# DIGITALLY ENHANCED DESIGN

Breakthrough tools, processes, and expressive potentials

edited by Maurizio Rossi and Davide Spallazzo

D.I. FrancoAngeli DESIGN INTERNATIONAL

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# Contents





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# 4. Design by data in adaptive morphologies

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## Abstract

Design practices have looked at natural systems as the source of inspiration for centuries to emulate their formal aspects and their life and evolutionary complexity. Since the advent of the digital revolution and the technological innovation related to computation, this issue has become increasingly part of the design plan. Today, thanks to the code-based generative tools and processes, design research is increasingly exploring the principles of biology and particularly the aspect of adaptability, which means "adaptive," the ability of an organism to transform its original structure into a different one relating to an environmental condition, and thereby designing a symbiotic relationship between body and surrounding context. As a result, this kinetic and adaptive matrix provides strategies for designing and constructing emerging morphologies and design elements to experience creative possibilities linked to the relationship with the environment.

The chapter proposes a conceptual framework for the topic's exploration in the context of computational design, that is a multidisciplinary area of study which can be defined as the application of computational strategies to the design process and whose relevant aspect concerns the creative, logical nature, and not the mere instrumental component of the "calculation". The essay also aims to encourage rethinking the project's territories, viewed as growingly hybrid context, where boundaries of the design's fields (mainly design, architecture, art, engineering, etc.) can virtuously intertwine with digital subjects of computation and therefore acquiring and increasing design value.

## 4.1 Introduction

Over the last decade, design has increasingly taken advantage of the growing availability of digital technologies of a computational nature, revisiting and reformulating previously little addressed problems due to their complexity, both in terms of the number of components and the relationships between them. It has led to concepts, techniques, and tools such as algorithmic design, parametric design, generative design, digital manufacturing, and, more recently, design by data. The latter, specifically, comes from representation and generative methodologies and deals with parametric definition and algorithmic processing. Its focus is the use of data from real-time sources, but not only to develop scenarios capable of integrating the variability of the data themselves, both in the dynamics of the simulation as in the adaptive capacity of the physical systems of a built environment. Computer science and new technologies have provided the main paradigms of the subject, while the design has outlined new models and research methodologies.

The reference context for research is the computational design, understood as the design process that, taking advantage of the potential of computation, integrates digital and emerging technologies in the development of a product structured on the interaction between form and information (Reas, 2010). In this framework, the programming and design domains integrate to identify a form of creativity where information becomes procedures and rules of interaction. Furthermore, where data drives a design transition from descriptive to prescriptive approaches establishes an unprecedented feedback loop in design research and production.

## 4.2 From data to computational design

The architecture has always made use of data in the design process. Specifically, data made of different nature and from various sources, which determined the premises, guided the construction, and reviewed and implemented phases. The quantitative and functional data are those that usually define the beliefs. In contrast, the qualitative data of the relationship with the environment (whether intended as context, people, etc.) structure the articulation, characterizing a specific morphological and spatial interpretation. In the context of this reflection, "set of data" means a collection of "raw" values, not determined to a specific form and scale, which through a process of helpful refinement for their interpretation (a method of translation within a particular domain of reference), become materials through which to build information or structure knowledge. In the case of architecture, this structuring process leads to composition.

The translation of data into representation has thus a double role: i) to build a sort of general framework of the project, which defines the framework of rules and the general principles of interaction; ii) to make the project emerge from an articulated whole, but not yet formed, which already possesses within itself all the elements that will characterize its generation.

Converting data from external domains into a project structure is a problem of rewriting in a different language and equivalence between the parts since the system of signs strictly connects its interpretation within other signs and semantic contexts (Fig. 4.1).

