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INTELLIGENT DEPLOYABLE MULTILAYER ADAPTIVE EFTE MEMBRANE

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1 HUMAN ORIENTED PARAMETRICISM[1] (H.O.P)

The current study considers a clear division between Dynamic vs. Static Parametric Architecture:

Static Parametric Architecture: architecture that obtains its form and configuration from several parameters used just to design its shape: Formalism[2].

Dynamic Parametric Architecture: architecture in which the basic inputs vary during the building lifetime: H.O.P.

The current study defends the concept of Human Oriented Parametricism, H.O.P., which considers the idea of "Time" as the lost parameter in Adaptive Complex Architecture.

Understanding Architecture as a Complex System, the current study will develop an example for this kind of design implementation introducing the idea of building morphogenetic behaviours.

1.1. The Emergency Health Deployable System, EmDeplo

EmDeplo is a parametrically designed health system composed of an Intelligent Deployable Membrane. An emergency health system —complex and alive— which parameters bases are human and environmentally linked.

1.2. Complex Systems. Morphogenetic Processes.

Morphogenesis (from the Greek *morphê* meaning "shape" and *genesis* meaning "creation") is the biological process that causes an organism to develop its shape. Artificial Intelligence is currently proposing processes based on biology as a solution for Intelligence Performance even in Architecture. Designed as a Complex System, the EmDeplo system will work with the environment and will not "defend" against it. A perfect optimization of the system, with the intelligent behaviour implemented, will be able to be reached implementing the advantages of a global + local behaviour vs. the nowadays common stimulus-reaction performance.

[1] Parametricism as a style was coined within the "Parametricist Manifesto" by Patrick Schumacher in 2008 in London. It was presented and discussed at the Dark Side Club at the 11th Architecture Biennale in Venice.
[2] In art theory, formalism presumed that the actual content of the work of art is the way. The formalist theory implies that aesthetic values can stand on their own and that judgment of art can be isolated from other considerations, e.g., ethical and social.

1.3. EmDeplo System design.

BODY: Multilayer deployable membrane + factory interface customized fabrication.
BRAIN: Arduino chip micro Controller + circuit implementation.
MIND: Artificial Intelligence IAlgorithm.

Bottom-up robotics and evolutionary processes allow the existence of Artificial Intelligent Systems with quasi-intelligent behaviour. Systems that simulate emergent and generative properties of natural processes, obtaining well-adapted and efficient forms: Complex Systems[3] in which behaviour is defined by more than the sum of their parts behaviour.

Through an abstract model for the system and the presence/absence of behaviours, the complex system that will configure EmDeplo will have two goals in two different scales: a goal-state simulation (in Nature, survival), plus system local goals interactions. The system will be working in two scales, learning to survive through patterns of behavioural adaptability without external control.

2. THE SYSTEM'S BODY: "EMERGENCY PARAMETRICALLY CUSTOMIZED DEPLOYABLE INTELLIGENT SYSTEM"

W.H.O.[4] states that natural disasters and other unpredictable events are common and urges architects to invent new kinds of high adaptable and rapidly deployable spaces for these different emergency scenarios. The Emergency Intermediate Health Deployable System (factory interface customized) will be able to satisfy most medical needs in the shortest time in any scenario as shown in Figure 1.

Deployable 3D structure from a flat surface, able to arrive directly from the factory to site, it is perfectly packed and ready for easy and quick employment. A *multi-layered membrane intelligent system* will be designed through 2D patterned deployable surface that expands into

[3] Complex Systems are defined by how their parts give rise to the collective behaviours of the system, and how the system interacts with its environment. Complex system energy exceeds the threshold for it to perform according to classical mechanics but does not reach the threshold for the system to exhibit properties according to chaos theory.

[4] The World Health Organization, W.H.O, is the directing and coordinating authority for health within the United Nations system. It is responsible for providing leadership on global health matters, shaping the health research agenda, setting norms and standards, articulating evidence-based policy options, providing technical support to countries and monitoring and assessing health trends.

a complete 3D space. High adaptability and rapid deployment are required in order to fulfill every kind of need.

2.1. The factory interface[5]

In recent decades the notion of time-based design has increased the architectural practice's interest to explore new kinds of design processes more linked to biology, philosophy and other disciplines. Its main potential is considered to be a real application into contemporary processes for changing the conventional architectural methods by diagramming, mapping and animation techniques.

