Contextualization of “the Digital”: Design through Material Behavior

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Abstract

Digital technologies have initiated new architectural languages and have eased the way to communicate them directly from initial design phase to production facilities, allowing for the construction of complex geometries with the use of ever evolving techniques and tools. The shift in concept of designing the ‘formation process’ rather than the ‘final forms’ are being taken forward by increasing application of the ‘digital’ from the very beginning of design process to the end of manufacturing process. However, there are crucial questions about its application in the building industries in the contexts which have lower access to Hi-tech technologies. Besides, the huge production cost has limited its adaptability in contexts where the construction field relies mainly on low-tech local methods.

Attention has to be given to explore the new-found freedoms of material computation in close connection with the socio-economical-cultural context by inventing new design processes and custom devices. Flexible, mobile and low-cost fabrication methods applicable to different scenarios should be explored while achieving the complexity of contemporary architectural geometries. Design process should be site-specific, customized and adapted to local technical know-how, in areas that traditionally have limited access to new technologies.

Keywords: New design process, Digital tectonics, Complex geometry, Material computation, Customized devices.
1. Introduction

Throughout the history, technology and culture have formed a feedback loop; advances in technology have accelerated the pace of innovations in architecture, the arts, sciences, and media; in turn, these cultural developments have fed back to the discoveries of new technologies. The contribution of contemporary techniques lies in the progress of a culture that is driven by a machinic process which produces emergent results as an outcome of a rigorous understanding of complex natural systems. Thus the construction solution for the complex geometry of contemporary architecture necessitates the development of new methods and tools, and this in turn demands the seamless integration of digital modeling and computer-aided manufacturing.

However this loop between the architectural advancement and contemporary technology are often burdened by the constraints of the place, time and available resources. Since the shift in concept of designing the ‘formation’ rather than the final form are being taken forward by intense application of the ‘digital’ from the very beginning of design process to the end of manufacturing process, there arise crucial questions about its application in contexts which traditionally have lower access to high-tech methods and machines.

There is a growing interest in research field, if not very evident in the current practice trend, to intervene the possibilities of customization of this ‘shift’ in architectural language that questions the standardized industrial mode of production by addressing the whole procedure as an integral part of the local knowledge of craft and construction responding to the specific cultural context. The paper emphasizes on the change that is required in our approach toward materiality by investigating the potential of the ‘digital’ to be applied in different scenario. The notion ‘Contextualization’ in this paper refers to the vigorous effort of getting the CAD driven target result by using and customizing local tools and techniques thus setting up a feedback-loop between the context and computation.

2. Research Objectives

The paper attempts to explore the new-found freedom of material computation, inventing a design process stemming from material behavior based on specific building scenario and available technology. It will focus on the hands on experiments and the operation of custom fabrication device to control the material formation process as an integral part of the design process. With a brief study of the pattern formations in natural systems and the work of the precedents who have set up references to work with material behavior applying laws of physics, the research explores a design process with flexible, mobile and low-cost fabrication system to generate complex digital outcomes.

Natural material formations will be briefly discussed to understand how sameness can give rise to diversity and how these rules of varying patterns can be implied to inanimate materials to make the process responsive to minute changes in each and every cross sections and thus achieving efficient structures. Structures designed/ built by using material physics as the core form finding agent have been studied as references to achieve newer complexities. Recent case studies of academic and research projects of complex geometries exhibiting the formation process in the form of the final product have been briefly discussed. The process so far achieved in the local context should be assessed as a start by using custom tools which are not yet controlled by computer numerics, thus limiting the target complexity of the end result whereas, in case of the academic projects the whole procedure was facilitated by the association of a very well equipped digital fabrication lab.

The rise of the ‘digital simulation’ which later gave the thematic and procedural base for the contemporary architectural practices like ‘digital materiality’, is to be linked, where the conceptualization of the design and the construction procedures informs about the infinite perceptual and construction possibilities of architectural built form. The role of an architect is also to be addressed regarding this kind of procedural practices.
3. Material Organization in Nature

Natural structures possess the highest level of seamless integration and precision with which they serve their functions (Janine M Benyus: 1997). Nature’s ability to distribute material properties by way of locally optimizing regions of varied external requirements, such as bone’s ability to remodel under altering mechanical loads, or wood’s capacity to modify its shape by way of containing moisture, is facilitated, fundamentally, by its ability to simultaneously model, simulate and fabricate material structuring (Oxman Neri: 2010). About the optimization process of nature, Oxman quoted that, Nature is demonstrably sustainable as it has been resolving its challenges over billions of years by enduring solutions with maximum performances with minimum resources. As Leonardo da Vinci posits: ‘In her (nature’s) inventions nothing is lacking, nothing is superfluous.’

