Levels of Mapping in Nature-informed Studies A case study on informed wall

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Nature provides a vast amount of information to be learnt in various scales with different level of complexities in architecture. Today, the increasing role of computational design and advents in new fabrication technologies enable architectural praxis to incorporate data coming from various disciplines in the design process. Among them, data coming from nature with its animate and inanimate parts are began to be revisited more than before via different approaches. In this study, information transfer from nature to architecture is described as a mapping process defined with different levels depending on the complexity of the information transfer process. Present study explains these levels and exemplifies through the study conducted in Nature-informed Computational Design course.

Keywords: *Biomimetics, Geomimetics, Data Mapping, Nature-Informed Studies*

INTRODUCTION

Throughout the history of design and architecture, nature is studied/decoded, and information gained from these studies are reflected back into various challenges that architects are facing with. In these explorations, responsiveness, and fitness as a part of research on performance in buildings become trending subjects for which nature become the major source of information.

Responsiveness in architecture, not only as the ability of change but also as a way to preserve/produce energy turns to be an important matter to re-direct architecture towards nature (Negroponte, 1970), (Reichert, Menges, & Correa, 2015) (Blok, 2016) (Gronostajska & Berbesz, 2019). Similarly, fitness which is defined in nature "as complex dispositional property of organisms" referring being an inhabitant, survival and reproductive (Mills & Beatty, 1994) becomes a strategy for efficiency, adaptiveness and responsiveness in architecture (Menges, 2012) (Öztoprak, 2018).

Today, with new observation/data capturing technologies and increasing data crunching capacity, we are more capable of retrieving and processing information from nature more than ever. Dealing with such massive data, needs new strategies, models, classifications, and thus novel methods. Most of these strategies mainly focus on the direction of this information transfer as either from biology to technology or from technology to biology (Baumeister, 2012) (Gebeshuber, 2008) (Oxman, 2016) (Speck, Harder, Milwich, Speck, & Stegmaier, 2006) (Vattam, 2007) (Benyus, 2002). Along with these strategies, classifications depending on the scale of living being (Knippers, Nickel, & Speck, 2016) are scrutinized. Studies are extended to consider Form, function, performance or behavior in nature and architecture (Zari, 2018) .

Currently these studies shift their focus on material research (Rahimizadeh, Sarvestani, Robles, & Ashrafi, 2022), building systems (Castriotto, Carvalho, & Celani, 2019), component design (Stachew, Houette, & Gruber, 2021) (Son, Kim, & Syal, 2022), and urban design (Zari & Hecht, 2020). As each field brings unique performance criteria, different level of complexity on the retrieved and transferred information from nature to architecture is unavoidable

In this context, this study proposes a new perspective approaching nature-based studies as a data mapping process to meet the needs of any specific problem defined in architecture. This approach introduces data, feature and behavior extraction, feature matching, data modelling as parts of this mapping process. Then, the levels constituting the mapping process are described from inspiration to information, from idea to knowledge in accordance with the complexity of the problem.

Levels are also implying strategies both for learning from animate or inanimate nature, based solely on data transfer, whatever the strategy is (top-down or bottom-up). The only scale that defines the levels is the complexity which arises from the problem of concern, captured information, and character of the information transfer process.

The role of the context and understanding of scale, which is defined as a measure of complexity in nature-informed studies, are found vital. Here, this scale determines how far the mapping process can go from inspiration to information.

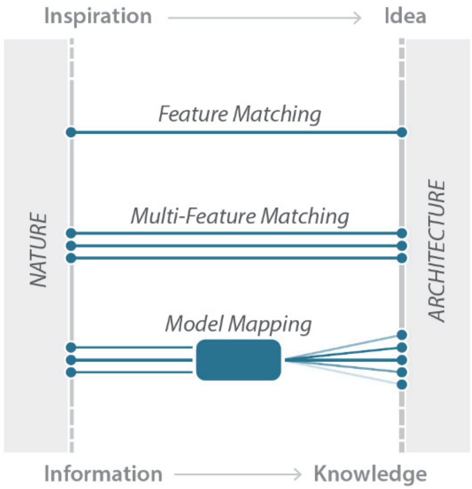


Figure 1
Levels of Data Mapping (developed by authors)

MAPPING IN NATURE-INFORMED STUDIES

As briefly introduced, the proposed approach aims to describe nature-based studies in the realm of architecture as a data transfer process. Focusing on data and data transfer, domain is defined as the dataset consisting of captured data in nature and similarly, codomain is the datasets of objectives, constraints of the targeted problem/performance.