The Factory Emergency Interface will help us to decide quickly in critic situations how the Unit must be customized for any particular scenario and will carry us through the design in real time. When an emergency occurs, the W.H.O. will work through the interface at the factory. The complete fabrication process of the membrane system will be perfectly customized for the emergency scenario. The interface connected to the factory will fabricate the system (customized, folded and packed) ready for deployment by truck, plane or boat through several containers.

The interface will design some compulsory parts for the case, already customized for the situation, but also will offer to the client the option of some non-compulsory parts and units. The questions the interface proposes are those which help the customization of the system like the kind of emergency, expected number of patients, kinds of diseases, etc.

Therefore, in the Emergency Health Deployable System, the parameters, apart from the human scale and measures, are the characteristics of the scenario disaster. The parametric customization of the membrane system through the interface through their fabrication is the main strength for the efficiency of the Emergency Units.

The clear properties of the material and some basic real controlled parameters will perform the unit, helping us to create a real transformable, transportable and customizable space.

2.2. Basic Triage Pack

The triage proposed consists of a negotiated mixed space where the interaction between doctors, nurses and patients takes place only when required. It will be composed of a number of "sensor-ized" pods that will react to the patient's weight and movement making a complete adaptable cellule, but always within the positions necessary for the doctor and patient's safety. With this new idea of triage system a maximum number of patients will be attended with a minimum number of doctors and nurses.

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[5] The Factory's Interface is understood in this paper as the contact mechanism between the final customized physical system and the required needs for a particular emergency scenario. A factory integrated software that according to the different emergency scenarios, number of people involved or injured, will fabricate one physical system or another depending on the adequacy it considers for that particular emergency. Samples of that can be an extra foundation for strong winds, special designs for earthquake scenarios, desert special insulation layers, number of triage units or operating theatres, etc.

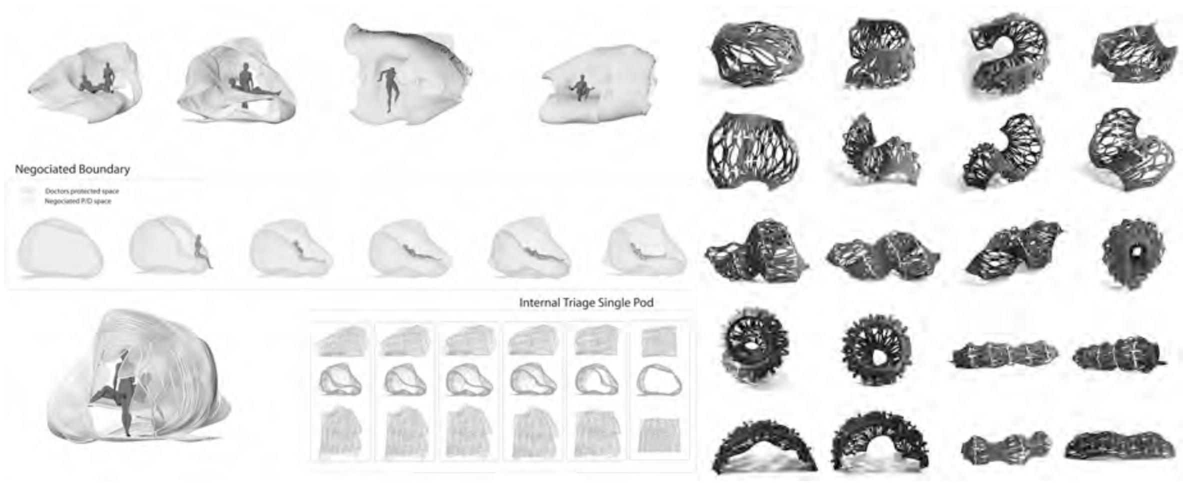

Figure 3: Triage individual medical pods

2.3. EmDeplo Material System

The patterns of the different layers controlled in four different scales will hold all the design's weight (Figure 4|5). Controlling some basic parameters, it is possible to tell the material how to behave and the hospital what to do, considering this kind of behaviour to be the basis of future adaptable customizable architecture.