Optimization process of Nature by organizing material density by differentiation and integration in the local level affects the global geometry of the whole system forming complex emergent patterns. This complexity is heterogeneous, with many varied parts that have multiple connections between them, and the different parts behave differently although they are not independent. Complexity increases when the variety and dependency of parts increases. The process of increasing variety is called differentiation, and the process of increasing the number or the strength of connections is called integration. Evolution produces differentiation and integration in many ‘scales’ that interact with each other, from the formation and structure of an individual organism to species and ecosystems. (Weinstock, Michael: 2004).

4. Design through Material Behavior

With due respect to the works of Antonio Gaudi, Frei Otto, Heinz isler and the others alike, there are innumerable scopes to intervene into the realm of geometries emerging from material behavior in full architectural scale. The behavior of a form evolved from self-forming process, has to be tested with physical experiments. Self-forming processes can be systematized by two distinct approaches. The first system emphasizes the force, which acts in a structure or can be transmitted by it, or which was acting during its development. The second system emphasizes the form of the developing object because its form is a primary parameter in the evaluation of a structure. Form and force are correlated, in that the form of a structure can be determined as the state in which the forces acting in and on it are in equilibrium. Furthermore, the flow of force can be shown through physical modeling. (Emergence and Design Group in Conversation with Frei Otto, 2004).
The ability of some materials to self-organize into a stable arrangement under stress has been the founding principle of structural form-finding in the physical experiments of Gaudí, Eisler and Otto. ‘Organization’ here refers to the reordering of the material, or the components of the material system, in order to produce structural stability. (Weinstock, Michael, 2006).

**5. Digital Evolvility and Existing Technology**

The complex interaction between form, material and structure of natural material systems has informed new industrial processes, generating new possibilities for controlling the whole process bit by bit with difference and repetition. Digital technologies have initiated new architectural languages easing the way to communicate them directly to production facilities for the construction of complex geometries with the use of high-tech CNC machines, Robots, 3D printing, Contour Crafting etc.

This technological shift has inevitably influenced the contemporary architectural expression, a seamless materiality, easing the construction of fluid smoothness of free forms with intricate control of details. It has explored the design of digitally crafted non-uniform patterns, textures, and structures. The increasing capacity of material entity to be enriched with digital technologies has subsequently transformed the physis of architecture where data and
material, programming and construction are interwoven. According to Gramazio and Kohler this ‘Digital Materiality’ is characterized by: a. unusually large number of precisely arranged elements, b. a sophisticated level of detail and c. the simultaneous presence of different scales of formation. Despite its intrinsic complexity there should be an ‘intuitive’ understanding of the system to address our ability to recognize naturally grown organizational forms and to interpret their internal order.

Digital materiality is not rooted solely in the ‘material world’ and its physical laws such as gravity, or in material properties. It is also enriched by the rules of the ‘immaterial world’, which is to be perceived and experienced by the ‘digital logics’. Gramazio and Kohler note the sense of becoming and commented, “In case of an observer, the tension spans the intuitively understandable behavior of a material and the design logic, which may not be immediately obvious. The logic can be sensed, but not necessarily explained. This obscurity seduces our senses, sending them on a voyage of discovery and inviting us to linger and reflect.” (Gramazio, Fabio and Kohler, Matthias, 2008).

6. Multiple potentialities
Architecture becomes increasingly rich and diversified through ‘digital materiality’. This diversification affects different scales, from materials and building components to spatial sequences and load bearing structures, to houses and urban development zoning. The architect’s human capabilities are extended and improvements are done in their overview and multiply the possibilities for control of the design. With the rise of digital materiality, the frontier between system and variation is renegotiated. Digital is an independent cultural achievement resulting from centuries of human engagement with logic. Precisely for this reason the computer is a fascinating instrument, one that motivates a designer to exploit the human potential for associative thinking in order to discover new organizing principles, and establish new relations with the perceived environment.