Accordingly, term mapping is employed as the synonym of transfer function (Weisstein, 2022) denoting information transfer from nature (N) to architecture (A):

$$f : N \mapsto A \quad (1)$$

Frequently, asymmetry in the scale of nature and architecture in terms of their complexities is the

Figure 2
Some of the examples of feature matching, retrieved from archdaily.com

major concern of the proposed mapping process. In general, obtaining related data, associating this data with its context, modeling and reflecting the information into architectural domain are seen as the main issues.

In relation with the problem, the complexity of the mapping process varies. As the depth and the complexity of the acquired/required information is increased, the transfer process from domain (nature) to codomain (architecture) changes from inspiration to information, and likewise, the codomain/ outcome turns from idea to knowledge. This study refers these two levels as (1) Feature Matching, and (2) Model Mapping which determines the complexity of the transfer process.

In **feature matching,** the process includes single or multiple features to be related among domain and codomain, disregarding their dependencies, coherences, and impacts on each other, and thus mostly resulting visual resemblances.

It is seen that, in feature matching the behavior of the subject of interest is mostly not to be conveyed into codomain. Hence, feature matching in architecture is mostly depicted as formal inspirations like in tiling, ornaments etc. From this perspective, the studies shown in Figure 2 can be acknowledged as the examples of feature mapping in different scales from tiling to façade, and from building to port design resembling/imitating animals, plants, and textures.

For the **model mapping** process, on the other hand, features are transferred among domains with their dependencies, coherences, and impacts to each other in regard with their context according to the observed behaviors, performances, and functions. In other words, models need to be constructed for the information transfer. In this approach, success of transfer, precision, level of information in the process are closely connected with the requirements of the problem, captured data in the reference domain and the relation found among them rather than the complexity of the model.

As presented in Figure3, Stuttgart Airport Passenger Terminal, Germany (1996) designed by Meinhard von Gerkan with its tree-like columns, ICD-ITKE pavilions: HygroScope: Meteorosensitive Morphology (ICD), and "HydroSkin" mapping the hygroscopic actuation of plant cones (Reichert, Menges, & Correa, 2015) and Eastgate Centre designed by Mick Pearce in Harare, Zimbabwe (1996) modelling the self-cooling mounds of African termites for less energy consumption (Doan, 2012) can be counted as examples of model mapping. There are also number of machine learning applications that can be counted in this level like "Machine Learning Model Inspired by Insects' Nervous Systems" (Hannes & Paul, 2020) or the study focusing on climate change to understand dynamic systems (Sibanda, 2020).

To sum up, these examples illustrates that the proposed schema can help to understand the complexity of information transfer as well as the impact on the final outcome. This understanding may help to contribute to nature-informed studies incorporating various methods coming from data sciences (*author's publication).

Moreover, nature-informed studies have already been adapted into the curricula of schools in different levels (Speck & Speck, 2021). The schema explained here is applied to the outcomes of the course developed and offered by the authors named "Nature-informed Computational Design".