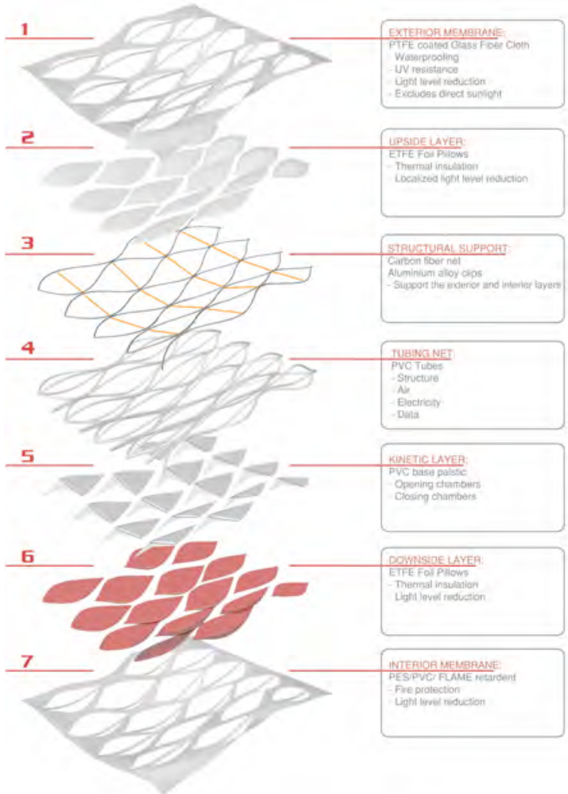

Figure 4: Membrane layers and patter performance studies

So that the system is not only an envelope for a space, it is not a space that after you can fix with the medical equipment. It is a fully integrated system. It will be designed including water, electricity and oxygen supplies as well as the necessary medical equipment. Also, the adaptable floor system will adapt to several ranges of different floor conditions.

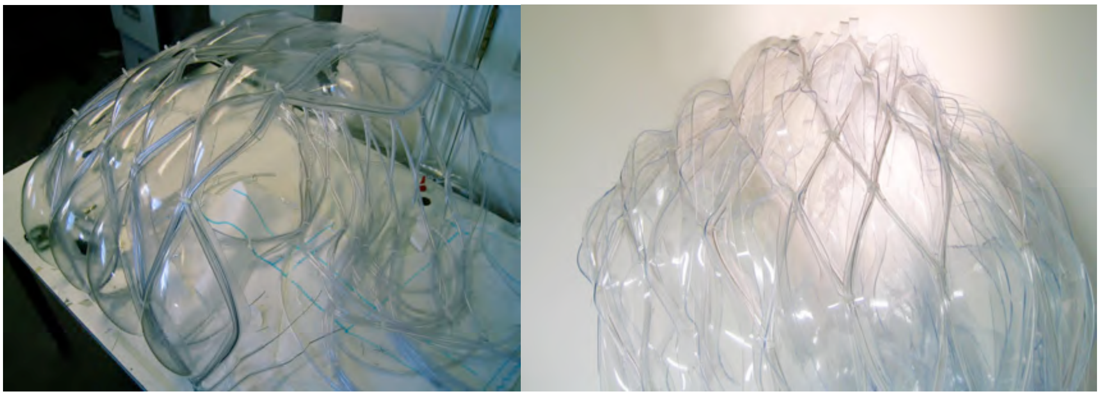

Figure 5 : Membrane physical studies

3. SYSTEM'S MIND: A.I. & MACHINE LEARNING ALGORITHMS SEARCH

The Artificial Intelligence approach that will be used in the current study will be the one in which, in a continuous loop, an intelligent agent6 will receive data from the environment through some sensors, and will change or not its state, interacting with the environment through some actuators.

The intelligent agent in this case will be the EmDeplo material system and its brain will be configured through and Arduino chip (figure 6).