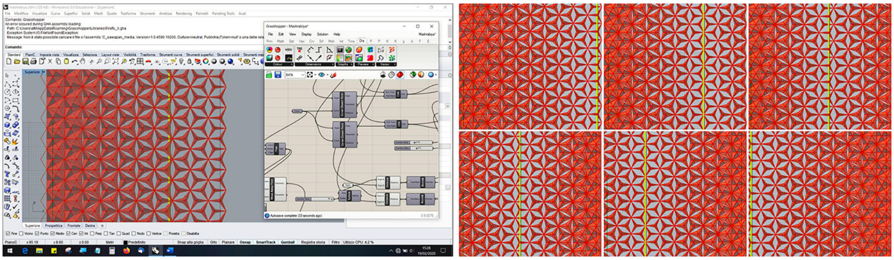

*Fig. 4.1 - Simulation of the responsive behavior implemented by facade petals in the Aegis architects' project Al Bahar Tower in Dubai (author's revision of façade detail). The algorithm determines the dynamic morphology of a star origami by calculating the distance of each center from the sun's line of incidence. The transversality of the data is the crucial factor in the design. The data obtained are continuously remapped between 0/1 domain, corresponding to the opening and closing positions of the petals, then used as input in the control of the distance between the points of the geometry.*

As Speed & Oberlander (2016) suggest, it is possible to distinguish three main approaches of the relationship between design and data:

i) design *from* data, ii) design *with* data and iii) design *by* data. These three classes, very different from each other, are defined by observing the flow of data. From a condition of substantial static and independence between the two domains (design *vs.* data), progressively changes to another more dynamic and interactive state that interprets the variability of the parameters as a valuable element to explore emerging and non-linear design suggestions.

Specifically, the approach that characterizes the design *from* data relates to those design systems entirely guided by the designer, who then identifies, selects, and draws inspiration from inputs obtained by measuring known elements of the context. And regardless of the methods (observation, interviews, tests, etc.) and tools used in such measurement (analog *vs.* digital). The data is consequently a premise of the project.

On the other hand, in the design *with* data approach, the process is still characterized by designers' determination to guide the implementation of the phases. Still, also it is flanked by data flow from intermediate levels of verification and control of processes/products. This process is not only to collect cold elements of experimental synthesis, useful in the design review but "a condition in which designers should anticipate the disruptive potential that is produced from streams of live data from networked artifacts" (Speed, Oberlander, 2016). In this case, data is played out between the premises and the implementation phases of the project.

With the approach of design *by* data, finally, are collected most of the experiences of the other two classes to project them into a new design dimension and in which systems with large margins of autonomy and not totally defined in their morphologies are governed by other systems, which interact to generate information. Thus emerge: "new products and services can be synthesized via the data-intensive analysis of existing combinations of humans, computers, things, and contexts" (ibid.). The condition of the data is, in this case, dynamic, and the project is structured on open variables.

The design *from* data represents the most classic and traditional approach to the project, in which the linearity of the process is the designer's responsibility. On the other hand, design *with* data is an intermediate phase where this linearity is questioned, and the project opens to interaction with the context. Finally, it is possible to speak of design *by* data when the importance of the data defining the project domain (constraints, requirements, etc.) is significantly marked. Results are therefore derived by developing an algorithm and leveraging new digital technologies and computational science tools. From data, we arrive at the project through the computation (here understood as the algorithm of a parametric function) that defines the behavior and configuration of the space when a set of parameters (geometric, logical, environmental, etc.) changes (Fig. 4.2).

