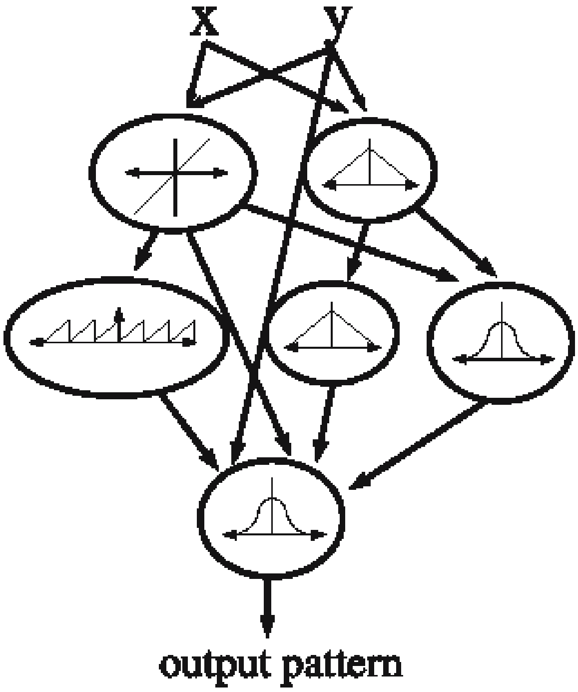

Figure 6 Compositional Pattern Producing networks are a type of artificial intelligence algorithm that can improve the topology of Neural Networks in an iterative process to achieve a goal that is represented to the system. These algorithms can also accommodate different functions than typical functions such as sigmoid, reLu and bipolar Sigmoid, in the neurons, which is usually common in the conventional Artificial Neural Networks.[3]

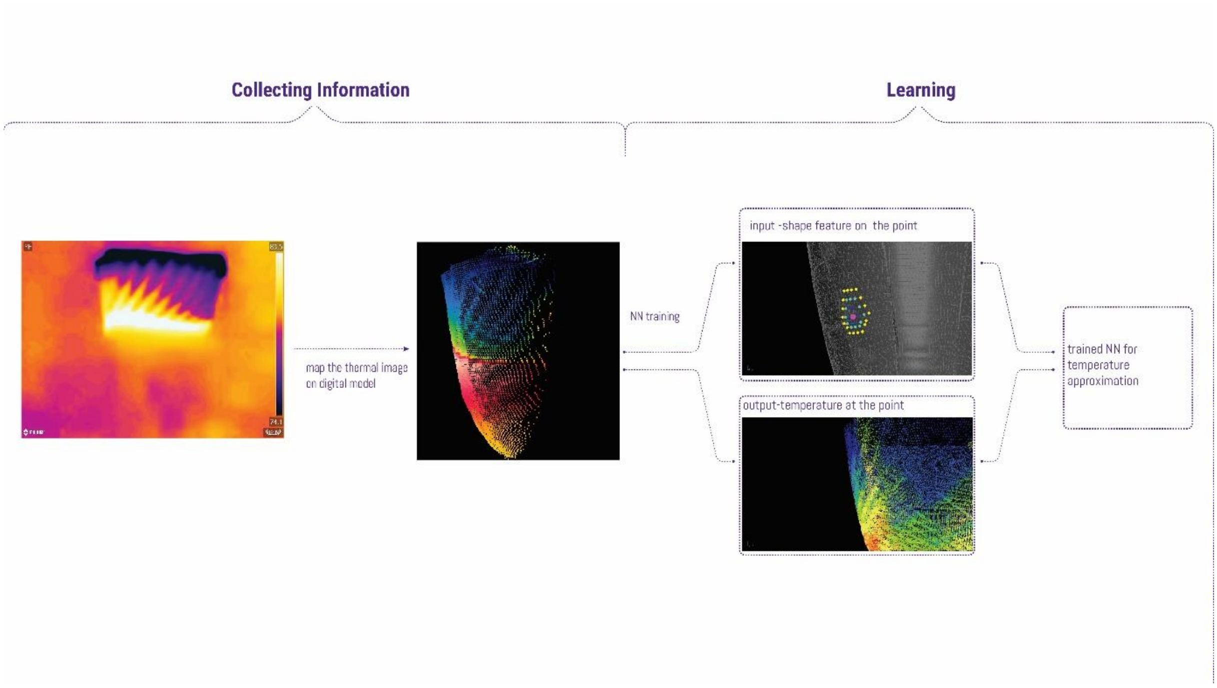

Figure 7Training process overview physically acquired data is mapped on the digital model.The digital model is represented to the BackProp Neural Network as a set of mesh points and their geometric features. As output, the mapped surface temperature on the certain mesh vertex is represented. (©Zeynep Aksöz)