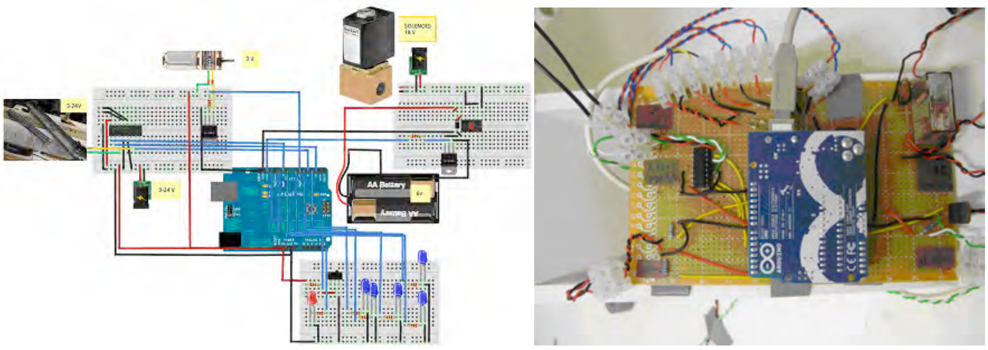

Figure 6 : Arduino’s configuration & circuit implemented

[6] In artificial intelligence, an intelligent agent (IA) is an autonomous entity that observes through sensors and acts upon an environment using actuators.

It will be a perception-action circle (Figure 7) benefiting the adaptability property of the system. AI will be studied as a method for uncertainty management and the aim will be finding actions for an agent (1).

$$act = AgentFn(percept) \quad (1)$$

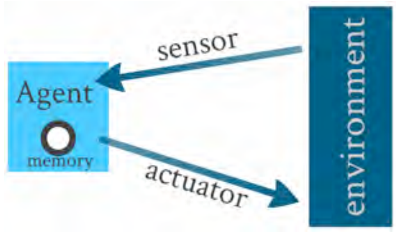

Figure 7 : Behaviour schema

Basic problems of A.I. applicable to EmDeplo's mind design will be:

Micro worlds. The sum of restricted domains will never be a real environment: the systems should work in a real environment.

Lack of scalability. It should be scalable.

Robustness. Cannot fail in a novel situation.

Real time operation.

Bottom-up design and embodiment.

Through the search of an algorithm for the system, the parameters related to which its adequacy was established were: Fully Observable vs. Partially Observable Environments7; Benign vs. Adversarial Environments8; Deterministic vs. Stochastic systems. The actions of the system being discrete vs. a Continuous set of actions, meaning infinite.

3.1. Problem Solving vs. Planning

Problem Solving as a method has demonstrated its efficacy within a fully observable environment and within a discrete, deterministic and known domain. So that it was not considered as a valid method for developing the understanding and decisions related to the learning of the climate in which the system was in, as, the intention of the current study was to develop the system in a partially observable environment.

3.2. Markov Models

A Markov model is still memory less but provides more options in the next state to the goal calculation. States in a Markov Model can be subdivided, increased and used. In the case,

[7] Fully Observable Environments are those in which at any point the information that the agent has is enough to take always the optimal decision. On the contrary in partially observable environment the agent will take the best decision for that particular sensing scenario.

[8] A Benign Environment is considered to be an environment that has no aim in its behaviour against your goals (i.e., weather); while an Adversarial Environment's goal is to not allow an agent to reach its objective.

for example, of Hidden Markov Models, in several complex applications such as Robotics. Markov models were discarded, as they are not a good algorithm for training memory. Nevertheless Second Order Markov Models consider a dependence not only on the previous state, but also, on the previous to the previous state. This kind of mathematical model resulted quite restricted for the learning that EmDeplo system is supposed to be able achieve and was thus discarded as a possible algorithm.

3.3. Machine Learning Algorithms

M.L. algorithms were considered a good starting point for EmDeplo's mind configuration. Making the system learn from existing, artificial or new environmental data models will be the main goal of the system's mind. Knowledge that will give the façade the possibility to adapt to the environment, learning from it and maximizing its efficacy.

A. Reinforced Learning.

Even though agent analysis has been a very effective learning technique, the idea of using EmDeplo as an agent, inside an unknown environment that has to take decisions for a goal and a reward, is clearly different to the learning process that our system must have, as the concept of reward function and goal might vary trough time during the existence of the building.

B. Unsupervised Learning algorithms: - Kohonen Network; - k-means; - Spectral cluster

Unsupervised Learning basically consists in Clustering Algorithms[9] whose purpose is to find patterns in unlabeled data. After a study of the most common unsupervised learning algorithms, it was concluded that unsupervised learning might not be the appropriate learning behaviour for EmDeplo's initial mind. Nevertheless, a more complex behaviour will be considered for a future system. To receive vast amounts of unlabelled data from the environment, and to try to find patterns in it for proposing new scenarios for acting, can mean an extremely big improvement in the adaptability behaviour of the membrane.