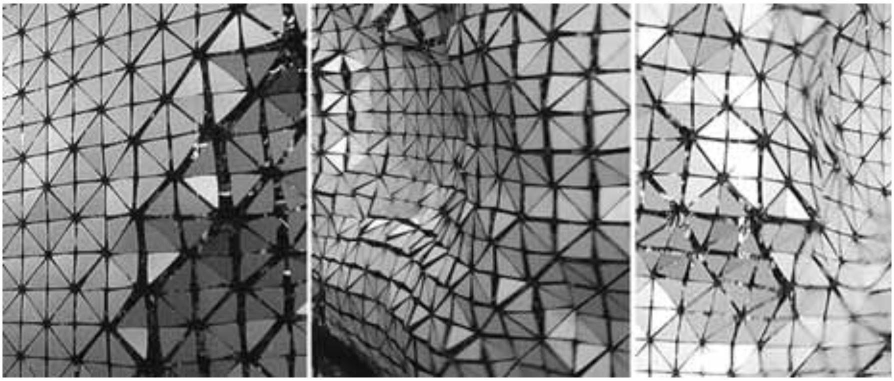

*Fig. 4.2 - The Aegis Hyposurface (© dECOi) marked a transition from determined to interactive morphologies. It was a faceted surface able to deform its morphology as a real-time response to environmental inputs: sound, video source, user input, or by pre-configured effects. The surface is made by aluminum facets glued to rubber articulations, able to ensure a fluid visual continuum. A set of pistons drove the facets to generate a dynamic surface as a response to electronic calculation.*

Emerging from the same physical space and employing real-time values, these morphologies may continuously reconfigure or adapt to follow environmental and user needs. Variability is what marks their character. This aspect does not relate to the final form of the physical object but to its being an open and indeterminate structure (expressed by the ability to vary along a curve of possibilities), which with this artifact shares the origin of its organization[1].

[1] Bernard Cache (1995) explains a generic design entity with the concept of objective, never completely defined, and more important than its specific elements. The antithesis to the

## 4.3 From computational design to adaptive morphologies

One of the critical strategies of the computational approach is to "think algorithmically" about the project or to code in the structure of an algorithm, the system of relations that links data to output by processing (Werner, 2015).

With the adoption of the computational approach, the designer does not necessarily leave traditional skills and experiences. Nevertheless, it is necessary to redefine them in terms of objectives, languages, and operating structures; from the mere representation of a single static configuration, the focus shifts to constructing and managing the system of relations that develops the project. Moreover, where the output represents only one of the n-possible interpretations. Thus, the focus of the project task becomes the definition of a design environment separated from the physical representation of its geometry, i.e., a space conceived as a system of relationships, in which the project is the place where a series of parameters generate design iterations.

The gain offered by the definition of the problem in algorithmic terms allows to generalize the problem itself and, therefore, to transfer it to similar contexts, in the way as everyday objects find a diversity of interpretations to the context within which they are inserted, redefining from time to time their skills.

Here is the main difference between classical to algorithmic models: design with algorithms means defining "an architecture of the architecture," and raising the design problem to its generalization finds the abstraction necessary to go beyond a single specificity.

finished object of industrial production follows a specified time, coded use, uniqueness, and invariance of the model to be reproduced. The peculiarity of the objectile is its potential to study an open set of morphologies, where the variety principle (distinctive element to be enhanced and not an imperfection to be eliminated) is more important than homogeneity by options. In order, the concept of objectile Mario Carpo (2011) states that designer's attention shifts from the autopoiesis vision of form to process and numerical matrix at the origin of an open and imperfect object, expression of a function rather than a finite image of geometry and space, able to restores roles and competencies: «new digital platforms for open-ended, interactive collaboration may beget endless design variations, revisions or versions, loss of design control and authorial recognition, and even, in the most extreme cases, collective or anonymous results (...) They may design objects, and then be digital interactors. Or they may design objectiles, and then be digital authors» (Carpo, 2011).

Alongside this, the spread of digital technologies and algorithmic modeling tools extends the ability to simulate and predict the behaviors of design solutions developed in the digital model. The opportunity is mainly due to the enabling possibilities of technologies to interact with the context, leaving potential internal configurations to change in design from an initial condition (Fox, 2013). Data can encode information and become a source to simulate behaviors and shows adaptive outcomes in time: from representation - 2D, or parametric modeling - 3D, design becomes a generative simulation process - 4D (Bier and Knight, 2014). Derived from biology, with "adaptivity," we mean the ability of an organism to modify in whole or in part the elements of its original structure to a different one when specific environmental conditions change.