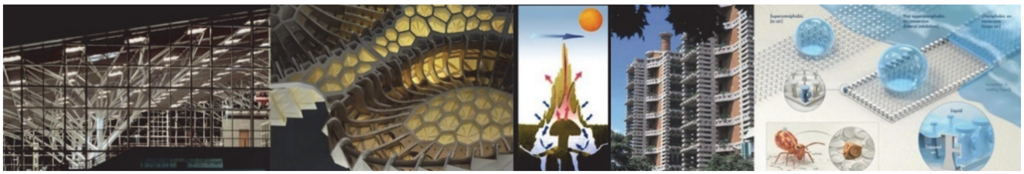


Figure 3
Some of the examples of model mapping [1][2][3][4]

FROM NATURE TO WALL COMPONENTS: A SERIES OF MAPPING STUDIES

In this part of the study, the mapping process explained briefly above was implemented in the course named “Nature-informed Computational Design "conducted with 41 students from METU Department of Architecture. Students were initially given an ill-defined problem as “the wall” that its function was expected to be defined by the students. Within the very first weeks of the study, the function of the wall was determined as “collecting the water”. Following this stage, groups consisting of 2-3 students design various components of the wall referring to different references in nature.

Initially, the discussions were based on well-known studies of Benyus (2002), Knippers et. al. (2016), Zari (2018) and Speck et.al. (2021) together with numerous examples and applications in the context of computational design approach. Moreover, students are also acquainted with concepts like emergence, swarm behavior, stigmergy etc., Also, along with these discussions, the notion of model, the precision of model and information transfer as well as feature-behavior extraction, are discussed in depth.

Class discussions guide students to develop their own strategies for which the complexity of the process is determined by their own targeted performance which yield different levels of information transfer process exemplifying aforementioned “levels of data mapping”.

The features and behaviors of the following natural beings are studied; sunflower, succulent, sponge, namib beetle, butterfly, cell cycle, hummingbird, fiddlehead, glow-worm, bismuth crystal, tent caterpillar, neuron, mimosa pudica, slime mold, blood vessels. Information gathered in these studies are then used to develop wall components, which later merged to constitute the adaptive wall system as it is aimed. Each entity’s mapping process has a different purpose and workflow, and therefore each study constructs a different level in the introduced schema.

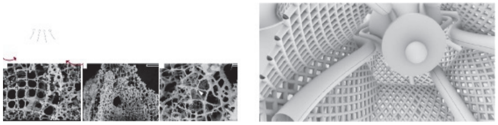


Figure 4
Feature matching of sponge module

The studies required to extract one or multiple features in relation with their aim are presented in Table 1 and the studies examining and modeling the natural behaviors and mapping these models into their targeted performance are listed in Table 2.

Among the feature matching examples; the sponge module is shown in Figure 4. As it can be seen in this example, the features related with the form of the sponge is directly matched with the form of the component.

For the sunflower part, which is an example of a model mapping process, the location is studied and modeled by the students (Figure5). This model is mapped into a kinetic model being controlled with sensors, motors and Arduino board depending on the wind direction. This movement was found important for the students to enhance the water preservation capacity of the wall.

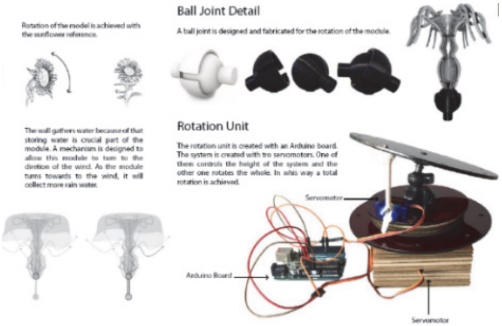


Figure 5
Model Mapping of sunflower module

The modules, which are based on 15 natural beings, are tested not only on the digital environment through simulations, but also with functional prototypes revealing the outcome whether the resultant models respond to the students’ targeted performances i.e., form, kinetic behavior, heat distribution etc.