C. Supervised Learning algorithms: - Linear & Logistic Regression; - ANN; - SVM. Linear Regression, Logistic Regression

Both models use Gradient Descent[10] algorithm to find local optima. The problem with these algorithms appears when the size of the features array gets really big. The probability of over fitting increases and we will be dealing with an extraordinary number of parameters. For example, for a medical prediction based in 100 parameters: x1= size; x2= age; ...; x100= wealth, we will be dealing with approximately 170.000 features. That makes this process clearly unreachable even if we are using only subsets of the training set. In this kind of

[9] Clustering algorithms develop the task of grouping objects in a way in which objects within the same cluster have a particular or several similarities.

[10] Gradient descend is an optimization algorithm which for reaching every local optima takes small steps proportional to the negative of the gradient at that particular point.

situation Linear Regression is not highly recommended.

Support Vector Machines (SVMs)

Alternative views of Logistic Regression are Support Vector Machines, SVMs. As non-probabilistic linear classifiers, they are a kind of algorithm that can be taken into account for the decision of EmDeplo's mind configurations. SVMs propose a much better error minimization as they are trained on the worst classified examples, known as support vectors. A large margin around the decision boundary guarantees us a smaller error that in conventional Logistic Regression.

A Neural Network, on the other hand, will be likely to work well for most of these settings, but may be slower to train. Accordingly it results, a priori, to be the best algorithm to try for EmDeplo's mind.

Nevertheless that was the conclusion reached, and, considering that real building implementation will be not develop at this stage, the slow training speed was not considered a basic disadvantage. In this way an Artificial Neural Network seem appropriate to start making the system work, not having to worry about the number of features and training set sizes.

Artificial Neural Networks (ANNs)

ANNs are normally adaptive to the external environment as they develop their learning from the data received from it. Modern neural networks are non-linear statistical data modelling tools trying to simulate the brain parallelism way of working and learning capability by training and pattern recognition, by feed forward and back propagation. The Multilayer Perceptron11 will be able to deal with initially non-linear separable operations. In this way, inputs that were not linearly separable in the beginning became able to be mapped and classified. Therefore, loop networks with feedback and the idea of back propagation are the definitive alternative for adaptability.

This kind of Machine Learning algorithm gives EmDeplo's mind the ability to distinguish between different kinds of environments and situations.

4. ARTIFICIAL NEURAL NETWORK AND GENETIC ALGORITHM MODEL. EVOLUTIONARY COMPUTATION FOR THE SYSTEM.

EmDeplo's mind has been designed as a complex system (non-divisible, and non-reducible) in which the only way to know its real behaviour is to run the system as a whole. The process is proposed in 3 steps:

1. To define the way of performing once the decision about what climate we are in is taken.
2. To be able to recognize after training and learning in which situation of Tº, radiation and

[11] Frank Rosenblatt presented the perceptron idea in 1957 as a supervised classification process for linearly separable patterns. Multilayer perceptrons have multiple layers and the ability to solve problems stochastically. They are able to classify XOR functions and allow us to obtain approximate solutions for extremely complex problems like fitness approximation.

sunshade we are in.

3. To define the dynamic process of the membrane once the training has been done and the decision about which Tº/sun-shade situation we are currently in.

The process desired for the deployable system learning has to be a mixed one. It will need the power of neural processes for choosing and decision situations, and the performance of a genetic algorithm for optimizing the pillows pattern and adaptability. The combination of both sub-processes will generate a global behaviour, where, since the very first day after deployment, the system will perform properly.

The system will be composed of:

An ANN for classifying and deciding the kind of situation we are in, which will learn through a series of labelled sets of situations for training. (Global Behaviour)

A Genetic Algorithm12 that will optimize the performance of the whole set of pillows creating a pattern for adaptability and improvement. Phenotype, genotype, fitness and mutation will decide and teach EmDeplo how to act in each situation. (Global Behaviour)

An off/on behaviour, for sunshade control, through the intermediate layer of a patterned ETFE Membrane, can be decided as a stimulus-reaction response depending on the light meters readings, not allowing the solar factor be higher than FS 10. (Local Behaviour)

4.0 Scenarios approach. Labelling Situations.

One of the main aims of the implementation of EmDeplo in natural disasters will be its customization and adaptation to different situations. Customization to different emergencies is based on different performances and designs.