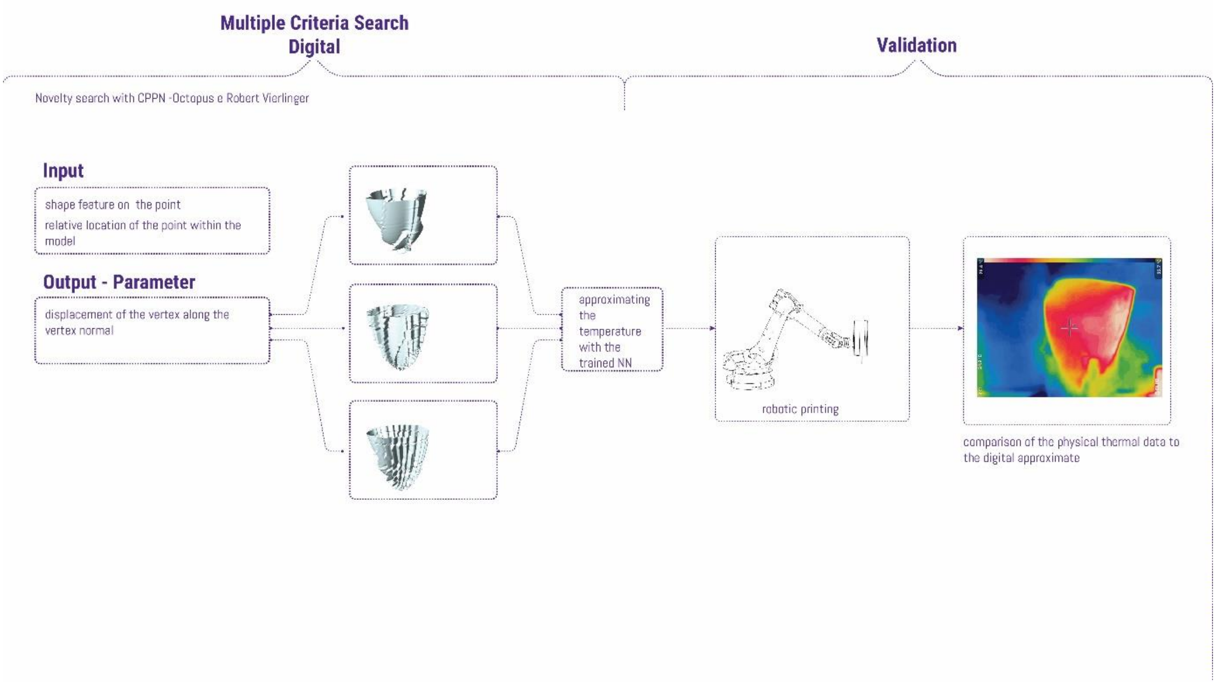

Figure 8 Generative design process using CPPNs to learn to develop good performing local geometric features basing on the previously trained temperature approximation NN and evaluation of the optimized model by robotic printing and tracking with thermal imaging. (© Zeynep Aksöz)