In architecture, adaptive systems are defined as complex systems that integrate both hardware and software components. The programming (coding of an algorithm) defines the rules of transformation related to environmental inputs. Hence the dynamic behavior is the adaptation of its morphology to the environment to which it refers. As it happens in natural systems, where changes in environmental conditions shape a slow and continuous process of adaptation of their structures, so in the design of adaptive architectures, the adoption of these principles leads to the emergence of artifacts and spatial organizations capable of setting their morphology on the dynamics of action and reaction to a series of external inputs (Fig. 4.3).

At the level of the design process, as well as the skills required to meet this challenge and expected results, there is a "technological horizon that needs a new culture, capable of hybridizing immaterial and material aspects" (Campioli, 2020). These aspects overcome the compositional logic of the whole object and the "solidity" of the building system. Because of the need to respond to specific local conditions, as opposed to generic overall configurations of the composition ordered by geometry, these artifacts are often described as non-standard architecture, and: «employ the building envelope and its articulation and multiplication as a spatial device and environmental modulator» (Hensel and Sørensen, 2014).

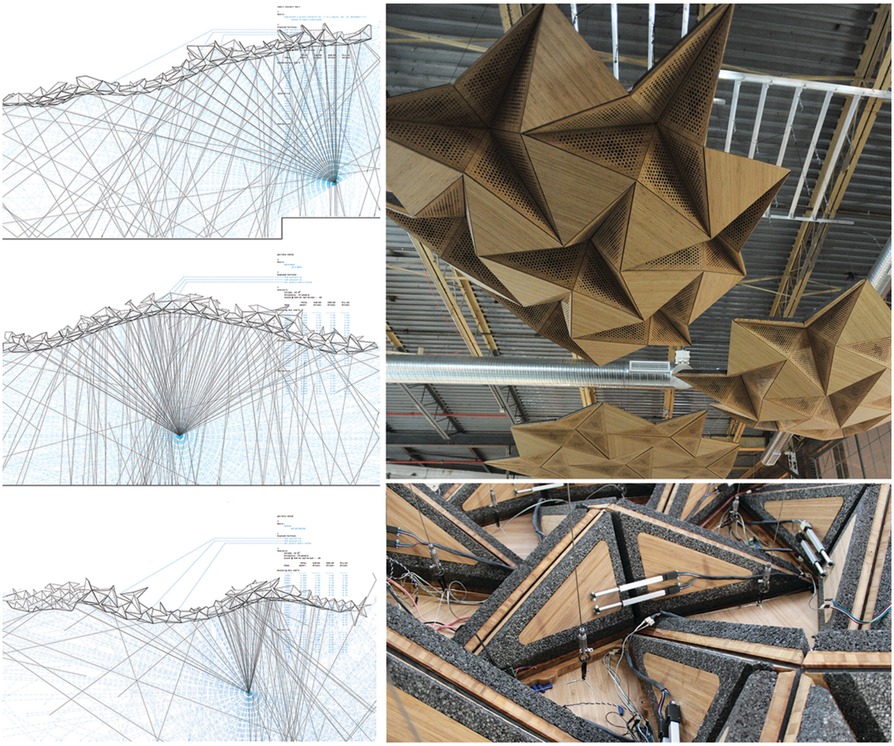

*Fig. 4.3 - The Resonant Chamber project (© rvtr) was iterative research and development in computational testing and full-scale prototype installation for the University of Michigan. The project was an exploration of kinetic tessellated architectural systems and variable acoustic surfaces that use specific geometries. The project aimed to develop a sound sphere able to adjust its tessellated origami patterns to achieve the optimal conditions for the sound.*

The context outlined by the two authors is hybrid, and the relationship between analog and digital takes on peculiar features. Moreover, where the different disciplinary fields (mainly design, architecture, art, engineering) intertwine with each other and with the topic of digital computation to acquire and increase design value. Boundaries of the various domains and the rigidity of the scale that drive additive compositional logic between the different layers of the construction are blurred (Nebuloni, 2020a). The surface is first discretized into basic modules and then populated by new families of technological artifacts from an organic whole: the adaptive component system.