The design customization will be done through the interface used for factory fabrication.

The performance customization will be done at site though the internal environmental control.

The first idea of the learning behaviour was to make the membrane able to decide in which scenario it was, not regarding kind of disaster but kind of weather and environment. An analysis was therefore done of all the earth's climates and possible scenarios based on the three parameters that were able to be evaluated by the membrane: temperature, humidity and sunlight.

4.1 EmDeplo's Artificial Neural Network.

ANN can learn associations between patterns so it will be used as a tool for making the membrane understand the situation through different patterns of temperatures and data recorded by the sensors. We will work with a sample of one hundred pillows. A supervised learning process will be developed consisting of learning training data based, data classified appropriately with known classifying patterns.

We will consider ten different possible scenario situations for the system during its lifetime

[12] John Henry Holland presented genetic algorithms, GAs, in 1970. They are based on the biological evolution and molecular-genetic basis. GAs make a population of individuals evolve randomly as it occurs in biological evolution.

in a particular climate. These situations will be the outputs to decide and to choose by classification.

The proposed ANN, (Figure 9), will have 100 neurons in the input layer, 150 neurons in the hidden layer, each one of these 100 neurons corresponding to the behaviour and temperature of one pillow of the façade. The proposed outputs will be 10 different performances of the façade, optimized for the GAs previously run. So, depending on the output, one behaviour or another will start.

The decided testing time for checking the input temperatures pattern will be every 30 minutes, a period during which the ANN will re-decide again within which scenario it is located, and will re-apply the GA. Then, in case some pattern of opening and closing pillows is found to be more efficient than the current one, the façade will be readjusted. Once a minimum amount of training has been done, we can test the learning of our system. Testing the system with less than one hundred trainings was demonstrated unsuccessful.

4.2 EmDeplo's Genetic Algorithm.

Once EmDeplo has decided trough the ANN in which scenario it is located, it will generate the chromosome of the façade through an array that will be a sequence of all opening and closing possibilities for the 100 ETFE pillows. In that way, the genotype, will be an array of 100 elements that indicates the initial position of the pillows the system is starting with. The positions considered will be: closed, open or half-open.

$$\text{Genes} = \text{new } [100]; \tag{2}$$
$$\text{Genes } [i] = [\text{ open/ close status}] \tag{3}$$
$$\text{Façade genotype} = [c, o, c, h, c, c, h, o, c...] \tag{4}$$

The general idea was to optimize the genes array of the façade for obtaining a desired temperature of 22º. Several simple fitness functions were implemented, based on the idea of obtaining an ideal temperature for each pillow of the façade. The trials were done with a percentage of mutations between 0.01-0.05%; basically: Probability of mutation = 1/chromosome length.

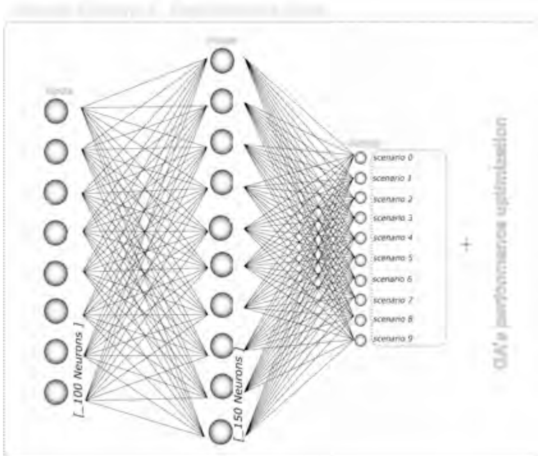

Figure 9 : Proposed Neural Network

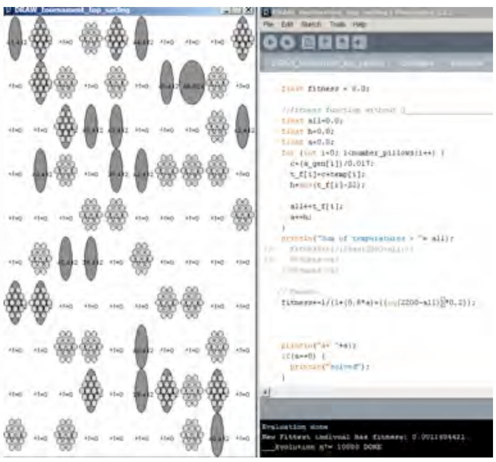

Figure 10: Proposed GA

Phenotype Definition

The thermal relationship between the degree of openness of the pillows and the temperature variability was implemented as the fitness function in the algorithm.