Table 1
Feature Matching Examples

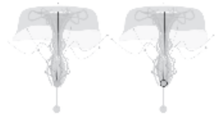
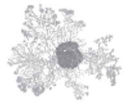
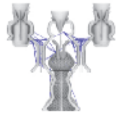
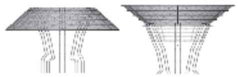
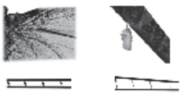
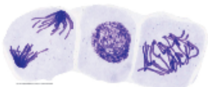
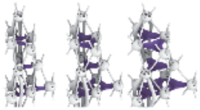
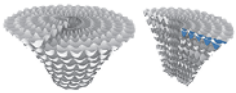
Reference Beings in Nature		Target: Wall Component	
Image	**Reference**	**Targetted Performance**	**Result**
	**Sponge:** Porous texture	Filtering water porous texture	
	**Dandelion** The connection of modules to the main body	Connection of the module to the wall	
	**Hummingbird** the fork form of the tongue enables it to reach further	Elastic pumping modules to transfer water from other modules	
	**Slime Mold** Formation of the network	Tensile elements to support the structure	
	**Glowworm** Weawing of silk treads	Weaved surface on the modules to help collect the water	
	**Bismuth Crystals** stair-step stucture of crystal cluster	The modular formation of the water tank	
	**Mimosa Pudica** The movement of mimosa leaves when an external agent touches	The movement of surface to direct the water to slide	

Table 2
Model Mapping Examples

Reference Beings in Nature		Target: Wall Component	
Image	Reference	Targetted Performance	Result
	**Sunflower:** turning towards sun	turning against wind direction	
	**Succulent:** water absorbtion and transfer leaf arrangement	water storage and tranfer	
	**Namib Beetle:** changing skin texture according to wind and fog	Adaptive Skin texture	
	**Butterfly** the cellular form of wings and its change during metamorphosis	The tensile connection to hold different components of the structure	
	**Cell Cycle** The movement of cells during division	Movement and Flexibility in between the modules	
	**Fiddlehead** The uncoiling spiral and its movement towards sun	Movement avoiding evaporation to protect collected water	
	**Tent Caterpillar** vaterpialrs movements in tents according to heat change and its environment	layered structure to balance the heat distibution of the wall	
	**Neuron** the number and distribution of neurons based on overall size	the distribution of kinetic elements creating the pumping movement	