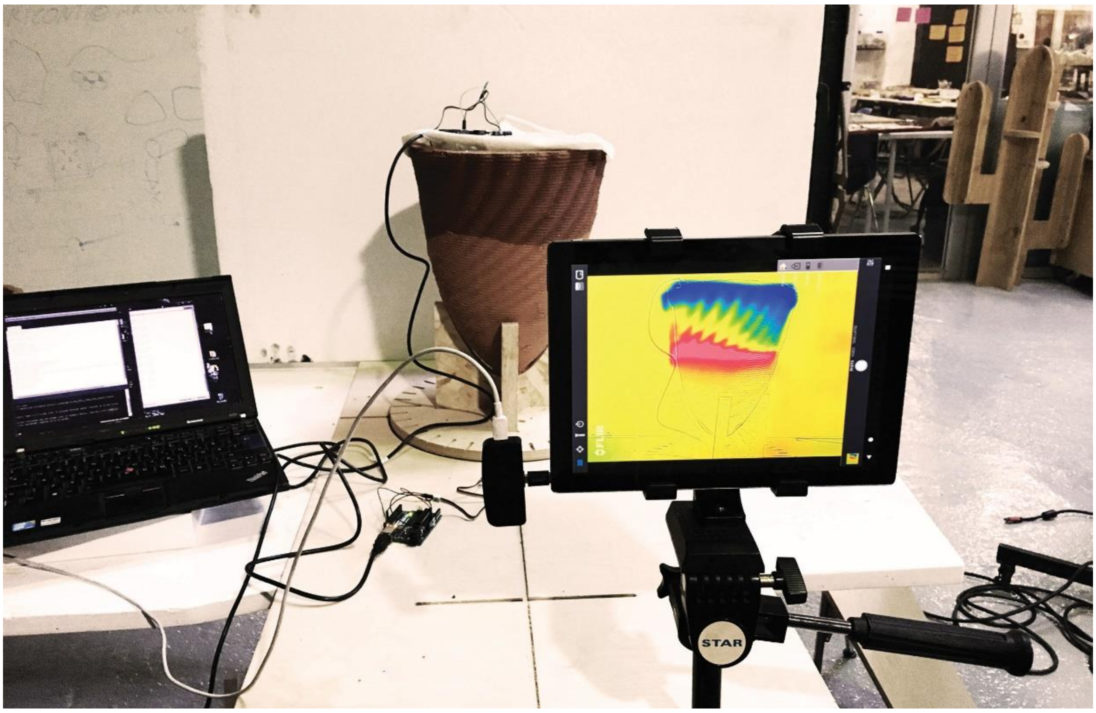

Figure 9The physical data was acquired using thermal imaging and through heat and humidity sensors placed in the pot. (©IaaC)

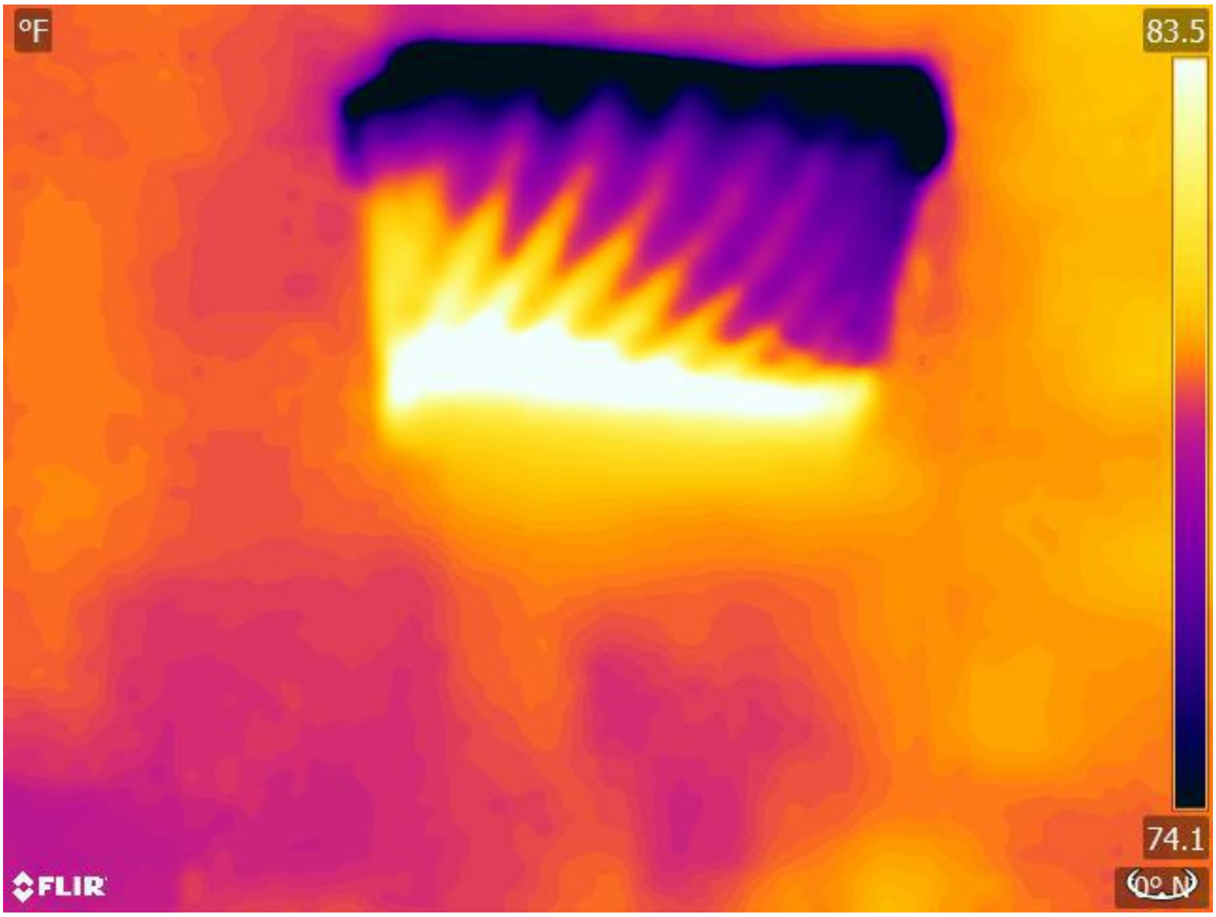

Figure 10 The physical data was acquired using thermal imaging and through heat and humidity sensors placed in the pot. (©IaaC)