For EmDeplo, this environment in which our phenotype exists is the thermal relationship environment-material. After implementing the new relation genotype-phenotype, a new fitness function should be included to avoid premature convergence and stagnation. This function will also be related to thermal behaviour:

$$\Delta \text{ Temperature} = (Q * \text{thickness})/\lambda \quad (5a)$$

It will be implemented in the phenotype for each of the 100 pillows:

$$t\_f[i]\text{-temperatures}[i] = G^* \text{ genes}[i]/ \lambda \quad (5b)$$

(Being genes[i], the thickness of that pillow)

T_f [ ] are the final temperatures and Temperatures[ ], are the input temperatures at the beginning of the optimization performance. This gene array will be the data needed to implement when the optimized result is sent to the Arduino. Possible configurations of different temperatures and spaces will be able to be programmed in the future. Also, it can be considered that different solar factors may be needed depending on use and timing.

Starting with a fitness smaller than -2000, stagnation appears with a fitness of -727 around evolution number 1000.

Selection method.

The study of the implementation of different selection methods was carried out to improve the genetic algorithm performance. The method implemented initially was the Alasdair Tuner interpretation of the Rank Selection [1]. Maximum fitness obtained, -727 will try to be improved with different combinations of selection methods and variations of the current fitness function.

The Roulette Wheel Selection will not be implemented due to the danger of premature convergence it generates if a clearly dominant individual exists. The methods considered will be Top Scaling and, as a second option, Tournament selection.

The implementation of the Tournament selection method improves the algorithm performance. The experiment has only proved to increment fitness 0,98 %.

On the other hand, when Top Scaling selection was implemented, the fitness decreases 1%, due to the variance decrease that it uses to produce.

Tournament selection will therefore be the method used.

Multi-objective optimization. Pareto frontier13.

As the fitness function should improve after choosing the more effective selection method, a serial of extra experiments of its definition will be done. The first step will be to implement Pareto frontier. Considering necessary the optimization of two values, Q, the thermal flux,

[13] Pareto frontier is considered to be the optimization barrier crossing in which it will be impossible to optimize one parameter without making another parameter worse.

and t_f, the final temperature, a multiobjective optimization will be implemented.

Obj. A: Thermal flux minimum

Obj B: t_f = 22ºC

Relative Weights: Wa, Wb, Wa =0,2 Wb =0,8

$$\text{Fitness function: } f(x)= 1/ (1+ Wa*A + Wb*B) \quad (5)$$

The results obtained in this final experiment showed a maximum fitness of 0,016, optimizing the maximum insulation properties of the material and ETFE pillows.

A homogeneous controlled decrease of temperatures has taken place across the whole façade as desired in the inputs of the programme. But due to the thermal properties relationship implemented,

$$t\_f\,[i]= Q^*\, genes[i]/0.017 + Temp\,[i] \quad (6)$$

and to the constrains on the degree of opening of the pillows, and that is,

$$genes\,[i] = 0,\ \ genes[i] = 0.5 \text{ or } genes\,[i] = 1 \quad (7)$$

That will be the maximum fitness that can be reached. Nevertheless, if we consider a free opening degree of possibilities, from thickness 0 to thickness 1, so, genes[i]=random (0,1), being all floats between 0 and 1 allowed as possible degrees of opening, maximum optimization of the material will be achieved.

5. CONCLUSIONS

After implementing the thermal relationship of the material in the façade performance, a complete process through the ANN and the GA, is carried out for each scenario possible and, particularly focused on the one chosen by the ANN, obtaining a much more efficient thermal performance.

The different façade patterns created by the learning of the system through the different scenarios and experiences, plus the local behaviour for shading, optimizes the material insulation performance of the façade, maximizing material insulation properties.

Even when a non-constrained opening of the pillows is allowed a maximum efficacy of the insulation properties of the façade is reached, the set of different layers proposed for the membrane configuration demonstrated not to be enough for a proper insulation and climate regulation.

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