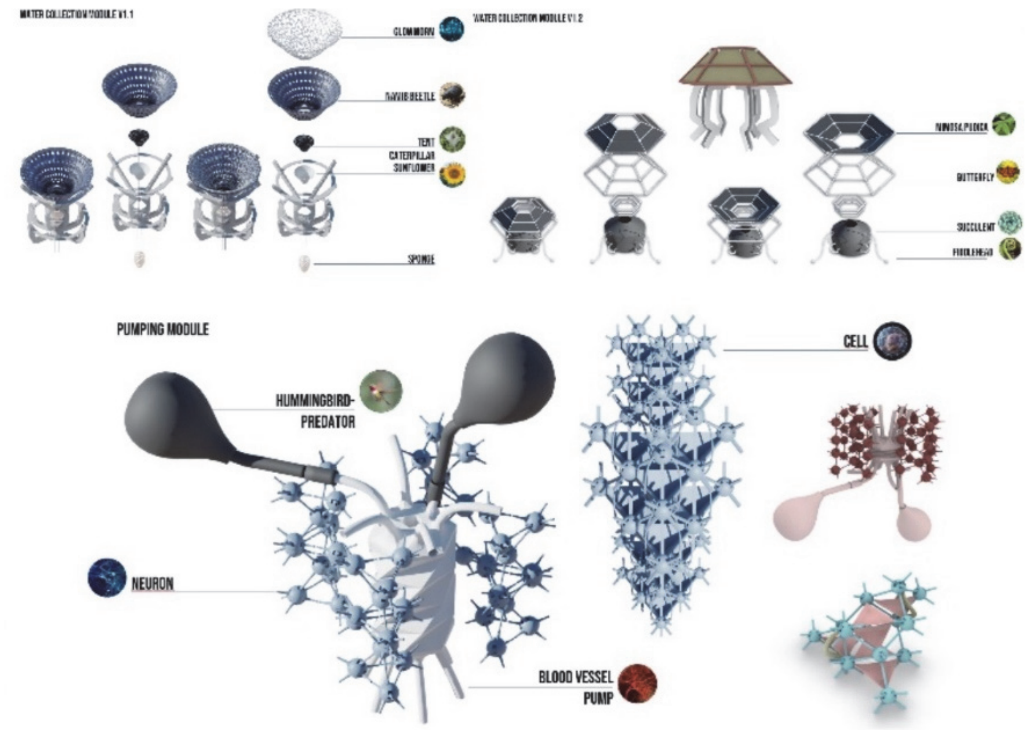


Figure 6
The relations between the components to form the wall

Finally, all these modules are brought together on a single wall by finding and defining the relations and dependencies with each other (Figure6). The wall which is called “Frankie” with reference to the monster of Victor Frankenstein is composed of 16 components informed by 16 different references from animate and inanimate nature (Figure7). In this process, students had also experienced their design in immersive environment to assess their design in terms of its scale and visual characteristics.

To conclude, Nature-informed Computational Design course is an example of current approach. It is fair to say that the task given students which is merging the components was almost an impossible one, especially during lock down and only working on online collaboration boards and meeting in online platforms. Yet, they succeeded in finding the correlations and common purpose to link their findings and their designs in one project. Hence, students achieved the following objectives of the course: the ability to understand, decode any information in nature and transfer them into architecture following the phases of modeling process namely problem definition, abstraction/simplification, mathematical/ computational modeling, and assessment.

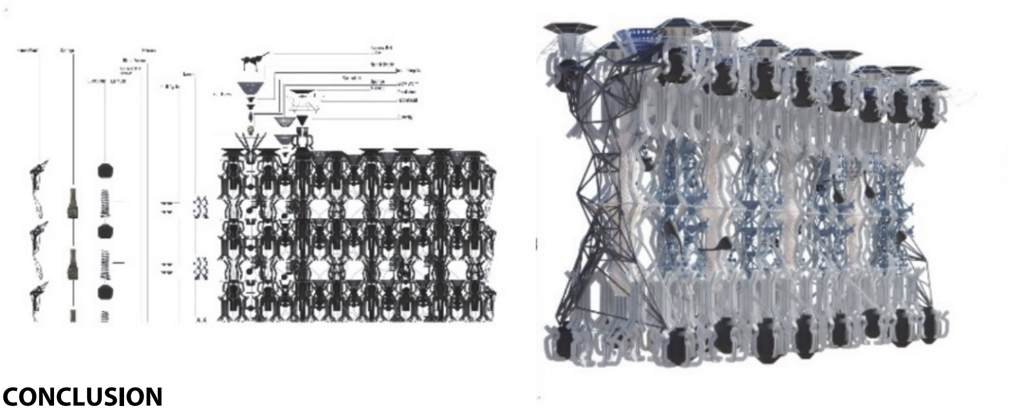


Figure 7
Overall wall design with the integrated components

CONCLUSION

In this paper, levels of data mapping are introduced based on data transfer from nature to architecture in relation with the complexity of problem and thus the process. Although this model is developed for nature-informed studies in architecture, it is likely to be applicable to be used in any information transfer process among two different domains.

It is important to note that the levels introduced in this study varies according to the problem of concern. Therefore, the structure of the transferred data is solely dependent on the problem that direct designers towards the nature in the first place. It is well known that a good model is just complex as it is necessary. Henceforth the transfer processes are required to be designed as complex as necessary. This fact is emphasized in the class several times and reflected back the works in the conducted design studio.

As a result of examination of current studies and the case study on wall components, this mapping definition is found applicable for many existing and future studies aiming to transfer information. However, the applications using biomaterials as in Hy-Fi: The Organic Mushroom-Brick Tower (Stott, 2014) or co-creation with animals like Silk Pavilion, Silk Pavilion II and plant-based materials like Bio-Plastic Column (Oxman, Neri Oxman, 2022) are the exceptions considering natural beings take a direct role and thus, scale difference does not cause a problem and they are not included in the proposed taxonomy.

To sum up, the proposed approach can serve to deepen the discussions on nature-informed studies and possible new strategies, models, and methods.

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