According to the level at which the relationship between design and data takes shape, these artifacts' adaptive systems are recognized as central and local. The former defines the control of the set of components on the main dimension of the structure (Fig. 4.4). The latter keeps it within the single element that, in this case, will be equipped with sensors, actuators, and microprocessors for data encoding and motion control (Fig. 4.5).

*Fig. 4.4 - Soma Studio. Thematic Pavilion for Yeosu Expo 2012 (©Soma). The design's concept for the 140 meters long and 3 to 13 meters height dynamic façade originated from biology and is an example of a central level system. The 108 kinetic lamellas controlled internal light conditions and created organic external animated patterns. Servomotors reduced the distance between the two bearings to originate the movement, resulting in a side rotation of the lamellas.*


*Fig. 4.5 - Jenny Sabin Studio. Lumen, New York (© Jenny Sabin Studio). Lumen consisted of 250 hanging tubular structures designed to capture and react to changes in sunlight over the day. The concept originated from biology, and its composition refers to a local-level systems typology. The structure's reactive surface was linked to human interaction and environment.*

Between the two systems, there are essential differences in the typological structure and data management: in the central systems, the scale of the components is greater, and the control over the whole process, as well as the harmonization between the elements themselves, develops more complex kinetics. In the local systems, the components are smaller and with a form of intelligence that allows them to produce individually simple movements and achieve complex and unexpected overall results.

The analogy is to the difference that occurs in nature between the plant systems - with a disseminated intelligence and largely autonomous -, and animal systems - where the control is at the central level. In the first system emerges a logical relationship between homogeneous parts, while in the second, a structure of superordinate elements and succession between them.

Therefore, the characteristic of adaptive architectures is an aesthetics of movement resulting from the ability of action of a plurality of dynamic artifacts like each other. The form - or rather the configuration, potential and induced by data - is a function of the parameters' degree, and a program (algorithm + coding) governs the behavior of the system: the algorithm founds the logic, while the code implements it in a formal language (Nebuloni, 2020b).

Most modeling software integrates interfaces or plug-ins (apps that add advanced functionality to the essential software) to explore these morphologies in the project. With proper programming languages, these interfaces allow the customization of the modeling environment, the definition of algorithms, and control data. In these environments, the algorithm often uses visual programming paradigm, mainly through block and flow diagrams.

These skills also enable interoperability between different digital design environments and platforms, which is essential for integrating external inputs into the process.

The result is the communication and interaction between different domains (e.g., Grasshopper and Firefly plug-ins) that connecting in a bi-directional way an algorithmic design environment to a microcontroller (e.g., Arduino). Data from sensors are, therefore, processes to simulate the physical behavior of a component. Virtual environment and a real physical one are both engaged (Fig. 4.6).

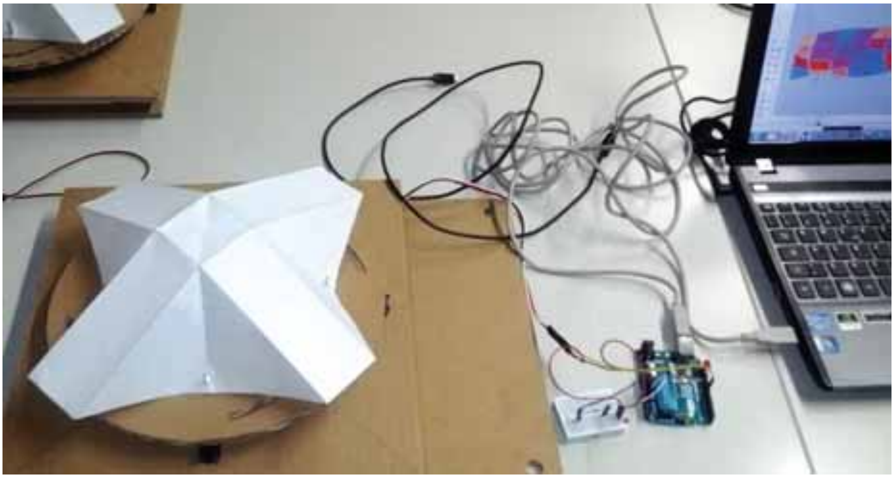

*Fig. 4.6 - Digital-physical interaction via a prototype. Simulation of the responsive behavior of a design component (Responsive morphologies Workshop, Polimi).*