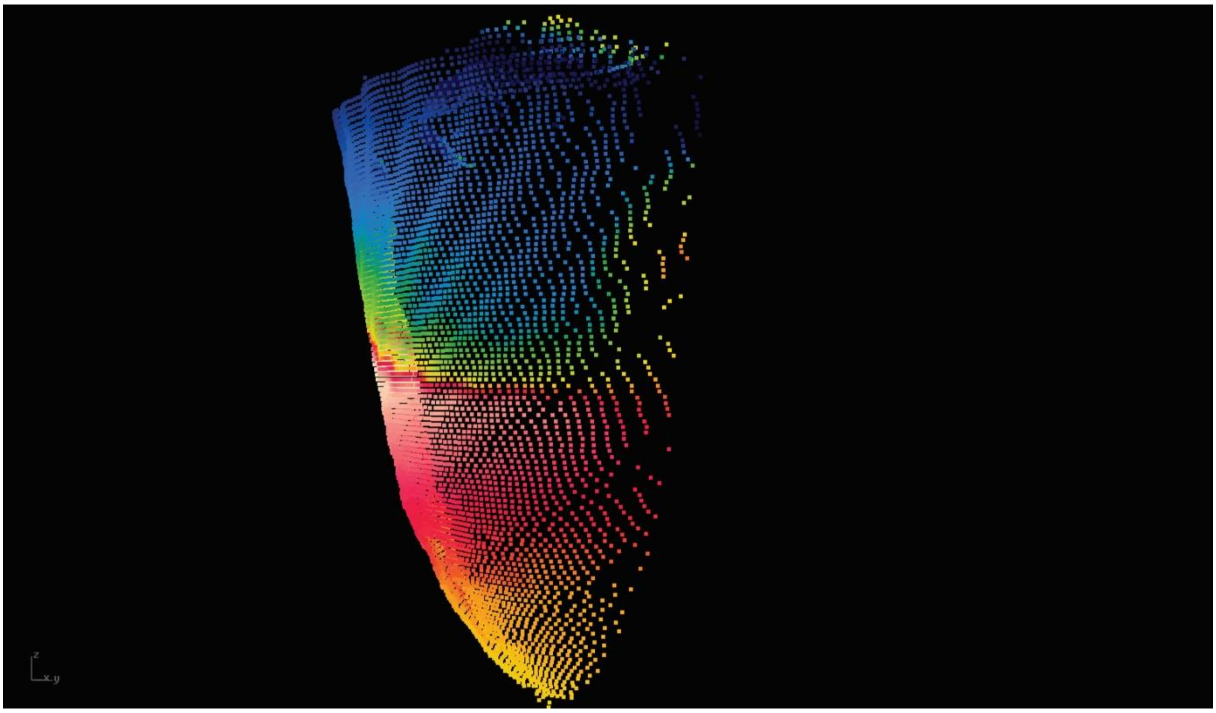

Figure 11Physically acquired surface temperature was mapped on the digital model to prepare for the ANN training (©Zeynep Aksöz)