7. Machine-ically informed procedure and Customized tools
Digital materiality is generated through the integration of construction and programming in the process. The digital tools like computer cannot substitute a designer in the procedures of design, but is an invaluable design tool. A computer program describes the processing of data as a sequence of individual calculation steps. Similarly, the manufacturing of a building component takes place as a temporal sequence of individual steps in fabrication.

The sequences of the construction steps is possibly the most radical analogy between construction, the knowledge and art of putting individual building components together as a built spatial ensemble, and computer programming. It is no longer about designing the form that will ultimately be produced, but the production process itself. The design incorporates the idea and knowledge of its production already at its moment of conception. In turn, the understanding of construction as an integral part of architectural design takes on greater significance. As named by Gramazio and Kohler, ‘Digital Craftsmanship’, thus continues the tradition of construction in architecture,(Gramazio, Fabio and Kohler, Matthias, 2008)
It should be mentioned that practical ‘hands on’ experience of programming demystifies digital technologies and fosters a liberated, autonomous approach to the computer. Through these practical skills an emancipation of engagement with existing CAAD tools and the passive applications of their built-in paradigms and menu functions, which are mostly, programmed simulations of traditional drawing processes? It is necessary to develop programming languages that account for the fact that when designing, the exception is often just as important as the rule that means hierarchical dependencies can change throughout the design process. The designers can intervene in this evolution by developing their own dialects that take up the subjects of construction, materials and space.

The architects should choose their means consciously and master their tools. Accessing these generic tools enables architects to create their individual design instruments and thus generates diverse forms of expression. Digital materiality has the tradition of construction connected to it and it changes the culture of architecture, both in its expression and in its productive capacity. Architects are predisposed to forge links between technology and the built environment.

8. The ‘Shift’ and the new ‘physis’

‘Digital Materiality’ leads us from the design of static forms to the design of material processes. But once we begin to invent such material processes, a new way of thinking about architecture reveals itself. It is a conceptual way of designing with architectural parameters, conditions, relationships and degrees of freedom. In this way of conceiving architecture, processes are not mere ‘metaphors’ for a process oriented approach to design, but are concrete sequences of operations, procedures that have to be designed. These procedures might have a determined beginning and an end but the possibilities are ‘open-ended’. There can be multiple procedures running at the same time with the continuous ‘feed-back’ from the contextual setting.

When, architecture becomes the design of material processes, there will be no longer a static plan before the designer, but a dynamic set of rules. Architect will design ‘behavior’. A set of rules like this has the advantage that even very fundamental interventions can still be implemented even late in the process, as long as they are anticipated as open parameter in the design. Architect will thus design architecture as an open system with different active participants. This type of design, detached from a drive towards form while doing justice to the material substance of architecture, including its sensual qualities. Designing architecture as processes thus strengthens the central role of the architect.

9. Constraints of Digital technologies

The technological advancement might enable architects to explore complex geometries but, it is also questioned for the large amount of financial involvement. Again, in case of its implication in a specified construction scenario which lacks high tech manufacturing equipments and technical knowhow, this could lead to the risk of the monopolization of novelty in the built environment. Digital construction is highly depended on the digitally driven tools and those are being in a state of development. Using these tools requires a very high-end technical know-how which is unavailable in most of the contexts. This situation might rouse the sense of ‘royal’ attitude towards the movement that addresses material behavior in the design process.

10. Towards Localization

The context taken primarily is Bangladesh where warm-humid climatic condition prevails and questions the reusability and energy efficiency of the construction formworks like; steel, wood, bamboo which is apparently widely used. Again, inclusion of the digital construction processes in its original form will have a very bleak future regarding the scarcity of digital tools and technical knowhow.
In order to achieve simplicity and truth in the process of constructing new construction method, there has to be pursued where materials assemble to controlled complex geometries, according to a design system that is the result of a thorough investigation of how these construction materials behave. The emphasis is to be given on the available material specification that would accommodate innovations in construction procedure and innovative formwork using local construction techniques. In case of Bangladesh, digitally derived formations can be transformed through rethinking the possibility of portable tools and flexible formwork using low cost local materials and technical knowledge. Sustainability of the whole procedure should be justified with local context and climatic conditions.

Following are the academic examples done in the Masters Studio and Open Thesis Fabrication Program at Institute for Advanced Architecture of Catalonia respectively where the research projects explored the innovative material processes, custom devices and computational methods that could be applied to different contexts that depend mainly on low tech construction procedures. These studio projects are done in a very advanced scenario in terms of construction technology that sets the background for the quest for achieving the computer driven formations by using apparently low tech local construction procedures.