## 4.4 Conclusions

Over the past few decades, digital technology has already contributed significantly to the redefinition of design practice.[2] Today, the greater diffusion of tools, techniques, and languages capable of integrating programming into modeling and the possibility for the designer to build custom working tools foreshadow even more important changes. Among them, in addition to the ability to analyze a plurality of data and information proper to computation, the role of enabling technologies in connecting environments and simultaneously

[2] There are three design research stages in the recent history of the digital revolution in architecture (Wiscombe, 2015): the first decade of openness (the nineties), characterized by the free and seemingly unconstrained forms brought by new tools and techniques, from which a figurative apparatus made of hybrid and not rigidly defined morphologies, far from the references of history and no longer articulated on the composition of the parts, but based on the processes of generation linked to the matter, has derived; the second (first decade of the two-thousands), markedly computational, of experimentation on the forms of programming and modeling algorithms, in a game of scale between the variability of a single element and the projection of the same on the morphology of the whole; the current (from 2010), which reinforce the loyalty to the relational aspects of the project focuses on adaptive objects and the dynamic logic of algorithms.

managing many design options. New references, resulting from the changing relationships between environment, construction, and design, are followed by the definition of new interpretative frameworks focused on the behavior of systems and the ability to connect contents and exchange information. Combining and harmonizing the skills necessary for effective and creative use of digital technologies is increasingly needed to explore the potential of the relationship between design and data, implying that designers "reset" the classic tools of the project to build new languages based on variation and complexity.

There are still many risks and obstacles that characterize this hybrid and creative phase of the digital project to make definitive statements about its viability. Above all, the relation to cultural references and examples that, although promising, identify architecture as a mere space of representation of concepts far from its disciplinary domain. Therefore, it will be essential to broaden the discussion to include: "beyond ontology and epistemology, the key issues of function, typology, and technology" (Wiscombe, 2015). Not least, to combine performance aspects with an aesthetics of movement leading to a definition of form that is increasingly dependent on dynamic environmental variables.

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The book explores evolving perspectives on furniture, interior, spatial and architectural design, providing a multifaceted view of how the design discipline and practice deal with the complex and ever-evolving interplay between the physical and the digital realms. It explores the new frontiers of digitally enhanced design, investigating how computation capabilities impact the design discipline and designers' thinking and practice. Today more than ever, the design discipline must cope with the need to absorb technical skills and dialogue with traditionally distant domains. The core competencies in the Human-Computer Interaction field are becoming essential to every design branch: the computational power is entering the design process, modifying how products and spaces are designed, how they are produced, and how they will impact the daily life of users.

The book explores these novel frontiers, proposing captivating portraits of digitally enhanced design possibilities, from tools and processes to expressive potentials.

Industry 4.0 and traditional craftsmanship hybridize in view of a circular and just economy for the furniture sector, imagining new approaches towards the European Green Deal. The sensing capabilities are intertwined with the materials to create a new form of animated objects, proposing a novel design approach beyond the user-centered one. The computational power of lighting design tools is entering the complex BIM methodology, exploring the problematic integration between the two worlds, and proposing solutions to support the design activity. Artificial Intelligence reframes the domestic landscape, thanks to Science Fiction Scenarios, to stimulate reflection on the designer's role in framing utopic/dystopic futures. Finally, data drive the design of adaptive morphologies, exploring the context of computational design with a conceptual framework and reflecting on how robotic design can contribute to architecture.

FrancoAngeli
La passione per le conoscenze