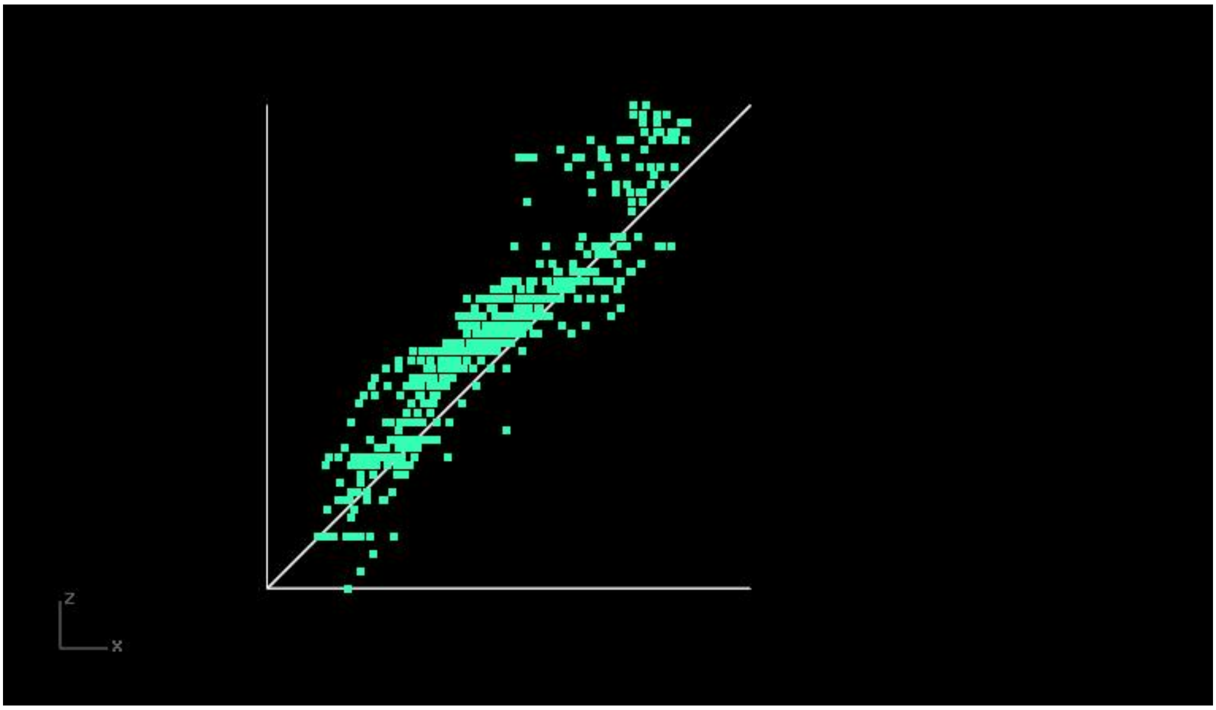

Figure 12 Cross-Validation of temperature approximation extrapolated by the artificial neural network. The diagonality of the graph represents the accuracy of the approximation. In this case, the approximation contains around errors, however still can be used as a good approximation model.

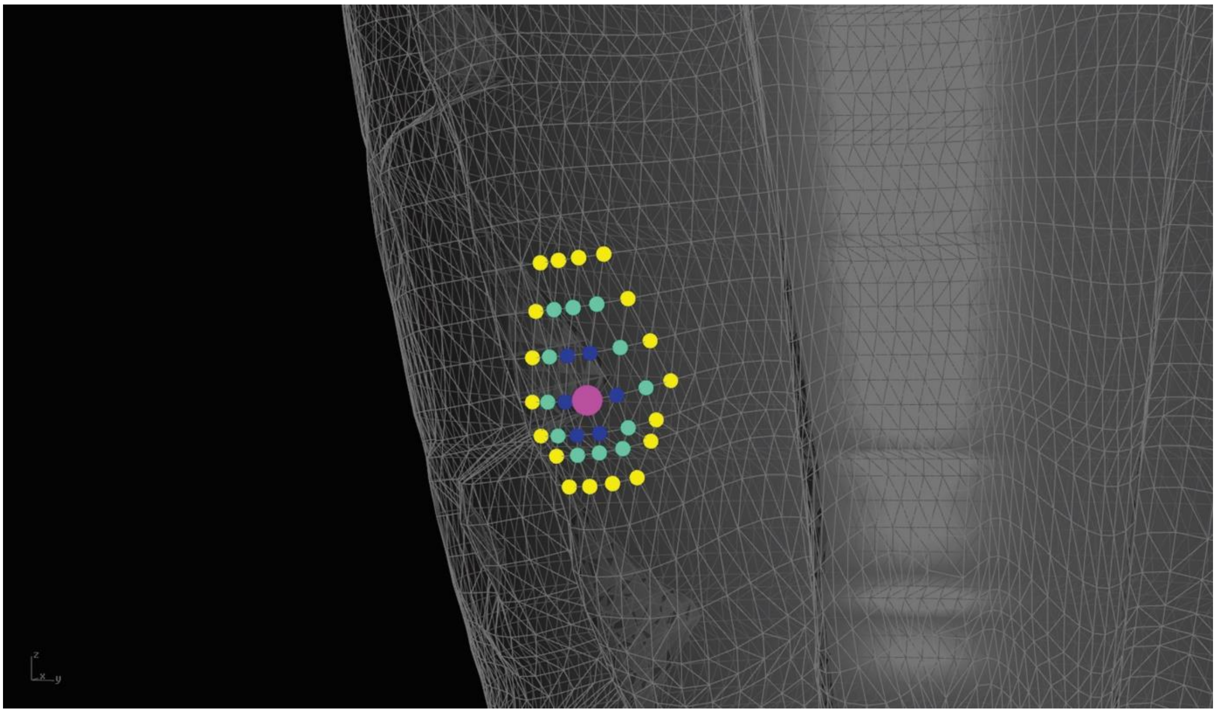

Figure 13 Analysing local geometric feature, i.e. convexity or concavity of the mesh vertex relative to its neighboring vertices . (©Zeynep Aksöz)