**Academic Example_1: Masters Studio (2010-2011)** Digital Tectonics led by Marta Male Alemany at Institute for Advanced Architecture of Catalonia (IAAC) investigated the workflow between computational design and formation methods, stemming from material behavior, exploring programmable custom devices. Recycled Fabrik done by a student team targeted recently demolished sites and re-instating the site found broken bricks as potent design components. The project utilized the atypical geometry of random polyhedra by designing emergent formation processes. The resultant was an outcome of user controlled design inputs and inherent properties of the bricks. The project also succeeds in establishing a site based active design system with areal-time interaction between the design and execution. The 3D scanned broken bricks are reproduced into a digital platform, sorted and the design outcome is evaluated conforming predefined performance criteria. The project creates an interaction platform where tags cross-check the positioning of the sorted bricks in accordance with the design.

This opens up an opportunity to verify the execution process in real-time. This re-evaluated design is communicated via a wireless device thus continuing the active interaction between the execution team and designer throughout the whole process. The whole Process is demonstrated by making one-one prototype with site found materials at a historical mountain villa in Barcelona to propose new fab-lab building for IAAC. The project is conceived as a portable design system which can be executed at sites which traditionally have lower access to technology. It can easily calculate required energy, manpower and resources thus forming a sustainable design system while achieving the complexity and intricacy of computational design.

**Figure 6: Academic Example_1: Evolutionary logic has been applied to find the 'best fit' from each generation of population for achieving different fitness criteria set by the designer with broken brick each having unique shapes.**
Academic Example 2: The Open Thesis Fabrication, a 4 months intensive research program at IAAC seeks to develop full-scale prototypes using advanced CNC machinery, innovative material solutions, and smart energy applications in collaboration with partner companies ranging from manufacturing materials to advanced robotics. The aim of the mentioned research done by the author was to design a mechanism to generate a structural screen stemming from material behavior responding to certain stimuli as observed in natural growth processes. The generative process would focus on the optimization of material organization according to the parameters such as applied stress, environmental conditions etc. A mono-material structural skin was proposed by generating pattern under different support and loading conditions to achieve lightweight structures of complex shapes. A system of simple Fabric Form-work is proposed to generate doubly curved showing variable cross section that could be achieved only with hi-tech technologies (3D printing) and not by conventional construction method. The challenge was to keep the manufacturing process as low-tech as possible to make it applicable in different contexts.

Figure 7: Rules are developed from the hands on experiments with Fabric and concrete, to generate 2d pattern to be sewn on fabric panels. Target 3D Double curvatures are obtained from this simple flat fabric formwork by transforming the digital data with the use of low tech custom device.

11. Open Ended Discourse Remarks:
The probability of encountering discoveries and innovations is accelerated by using computational means of design. Architectural forms are produced in the course of the design and materialization process and takes on its character bit by bit. Digital materiality changes the ‘physis’ of architecture and ultimately the image that society has of architecture.

Figure 8: Formation of brick on X-Y axis configured the basic Plan of the installation. By the layering of a brick unit on X-Y single parameter shift created the obvious sloped/inclined surface. At a point the X-Y shift and the layering creates an end of that line of assemblage and turns into an opening for the surface.

The potential of customized devices through the thorough study of physical models informed by digitally based pattern formations and its application in the context of Bangladesh addressing existing constrains is the current research agenda.
The paper is a brief description of a part of our ongoing design research where the target so far achieved is to get the complexity of the ‘digital materiality’ using simple low-tech construction process with affordable and portable tools and formwork. Current state of our research agenda is a small installation for the Rama Krishna Mission in Chittagong which is taking its shape as a start to demonstrate the construction of a ‘formation’ computationally derived from very simple set of rules given to brick modules.

Though the end result here is not something unique in the sense of digitally transformed formation but, the learning process gives us the base for dealing with multi-parametric cases through local ‘hands-on’ construction process for the initial instances.

On the basis of this current state of the ‘complex formation’ generating exercise derived from the material behavior, using Rhino Grasshopper, 3ds max and AutoCAD as the main computational tool, the next steps will focus on more ‘technical issues’ relating structural and environmental factors using computer simulation. Thus the research is an attempt to unite the delicacy of material computation and the artistic imperfection of the handcrafted into an efficient structure facilitating local techniques and masons with affordable custom devices.
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