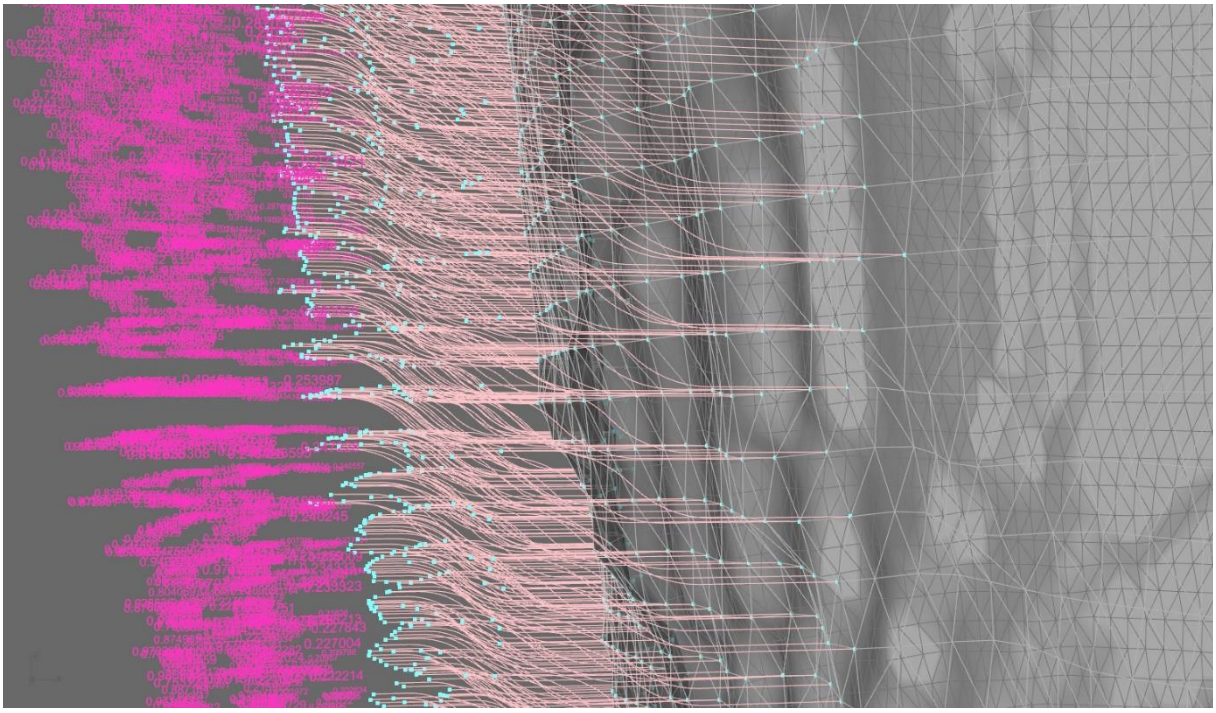

Figure 14 A 21-dimensional vector is generated to represent the local geometric feature of a mesh vertex. This is inputted to train a BackPropNN. The local temperature on the vertex is represented as the output.

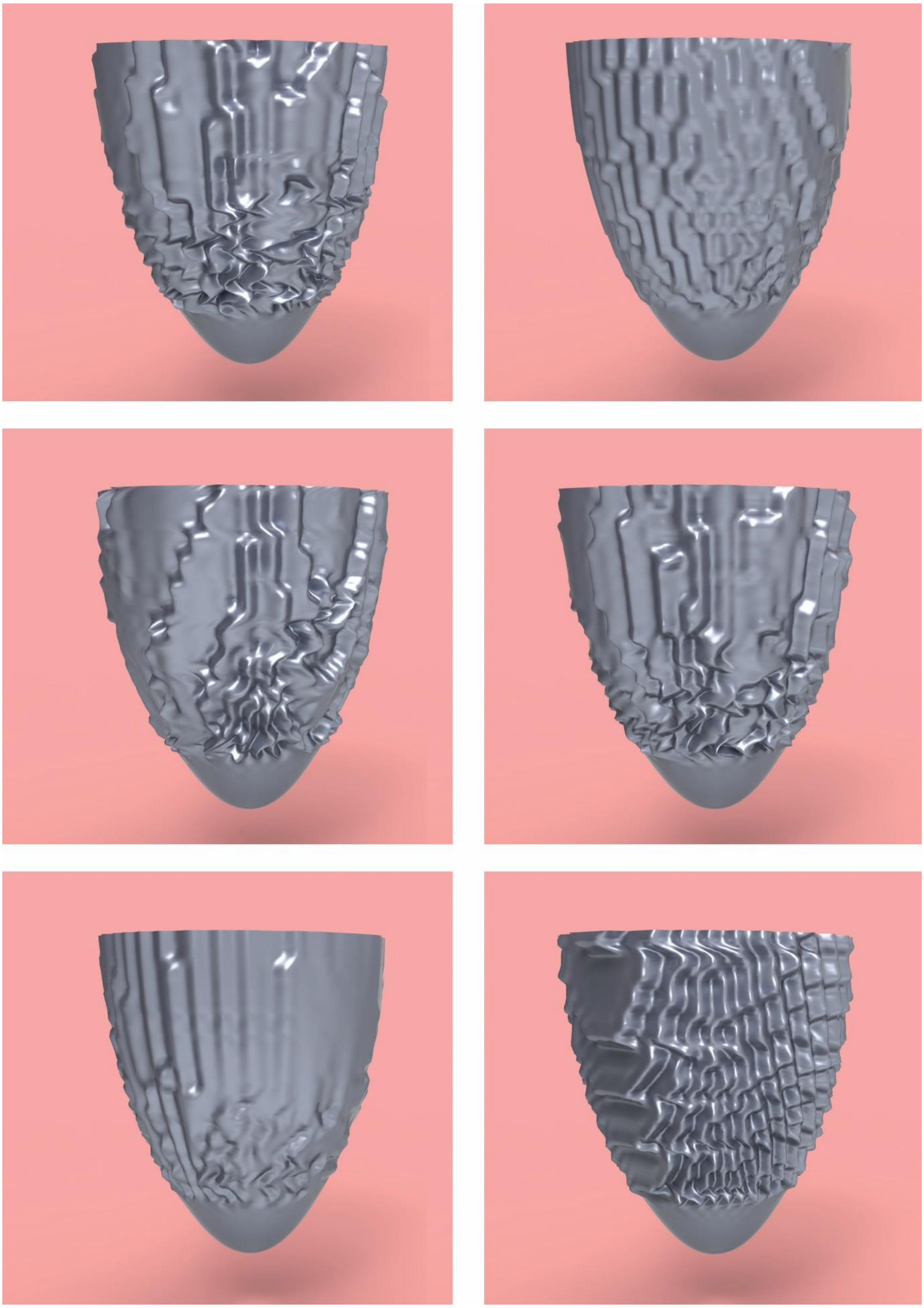

Figure 15 Set of generated noise patterns using Compositional Pattern Producing Networks. The CPPN was trained to extrapolate a rule of displacement along the surface normal at a given location on the pot to improve the cooling performance approximated by ANN on the certain location. (© Zeynep Aksöz).

Figure 16 Sample pot and one of the pots generated using CPPNs was robotically printed and tracked during the evaporative cooling process using thermal imaging to test the validity of developed prediction method(Kunaljit Chadha,07.18, © IaaC)

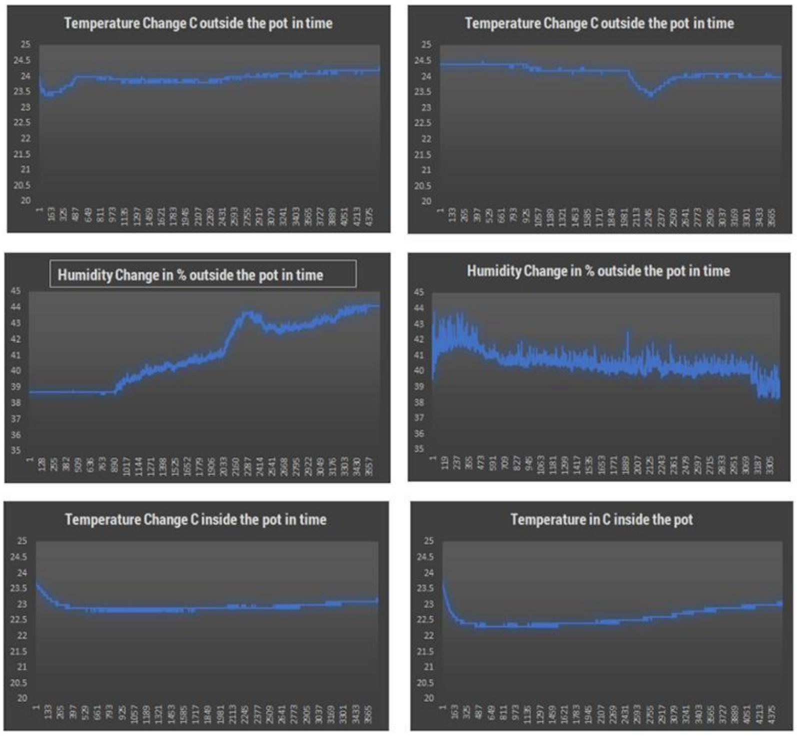

Figure 17 Diagrams A,B,C,D,E,F display performance comparison between initial clay pot without any surface differentiation(a ,b,c) and the CPPN optimized Clay pot As also can be observed in the diagrams even though the final interior temperature is similar to each other the humidity outside the pot drastically drops with time in the pot with surface differentiation. This occurs because through the increased surface area the evaporation is accelerated and the pot dries faster, whereas the pot with lower surface area absorbs the water and remains humid. (© Zeynep Aksöz).

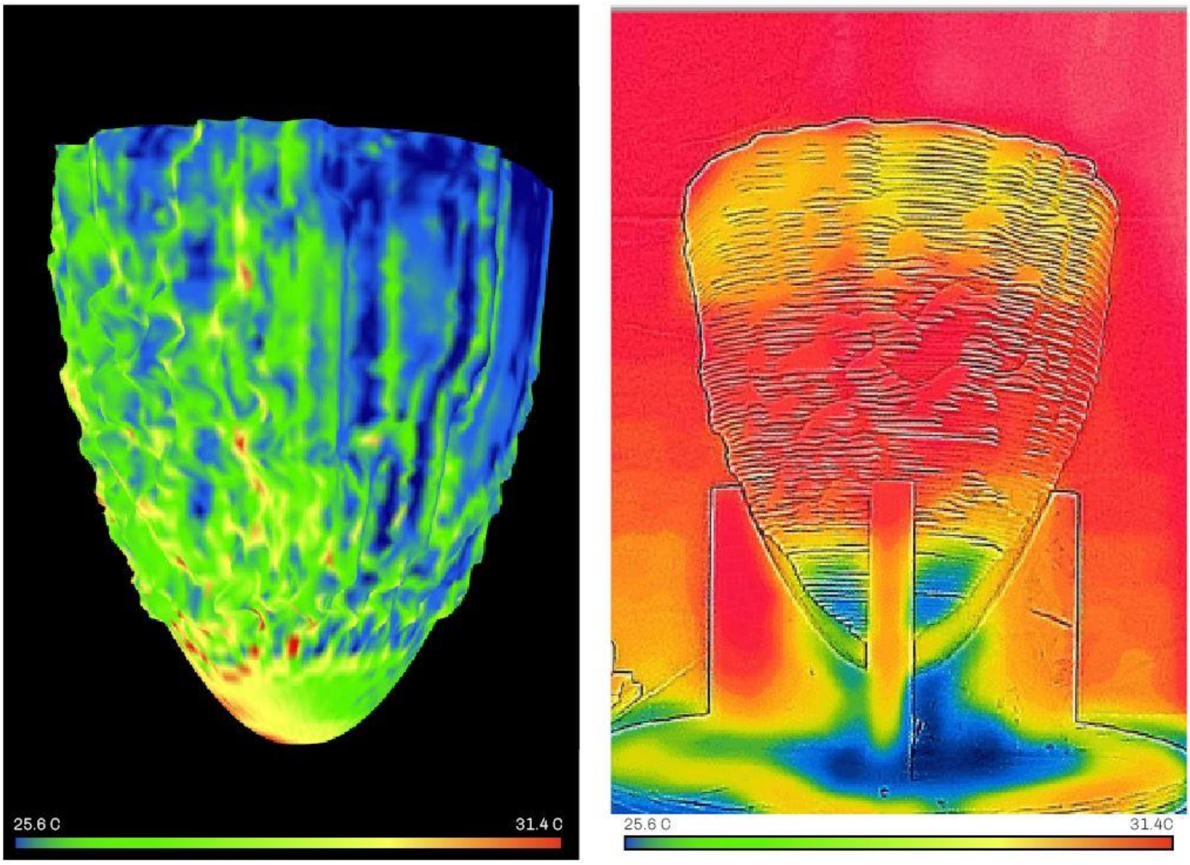

Figure 18 Approximated surface temperature of the digitally generated pot. (left) (© Zeynep Aksöz)*Measured surface temperature on robotically printed pot(right).* (© IaaC)

Figure 19 Close up photograph of the robotically printed pot. (Kunaljit Chadha,07.18, © IaaC)

Image References

[1] https://www.youtube.com/watch?v=An5z8lR8asY

[2] https://www.extremetech.com/extreme/215170-artificial-neural-networks-are-changing-the-world-what-are-they

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